BLACKWATER RIVER SUB-WATERSHED AND PHYTOPLANKTON ASSESSMENT

FRANKLIN COUNTY, VIRGINIA

JULY 2024; REVISED SEPTEMBER 2024

PREPARED FOR:

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1.1 METHODS

Smith Mountain Lake is an artificial impoundment of the Roanoke and Blackwater Rivers, constructed in the 1960s as a source of energy for the region. Currently, the lake provides hydroelectric power generation and potable water and is a highly valued recreational, ecological, and economical resource. Historically, the Roanoke sub watershed accounts for the majority (approximately 72%) of the phosphorus loading entering the lake, with 90% of this load originating from non-point source (NPS) pollution. While the Roanoke sub watershed is more urbanized, the Blackwater sub watershed is rural / agricultural in composition, with a substantial portion of the NPS phosphorus loading originating from agricultural land uses. This report updates and revises the annual phosphorus loading to Smith Mountain Lake.

Princeton Hydro has collected historical data from the Smith Mountain Lake Association (SMLA), as well as regulatory agencies, (such as VDEQ, USGS and USACE), and reviewed it in advance of implementing the watershed assessment for the Blackwater River sub-watershed outlined in Sections 2 and 3 (below). By doing so, a capitalization on established water quality trends, problems and issues raised through any past sampling efforts, and evaluation of the relative success of any past restoration efforts was accomplished. This review also examined available surface water data for streams within the Blackwater River sub-watershed. This information was then used as the foundation of the watershed assessment as well. This is part of a standard study approach for any aquatic system; integration of reliable data developed in past studies. Making use of these supplemental data collected by others to complement field efforts is beneficial, assuming that the data were collected by properly trained personnel in a manner consistent with standard VDEQ quality assurance protection plan protocols.

This section of this report provides a brief survey and summary of the various studies and analyses that have been conducted at Smith Mountain Lake and its watershed.

1.2 RESULTS

1972 A PRODUCTIVITY STUDY OF SMITH MOUNTAIN LAKE, MASTER OF SCIENCE THESIS FOR ROBERT H. SPARGER, VIRIGINA POLYTECHNIC INSTITUTE AND STATE UNIVERSITY.

Some water quality monitoring was conducted over the summer of 1971 to study and document the impact select water quality parameters have on the trophic state of Smith Mountain Lake and Lower Leesville Lake. Elevated nutrient concentrations in the Roanoke River and entering the upper reaches of Smith Mountain Lake were contributing to the observed eutrophic conditions in the upper reaches of the lake. High concentrations of total suspended solids limited high levels of primary productivity in the upper reaches of the lake. However, a good correlation was identified between light extinction coefficients and levels of productivity in the lower half of Smith Mountain Lake.

1975 NATIONAL EUTROPHICATION SURVEY REPORT ON SMITH MOUNTAIN RESERVOIR, WORKING PAPER NO. 465 (US EPA)

As part of US EPA's National Eutrophication Survey initiated in 1972, a eutrophication analysis and quantification of point and non-point source pollution loads was conducted for Smith Mountain Lake in 1975. This survey revealed that at the time the Roanoke River Arm of the Lake was eutrophic, while the Blackwater River Arm was mesotrophic. An algal assay conducted in April of 1973 indicated that the lake was phosphorus limited. Finally, at the time, point sources of phosphorus accounted for 51.3% of the annual load to the lake, while the non-point sources of phosphorus accounted for 48.6% of the total annual load.

2002 FECAL COLIFORM TMDL (TOTAL MAXIMUM DAILY LOAD) DEVELOPMENT FOR GILLS CREEK, VIRIGINA (VIRGINA DEPARTMENT OF ENVIRONMENAL QUALITY AND VIRGINA DEPARTMENT OF CONSERVATION AND RECREATION)

MapTech, Inc. developed a fecal coliform TMDL for Gills Creek, a tributary that discharges into Smith Mountain Lake. The TMDL was developed to address the documented impairments associated with elevated fecal coliform counts that result in the stream not supporting primary contact recreation activities such as swimming, wading, and fishing. Both point and non-point sources of fecal coliform were identified. After the modeling was completed a phased implementation plan was developed. The first phase was to foster local support for the implementation plan. The specific components of the plan included a 100% reduction in uncontrolled discharges and a 90% reduction in livestock's direction deposition to the stream.

2004 TOTAL MAXIMUM DAILY LOAD (TMDL) DEVELOPMENT FOR THE UPPER BLACKWATER RIVER WATERSHED (US EPA AND VIRGINA DEPARTMENT OF ENVIRONMENAL QUALITY)

Tetra Tech, Inc. developed a TMDL for aquatic life (benthic) impaired streams for the Upper Blackwater River Watershed for US EPA and the Virigina Department of Environmental Quality. Sections of the river were identified as impaired for aquatic life, as per the US EPA's Rapid Bioassessment Protocol. The benthic impairments in the mainstem and North Fork Blackwater River were attributed to sediment loading while phosphorus was also identified as contributing toward impairments in the North Fork. When this report was completed, there were no nutrient criteria in Virigina. It is our understanding that currently there is still no nutrient criteria in Virigina. Thus, for this 2004 report the impairment relative to phosphorus was comparing the Upper Blackwater River watershed to a non-impaired, reference watershed for a desired phosphorus loading rate. The impairment of elevated phosphorus loading on local benthic communities would be related to high amounts of filamentous mat algae and macrophyte growth, reducing the quality of structure habitat for macroinvertebrates as well as large swings and declined in dissolved oxygen concentrations under seasonally low flow conditions.

The developed TMDL took into account all sources of sediment and phosphorus in the watershed, plus a margin of safety, to ensure water quality conditions will be met relative to benthic impairments.

2009 ROANOKE RIVER PCB TMDL DEVELOPMENT (VIRGINIA) (US EPA SECTION III)

Tetra Tech, Inc developed a TMDL to identify sources of polychlorinated biphenyl (PCB) contamination in the watershed and determine the reductions in pollutant loadings to achieve desired water quality standards. The listed impairments were based on historical fish tissue and sediment monitoring data. The TMDL endpoints were developed to be protective of fish for human consumption and thus are more stringent than those established for human health. Thus, the developed endpoints were more than adequate to protect local water supplies.

LONG-TERM WATER QUALITY DATA AND A BRIEF SUMMARY OF RECENT WATER QUALITY CONDITIONS AT SMITH MOUNTAIN LAKE

Since the 1930s a variety of physical and chemical water quality data have been collected in the Smith Mountain Lake Watershed. From the 1930s through the mid-2010s the USGS Virginia Water Science Center collected samples of both water and sediment for these analyses. More recently, in the 2000s and 2010s the USGS collected groundwater samples as well.

From the end of the 1960s into 2024 the Virigina Department of Environmental Quality was also monitoring and most of this focused on water sampling. The National Park Service Water Resources Division collected a variety of air, water, and sediment samples in 1976 with the majority of these samples being sediments. In 1977 the Division also collected a limited amount of sediment samples. Finally, these organizations periodically conducted limited water and/or sediment sampling through the 1980s to the 2020s.

Starting in 1987, Ferrum College initiated a water quality monitoring program at Smith Mountain Lake. Data are collected by students and staff of the College as well as trained Smith Mountain Lake Association volunteers.

Monitoring tends to start around Memorial Day weekend and conclude sometime in mid- to late August. Over the last few years monitoring included the collection of samples from 22 tributary sites and include total phosphorus and chlorophyll-a concentrations. Samples are also collected for *E. coli*.

Since 2005 vertical profiles on in-situ data, including dissolved oxygen (DO), temperature, conductivity and pH have been collected through the water column at specific locations in the main body of the lake. Additionally, since 2008 plankton tows have been collected for the identification of phytoplankton to genus and/or species.

LONG-TERM WATER QUALITY CONDITIONS

The Ferrum College long-term database provides a wealth of valuable information on the overall conditions of Smith Mountain Lake and some of the overarching conclusions are identified below:

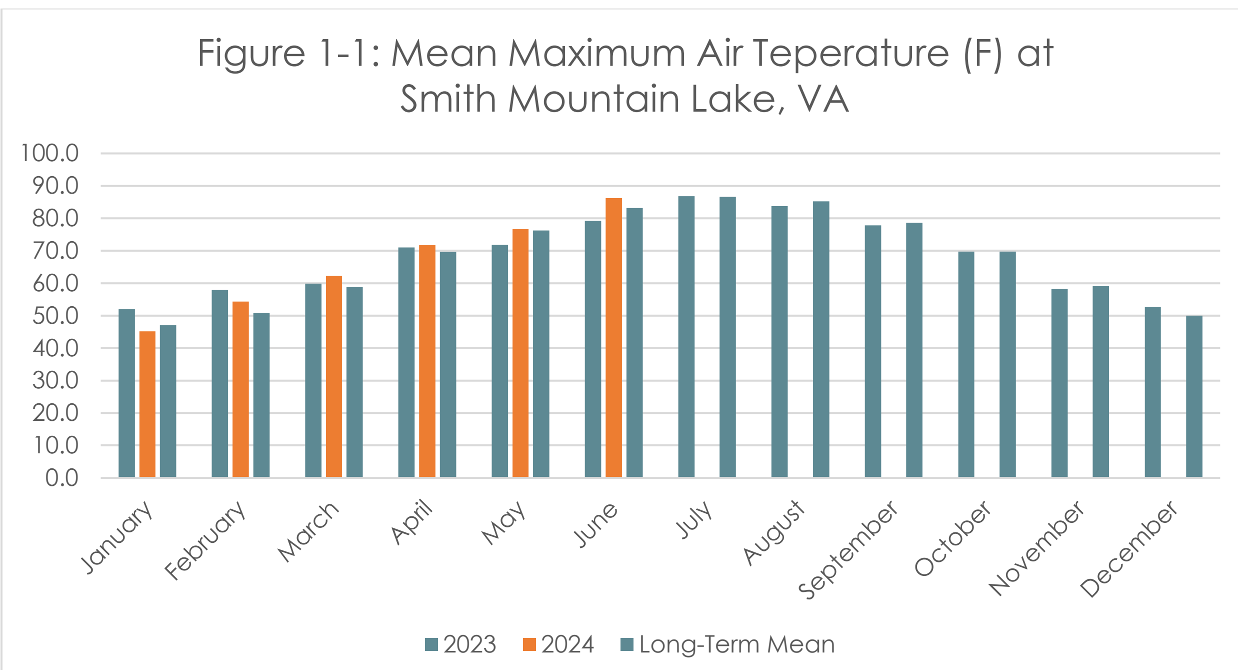
1. As with many run-of-the-river reservoirs, water quality conditions improve as water flows from the upper reaches of the tributaries down to the main body of the lake and dam. This is a result of the settling of particulate material as water flow slows down from the riverine zone into the reservoir's transitional zone. Nutrients such as phosphorus can be adsorbed onto sediment particles so the settling of this material in the transitional zone can also contribute toward limiting planktonic algal growth. However, depending on water clarity and water depths in the transitional zone, this phosphorus may stimulate benthic algal growth.
2. According to Ferrum College the bottom water of the lake becomes depleted of DO (typically concentrations fall below 1 mg/L and are known as anoxic conditions). They also noted that since 2015, this depletion of DO has been occurring in June rather than July. Princeton Hydro has also documented similar increases in volume, aerial bottom sediment distribution, and duration of anoxic conditions in other waterbodies in the Mid-Atlantic region of the US. Based on our analysis and comparison with regional weather data, this is at least partially attributed to climate change.
3. It should be noted that when the DO over the sediments falls below 1 mg/L, the bond between phosphorus and iron is broken and phosphorus may accumulate in these deeper waters. This internal phosphorus load may be transferred to the surface through storm events or be accessed by cyanobacteria that possess gas vacuoles such as *Aphanizomenon* and *Dolichospermum* (formally known as *Anabaena*).
4. As shown by Ferrum College's water quality data, algal growth in Smith Mountain Lake is largely driven by external (watershed) source of nutrients such as point and non-point source pollution. However, the Association may want to use the existing data to quantify the lake's internal phosphorus load. More than likely the internal phosphorus load is minor compared to the external load on an annual basis. However, during the summer months, particularly during a dry summer season, the internal phosphorus load can account for a substantial amount of the available phosphorus, particularly for those cyanobacteria that possess gas vacuoles and can quickly migrate through the water column. Thus, we would recommend quantifying the load sometime in the near future.
5. Since the College initiated monitoring of *E. coli* in 2004, a comparison of marinas, non-marinas, and headwaters shows differences in *E. coli* values consistent with data collected over the last ten years. Based on this database the majority of bacteria entering Smith Mountain Lake comes from the headwaters. It should also be noted that most of the elevated E. coli values in the summer originate from areas that have heron rookeries or high populations of other waterfowl.
6. The College has a long-term (1987-2023) water quality database of several important trophic state parameters for the lake and a few points should be made based on these data. First, there has been a very slight increase in the lake-wide mean of total phosphorus over the decades. Second, there is a more

distinct increasing trend in chlorophyll-a concentrations over the decades. Associated with the increasing trend in chlorophyll-a there was an observable decline (reduction) in the water clarity of the lake, as measured with a Secchi disk. Thus, algal productivity is increasing in the lake in the long-term. This increase in productivity originates from sources of phosphorus other than the availability of this nutrient in the water column. Thus, internal phosphorus loading and/or the mobilization and interaction with vegetative cells / akinetes over the sediment in near-shore, shallow sections of the lake, may be fueling this rise in algal productivity. In turn, as least part of this is due to climate change.

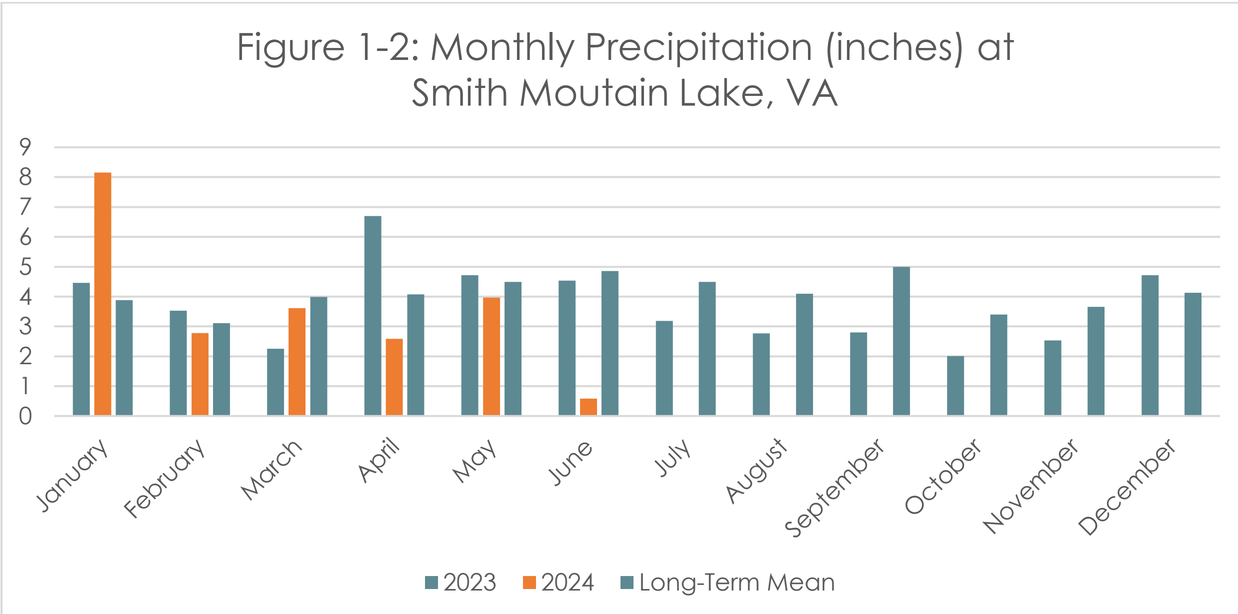
RECENT WATER QUALITY CONDITIONS

A HAB event was experienced in nearshore areas in Smith Mountain Lake in 2023. Specifically, this HAB event occurred in early June 2023 and involved the identification of unsafe cyanobacteria cell concentrations, as per the Viriginia Department of Health (VDH) for the entire Blackwater Arm of Smith Mountain Lake. Swimming Advisories were issued by the VDH and lasted until late August. To date, as of late August / early September 2024, similar conditions have not been brought to Princeton Hydro's attention. Thus, a brief review of overall conditions over the last two years will be briefly reviewed.

First, regionally, the last two winters (2022/2023 and 2023/2024) have been unusually mild for the Mid-Atlantic region of the United States. This has allowed the cyanobacteria to remain more active over the winter months as vegetative cells or hatch from akinetes earlier in the year. As shown in Figure 1-1, the winter 2023 and 2024 mean maximum air temperatures in the area were higher than the respective winter, long-term mean maximum values. Additionally, the 2024 spring temperatures were higher than the respective spring long-term values.



In 2023, with the exception of March, the months between January and May had higher amounts of precipitation than their respective long-term values (Figure 1-2). The additional amounts of runoff, particularly in April of 2023, transported nutrients to the lake and more than likely contributed toward the HABs experienced in early June 2023. In contrast, with the exception of January 2024, the monthly precipitation values in 2024 were lower than their respective long-term values (Figure 1-2). In particular, very little precipitation fell in June of 2024. These identify that the lower amounts of precipitation in the spring of 2024 contributed toward limiting algal growth, at least during the early summer season.



SUGGESTIONS / RECOMMENDATIONS

Based on a review of the historic and relatively recent data, Princeton Hydro has identified some suggestions and recommendations for the long-term management of Smith Mountain Lake.

1. The examination of the lake-wide trophic parameters is extremely valuable in identifying long-term and system-wide trends, particularly in light of climate change. However, data from specific coves, bays or sections of the lake that are more susceptible to HABs should be more closely examined and reviewed to identify specific trends or seasonal / hydraulic changes. These efforts are needed to better predict and eventually manage the development of near-shore, localized HABs.
2. It is strongly recommended that discrete samples should be collected in these near-shore sampling stations for the identification and enumeration of phytoplankton with a focus on cyanobacteria. The enumeration analysis should be presented as cells per mLs.
3. Depending on the depth of the sampling station as well as the findings of the overwintering incubation study, surface, and bottom (immediately over the sediments) samples should be considered for sampling phytoplankton densities.
4. Integrate *in-situ* phycocyanin readings with a Turner meter to provide a cost-effective means of assessing the relative risks associated with HABs. In order to do this a set of cyanobacteria samples should also be collected for enumeration at the same time the phycocyanin readings are taken. This will provide the data needed to conduct a regression analysis to predict cell count thresholds based on phycocyanin readings.
5. Finally, consider comparing 2024 plankton results to those of the March 2024 overwintering incubation study. It would be useful to see how the incubation study results can be used as a predictive tool in managing HABs in Smith Mountain Lake.

2. HYDROLOGIC AND POLLUTANT LOADING ANALYSIS

2.1 METHODS

Watersheds and sub-watersheds were delineated for the lake using watershed tools on ESRI's ArcGIS Pro 3.2 with 2018 LiDAR data as the original input file (obtained from the Virginia Geographic Information Network data portal, https://vgin.vdem.virginia.gov). For the purposes of this study, watershed areas listed include only the Blackwater Arm of the lake. Maps displaying watersheds and sub-watersheds are provided in Appendix I. GIS shapefiles for each sub-watershed and total watershed were imported into Model My Watershed, which produced a .gms file containing hydrologic and nutrient data for a 30-year period. This file was subsequently entered into Penn State's Generalized Watershed Loading Functions-Enhanced (GWLF-E) tool.

Edits to the .gms file were made in Model my Watershed prior to export and in GWLF-E. Weather data was obtained from CLIMOD2 (Station ID 441999: COPPER HILL, Station ID 447285: ROANOKE-BLACKSBURG RGNL AP, and Station ID 447338: ROCKY MOUNT) and converted to a formatted CSV file for upload to Model My Watershed. In order to assess septic system loading, all houses within each watershed were counted, with the number of houses within 15 meters (m) of the lake or stream were also noted. Populations within 15 m of the lake or any inflowing waterways, as well as 5% of the total population, were assumed to "short circuit" or contribute nutrients to waterways and/or groundwater prematurely; these systems usually contribute higher amounts of nutrients than systems with no issues.

Farm animal data was also entered into the GWLF-E prior to running. Animal data was obtained from the USDA's 2022 Census of Agriculture (Vilsack, T., and H. Hamer. 2024. 2022 Census of Agriculture. Virginia State and County Data. Volume 1, Geographic Area Series, Part 46. United States Department of Agriculture Report AC-22-A-46). Counts for Franklin County, VA were divided by 3 to represent an estimation of animals occurring in the full Blackwater River watershed. The percentage of the total watershed's area represented by each sub-watershed was estimated using land use data. This percentage was applied to each animal type total for the entire watershed to obtain estimates of each type for each sub watershed.

GWLF-E was run for a 30-year period following all necessary data edits. The model simulates loading and transport for each day based on actual weather records during the period of record. The data output includes monthly and annual averages. External watershed nutrient loading results are provided in Appendix IV.

Dryfall, or atmospheric nitrogen and phosphorus loads, were calculated by multiplying pre-established coefficients by the total area of the watershed and lake. Nitrogen was estimated to occur at a rate of 0.4 kg/ha/yr, while phosphorus was estimated to occur at a rate of 0.002 kg/ha/yr (USEPA, 1980). Dryfall was only calculated the full Blackwater watershed.

2.2 RESULTS

PHYSICAL CHARACTERISTICS

The full Blackwater River watershed covers an area of approximately 171,017 acres. Over half of this area (58%) is classified as forested land. While this land-type is present throughout the watershed, the largest continuous areas of forested land are located closer to the watershed's western edge, represented by the Blue Ridge Mountains. Agricultural land, particularly that classified as "Hay/Pasture", also covers a notable area of the watershed (23.6%). This is significant, as this land-use type is estimated to yield a large amount of runoff-based nutrients and sediment per unit area. The watershed is largely not urbanized, with only approximately 8.7% of the full area being classified as one of the developed land-use types. Most of this area is represented by areas along US Highway 220, particularly in the communities of Boones Mill and Wirtz. Several areas around the edge of Smith

Mountain Lake also contain a larger degree of urbanization, such as the western portion of the Pelican's Point area, the Waters Edge Country Club, and the areas along Dudley Amos Road and Hillcrest Heights Drive. The amount of urbanized landcover in an area is significant, as these land-use types often contain higher amounts of impervious landcover, such as concrete and asphalt paving, which allow for higher rates of runoff.

Descriptions of the waterbody's sub watersheds are as follows:

- **Gills Creek:** This sub watershed is located along the northern portion of the full Blackwater River watershed, covering an area of approximately 26,631 acres. Approximately 58% of the area contains forested land, while land categorized as hay/pasture covers an additional 25.5%.
- **Little Creek:** This sub watershed is located in the western half of the full watershed, covering an area of approximately 16,106 acres. A majority (48.5%) of the area is classified as forested, with the hay/pasture land-use type covering an additional 32.7%.
- **Lower Blackwater River:** This sub watershed is located at the eastern end of the full Blackwater River watershed, covering an area of approximately 11,790 acres. A majority (56.7%) of this area is forested, with an additional 19% of the area being classified as hay/pasture. This sub watershed also contains a larger amount of urbanized land use than any of the other sub watersheds, with these land-use categories being represented by over 15% of the area.
- **Maggodee Creek:** This sub watershed is located in the central-north portion of the full Blackwater River watershed, featuring an area of approximately 29,178 acres. Approximately 64% of the area is covered by forested land, with the hay/pasture land-use type being represented in an additional 21.2% of the area.
- **Middle Blackwater River:** This sub watershed is located in the eastern portion of the full Blackwater River watershed and contains the confluence of Maggodee Creek and the mainstem of the Blackwater River. The sub watershed encompasses an area of approximately 27,753 acres, with approximately half of this area featured forested land. Land categorized as hay/pasture covers an additional 31.3% of the area.
- **North Fork Blackwater River:** This sub watershed is located in the western portion of the full Blackwater River watershed, covering an area of approximately 20,427 acres. Over 72% of the area is forested, with the hay/pasture land-use type covering an additional 18.2%.
- **South Fork Blackwater River:** This sub watershed is located at the western end of the Blackwater River watershed, bordering the Blue Ridge Mountains. The sub watershed features an area of approximately 18,023 acres, with 73.3% of this area containing forested areas. An additional 15.9% of the area is categorized as hay/pasture.
- **Upper Blackwater River:** This sub watershed is located along the southern portion of the full Blackwater River sub watershed, covering an area of approximately 21,109 acres. Approximately 58% of the area is forested, while an additional 22.2% features land categorized as hay/pasture.

According to the USDA's Gridded Soil Survey Geographic (SSURGO) 2016 hydrologic soil groups data, the Blackwater River watershed consists largely of group "B – Moderate Infiltration" soils. This soil group allows for a degree of infiltration into ground by rainwater prior to runoff occurring. Areas with slower-infiltrating soils may produce more runoff and erosion. It should be noted that the North Fork Blackwater River sub watershed features an approximately 33% coverage with soil group "A – High Infiltration", suggesting that the soils in this sub watershed may allow for less runoff.

Variations in elevation change in a watershed can determine the impact water runoff has on soil erosion, with steeper slopes causing higher erosion rates, especially if little vegetation is present. While the percent slope in the full watershed averages approximately 16.3%, the maximum percent slope is approximately 107%, which occurs in the South Fork Blackwater River sub watershed. This sub watershed also yielded the highest average slope of

24.3%. Given the inclusion of the Blue Ridge Mountains in the sub watersheds in the North Fork and South Fork of the Blackwater River, it may be expected that these two sub watersheds have the overall steeper slopes.

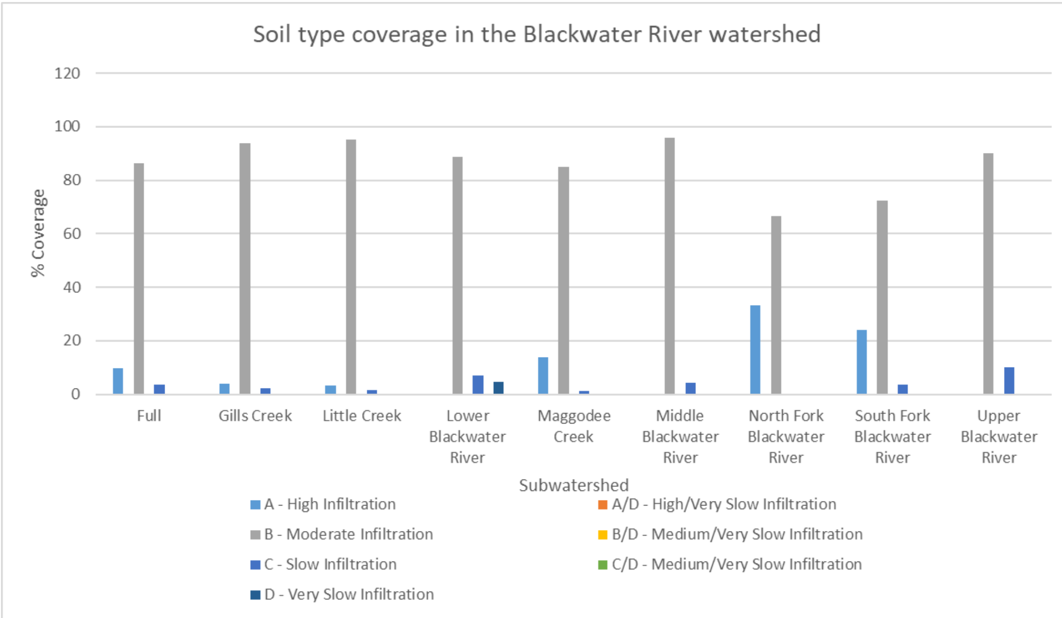


Figure 2-1. Percent coverage of the Blackwater River watershed and sub watersheds by different hydrologic soil groups.

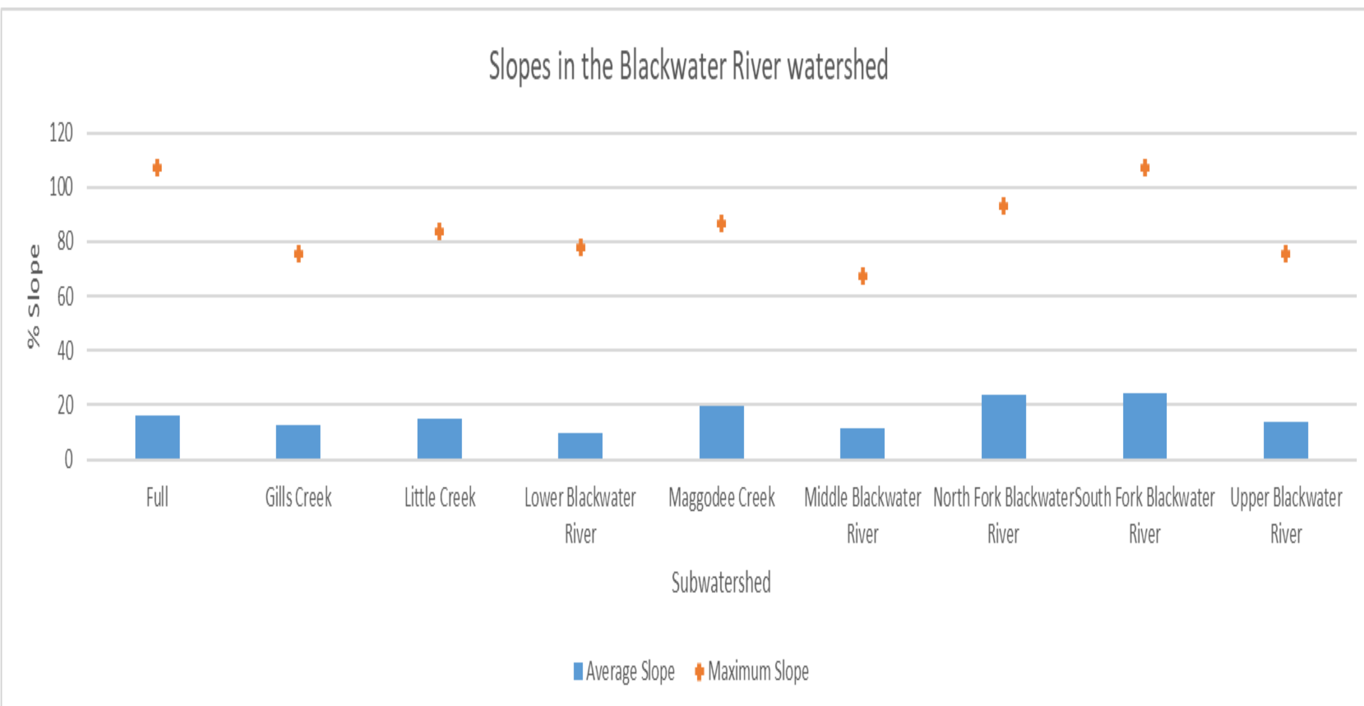


Figure 2-2. Variation in average and maximum percent slope between sub watersheds in the Blackwater River watershed.

HYDROLOGY

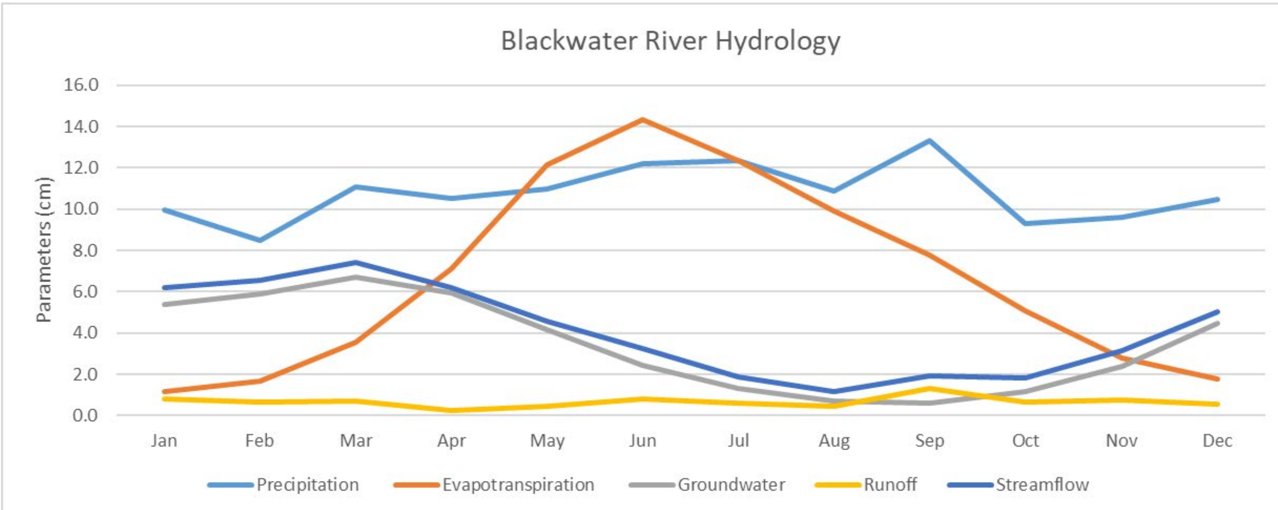


Figure 2-3. Estimated seasonal changes in hydrology in the Blackwater River Watershed

Table 2-1. Total hydrological parameters in the Blackwater River watershed

Month	Precipitation	Evapotranspiration	Groundwater	Runoff	Streamflow	
	cm	cm	cm	cm	cm	cfs
Jan	9.9	1.2	5.4	0.8	6.2	564.8
Feb	8.5	1.7	5.9	0.7	6.5	654.9
Mar	11.1	3.5	6.7	0.7	7.4	675.3
Apr	10.5	7.1	6.0	0.3	6.2	584.6
May	11.0	12.1	4.2	0.4	4.6	417.9
Jun	12.2	14.3	2.4	0.8	3.2	305.5
Jul	12.3	12.4	1.3	0.6	1.9	172.5
Aug	10.9	9.9	0.7	0.5	1.2	106.8
Sep	13.3	7.8	0.6	1.3	1.9	182.9
Oct	9.3	5.1	1.2	0.7	1.8	165.2
Nov	9.6	2.8	2.4	0.8	3.1	296.1
Dec	10.5	1.8	4.5	0.5	5.0	457.2
Total	129.0	79.7	41.2	8.0	49.1	380.6

Runoff varied between the different sub watersheds by as much as approximately 50%, with the Lower Blackwater River sub watershed yielding the highest runoff throughout the year. The North Fork Blackwater River was estimated to produce notably less runoff throughout the year, likely as a product of its relatively high-infiltration soils.

As displayed in Table 2-1, most hydrologic data is presented in the one-dimensional unit of centimeters, in order to relate these metrics back to precipitation, the base of a watershed's hydrology. This allows for a simpler comparison between watersheds. The total amount of water in m³ each of these values represents can be calculated by multiplying the value by 0.01 (in order to convert the unit to m²) and multiplying this product by the total watershed area in m². As displayed above, streamflow is also reported as cubic feet per second (cfs), a common measurement of waterflow. The streamflow component is the sum of the groundwater and runoff components, which themselves are influenced by modeled evapotranspiration, precipitation, groundwater intrusion, and other factors.

Based on the above hydrologic components, when multiplied by the total area of the watershed as described above, the full Blackwater River Watershed is estimated to yield approximately 339,881,497 m³ or 89.8 billion gallons of water during an average year.

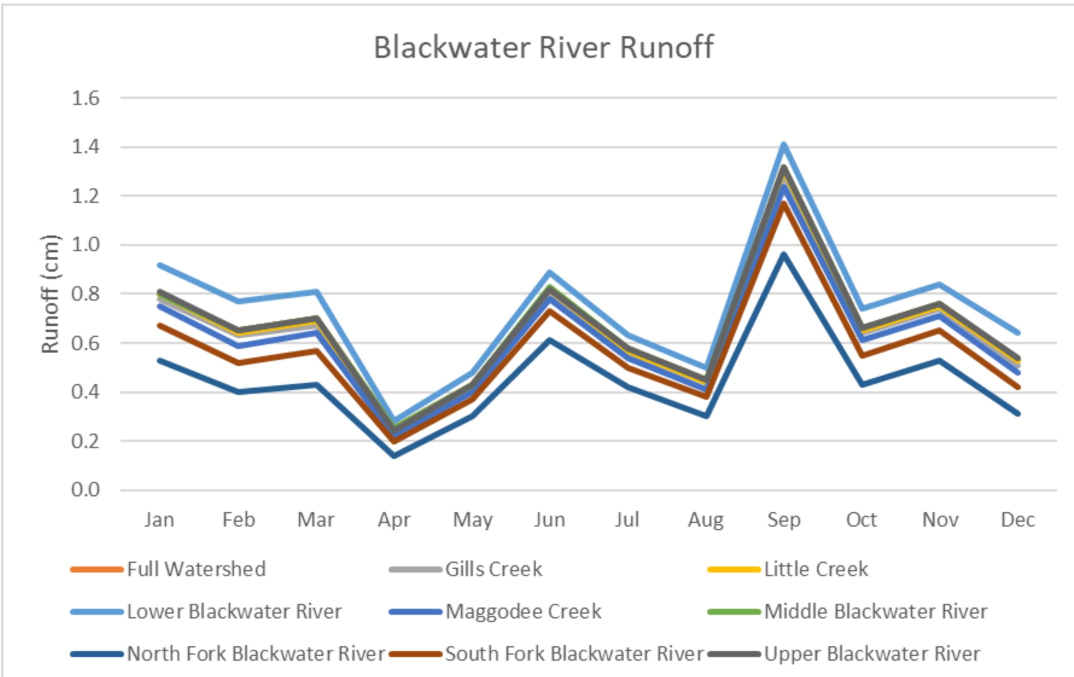


Figure 2-4. Average monthly runoff occurring by sub-watershed in the Blackwater River watershed

NUTRIENTS, SEDIMENT, AND BACTERIA

Almost half (46.1%) of the annual estimated nitrogen load for the Blackwater River watershed is estimated to occur via groundwater flows. It should be noted that groundwater typically contains naturally higher concentrations of nitrogen than most surface waters, due to the high solubility of nitrogen in water. Septic leachate also usually enters into the groundwater when present, further influencing this, as can be observed in the results from the watersheds with more houses. A notable amount of the total estimated load (21.8%) is also estimated to occur from farm animals in the watershed. The Magodee Creek sub watershed is estimated to yield the overall highest annual nitrogen load each year at approximately 73,808 kg. On a per-unit-area basis, however, the Little Creek and Upper Blackwater River sub watersheds are estimated to yield the highest annual rate of nitrogen at 3.5 kg/acre. The full watershed is estimated to yield approximately 481,162 kg of nitrogen during an average year, or approximately 2.8 kg/acre.

Farm animal impacts were estimated to contribute the largest annual load (31.7% of the total) of phosphorus, with stream bank erosion and runoff from land categorized as hay/pasture also yielding large percentages, at 21.8% and 25%, respectively. As mentioned above, the hay/pasture land-use category produces a large amount of nutrients and sediment via runoff in the GWLF-E model. On the basis of individual sub watersheds, this was often modeled to be the leading source of phosphorus. The Middle Blackwater River sub watershed was estimated to yield the overall highest annual phosphorus load at approximately 13,973 kg/year. The Little Creek sub watershed, however, was estimated to yield the highest amount of phosphorus per acre, at approximately 0.65 kg/acre. The full watershed is estimated to yield approximately 72,934 kg of phosphorus during an average year, or approximately 0.43 kg/acre.

The annual estimated sediment load in the Blackwater River watershed was dominated by sediment originating from streambank erosion, which was estimated to yield over 75% of the annual total. An additional 16.7% was estimated to originate as runoff from land categorized as hay/pasture. As with phosphorous loading, the Middle Blackwater River sub watershed was estimated to yield the highest annual sediment load at approximately 8,278,774 kg/yr. The Little Creek sub watershed was estimated to yield the highest amount of sediment per acre at 417 kg/acre. In total, the Blackwater River Watershed is estimated to yield approximately 73,587,681 kg of sediment during an average year, or approximately 430.3 kg/acre.

Almost the entirety of the Blackwater River's annual bacterial load is estimated to originate from farm animals, with the Middle Blackwater River sub watershed yielding the highest annual load, at approximately 7.83E+15 organisms during an average year. The full watershed is estimated to yield approximately 3.85E+16 organisms during an average year.

3. GENERALIZED ANALYSIS OF THE POLLUTANT REMOVAL ACHIEVABLE THROUGH THE IMPLEMENTATION OF SPECIFIC WATERSHED BASED MANAGEMENT TECHNIQUES

3.1 METHODS

The primary reason for conducting this study is to identify what can be done in the Blackwater River sub-watershed of the Lake to minimize the annual pollutant loading. As can be seen below, these pollutants consist of the common ecological nutrients: phosphorus, nitrogen, and suspended solids. These pollutants are also known to be the primary cause of eutrophication in lakes, which can lead to conditions that are prone to the development of harmful algal blooms (HABs). With this data the watershed-based management options can be determined, with the ultimate goal being minimization of surface water quality issues.

3.2 RESULTS

As can be seen in Section 2, using the above referenced method allows for the identification of those sub-watersheds of the Blackwater River sub-watershed having the greatest impact on total pollutant loading as well as those sub watersheds having the most manageable (correctable) loads. Using the data generated from Section 2, a full set of cut sheets that detail generalized Best Management Practices (BMPs) and Green Infrastructure (GI) techniques that could effectively manage the pollutant loads generated by each major sub-watershed's specific pollutant loads has been generated. Our data review suggests emphasis should be given to bioretention type systems that can be implemented on a lot-specific or regional scale in the Blackwater River sub-watershed. Such BMPs have a high capacity for the removal of nutrients. These cut sheets can be found in Appendix V.

In addition to the recommendations within the cut sheets, Princeton Hydro also provides the following general recommendations for implementation throughout the watershed. These include such common practices as bank stabilization, riparian zone enhancement, and easy to implement individual homeowner suggestions.

STREAMBANK STABILIZATION AND RIPARIAN BUFFER ENHANCEMENTS

Streambank Stabilization

An important set of watershed management measures throughout the watershed involves streambank stabilization and riparian buffer enhancements. Given the moderate grade throughout many of the watersheds of Smith Mountain Lake, there are likely additional stream sites that could be restored or enhanced through streambank and streambed stabilization as well as riparian buffer enhancements. As such, this section will provide a brief overview of these general stream restoration measures and how they can reduce pollutant loading.

One of the most important functions of streams is sediment transport, and there are a variety of factors that contribute to erosion and sediment loading. One of these main factors is the moderate grade throughout portions of the watershed. Anthropogenic stressors also increase erosion and sediment loading, including high impervious cover and stormwater loading, as well as buffer impairments related to general development patterns.

Stream restoration and riparian buffer enhancements have advanced considerably in recent years. Previously, channel management focused on hard engineering designs meant to lock channels in place, channel "cleaning" exercises to remove substrate and increase flow velocities and straightening. These actions have largely proven futile, are subject to high failure rates, and ultimately do not account for naturalistic stream functions. Many stream restoration efforts today focus on correcting those earlier management activities. This is due to better understanding of riverine dynamics and a different management approach, one that is dependent on the theory of dynamic equilibrium, as well as floodplain connectivity, and improving aquatic habitat value. The major streambank restoration measures that are the most relevant include the following:

Riparian Buffer Enhancements

The enhancement, preservation, and protection of riparian buffers are important measures for protecting water quality in a waterbody. One of the reasons that riparian buffer enhancement is so important is that the benefits are multi-lateral. For instance, the enhancement of a degraded buffer, one that is characterized by lack of native vegetation including shrubs and trees, soil disturbances, and impervious surfaces among other problems, offers improved canopy coverage and stream shading which reduces stream temperature thereby improving benthic macroinvertebrate and fisheries habitat with resultant improvements in community structure, as well as decreased biological productivity related to periphyton growth thus leading to improvements in both dissolved oxygen and pH. The following list exhibits some of the benefits of riparian buffer enhancement:

- Increased shading and maintenance of lower temperatures,
- Decreased algal productivity,
- Nutrient removal through vegetative uptake,
- Vegetative trapping of solids and other pollutants from the surrounding watershed,
- Reduced runoff velocity and increased infiltration and evapotranspiration,
- Increased bank stability and decreased erosion and sedimentation,
- Functional wildlife habitat and protection of rare species,
- Barrier to waterfowl access and decreased coliform loading,
- Reduced flood damage,
- Improved carbon cycling and allochthonous material deposition, and
- Reduced invasive vegetation colonization

No Mow Zones - The establishment of no-mow zones is probably the most easily implemented BMP that can improve stream function. The mowing of riparian buffers or the establishment of maintained lawn space is typical in developed watersheds and mowing often continues to the very top of the streambank within feet of the wetted channel. This leads to severe bank instability often characterized by mass wasting and severe undercutting. Besides the erosion and subsequent sediment deposition of the unstable banks much of the function associated with vegetated buffers, including shading, nutrient uptake, and wildlife habitat, among others, is lost.

Riparian Buffer Planting - The next step in riparian buffer enhancement is a more thorough approach focused on the restoration of native vegetation. Crucial to this scheme is the replication of natural riparian vegetation communities which integrate multiple vegetation types including herbaceous plants, shrubs, and trees, and may be structured to match different communities including riparian forests and herbaceous and scrub/shrub wetlands. In addition, these planting plans can be tailored as necessary to provide enhancement of existing but degraded buffers or the complete mitigation of severely degraded or non-existent buffers such as in maintained lawns. The design philosophy of riparian buffer planting is to restore the natural pollutant removal capabilities and stabilizing properties of fully functioning riparian buffers by adapting to site specific conditions such as soil moisture and incorporating those considerations into a three-dimensional plan that prominently features vertical design elements, such as trees, to produce a self-sustaining plant community.

Bank Stabilization

A variety of methods are used to stabilize streambanks ranging from simple projects such as planting to more complex methods such as grading and potentially the placement of rock for toe protection or grade controls. The choice of method depends on a variety of factors including site hydraulics, stream order, erosion severity, channel incision, floodplain connectivity, and proximity to structures. Most stream stabilization and restoration projects rely heavily on a vegetative component. As with riparian buffer enhancement, vegetation serves a variety of functions, the most important of which is the stabilization of the bank through the rooting.

Grade Control

In-stream grade control is also another important component of bed and bank stabilization. While erosion is mostly thought of as a problem with the banks, channel incision includes both horizontal (bank) and vertical (bed) erosion. The erosion of bed materials results in entrenchment or a hydraulic disconnect of the channel with the floodplain. Since the stream no longer can leave its banks all the flow is forced through the incised channel resulting in even greater erosion due to low flow area which yields increased velocities. Under these conditions a typical type of erosional process that develops is the head cut, an erosional feature in the bed that migrates upstream. Grade controls therefore mitigate these processes and could include several types of engineered features such as rock riffles, step pools, and cross vanes or V-weirs. Grade control measures are also frequently used when stream channels have been extensively reshaped or when impoundments have been removed to prevent the formation of head cuts and to align flows in the center of the channel. Another use of grade control structures is to elevate the entire channel of severely incised streams to restore floodplain connectivity.

STORMWATER MANAGEMENT

Downspout Disconnection

Downspout disconnection is a simple practice that involves the rerouting of rooftop drainage pipes (gutter downspouts) from draining to an impervious surface that drains directly to the stormwater sewer, to draining rainwater into rain barrels, cisterns, or other permeable areas such as grassy or vegetated areas. It is important to divert the rainwater away from the foundation of a house, especially if there is a basement or crawlspace.

Rainwater Harvesting

Rainwater harvesting is one of the easiest and cheapest methods of managing stormwater runoff from impervious roofs. Rainwater harvesting simply involves capturing runoff from the gutter downspout of a roof and temporarily storing it in a container. Harvesting stormwater from the gutter downspout reduces the erosive force that occurs when the downspout drains directly to the ground. The rain barrel overflow can be directed to vegetated areas to allow for infiltration into the soil rather than draining directly to an impervious surface. The harvested rainwater is also an ideal source of irrigation for gardening or lawn maintenance.

For a small roof such as a house, a rain barrel is the ideal container for rainwater harvesting. Rain barrels are typically 55-gallon drums but can be purchased or built to accommodate larger volumes. Additionally, multiple rain barrels can be connected with hoses for increased storage capacity. There are countless resources on how to build and install a rain barrel at home and can cost from around $30 - $300 or more, depending on availability of the materials. There are a number of websites dedicated to rain barrels, including on how to build one.

For commercial rooftops or any rooftop with a large surface area, cisterns and dry wells are superior to rain barrels for rainwater harvesting. Cisterns are used for larger rooftops and can capture and store between 100 and 10,000 gallons of runoff. Drywells are small, subsurface detention basins that collect stormwater runoff from smaller drainage areas. Water collected by drywells slowly infiltrates into the ground to contribute to recharge. Generally, the costs for cisterns and dry wells can range anywhere from $150 - $700+ for units <500 gallons to $500 - $3000+ for units >500 gallons ($3000+ for a sub-surface, 800 gallon two-tank unit). Costs will vary greatly depending on size, number of downspouts, above ground or below ground, etc. and do not include design and installation.

Downspout Planters

Downspout planters or planter boxes are small structures that contain an engineered soil/gravel mix and native vegetation that enhance stormwater infiltration and nutrient removal. They are essentially small-scale rain gardens and can create the visual appeal of standard landscape planters with an enhanced ability for infiltration and nutrient removal. These systems are placed directly adjacent to a building, similar to a rain-barrel, where rainwater from the roof of a structure flows into the structure through the gutter downspout. Similar to a rain garden, these systems can be designed with an underdrain pipe or they can be designed to infiltrate into the subsoil.

Green Roof

Green roofs are roofing surfaces that are partly or completely covered with vegetation. Green roofs provide stormwater management by slowing down rainfall and by allowing a portion of the precipitation to be returned to the atmosphere through evapotranspiration. Green roofs have been shown to hold a significant amount of the rainfall that reaches their surface in the summer. Green roofs decrease stress on storm sewer systems by retaining and delaying the release of stormwater.

A professional company can install a green roof, typically for approximately $10 to $40 per square foot. Note, site specific issues or constraints may result in additional costs in the installation; considerations include roof loading, accessibility for maintenance, the height and the pitch of the roof, and maintenance budgets. Such considerations often necessitate the need for professional installation. An extensive green rooftop is one that is limited to grasses and mosses and has a shallow substrate (< 4").

Curb Bumpout

Curb bumpouts are relatively small extensions of the curb that extend into the roadway. These areas are designed in a similar fashion to rain gardens, with a bottom layer of gravel or stone, followed by soil and native plants. They are designed with inlets and/or curb-cuts along the street and/or sidewalk that directs stormwater runoff into the system. In addition to improving stormwater management in the community through enhanced infiltration and filtration of nutrients and other pollutants, they improve the appearance of the community. They can also be strategically placed at intersections to help slow traffic and improve pedestrian safety.

Stormwater Planter

Stormwater planters are a type of linear bioretention system often used in urban areas. However, they can also be used in residential neighborhoods when space is limited for larger green infrastructure practices, such as bioswales. Stormwater planters are rectangular structures, usually with four concrete curbs around the perimeter. They are vegetated structures that are often installed within an existing sidewalk, between the walkway and the road. They are designed to receive stormwater runoff from both the road and the sidewalk through curb cuts and drains. They are similar to curb bumpouts and other bioretention systems in that they incorporate gravel or stone, soil, and native plants to enhance stormwater infiltration and nutrient filtration. Wherever possible, these systems are designed to infiltrate water into the subsoil; however, they can also be designed with an outlet structure that conveys the stormwater back to the existing subsurface stormwater system. The latter type of system is only recommended when the soil is not suitable for proper infiltration.

Tree Boxes

Tree boxes are manufactured treatment devices that incorporate soil and vegetation, thus classifying them as green infrastructure. These devices are large concrete boxes that incorporate a specialized soil media and a tree. They are often installed along a curb, similar to a curbside catch basin, and allow for high volume/flow treatment in a compact system. Unlike a standard bioretention system, they do not result in volume reduction, however, they do provide pollutant removal.

Pervious Pavers/Pavement

Pervious pavement may be considered as a retrofit option where functionality of an otherwise impervious surface, such as a parking stall or roadway shoulder, is pertinent to a design but additional infrastructure may be required if the project is large enough to trigger water quality and/or groundwater recharge requirements. The systems can consist of porous surface course, interlocking paver units that allow for runoff to filter vertically through the pavement into the subsoil, or an underdrain. In addition to serving the functionality of both stormwater management treatment and driveable/walkable area, pervious pavement can also reduce loads on storm sewer systems, allowing for smaller pipes, fewer inlets, and reduced ponding.

Pervious pavement is subject to very specific loading ratios and the design is governed by the hydraulic conductivity of the underlying soil and depth to seasonal high groundwater table (SHWT), as with all infiltrating BMPs. Consideration must also be given to the maintenance and operations costs associated with pervious pavement installations as regular vacuum street sweeping is vital to their continued operation.

PET WASTE MANAGEMENT

The key to this group of watershed management involves widespread implementation followed by consistent enforcement. As such, it is important to highlight primary elements of a successful pet waste management plan. Areas throughout the watershed that should be targeted for pet waste and wildlife management include public areas such as parks, beaches, and other recreational areas. Since they are public places, people may not always be equipped with the proper waste disposal items, such as small bags. Incorporating cultural practices like this also raises the general awareness of surface water protection and environmental stewardship by getting the community involved.

- Education and Outreach – As a program that is dependent on individual pet owners, education and outreach is key to success. Educational elements should address public health and water quality impacts. Outreach can be done through multiple means including educational brochures, public meetings and committee formation, signage, and media campaigns including press releases and website publishing.
- Investigation – Identifying and prioritizing problem areas is important for managing the problem and will direct where waste management tools should be employed. Researching pet owner behavior through surveys and field studies can also be utilized.
- Waste Management – Providing waste receptacles and bags in public spaces encourages proper waste disposal.
- Public Policy – Leash laws, pet waste ordinance, and policy regarding animals in public spaces should be implemented with reasonable enforcement mechanisms.

NATURAL LANDSCAPING

Another watershed management method that can reduce the nutrient and sediment loading is the implementation of alternative landscaping and lawn cover. The basis of alternative or natural landscaping is to replace typical turf grass areas with native vegetation plantings which have lower fertilizer and irrigation requirements. Research has widely documented that natural landscaping practices decrease the bulk density (compaction) of soil and provide drastically increased infiltration capacity. Therefore these areas tend to produce significantly less runoff when compared to typical turf lawns areas. When properly implemented, these naturally landscaped areas can also provide treatment for remaining lawn areas of the property.

Public education efforts should focus on the aesthetic, economic, and ecological advantages of maintaining portions of their property with natural landscaping techniques. This outreach could include brochures and newsletters which illustrate and describe the advantages of a natural landscape approach. The information should provide the public with resources where they can find native vegetation and mulch.

FERTILIZER MANAGEMENT

The primary developed land use in most watersheds is the single family, residential lot, with some of those located in close proximity to the Lake(s). The majority of the land area in the typical residential development within these watersheds is thus devoted to turf cover. Research has widely documented that lawns and turf areas can be major contributors of nutrients and sediment loads (Center for Watershed Protection, 2003). The propensity for lawn areas to contribute nutrients is directly related to the management and fertilizer application provided by the homeowner and therefore this is a behavior issue. Studies have shown that the majority of fertilizer application (75%) is done by homeowners. Furthermore, studies have also shown that the majority (50-70%) of fertilizers (homeowner and lawn care providers) apply fertilizer in excess of the lawn requirements. Proper fertilization application rates and types (if necessary at all) can only be determined through soil tests, however public surveys and research have indicated that less than 10% of home owners have ever had any soil tests conducted to assess the fertilizer requirement of their lawn. Unfortunately, many homeowners base their fertilizer application rates on information from commercial sources (fertilizer packaging labels, sales personnel, lawn care companies and other purveyors of fertilizer) (Center for Watershed Protection, 2005).

Fertilizer applications must also be timed properly to account for plant needs and to anticipate rainfall events. For example, nutrients are most needed in the spring and fall, not throughout the summer. Also, rain induced fertilizer losses are greatest immediately following an application because the material has neither become adsorbed by the soil nor taken up by the plants. Fertilizer uptake and retention is promoted by proper soil pH. Although soil pH can have a significant bearing on the ability of soils to retain nutrients, such testing is also not commonly conducted by property owners. The application of lime, especially in areas of acidic soils, can improve phosphorus uptake and retention. Other non-chemical lawn care treatments such as de-thatching and aeration are also rarely conducted (Watershed Protection, 1994). Urban soils, even those associated with lawns, can become compacted due to site clearing and grading practices and function similar to impervious areas in respect to the generation of storm water runoff (Schueler, 1995). Aerating lawns helps promote better infiltration and the generation of less runoff and therefore less export of nutrients.

Public Education is the main pathway to address these behavior issues related to NPS pollution. Homeowner behavioral changes that can have a significant impact on the NPS pollution related to lawn and turf area management include proper fertilizer application and reduced total turf areas. The reduction of turf areas is addressed in the following section. By applying only the necessary quantity and proper type of fertilizer necessary for optimum plant growth, the amount of nutrients that can potentially be mobilized and transported to surface and groundwater resources is minimized. Use of non-phosphorus fertilizers or slow-release nitrogen fertilizers also decreases the loading to receiving waters. The effectiveness of fertilizer management is dependent upon cumulative effects within a watershed and requires commitment on an area-wide basis.

The most effective public education techniques related to lawn care are those that illustrate the benefits of proper and educated lawn care behavior. Educational techniques should inform the residents that proper lawn management techniques can have direct financial benefits while still provide a desirable or potentially improved lawn.

Specific educational techniques that could be implemented by the SMLA include media awareness campaigns including the distribution of outreach materials related to proper lawn care techniques. These techniques should be focused (geographically) and timed to during the periods of peak fertilizer application (spring and fall). The outreach materials should include resources where homeowners can get their soil tested to determine proper fertilizer requirements. Programs for free or reduced cost soil tests will greatly increase public participation. The Public Education techniques should also focus on fertilizer retailers and attempt to provide informational brochures at retail locations during periods of high fertilizer sales. Specifically, the SMLA and any other pertinent stakeholders should conduct the public education campaign that informs all the residents of the benefits of fertilizer and pesticide management, stressing the low-cost alternatives and environmental benefits of such techniques. Residents should be educated about conducting soil pH and nutrient testing before applying any lawn care product to their lawn. They should also be informed about the benefits of liming, aeration, thatch control, and other non-chemical lawn care measures.

SEPTIC SYSTEM MANAGEMENT

Traditional septic systems consist of a septic tank that receives wastewater which is then discharged to a distribution box and then distributed to the drainage field via perforated conveyance lines. The tanks provide primary treatment that includes the separation of solids that sink from the wastewater and subsequent bacterial decomposition of the solids. Secondary treatment is provided as the wastewater infiltrates the subsurface soils, through adsorption, filtration, oxidation, and other means. There are other types of septic systems that may be present, such as sand-mound systems. These systems consist of a septic tank that receives wastewater which is then discharged to a pump chamber where it is pumped to the sand mound in prescribed doses. Similar to the traditional system, the tanks provide primary treatment that includes the separation of solids that sink from the wastewater and subsequent bacterial decomposition of the solids. Secondary treatment of the effluent is then provided as it discharges to the trench and filters through the sand, then dispersing into the soil. These systems are typically installed in areas of shallow soil depth, high groundwater, or shallow bedrock

Septic System Failure

Septic systems are an important component of managing wastewater, especially in rural and lake communities where treatment and conveyance infrastructure does not exist. Treatment capacity of these systems can be high when maintained properly. However, septic system failure can be a serious concern, especially for older systems. Some failures can be obvious while others are less so. Failures can result from design, performance, or age, but these often overlap. Common failure types according to EPA are:

Hydraulic – Excessive hydraulic loading to undersized systems, low soil permeability, ponding, poor maintenance, or increasing water use over the design capacity.

Organic – Excessive organic loading from unpumped, sludge-filled tanks results in biomat loss of permeability (a stratum of anaerobic bacteria lining the trenches in the drain field).

Depth to Limiting Zone – Insufficient soil depths, high water tables, and impermeable layers can diminish pathogen removal and hydraulic performance. Sand mound systems correct for depth to limiting zones by mounding appropriate soil for treatment.

System Age – Systems more than 25 to 30 years old on average. Failure rates in older systems triple. Regular maintenance, e.g., tank pumping and alternating leach fields, can substantially prolong system life.

Design Failure – Inappropriate system design for site characteristics including hydraulic load or restrictions.

System Density – Cumulative effluent load from all systems in watershed or groundwater recharge area exceeds the capacity of the area to accept or properly treat effluent.

Signs of Septic System Failure

The following are a list of common warning signs of septic system inadequacy/failure that owners can monitor:

- Sewage backs up into the household plumbing,
- Untreated sewage emerges at the land surface,
- Untreated sewage leaches into the groundwater,
- The ground above the absorption area is very spongy,
- Sewage odor is noticeable in the house or well water,
- Dosing tank alarm light is on, and
- Dosing pump runs constantly or not at all.

Proper septic system management is vital to reduce the potential for failures, prolong the life of the system, and to protect local waterways. At its most basic, septic system management for existing systems must incorporate actions for the following elements:

- Inspection
- Maintenance
- Repair
- Replacement

For the most part, these items will be the responsibility of the system owner. It is important to stress that there are cost savings involved in minimizing repairs or replacement through spending on inspection and maintenance.

Inspection

To avoid septic system failure, systems must be inspected by trained professionals regularly. Inspections often include, but are not limited to the following elements:

- Check accumulation of sludge, scum, or trash,
- Review previous inspections and maintenance,
- Piping to and from the box should be assessed for clogs, cracks, and failures,
- Assess tank conditions for cracks, rust, baffle integrity, misalignment, and malfunction, and
- Assess leach field conditions, which may include digging a cross-section.

Maintenance and Best Management Practices

Maintenance is one of the most important factors in the management of septic systems. Without regular maintenance performance suffers and they may not properly treat the effluent leading to excessive nutrient and bacteria loading. The following maintenance tasks and best management practices should be part of the routine operation of all septic systems:

- Septic tanks should be pumped out and inspected every 3 years for full-time residents and every 5 years for part-time residents. For systems that may be undersized, experience heavy use, have exhibited performance problems, are subject to non-flushable wipes, or are nearing the end of their life cycle, pumping frequency may need to be increased.
- Maintain inspection records and know the location of the access manhole, inspection ports, and drainfield.
- Practice water conservation and limit, where possible, excessive wastewater generation
- Do not drive and park on the septic as this has the potential to damage septic components and compact soils.
- Divert runoff from impervious areas including roofs and driveways away from the system.
- Limit vegetation on the systems to grass; woody vegetation can damage pipes and tanks.
- Use low-phosphorus or no-phosphorus detergents.
- Septic system additives are not effective and may compound problems or leach organic solvents.
- Do not dispose of non-degradable material such as grease, cigarette butts, or personal hygiene items, do not use garbage disposals as these can overload the system with organic materials, and do not dispose of medicines, solvents, paints, poisons, or excessive household cleaning chemicals.

These maintenance measures can improve performance and increase the longevity of septic systems. Solids pumping is the most important action because if a system is not properly cleaned, sludge will buildup in the system and could either clog pipes and the outlet or foul the drainfield which could cause flooding of untreated effluent or backup into the structure. A properly maintained septic system will cost far less over the long run.

Repairs, Replacements, and New Construction

Professional special inspections, inspections during pump outs, and general operator awareness may necessitate system repairs to maintain system efficacy or correct deficiencies. These repairs can be minor or major, and given the severity of the impairment could require outright system replacement. Major repairs and other alterations could require township, county and/or Lake Association approval, as would replacements. Replacements in particular may make a major difference in pollutant loading to the lakes as replacements systems will adhere to current technical regulations that ensure better treatment of effluent.

4. OVERWINTERING PHYTOPLANKTON ASSESSMENT

4.1 OVERVIEW AND METHODS

A nearshore assessment of overwintering algae was conducted by Princeton Hydro. In the Blackwater arm of the lake, some genera of cyanobacteria form resting spores known as akinetes. The akinetes are very hardy and can withstand harsh environmental conditions including low temperatures. After their formation, some of these akinetes may settle on the sediments. In the spring, environmental cues including increasing water temperature and increasing light, trigger these cells to come out of dormancy, effectively seeding the plankton at the beginning of the growing season. Some cyanobacterial cells also overwinter in the sediments in typical vegetative form, but the survival is much lower relative to akinetes.

This assessment therefore seeks to help characterize the potential early growing season emergence of cyanobacteria. Such data may provide insights on where, when, and how to manage the crop of cyanobacteria emerging from the sediments. Additionally, early season proactive management may provide an effective alternative to later reactive management practices and help lower overall growing season algal productivity.

A bench-scale experiment was therefore conducted to develop this data. Essentially, sediment samples were collected from a number of stations in the lake which had been previously identified as areas subject to HABs. These sediment samples were brought back to Princeton Hydro's biological laboratory, placed in beakers with filtered lake water, and incubated under controlled temperature and light conditions to mimic the environmental conditions to promote cyanobacteria growth from the sediments. After two weeks, phytoplankton samples were collected, processed, and analyzed to characterize the resultant growth. Note, the methodology used for this incubation experiment was originally developed by the US Army Corps of Engineers (Calomeni et.al., 2023). Princeton Hydro slightly modified this methodology to accommodate our project goals and objectives for Smith Mountain Lake.

4.2 METHODS

Sediment, plankton, and water quality samples were collected at six locations subject to HABs during the summer of 2023. Those locations, provided as a map in Appendix III, include:

- Anthony Ford
- Crafts Church
- Gills Creek
- Pine Cone(reference station, no prior HAB)
- Sandy Point
- Virginia Key

In-situ measurements were collected with a calibrated multi-probe water quality meter in profile at each station including a surface, mid-depth, and deep sample near the sediments. Parameters included:

- Temperature
- Dissolved oxygen (concentration and percent saturation)
- Specific Conductivity
- pH
- Chlorophyll-a

Two additional photosynthetic pigments, phycocyanin and phycoerythrin, were sampled with a Turner AquaFluor fluorometer. Phycocyanin (PC) is a pigment associated with cyanobacteria, although it is also produced by cryptomonads. Phycoerythrin (PE) is another pigment produced by cyanobacteria, but tends to be more common in benthic genera like *Oscillatoria* and is also known to be produced by cryptomonads. Separating the PC signals between cyanobacteria and cryptomonads cannot be done using pigment concentrations alone, but the pigments provide a good method of advance warning of HAB formation.

Sediment samples, to be used for incubation, were collected using a petite Ponar dredge. Only the upper four centimeters of the sample were retained. In samples where there was insufficient material, chiefly those with coarser grain-size distribution, a second sample was collected. Sediment samples were split into replicates for all stations, labeled 1 and 2 respectively, except Gills Creek due to incubator space limitations.

Phytoplankton samples consisted of whole water grabs and preserved with Lugol's solution. The samples were allowed to settle at least 24 hours before being concentrated. They were examined with a light microscope at 400x using a Palmer counting cell. Cell counts were reported as cells/mL in which each cell was counted including each cell within colonies; this is in contrast to organism counts, sometimes referred to as natural counts, which count colonies as a single unit. Due to variance in colony size within and between genera affected by seasonality, handling, and other factors, cell counts yield more accurate data.

For incubation, each sediment sample was homogenized, 30 g placed in a 250 mL beaker, and the sediment described. Lake water collected at each station was then filtered and gently poured over the sediment sample in the corresponding sample bringing the volume up to 200 mL. Filtration was performed using a medium filter with mean pore size of approximately 30 µm and a hand pump; filtration efficiency was approximately 90%. A control sample was used and prepared using coarse sand, sterilized with hydrogen peroxide, and filtered lake water.

The prepared beakers were then placed in an incubator set at approximately 25.0°C. The samples were illuminated with LED lights with illuminance in the empty chamber at 3,000 lux. Lighting simulated diel cycles with 12 hours of light followed by 12 hours of darkness. The samples were incubated for 15 days. The first day of the incubation is denoted as Day 1.

On Day 8, the samples were taken out and *in-situ* measurements recorded after a gentle stirring. Beakers from the top shelf were placed on the bottom, while those on the bottom were placed on top.

On Day 15, the samples were again processed for *in-situ* measurements and 100 mL plankton samples collected and preserved with Lugol's solution prior to processing following the methodology outlined above.

4.3 IN-SITU WATER QUALITY DATA

Sampling was conducted on March 7, 2024. The *in-situ* water quality results are provided in Table 4-1 below.

Table 4-1: In-Situ Data 2024.03.07

Station	Depth	Temp °C	DO mg/L	DO % % Sat.	SpC µS/cm	pH s.u.	Chl µg/L	PC µg/L	PE µg/L
Anthony Ford	Surface	11.88	10.79	102.6	188.6	7.47	6.20	2.34	1.37
	Mid	11.41	10.50	98.8	189.6	7.48	0.03	0.59	1.79
	Deep	11.11	10.59	99.0	186.4	7.44	0.03	1.21	1.68
Crafts Church	Surface	16.15	9.19	96.3	37.0	8.07	0.03	17.12	9.50
	Mid	14.60	9.37	94.7	69.3	7.75	0.03	16.78	11.88
	Deep	14.58	9.15	92.5	69.8	7.67	0.03	20.45	12.70
Gills Creek	Surface	15.73	11.82	122.6	99.3	8.33	1.07	8.54	4.60
	Mid	14.01	12.82	128.1	125.2	8.26	1.07	13.46	5.97
	Deep	13.41	12.97	127.9	125.1	8.30	0.71	5.48	4.23
Pine Cone	Surface	13.23	10.96	107.5	66.6	7.93	0.02	4.43	1.41
	Mid	12.47	11.20	108.0	74.5	7.92	0.02	3.38	1.54
	Deep	12.08	11.40	109.0	77.7	7.90	0.02	3.16	1.29
Sandy Point	Surface	16.64	11.53	122.0	117.6	8.49	0.35	4.16	2.89
	Mid	14.93	12.86	131.2	119.5	8.64	0.29	4.99	3.50
	Deep	14.25	13.35	134.0	119.1	8.66	0.56	5.08	2.46
Virginia Key	Surface	12.23	10.88	104.4	159.6	6.69	0.45	25.29	5.70
	Mid	12.03	11.28	107.7	151.2	6.82	0.06	18.46	4.25
	Deep	12.11	11.43	109.4	151.7	6.93	0.14	12.50	6.13

Despite the early date, water temperatures were already well advanced for the season, ranging from 11.9°C to 16.6°C (53.4°F to 62.0°F) at the surface. As a result, biological productivity in the system was high. Dissolved oxygen (DO) concentrations were quite high, and all stations, with the exception of Crafts Church, were supersaturated at the surface with DO saturation in excess of 100%. Gills Creek and Sandy Point were exceptional in this regard, with both stations exceeding 120% saturation throughout the entire water column. Supersaturation, particularly values over 105% to 110% in lake, indicates high levels of primary productivity, that is the growth of plants and algae, and high rates of photosynthetic oxygen generation.

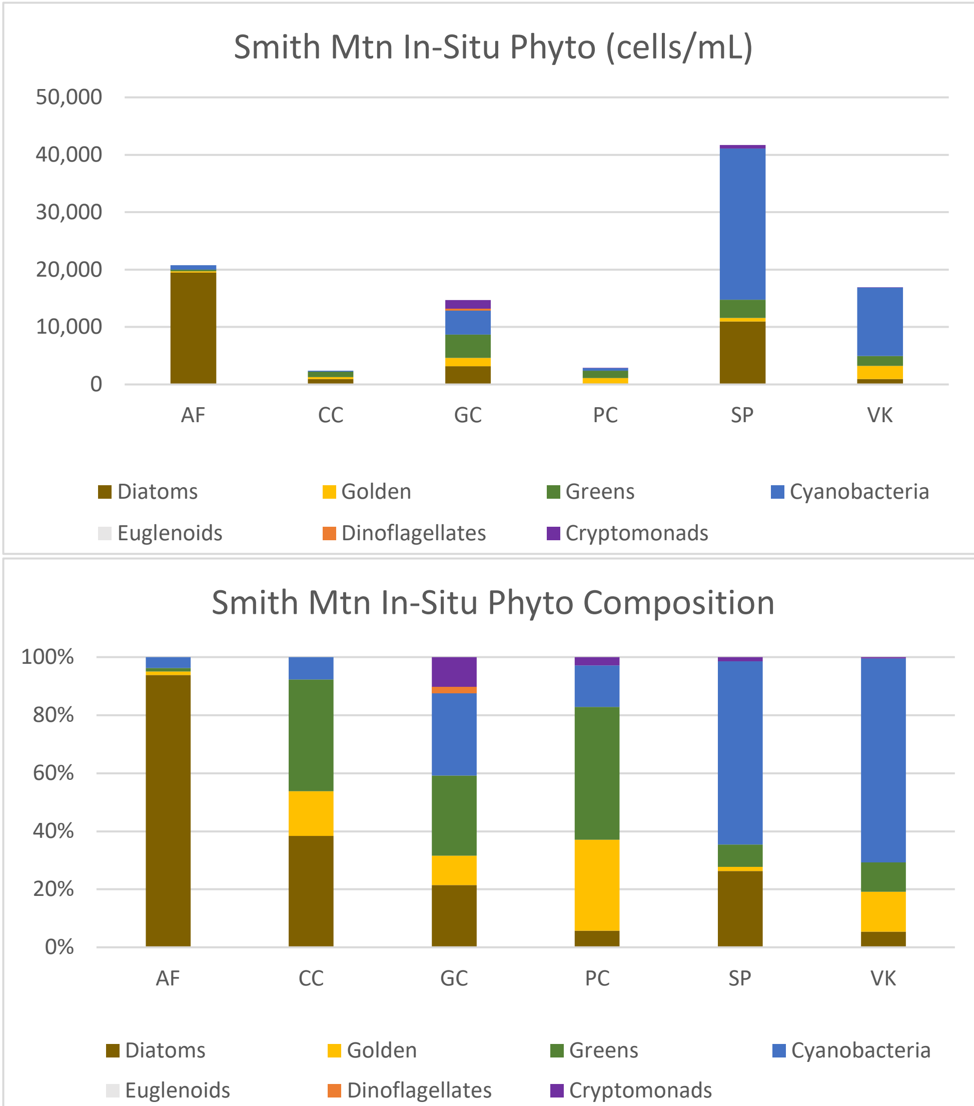
Specific conductivity (SpC), a proxy for dissolved solids, was generally low to moderate. Crafts Church and Pine Cone stations showed water column SpC of less than 80 µS/cm (µmhos/cm). pH varied signficantly between the stations, from mild acidic conditions (pH < 7.0) at Virginia Key to strongly basic values at Sandy Point. pH is affected by both abiotic and biotic factors. Abiotic factors would include sub watershed characteristics among other factors. Some elevation of pH can also be expected from high levels of primary productivity, which likely drove up measured values at Sandy Point and Gills Creek.

For the most part, chlorophyll values were quite low, with the exception of the Anthony Ford station, where values exceeded 6.0 µg/L. Some caution must be used with interpreting these field fluorometer data, which are not as accurate as laboratory analytical chemistry. Phycocyanin (PC) was detected in all samples, and exceeded 20.0 µg/L in some stations. Phycoerythrin (PE) was also detected in all samples, generally at low levels.

4.4 IN-SITU PHYTOPLANKTON DATA

The phytoplankton exhibited significant variability in both density and community composition across the samples (Figures 4-1a and b). Total counts ranged from a low value of 2,400 cells/mL at Crafts Church to 41,700 cells/mL at Sandy Point, a high density. Four major taxa dominated the composition including cyanobacteria, chlorophytes (green algae), chrysophytes (golden algae), and diatoms. Cyanobacterial counts ranged from 185 cells/mL to 26,400 cells/mL. Percent cyanobacteria ranged from 3.7% to 70.3%. While the lake was not experiencing a HAB, cyanobacteria were dominant in some samples. A number of cyanobacteria were observed in the plankton, with the most common being *Aphanizomenon*, a filamentous colonia cyanobacterium. This genus tends to show somewhat higher growth rates at lower water temperatures than many other genera and therefore tends to appear in the plankton earlier in the season. It is also a nitrogen-fixer, meaning it can fix gaseous nitrogen in a process conceptually similar to the fixing of carbon achieved through photosynthesis. As a result, it can overcome nitrogen limitation. It also tends to increase the available store of nitrogen in the system and tends to be followed later in the year by genera that do not fix nitrogen, such as *Microcystis.* In addition to these adaptations which confer various competitive advantages, *Aphanizomenon* is one of the genera that produces akinetes.

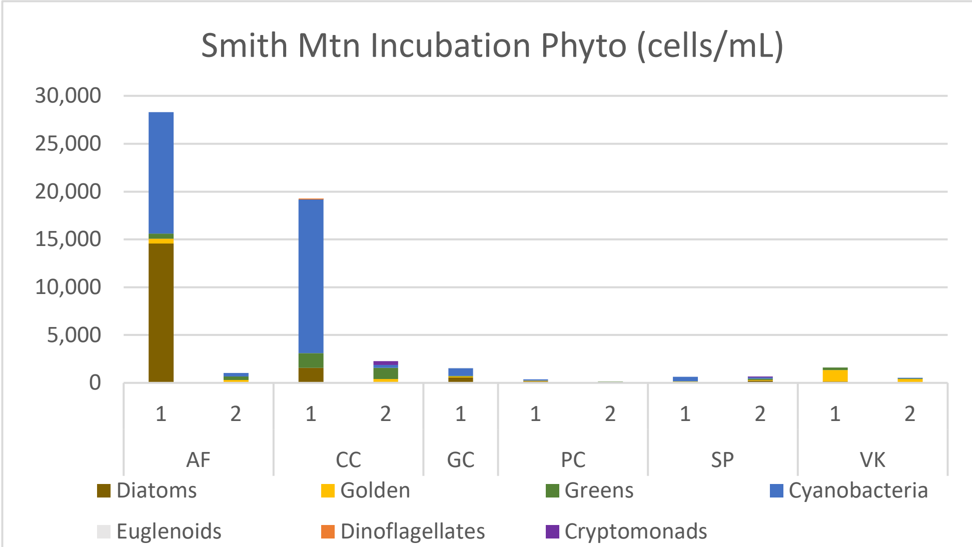
While the presence of cyanobacteria is notable, particularly in the Virginia Key, Sandy Point, and Gills Creek stations, diatoms were well distributed and dominated the Anthony Ford sample. Diatoms often prefer cooler water temperatures and dominance of the plankton in the early part of the growing season is common in many lake systems. Chlorophytes and chrysophytes were also well distributed. These taxa tend to be more easily controlled than many others and are heavily grazed by zooplankton. Dense chrysophytes growth can often lend a brownish color to the water. Cryptomonads were a small component, but genera like *Cryptomonas* are quite large and may account for a more significant portion of algal biomass than cell counts would dictate. Elevated cryptomonad density at Gills Creek is likely partly responsible for the elevated PE concentrations measured at that station.

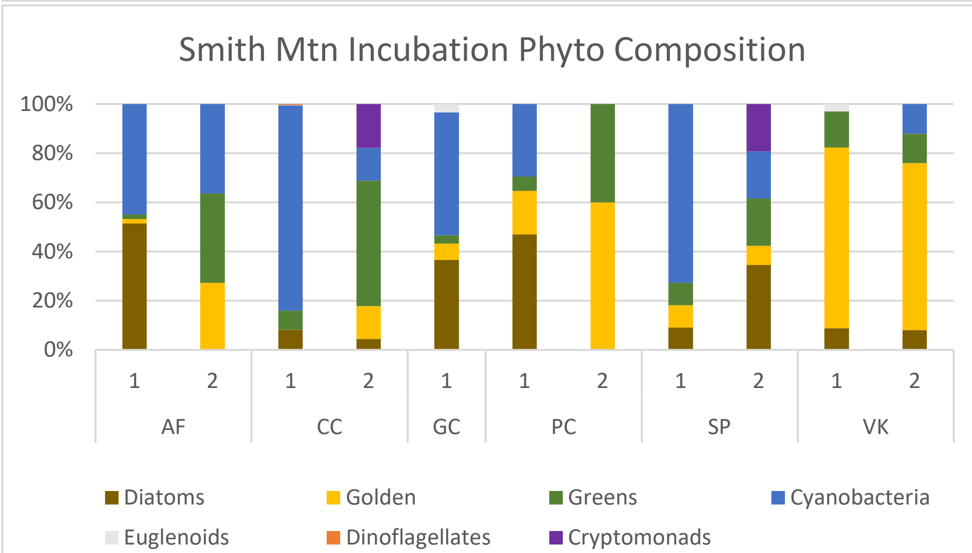


Figures 4-1a and 4-1b: Smith Mountain In-Situ Phytoplankton Density and Composition

4.5 INCUBATION PHYTOPLANKTON DATA

The incubation period was 15 days, starting on March 8 and extending through March 22. Upon completion of the incubation, phytoplankton samples were retrieved and subsequently processed. It should be noted that replicate samples were used for all stations except Gills Creek, which was limited by incubator space. Only two of the samples saw significant growth: Anthony Ford 1 at 28,300 cells/mL and Crafts Church 1 at 19,300 cells/mL, and both were dominated by cyanobacteria. Only two other samples had cell densities in excess of 1,500 cells/mL: Gills Creek and Virginia Key 1. The remaining samples were all less than 700 cells/mL. Summary figures are provided below showing both cell counts and composition (Figures 4-2a and b).





Figures 4-2a and 4-2b: Smith Mountain Incubation Phytoplankton Density and Composition

In general, incubation cell counts were quite low, although Anthony Ford and Crafts Church deserve additional scrutiny. Anthony Ford had the second highest in-situ cell density at 20,700 cells/mL, but cyanobacteria only accounted for 3.7% of the total and the sample was strongly dominated by diatoms. Post-incubation total cell density was 28,300 cells/mL with cyanobacteria accounting for 12,700 cells/mL, nearly 17-fold higher than in-situ densities. The dominant cyanobacterium in the post-incubation sample was *Oscillatoria*, which was not present in the in-situ sample. The dominant organism in the in-situ sample, the diatom *Eunotia* was replaced by the diatom *Melosira*. As such, the Anthony Ford site seems to be an area that has a store of viable cyanobacteria and diatoms in the sediments and is likely a localized hotspot for cyanobacteria production in the early part of the growing season. It should be noted that *Oscillatoria*, some species of which are synonymous with *Planktothrix*, forms on the sediments, but often detaches under certain environmental conditions to cause unsightly surface blooms often likened to paint slicks. While *Oscillatoria* tends to be benthic and filaments can be clustered together, while *Planktothrix* tends to be planktonic and found as solitary filaments.

Crafts Church exhibited in-situ total cell counts of just 2,400 cells/mL but ballooned to 19,300 cells/mL post-incubation of which 83.4% was cyanobacteria. The dominant cyanobacterium was *Microcystis*, which was absent in the in-situ sample. This site also seems to be an important area of cyanobacteria production.

Some other interesting patterns were observed. The cyanobacterium *Cylindrospermopsis* was observed in just one of the samples in in-situ plankton, at Gills Creek, but was found in four stations post-incubation including Anthony Ford, Crafts Church, Gills Creek, and Sandy Point. *Aphanizomenon*, which was dominant and well-distributed in the in-situ plankton, did not appear in any of the post-incubation samples. This is a puzzling finding, but may suggest that most of the viable akinetes or vegetative cells may have already entered the plankton. Additionally, as previously mentioned *Aphanizomenon* is more tolerant of cooler water temperatures. Since the samples were incubated at 25°C other cyanobacteria that do better under warmer conditions may have outcompeted any *Aphanizomenon* that may be remerging from the sediments for the available resources.

Another important finding was that the first replicate for the stations had much higher cell densities than the corresponding second replicate in four of the five replicated stations, and in the outlier the densities were equivalent. The first replicate samples were collected from the uppermost portion of the dredge samples right at the sediment-water interface. Not surprisingly, this shows the most biologically active part of the sediments is immediately adjacent to the surface. Somewhat deeper samples probably show reduced viability both because depositional rate would be lower relative to the surface and increasingly harsh conditions lower down in the sediments.

Lastly, it is worth examining the Gills Creek and Sandy Point stations. Both had moderate to high cell densities in-situ and were dominated by *Aphanizomenon*, but low cell densities post-incubation. This may suggest that neither area is an important producer of cyanobacteria and instead accumulations arrive as a result of wind and wave action. The low cell densities may also reflect earlier production in the sediment. Likely, both of these factors contribute to the observed results.

4.6 INCUBATION IN-SITU DATA

Two photosynthetic pigments, PC and PE, were measured twice during the incubation period, at Day 8 and at the close of the experiment on Day 15. These were also measured in-situ at the lake and reported in Section 4.3. A table summarizing those values as well as post-incubation cyanobacterial cell counts and total cell counts is provided below (Table 4-2).

In general, there is relatively good agreement between cell counts and the corresponding pigment concentrations. In particular, high cyanobacterial density at Anthony Ford and Gills Creek also returned good pigment concentrations. This suggests that measuring these pigments may be an easy and cost effective means of quickly assessing the presence and density of cyanobacteria in the lake.

Table 4-2: Incubation Pigment Summary

Sample	Phycocyanin (µg/L)		Phycoerythrin (µg/L)		Cell Counts (cells/mL)	
	2024.03.15	2024.03.22	2024.03.15	2024.03.22	Cyanos	Total
Anthony Ford 1	0.000	37.900	0.155	17.110	12,705.7	28,323.1
Anthony Ford 2	0.000	0.000	0.371	0.000	377.4	1,037.7
Crafts Church 1	0.000	7.265	3.778	3.500	16,078.3	19,273.7
Crafts Church 2	12.620	5.955	6.056	10.100	304.3	2,282.4
Gills Creek	0.000	0.000	0.736	0.432	786.2	1,572.3
Pine Cone 1	0.000	0.000	0.350	0.000	102.8	349.4
Pine Cone 2	6.039	0.000	2.033	0.000	0.0	132.4
Sandy Point 1	0.000	0.000	0.000	0.000	461.2	634.2
Sandy Point 2	0.000	0.000	0.000	0.000	131.0	681.3
Virginia Key 1	0.000	0.000	0.000	0.000	0.0	1,636.5
Virigina Key 2	0.000	0.000	1.535	0.000	62.9	524.1

4.7 SAMPLE SEDIMENT CHARACTERISTICS

While sediment grain-size distribution and organic content analyses were not included as part of this study, the sediments were described visually using USDA particle size classification. A summary of those descriptions as well as cell count data is provided below (Table 4-3). Besides the written descriptions of the sediments, a relative coarseness metric has also been included to compare the sediment quality among the samples.

It became apparent during the review of the data that grain-size and general sediment characteristics were well-correlated with post-incubation cell density. In general, finer sediments with higher quantities of organic materials, either as fines or detritus, produced higher incubation growth rates. Finer sediments are typically found in depositional environments, usually sites that are protected from wind and wave action where flow velocity and shear stress is low. These types of depositional environments would therefore be expected to see higher depositional rates not just of soil particles, but akinetes and vegetative cells. As such, it is in the areas with the finest sediments, Anthony Ford and Crafts Church, that produced the highest cell densities during incubation. Areas with sediments described as coarse or mixed (including both coarse and fine particles) generally saw the lowest growth rates. While conditions may occasionally foster the deposition of fine materials in these areas, periodic flushing or scouring events would be prone to removing any overwintering algae in the sediments and thus limit production during the succeeding growing season. In the future Princeton Hydro will be adding grain-size analysis as a standard component of overwintering algae assessments. From a management standpoint, areas with fine sediments should be targeted as potential producers of cyanobacteria.

Table 4-3: Sediment Descriptions and Cell Count Data

Sample	Characterization	Relative Coarseness	Cell Counts (cells/mL) Cyanos	Total
Anthony Ford 1	Clayey silt and organic flocs, light brown.	Extremely Fine	12,705.7	28,323.1
Anthony Ford 2	Clayey silt and very fine organic detritus, light brown.	Extremely Fine	377.4	1,037.7
Crafts Church 1	Organic fines and silts, medium brown.	Very Fine	16,078.3	19,273.7
Crafts Church 2	Organic fines, some coarse organics, medium brown.	Very Fine	304.3	2,282.4
Gills Creek	Sands, some organic detritus, and coarse gravel, brown.	Coarse	786.2	1,572.3
Pine Cone 1	Silts and sands, some coarse sand, some coarse detritus, rusty colored.	Mixed	102.8	349.4
Pine Cone 2	Fines, including silt and very fine sand, rusty. Some floating organic scum.	Mixed	0.0	132.4
Sandy Point 1	Organic fines, silts, and fine sands, some coarse organics, reddish brown.	Mixed	461.2	634.2
Sandy Point 2	Fines with fine gravel, some organic detritus, brown. Organic scum at surface.	Mixed	131.0	681.3
Virginia Key 1	Very fine sands with lots of quartz, medium brown.	Fine	0.0	1,636.5
Virigina Key 2	Silts and very fine sand, full of quartz particles, light brown.	Fine	62.9	524.1

4.8 INCUBATION CONCLUSIONS

To conclude, based on the incubation study the following statements can be made with the supporting evidence:

1. In Smith Mountain Lake, coarser sediments do not tend to be good habitat for overwintering cyanobacteria. This means that blooms experienced in these near-shore sections of the lake more than likely originate from other areas of the lake and accumulate along the shoreline areas as a result of wind and wave action.

2. In contrast, sediments that were siltier and/or organic in nature appeared to possess the conditions necessary to allow overwinter cyanobacteria to grow and bloom as temperatures increase in the spring. Such conditions indicate that in-lake management measures that directly address these siltier / organic sediments may result in a reduction in the size, frequency and/or HABs.

3. The routine measurement of various photosynthetic pigments including PC and PE may be an effective means of estimating the presence and relative abundance of cyanobacteria while the ratio of those pigments may provide clues as to the composition of planktonic and benthic genera. Again, such information can provide useful information in the long-term monitoring and management of near-shore areas of the lake.

4. The incubation experiments yielded a very different community than what was observed in the lake. Importantly, *Oscillatoria* and *Cylindrospermopsis*, which were absent from the lake, appeared in the incubation samples and suggest that these genera may appear later in the growing season. The dominant cyanobacterium in the lake at the time of sampling, *Aphanizomenon*, was absent from the incubation samples, which may suggest that overwintering cells had already emerged and entered the plankton or were not present in the areas sampled.

5. Finally, by collecting water samples from these near-shore locations over the 2024 growing season for the identification / enumeration of cyanobacteria, we can better assess how strong the relationship is between overwintering cyanobacteria in the sediments and HAB events. In turn, such relationships can be used as predictive tools for HABs.

5.0 GLOSSARY OF KEY TERMS

- Acidity - The state of being acid that is of being capable of transferring a hydrogen ion in solution; solution that has a pH value lower than 7.

- Alkalinity - The capacity of water for neutralizing an acid solution. Alkalinity of natural waters is due primarily to the presence of hydroxides, bicarbonates, carbonates and occasionally borates, silicates and phosphates. It is expressed in units of milligrams per liter (mg/l) of $CaCO_3$ (calcium carbonate) or as microequivalents per liter (µeq/l) 20 µeq/l = 1 mg/l of $CaCO_3$. A solution having a pH below 4.5 contains no alkalinity. Low alkalinity is the main indicator of susceptibility to acid rain. Increasing alkalinity is often related to increased algal productivity. Lakes with watersheds having a sedimentary carbonate rocks geology then to be high in dissolved carbonates (hard-water lakes), whereas those in a watershed with a granitic or igneous geology tend to be low in dissolved carbonates (soft water lakes).

- Anthropogenic activities – Impacted by, created by or resulting from human activities.

- Aeration - A process which promotes biological degradation of organic matter in water. The process may be passive (as when waste is exposed to air), or active (as when a mixing or bubbling device introduces the air).

- Algae - Microscopic plants which contain chlorophyll and live floating or suspended in water. They also may be attached to structures, rocks or other submerged surfaces. They are food for fish and small aquatic animals. Excess algal growths can impart tastes and odors to potable water. Algae produce oxygen during sunlight hours and use oxygen during the night hours. They can affect water quality adversely by lowering the dissolved oxygen in the water.

- Alum Treatment - Process of introducing granular or liquid alum (*Aluminum sulfate*) into the lake water, to create a precipitate or floc that is used to strip the water column of fine particles and algae or used to treat the bottom sediment for the purpose of limiting the internal recycling of phosphorus.

- Ammonia - A colorless gaseous alkaline compound that is very soluble in water, has a characteristic pungent odor, is lighter than air, and is formed as a result of the decomposition of most nitrogenous organic material.

- Barrier to migration - A man-made structure consisting of cobble, wood, cement or other materials that impede the free movement of fish between stream sections.

- Bathymetry - The measurement and mapping of water depths and bottom contours.

- Best Management Practices - Schedules of activities, prohibitions of practices, maintenance procedures, and other management practices to prevent or reduce the pollution of waters of the United States. BMPs also include but are not limited to treatment requirements, operating procedures, and practices to control plant site runoff, spillage or leaks, sludge or wastewater disposal, or drainage from raw material storage. Practices or structures designed to reduce the quantities of pollutants -- such as sediment, nitrogen, phosphorus, and animal wastes that are washed by rain and snow melt from farms into surface or ground waters.

- Chlorophyll a - A green pigment found in photosynthetic organisms; used as an indicator of algal biomass.

- Clarity - The transparency of a water column. Commonly measured with a Secchi disk

- Composite water quality sample - A composite sample is a collection of individual samples obtained at regular intervals, usually every one or two hours during a 24-hour time span. Each individual sample is combined with the others in proportion to the rate of flow when the sample was collected; the resulting mixture (composite sample) forms a representative sample and is analyzed to determine the average conditions during the sampling period.

- Debris - A broad category of large manufactured and naturally occurring objects that are commonly discarded (e.g., construction materials, decommissioned industrial equipment, discarded manufactured objects, tree trunks, boulders).

- Detritus - Any loose material produced directly from disintegration processes. Organic detritus consists of material resulting from the decomposition of dead organic remains.

- Dissolved oxygen - The amount of oxygen dissolved in a stream, river or lake is an indication of the degree of health of the stream and its ability to support a balanced aquatic ecosystem. The oxygen comes from the atmosphere by solution and from photosynthesis of water plants. The maximum amount of oxygen that can be held in solution in a stream is termed the saturation concentration and, as it is a function of temperature, the greater the temperature, the less the saturation amount. The discharge of an organic waste to a stream imposes an oxygen demand on the stream. If there is an excessive amount of organic matter, the oxidation of waste by microorganisms will consume oxygen more rapidly than it can be replenished. When this happens, the dissolved oxygen is depleted and results in the death of the higher forms of life.

- Dredging - Removal of sediment from the bottom of a water body.

- Epilimnion- The upper layer of water in a thermally stratified lake or reservoir. This layer consists of the warmest water and has a fairly uniform (constant) temperature. The layer is readily mixed by wind action.

- Eutrophication - A process that occurs when a lake or stream becomes over-rich in plant nutrient; as a consequence it becomes overgrown in algae and other aquatic plants. The plants die and decompose. In decomposing the plants rob the water of oxygen and the lake, river or stream becomes lifeless. Eutrophication can be a natural process or it can be a cultural process accelerated by an increase of nutrient loading to a lake by human activity. Fertilizers which drain from the fields, nutrients from animal wastes and human sewage are examples of cultural processes and are often the primary causes of the accelerated eutrophication of a waterbody.

- Erosion- The wearing away of land surface by wind or water. Erosion occurs naturally but can be caused by farming, residential or industrial development, mining, or timber-cutting.

- Fecal contamination - The presence in water bodies of living organisms (bacteria and viruses) or agents derived by fecal bacteria that can cause negative human health effects. Fecal contamination may be a result of wildlife, livestock, pet, waterfowl or septic and sewage discharges.

- Herbicides - A compound, usually a man-made organic chemical, used to kill or control plant growth.

- Hydrology - The occurrence, circulation, distribution, and properties of the waters of the earth, and their reaction with the environment. For lakes this is usually associated with the quantification of the water flow into and out of the system and the study of pollutant transport that occurs in concert with the inflow.

- Hypolimnion - Bottom waters of a thermally stratified lake. This layer consists of colder, denser water. Its water temperatures remain relatively constant year around and it may experience little or no mixing with the upper warmer layers of the water body. The hypolimnion of a eutrophic lake is usually low or lacking in oxygen.

- Hypereutrophic - Pertaining to a lake or other body of water characterized by excessive nutrient concentrations such as nitrogen and phosphorus and resulting high productivity. Such waters are often shallow, with algal blooms and periods of oxygen deficiency. Slightly or moderately eutrophic water can be healthful and support a complex web of plant and animal life. However, such waters are generally undesirable for drinking water and other needs. Degrees of *Eutrophication* typically range from *Oligotrophic* water (maximum transparency, minimum chlorophyll-a, minimum phosphorus) through *Mesotrophic*, *Eutrophic*, to *Hypereutrophic* water (minimum transparency, maximum chlorophyll-a, maximum phosphorus). Also see *Carlson's Trophic State Index (TSI)* and *(Mean) Trophic State Index (TSI)*.

- *In situ* water quality parameters - in place; in situ measurements consist of measurements of water quality parameters in the field, rather than in a laboratory.

- Invasive species - A species whose presence in the environment causes economic or environmental harm or harm to human health.

- Limnology - The study of bodies of fresh water with reference to their plant and animal life, physical properties, geographical features, etc. The study of the physical, chemical, hydrological, and biological aspects of fresh water bodies.

- Littoral zone - 1. That portion of a body of fresh water extending from the shoreline lakeward to the limit of occupancy of rooted plants. 2. A strip of land along the shoreline between the high and low water levels.

- Land use/ Land cover - The arrangement of land units into a variety of categories based on the properties of the land or its suitability for a particular purpose. It has become an important tool in rural land-use planning.

- Macroinvertebrates - An organism that lacks a backbone and can be seen with the naked eye.

- Macrophyte - A large macroscopic plant, used especially of aquatic forms such as kelp (variety of large brown seamacrophyte which is a source of iodine and potash).

- Mesotrophic - Reservoirs and lakes which contain moderate quantities of nutrients and are moderately productive in terms of aquatic animal and plant life.

- Nitrogen - An essential nutrient in the food supply of plants and the diets of animals. Animals obtain it in nitrogen-containing compounds, particularly amino acids. Although the atmosphere is nearly 80% gaseous nitrogen, very few organisms have the ability to use it in this form. The higher plants normally obtain it from the soil after micro-organisms have converted the nitrogen into ammonia or nitrates, which they can then absorb.

- Non point source pollution - Water pollution that cannot be traced to a specific source. Human-made or human-induced pollution caused by diffuse, indefinable sources that are not regulated as point sources, resulting in the alteration of the chemical, physical, biological, and/or radiological integrity of the water.

- Oligotrophic - Deep lakes that have a low supply of nutrients and thus contain little organic matter. Such lakes are characterized by high water transparency and high dissolved oxygen.

- pH - A measure of the acidity or alkalinity of a material, liquid or solid. pH is represented on a scale of 0 to 14 with 7 representing a neutral state, 0 representing the most acid and 14, the most alkaline.

- Periphyton abundance - Microscopic underwater plants and animals that are firmly attached to solid surfaces such as rocks, logs, and pilings. In smaller streams this can indicate nutrient and thermal enrichment.

- Phosphorus - An element that while essential to life, contributes to the eutrophication of lakes and other bodies of water.

- Photosynthesis - The process by which plants transform carbon dioxide and water into carbohydrates and other compounds, using energy from the sun captured by chlorophyll in the plant. Oxygen is a by-product of the process. Photosynthesis is the essence of all plant life (autotrophic production) and hence of all animal life (heterotrophic production) on the planet Earth. The rate of photosynthesis depends on climate, intensity and duration of sunlight, available leaf area, soil nutrient availability, temperature, carbon dioxide concentration, and soil moisture regimes.

- Phytoplankton - Very tiny, often microscopic, plants found in fresh and saltwater. Phytoplankton drifts near the surface of the water where there is plenty of sunlight for growth. Phytoplankton forms the basis for all food chains.

- Point source pollution - Easily discernible source of water pollution such as factories, gas stations, etc.

- Pollutant loading - The amount of polluting material that a transporting agent, such as a stream, a glacier, or the wind, is actually carrying at a given time.

- Residential discharge - Any flow of surface water or the collective flow of residential development generated in single and multi-family homes. May include storm water collected from the roof, lawn, driveway, a basement sump pump, or effluent from a malfunctioning septic system.

- Secchi disc transparency - A flat, white disc lowered into the water by a rope until it is just barely visible. At this point, the depth of the disc from the water surface is the recorded Secchi disc transparency.

- Sedimentation - 1. Process of deposition of waterborne or windborne sediment or other material; also refers to the infilling of bottom substrate in a waterbody by sediment (siltation). 2. When soil particles (sediment) settles to the bottom of a waterway.
- Specific conductance - A rapid method of estimating the dissolved-solids content of a water supply. The measurement indicates the capacity of a sample of water to carry an electrical current, which is related to the concentration of ionized substances in the water. Also called conductance.

- Stormwater runoff - Stormwater runoff, snow melt runoff, and surface runoff and drainage; rainfall that does not infiltrate the ground or evaporate because of impervious land surfaces but instead flows onto adjacent land or watercourses or is routed into drain/sewer systems.

- Stratification - Formation of water layers each with specific physical, chemical, and biological characteristics. As the density of water decreases due to surface heating, a stable situation develops with lighter water overlaying heavier and denser water.
- The tendency in deep water bodies for distinct layers of water to form as a result of vertical change in temperature and, therefore, in the density of water. During stratification, dissolved oxygen, nutrients, and other parameters of water chemistry do not mix well between layers, establishing chemical as well as thermal gradients.

- Submerged aquatic macrophyte - Large vegetation that lives at or below the water surface; an important habitat for young fish and other aquatic organisms.

- Suspended solids - 1) Solids that either float on the surface or are suspended in water or other liquids, and which are largely removable by laboratory filtering. 2) The quantity of material removed from water in a laboratory test, as prescribed in standard methods for the examination of water and wastewater.

- Thermocline - The middle layer in a thermally stratified lake or reservoir. In this layer there is a rapid decrease in temperature with depth. Also called the Metalimnion

- Turbidity - A cloudy condition in water due to suspended silt or organic matter often attributable to algae blooms or increased sediment loads.

- Water quality - The biological, chemical, and physical conditions of a waterbody. It is a measure of a waterbody's ability to support beneficial uses.

- Watershed management - A holistic approach applied within an area defined by hydrological, not political, boundaries, integrating the water quality impacts from both point and nonpoint sources. Watershed management has a premise that many water quality and ecosystem problems are better solved at the watershed scale rather than by examining the individual waterbodies or dischargers. Use, regulation and treatment of water and land resources of a watershed to accomplish stated objectives.

- Macrophyte harvesting – A mechanical means of controlling the growth of aquatic macrophytes. Involves both the cutting and removal of macrophyte biomass. Can be implanted on large scale using floating barge like machines or a small localized scale using hand tools.

- Zooplankton - Tiny, sometimes microscopic, floating, aquatic animals. Zooplankton generally feed upon phytoplankton and each other.

APPENDIX I: IN-SITU PLANKTON

Phytoplankton Community Composition Analysis

Sampling Location: Smith Mountain	**Sampling Date: 2024.03.07**	**Examination Date: 2024.03.19**
Site A: Anthony Ford	**Site B:**	

Phytoplankton (cells/mL)

Diatoms	**A**	**B**	**Chlorophytes**	**A**	**B**	**Cyanophytes**	**A**	**B**
Amphora			*Actinastrum*			*Aphanizomenon*		
Asterionella			*Ankistrodesmus*			*Aphanocapsa*	253.0	
Cocconeis	126.5		*Brachiomonas*			*Chroococcus*		
Cyclotella			*Chlamydomonas*	126.5		*Coelosphaerium*		
Cymbella			*Chlorella*			*Cylindrospermopsis*		
Eunotia	10120.7		*Chlorogonium*			*Dactylococcopsis*		
Fragilaria	9108.7		*Coccomonas*			*Gloeocapsa*		
Frustulia			*Crucigenia*			*Lyngbya*		
Gomphonema			*Dictyosphaerium*			*Merismopedia*		
Gyrosigma			*Didymocystis*			*Microcystis*	253.0	
Melosira			*Franceia*			*Oscillatoria*		
Navicula			*Gloeococcus*			*Planktothrix*		
Nitzschia			*Gloeomonas*			*Pseudanabaena*	253.0	
Pinnularia			*Golenkinia*			*Synechococcus*		
Rhoicosphernia			*Kirchneriella*			*Woronichinia*		
Stauroneis			*Koliella*			Akinete		
Stephanodiscus	126.5		*Lagerheimia*					
Synedra			*Nannochloris*			**Euglenoids**	**A**	**B**
Tabellaria			*Oocystis*			*Euglena*		
			Pandorina			*Phacus*		
			Pediastrum			*Trachelomonas*		
Chrysophytes	**A**	**B**	*Phacotus*					
Chromulina	253.0		*Scenedesmus*			**Dinoflagellates**	**A**	**B**
Dinobryon			*Selenastrum*			*Ceratium*		
Mallomonas			*Sphaerocystis*			*Gymnodinium*		
Synura			*Spinoclosterium*			*Tetradinium*		
			Spirogya					
Xanthophytes	**A**	**B**	*Staurastrum*	126.5		**Cryptophytes**	**A**	**B**
Isthmochloron			*Teilingia*			*Chroomonas*		
			Tetraselmis			*Cryptomonas*		
			Treubaria					
			Ulothrix					
			Zygnema					

Sites:	**A**	**B**	**Comments:**
Cyanobacteria Count	759	0	
Total Count	20,747	0	
Genera Richness	10	0	

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Phytoplankton Community Composition Analysis

Sampling Location: Smith Mountain	Sampling Date: 2024.03.07	Examination Date: 2024.03.19
Site A: Crafts Church	Site B:	

Phytoplankton (cells/mL)

Diatoms	A	B	Chlorophytes	A	B	Cyanophytes	A	B
Amphora			*Actinastrum*			*Aphanizomenon*		
Asterionella			*Ankistrodesmus*			*Aphanocapsa*		
Cocconeis			*Brachiomonas*			*Chroococcus*		
Cyclotella			*Chlamydomonas*	370.9		*Coelosphaerium*		
Cymbella			*Chlorella*	185.5		*Cylindrospermopsis*		
Eunotia			*Chlorogonium*			*Dactylococcopsis*		
Fragilaria			*Coccomonas*			*Gloeocapsa*		
Frustulia			*Crucigenia*			*Lyngbya*		
Gomphonema			*Dictyosphaerium*			*Merismopedia*		
Gyrosigma			*Didymocystis*			*Microcystis*		
Melosira			*Franceia*			*Oscillatoria*		
Navicula	370.9		*Gloeococcus*			*Planktothrix*		
Nitzschia			*Gloeomonas*			*Pseudanabaena*		
Pinnularia			*Golenkinia*			*Synechococcus*	185.5	
Rhoicosphernia	370.9		*Kirchneriella*			*Woronichinia*		
Stauroneis			*Koliella*			Akinete		
Stephanodiscus			*Lagerheimia*	370.9				
Synedra	185.5		*Nannochloris*			**Euglenoids**	**A**	**B**
Tabellaria			*Oocystis*			*Euglena*		
			Pandorina			*Phacus*		
			Pediastrum			*Trachelomonas*		
Chrysophytes	**A**	**B**	*Phacotus*					
Chromulina	185.5		*Scenedesmus*			**Dinoflagellates**	**A**	**B**
Dinobryon	185.5		*Selenastrum*			*Ceratium*		
Mallomonas			*Sphaerocystis*			*Gymnodinium*		
Synura			*Spinoclosterium*			*Tetradinium*		
			Spirogya					
Xanthophytes	**A**	**B**	*Staurastrum*			**Cryptophytes**	**A**	**B**
Isthmochloron			*Teilingia*			*Chroomonas*		
			Tetraselmis			*Cryptomonas*		
			Treubaria					
			Ulothrix					
			Zygnema					

Sites:	A	B	Comments:
Cyanobacteria Count	186	0	
Total Count	2,411	0	
Genera Richness	9	0	

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Phytoplankton Community Composition Analysis

Sampling Location: Smith Mountain	Sampling Date: 2024.03.07	Examination Date: 2024.03.19
Site A: Gills Creek	**Site B:**	

Phytoplankton (cells/mL)

s	A	B	Chlorophytes	A	B	Cyanophytes	A	B
Amphora			*Actinastrum*			*Aphanizomenon*	1946.7	
Asterionella	149.7		*Ankistrodesmus*			*Aphanocapsa*		
Cocconeis			*Brachiomonas*			*Chroococcus*		
Cyclotella			*Chlamydomonas*	599.0		*Coelosphaerium*		
Cymbella			*Chlorella*	449.2		*Cylindrospermopsis*	149.7	
Eunotia			*Chlorogonium*	149.7		*Dactylococcopsis*		
Fragilaria			*Coccomonas*			*Gloeocapsa*		
Frustulia			*Crucigenia*			*Lyngbya*		
Gomphonema			*Dictyosphaerium*			*Merismopedia*	599.0	
Gyrosigma			*Didymocystis*	149.7		*Microcystis*	1497.5	
Melosira	299.5		*Franceia*			*Oscillatoria*		
Navicula	449.2		*Gloeococcus*			*Planktothrix*		
Nitzschia	1946.7		*Gloeomonas*			*Pseudanabaena*		
Pinnularia			*Golenkinia*			*Synechococcus*		
Rhoicosphernia			*Kirchneriella*	449.2		*Woronichinia*		
Stephanodiscus			*Koliella*			Akinete		
Suriella	299.5		*Lagerheimia*	1497.5				
Synedra			*Nannochloris*	149.7		**Euglenoids**	**A**	**B**
Tabellaria			*Oocystis*			*Euglena*		
			Pandorina			*Phacus*		
			Pediastrum			*Trachelomonas*		
phytes	**A**	**B**	*Phacotus*					
Chromulina	1497.5		*Scenedesmus*	599.0		**Dinoflagellates**	**A**	**B**
Dinobryon			*Selenastrum*			*Ceratium*		
Mallomonas			*Sphaerocystis*			*Gymnodinium*	299.5	
Synura			*Spinoclosterium*			*Tetradinium*		
			Spirogya					
phytes	**A**	**B**	*Staurastrum*			**Cryptophytes**	**A**	**B**
Isthmochloron			*Teilingia*			*Chroomonas*	599.0	
			Tetraselmis			*Cryptomonas*	898.5	
			Treubaria					
			Ulothrix					
			Zygnema					

Sites:	A	B	Comments:
Cyanobacteria Count	4,193	0	
Total Count	14,675	0	
Richness	21	0	

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Phytoplankton Community Composition Analysis

Sampling Location: Smith Mountain	**Sampling Date: 2024.03.07**	**Examination Date: 2024.03.19**
Site A: Pine Cone	**Site B:**	

Phytoplankton (cells/mL)

Diatoms	**A**	**B**	**Chlorophytes**	**A**	**B**	**Cyanophytes**	**A**	**B**
Amphora			*Actinastrum*			*Aphanizomenon*		
Asterionella			*Ankistrodesmus*			*Aphanocapsa*		
Cocconeis			*Brachiomonas*			*Chroococcus*		
Cyclotella			*Chlamydomonas*	166.8		*Coelosphaerium*		
Cymbella			*Chlorella*	500.3		*Cylindrospermopsis*		
Eunotia			*Chlorogonium*			*Dactylococcopsis*		
Fragilaria			*Coccomonas*			*Gloeocapsa*		
Frustulia			*Crucigenia*			*Lyngbya*		
Gomphonema			*Dictyosphaerium*			*Merismopedia*	333.5	
Gyrosigma			*Didymocystis*	83.4		*Microcystis*	83.4	
Melosira			*Franceia*			*Oscillatoria*		
Navicula	83.4		*Gloeococcus*			*Planktothrix*		
Nitzschia	83.4		*Gloeomonas*			*Pseudanabaena*		
Pinnularia			*Golenkinia*	83.4		*Synechococcus*		
Rhoicosphernia			*Kirchneriella*	166.8		*Woronichinia*		
Stephanodiscus			*Koliella*			Akinete		
Suriella			*Lagerheimia*	250.1				
Synedra			*Nannochloris*			**Euglenoids**	**A**	**B**
Tabellaria			*Oocystis*			*Euglena*		
			Pandorina			*Phacus*		
			Pediastrum			*Trachelomonas*		
Chrysophytes	**A**	**B**	*Phacotus*					
Chromulina	833.8		*Scenedesmus*			**Dinoflagellates**	**A**	**B**
Dinobryon	83.4		*Selenastrum*			*Ceratium*		
Mallomonas			*Sphaerocystis*			*Gymnodinium*		
Synura			*Spinoclosterium*			*Tetradinium*		
			Spirogya					
Xanthophytes	**A**	**B**	*Staurastrum*			**Cryptophytes**	**A**	**B**
Isthmochloron			*Teilingia*			*Chroomonas*		
			Tetraselmis			*Cryptomonas*	83.4	
			Treubaria	83.4				
			Ulothrix					
			Zygnema					

Sites:	**A**	**B**	**Comments:**
Cyanobacteria Count	417	0	
Total Count	2,919	0	
Genera Richness	14	0	

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Phytoplankton Community Composition Analysis

Sampling Location: Smith Mountain	Sampling Date: 2024.03.07	Examination Date: 2024.03.19
Site A: Sandy Point	Site B:	

Phytoplankton (cells/mL)

Diatoms	A	B	Chlorophytes	A	B	Cyanophytes	A	B
Amphora			*Actinastrum*			*Aphanizomenon*	19966.1	
Asterionella	998.3		*Ankistrodesmus*			*Aphanocapsa*	199.7	
Cocconeis			*Brachiomonas*			*Chroococcus*		
Cyclotella	199.7		*Chlamydomonas*	199.7		*Coelosphaerium*		
Cymbella	399.3		*Chlorella*	399.3		*Cylindrospermopsis*		
Eunotia			*Chlorogonium*			*Dactylococcopsis*		
Fragilaria	199.7		*Coccomonas*			*Gloeocapsa*		
Frustulia			*Crucigenia*			*Lyngbya*		
Gomphonema			*Dictyosphaerium*			*Merismopedia*	798.6	
Gyrosigma			*Didymocystis*	998.3		*Microcystis*	399.3	
Melosira	5191.2		*Franceia*			*Oscillatoria*		
Navicula	1996.6		*Gloeococcus*			*Planktothrix*		
Nitzschia	1796.9		*Gloeomonas*			*Pseudanabaena*	4991.5	
Pinnularia			*Golenkinia*			*Synechococcus*		
Rhoicosphernia			*Kirchneriella*	199.7		*Woronichinia*		
Stephanodiscus			*Koliella*			Akinete		
Suriella			*Lagerheimia*	599.0				
Synedra	199.7		*Nannochloris*	399.3		**Euglenoids**	**A**	**B**
Tabellaria			*Oocystis*			*Euglena*		
			Pandorina			*Phacus*		
			Pediastrum			*Trachelomonas*		
Chrysophytes	**A**	**B**	*Phacotus*					
Chromulina	599.0		*Scenedesmus*			**Dinoflagellates**	**A**	**B**
Dinobryon			*Selenastrum*			*Ceratium*		
Mallomonas			*Sphaerocystis*	199.7		*Gymnodinium*		
Synura			*Spinoclosterium*			*Tetradinium*		
			Spirogya					
Xanthophytes	**A**	**B**	*Staurastrum*			**Cryptophytes**	**A**	**B**
Isthmochloron			*Teilingia*			*Chroomonas*		
			Tetraedron	199.7		*Cryptomonas*	599.0	
			Treubaria					
			Ulothrix					
			Zygnema					

Sites:	A	B	Comments:
Cyanobacteria Count	26,355	0	
Total Count	41,729	0	
Genera Richness	23	0	

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Phytoplankton Community Composition Analysis

Sampling Location: Smith Mountain	Sampling Date: 2024.03.07	Examination Date: 2024.03.19
Site A: Virginia Key	Site B:	

Phytoplankton (cells/mL)

Diatoms	**A**	**B**	**Chlorophytes**	**A**	**B**	**Cyanophytes**	**A**	**B**
Amphora			*Actinastrum*			*Aphanizomenon*	9467.1	
Asterionella	331.0		*Ankistrodesmus*			*Aphanocapsa*		
Cocconeis			*Brachiomonas*			*Chroococcus*		
Cyclotella			*Chlamydomonas*	132.4		*Coelosphaerium*		
Cymbella			*Chlorella*	463.4		*Cylindrospermopsis*		
Diatoma	66.2		*Chlorogonium*			*Dactylococcopsis*		
Eunotia			*Coccomonas*			*Gloeocapsa*		
Fragilaria			*Crucigenia*			*Lyngbya*		
Gomphonema			*Dictyosphaerium*			*Merismopedia*	264.8	
Gyrosigma			*Didymocystis*			*Microcystis*	1655.1	
Melosira	66.2		*Franceia*			*Oscillatoria*		
Navicula	397.2		*Gloeococcus*			*Planktothrix*		
Nitzschia			*Gloeomonas*			*Pseudanabaena*	463.4	
Pinnularia			*Golenkinia*	66.2		*Synechococcus*	66.2	
Rhoicosphernia			*Kirchneriella*	595.8		*Woronichinia*		
Stephanodiscus			*Koliella*			Akinete		
Suriella			*Lagerheimia*					
Synedra	66.2		*Nannochloris*			**Euglenoids**	**A**	**B**
Tabellaria			*Oocystis*			*Euglena*		
			Pandorina			*Phacus*		
			Pediastrum			*Trachelomonas*		
Chrysophytes	**A**	**B**	*Phacotus*					
Chromulina	2317.1		*Scenedesmus*			**Dinoflagellates**	**A**	**B**
Dinobryon			*Selenastrum*			*Ceratium*		
Mallomonas			*Sphaerocystis*			*Gymnodinium*		
Synura			*Spinoclosterium*			*Tetradinium*		
			Spirogya					
Xanthophytes	**A**	**B**	*Staurastrum*			**Cryptophytes**	**A**	**B**
Isthmochloron			*Teilingia*			*Chroomonas*		
			Tetraedron			*Cryptomonas*	66.2	
			Treubaria	463.4				
			Ulothrix					
			Zygnema					

Sites:	**A**	**B**
Cyanobacteria Count	11,917	0
Total Count	16,948	0
Genera Richness	17	0

Comments:

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APPENDIX II: POST-INCUBATION PLANKTON

Phytoplankton Community Composition Analysis

Sampling Location: Smith Mountain	Sampling Date: 2024.03.22	Examination Date: 2024.03.25
Site A: Anthony Ford 1	Site B: Anthony Ford 2	

Phytoplankton (cells/mL)

Diatoms	A	B	Chlorophytes	A	B	Cyanophytes	A	B
Amphora			*Actinastrum*			*Aphanizomenon*		
Asterionella			*Ankistrodesmus*			*Aphanocapsa*		
Cocconeis			*Brachiomonas*			*Chroococcus*		
Cyclotella			*Chlamydomonas*		94.3	*Coelosphaerium*		
Cymbella			*Chlorella*	132.4		*Cylindrospermopsis*	397.1	
Eunotia	661.8		*Chlorogonium*			*Dactylococcopsis*		
Fragilaria			*Coccomonas*			*Gloeocapsa*		
Frustulia			*Crucigenia*			*Lyngbya*		
Gomphonema			*Dictyosphaerium*			*Merismopedia*		
Gyrosigma			*Didymocystis*			*Microcystis*	264.7	
Melosira	13367.4		*Franceia*			*Oscillatoria*	11911.6	
Navicula			*Gloeococcus*			*Planktothrix*		
Nitzschia	397.1		*Gloeomonas*			*Pseudanabaena*		
Pinnularia			*Golenkinia*			*Synechococcus*	132.4	377.4
Rhoicosphernia			*Kirchneriella*	264.7		*Woronichinia*		
Stauroneis			*Koliella*	132.4		Akinete		
Stephanodiscus			*Lagerheimia*					
Synedra	132.4		*Nannochloris*		283.0	**Euglenoids**	**A**	**B**
Tabellaria			*Oocystis*			*Euglena*		
			Pandorina			*Phacus*		
			Pediastrum			*Trachelomonas*		
Chrysophytes	**A**	**B**	*Phacotus*					
Chromulina	529.4	283.0	*Scenedesmus*			**Dinoflagellates**	**A**	**B**
Dinobryon			*Selenastrum*			*Ceratium*		
Mallomonas			*Sphaerocystis*			*Gymnodinium*		
Synura			*Spinoclosterium*			*Tetradinium*		
			Spirogya					
Xanthophytes	**A**	**B**	*Staurastrum*			**Cryptophytes**	**A**	**B**
Isthmochloron			*Teilingia*			*Chroomonas*		
			Tetraselmis			*Cryptomonas*		
			Treubaria					
			Ulothrix					
			Zygnema					

Sites:	A	B	Comments:
Cyanobacteria Count	12,706	377	
Total Count	28,323	1,038	
Genera Richness	12	4	

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Phytoplankton Community Composition Analysis

Sampling Location: Smith Mountain	**Sampling Date: 2024.03.22**	**Examination Date: 2024.03.25**
Site A: Crafts Church 1	**Site B: Crafts Church 2**	

Phytoplankton (cells/mL)

Diatoms	**A**	**B**	**Chlorophytes**	**A**	**B**	**Cyanophytes**	**A**	**B**
Amphora			*Actinastrum*		50.7	*Aphanizomenon*		
Asterionella			*Ankistrodesmus*	101.4		*Aphanocapsa*	811.5	
Bacillaria	1115.8		*Brachiomonas*			*Chroococcus*		
Cyclotella			*Chlamydomonas*	50.7	202.9	*Coelosphaerium*		
Diatoma	50.7		*Chlorella*		405.8	*Cylindrospermopsis*	50.7	101.4
Eunotia			*Chlorogonium*	202.9	50.7	*Dactylococcopsis*		
Fragilaria			*Coccomonas*			*Gloeocapsa*		
Frustulia			*Crucigenia*			*Lyngbya*		
Gomphonema			*Dictyosphaerium*			*Merismopedia*		
Gyrosigma			*Didymocystis*	913.0	50.7	*Microcystis*	15216.1	202.9
Melosira			*Franceia*			*Oscillatoria*		
Navicula	202.9	50.7	*Gloeococcus*			*Planktothrix*		
Nitzschia	202.9	50.7	*Gloeomonas*			*Pseudanabaena*		
Pinnularia			*Golenkinia*	202.9	355.0	*Synechococcus*		
Rhoicosphernia			*Kirchneriella*			*Woronichinia*		
Stauroneis			*Koliella*			Akinete		
Stephanodiscus			*Lagerheimia*					
Synedra			*Nannochloris*		50.7	**Euglenoids**	**A**	**B**
Tabellaria			*Oocystis*			*Euglena*		
			Pandorina			*Phacus*	50.7	
			Pediastrum			*Trachelomonas*		
Chrysophytes	**A**	**B**	*Phacotus*					
Chromulina		101.4	*Scenedesmus*			**Dinoflagellates**	**A**	**B**
Dinobryon			*Selenastrum*			*Ceratium*		
Mallomonas		202.9	*Sphaerocystis*			*Gymnodinium*	50.7	
Synura			*Spinoclosterium*			*Tetradinium*		
			Spirogya					
Xanthophytes	**A**	**B**	*Staurastrum*			**Cryptophytes**	**A**	**B**
Isthmochloron			*Teilingia*			*Chroomonas*		50.7
			Tetraselmis			*Cryptomonas*		
			Treubaria	50.7		*Rhodamonas*		355.0
			Ulothrix					
			Zygnema					

Sites:	**A**	**B**	**Comments:**
Cyanobacteria Count	16,078	304	
Total Count	19,274	2,282	
Genera Richness	15	15	

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Phytoplankton Community Composition Analysis

Sampling Location: Smith Mountain	**Sampling Date: 2024.03.22**	**Examination Date: 2024.03.25**
Site A: Gills Creek	**Site B:**	

Phytoplankton (cells/mL)

Diatoms	**A**	**B**	**Chlorophytes**	**A**	**B**	**Cyanophytes**	**A**	**B**
Amphora	52.4		*Actinastrum*			*Aphanizomenon*		
Asterionella			*Ankistrodesmus*			*Aphanocapsa*		
Cocconeis	52.4		*Brachiomonas*			*Chroococcus*		
Cyclotella			*Chlamydomonas*			*Coelosphaerium*		
Cymbella	52.4		*Chlorella*	52.4		*Cylindrospermopsis*	419.3	
Eunotia			*Chlorogonium*			*Dactylococcopsis*		
Fragilaria			*Coccomonas*			*Gloeocapsa*		
Frustulia			*Crucigenia*			*Lyngbya*		
Gomphonema			*Dictyosphaerium*			*Merismopedia*		
Gyrosigma			*Didymocystis*			*Microcystis*	209.6	
Melosira			*Franceia*			*Oscillatoria*		
Navicula	314.5		*Gloeococcus*			*Planktothrix*		
Nitzschia	52.4		*Gloeomonas*			*Pseudanabaena*		
Pinnularia	52.4		*Golenkinia*			*Synechococcus*	157.2	
Rhoicosphernia			*Kirchneriella*			*Woronichinia*		
Stephanodiscus			*Koliella*			Akinete		
Suriella			*Lagerheimia*					
Synedra			*Nannochloris*			**Euglenoids**	**A**	**B**
Tabellaria			*Oocystis*			*Euglena*		
			Pandorina			*Phacus*		
			Pediastrum			*Trachelomonas*	52.4	
Chrysophytes	**A**	**B**	*Phacotus*					
Chromulina	104.8		*Scenedesmus*			**Dinoflagellates**	**A**	**B**
Dinobryon			*Selenastrum*			*Ceratium*		
Mallomonas			*Sphaerocystis*			*Gymnodinium*		
Synura			*Spinoclosterium*			*Tetradinium*		
			Spirogya					
Xanthophytes	**A**	**B**	*Staurastrum*			**Cryptophytes**	**A**	**B**
Isthmochloron			*Teilingia*			*Chroomonas*		
			Tetraselmis			*Cryptomonas*		
			Treubaria					
			Ulothrix					
			Zygnema					

Sites:	**A**	**B**	**Comments:**
Cyanobacteria Count	786	0	
Total Count	1,572	0	
Genera Richness	12	0	

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Phytoplankton Community Composition Analysis

Sampling Location: Smith Mountain	Sampling Date: 2024.03.22	Examination Date: 2024.03.25
Site A: Pine Cone 1	Site B: Pine Cone 2	

Phytoplankton (cells/mL)

Diatoms	**A**	**B**	**Chlorophytes**	**A**	**B**	**Cyanophytes**	**A**	**B**
Amphora			*Actinastrum*			*Aphanizomenon*		
Asterionella			*Ankistrodesmus*			*Aphanocapsa*		
Cocconeis			*Brachiomonas*			*Chroococcus*		
Cyclotella			*Chlamydomonas*	20.6		*Coelosphaerium*		
Cymbella			*Chlorella*			*Cylindrospermopsis*		
Eunotia			*Chlorogonium*			*Dactylococcopsis*		
Fragilaria	143.9		*Coccomonas*			*Gloeocapsa*		
Frustulia			*Crucigenia*			*Lyngbya*		
Gomphonema			*Dictyosphaerium*			*Merismopedia*		
Gyrosigma			*Didymocystis*		26.5	*Microcystis*	41.1	
Melosira			*Franceia*			*Oscillatoria*		
Navicula	20.6		*Gloeococcus*			*Planktothrix*		
Nitzschia			*Gloeomonas*			*Pseudanabaena*		
Pinnularia			*Golenkinia*			*Synechococcus*	61.7	
Rhoicosphernia			*Kirchneriella*			*Woronichinia*		
Stephanodiscus			*Koliella*			Akinete		
Suriella			*Lagerheimia*		26.5			
Synedra			*Nannochloris*			**Euglenoids**	**A**	**B**
Tabellaria			*Oocystis*			*Euglena*		
			Pandorina			*Phacus*		
			Pediastrum			*Trachelomonas*		
Chrysophytes	**A**	**B**	*Phacotus*					
Chromulina	61.7	79.4	*Scenedesmus*			**Dinoflagellates**	**A**	**B**
Dinobryon			*Selenastrum*			*Ceratium*		
Mallomonas			*Sphaerocystis*			*Gymnodinium*		
Synura			*Spinoclosterium*			*Tetradinium*		
			Spirogyra					
Xanthophytes	**A**	**B**	*Staurastrum*			**Cryptophytes**	**A**	**B**
Isthmochloron			*Teilingia*			*Chroomonas*		
			Tetraselmis			*Cryptomonas*		
			Treubaria					
			Ulothrix					
			Zygnema					

Sites:	**A**	**B**	**Comments:**
Cyanobacteria Count	103	0	
Total Count	350	132	
Genera Richness	6	3	

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Phytoplankton Community Composition Analysis

Sampling Location: Smith Mountain	Sampling Date: 2024.03.22	Examination Date: 2024.03.25
Site A: Sandy Point 1	Site B: Sandy Point 2	

Phytoplankton (cells/mL)

Diatoms	**A**	**B**	**Chlorophytes**	**A**	**B**	**Cyanophytes**	**A**	**B**
Amphora			*Actinastrum*		26.2	*Aphanizomenon*		
Asterionella			*Ankistrodesmus*			*Aphanocapsa*		
Cocconeis			*Brachiomonas*			*Chroococcus*		
Cyclotella		26.2	*Chlamydomonas*			*Coelosphaerium*		
Cymbella			*Chlorella*		52.4	*Cylindrospermopsis*	57.7	78.6
Eunotia		131.0	*Chlorogonium*		26.2	*Dactylococcopsis*		
Fragilaria			*Coccomonas*			*Gloeocapsa*		
Frustulia			*Crucigenia*			*Lyngbya*		
Gomphonema			*Dictyosphaerium*			*Merismopedia*		
Gyrosigma			*Didymocystis*			*Microcystis*	57.7	26.2
Melosira			*Franceia*			*Oscillatoria*		
Navicula	57.7	52.4	*Gloeococcus*			*Planktothrix*		
Nitzschia		26.2	*Gloeomonas*			*Pseudanabaena*		
Pinnularia			*Golenkinia*			*Synechococcus*	345.9	26.2
Rhoicosphernia			*Kirchneriella*			*Woronichinia*		
Stephanodiscus			*Koliella*			Akinete		
Suriella			*Lagerheimia*					
Synedra			*Nannochloris*	57.7	26.2	**Euglenoids**	**A**	**B**
Tabellaria			*Oocystis*			*Euglena*		
			Pandorina			*Phacus*		
			Pediastrum			*Trachelomonas*		
Chrysophytes	**A**	**B**	*Phacotus*					
Chromulina	57.7	52.4	*Scenedesmus*			**Dinoflagellates**	**A**	**B**
Dinobryon			*Selenastrum*			*Ceratium*		
Mallomonas			*Sphaerocystis*			*Gymnodinium*		
Synura			*Spinoclosterium*			*Tetradinium*		
			Spirogyra					
Xanthophytes	**A**	**B**	*Staurastrum*			**Cryptophytes**	**A**	**B**
Isthmochloron			*Teilingia*			*Chroomonas*		131.0
			Tetraedron			*Cryptomonas*		
			Treubaria					
			Ulothrix					
			Zygnema					

Sites:	**A**	**B**	**Comments:**
Cyanobacteria Count	461	131	
Total Count	634	681	
Genera Richness	6	13	

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Phytoplankton Community Composition Analysis

Sampling Location: Smith Mountain	Sampling Date: 2024.03.22	Examination Date: 2024.03.25
Site A: Virginia Key 1	Site B: Virigina Key 2	

Phytoplankton (cells/mL)

Diatoms	**A**	**B**	**Chlorophytes**	**A**	**B**	**Cyanophytes**	**A**	**B**
Amphora			*Actinastrum*			*Aphanizomenon*		
Asterionella		21.0	*Ankistrodesmus*			*Aphanocapsa*		
Cocconeis			*Brachiomonas*			*Chroococcus*		
Cyclotella			*Chlamydomonas*	48.1		*Coelosphaerium*		
Cymbella			*Chlorella*	144.4	21.0	*Cylindrospermopsis*		
Diatoma			*Chlorogonium*			*Dactylococcopsis*		
Eunotia			*Coccomonas*			*Gloeocapsa*		
Fragilaria			*Crucigenia*			*Lyngbya*		
Gomphonema			*Dictyosphaerium*			*Merismopedia*		
Gyrosigma			*Didymocystis*			*Microcystis*		
Melosira			*Franceia*			*Oscillatoria*		
Navicula	96.3	21.0	*Gloeococcus*			*Planktothrix*		
Nitzschia			*Gloeomonas*			*Pseudanabaena*		
Pinnularia			*Golenkinia*			*Synechococcus*		62.9
Rhoicosphernia			*Kirchneriella*	48.1		*Woronichinia*		
Stephanodiscus			*Koliella*			Akinete		
Suriella			*Lagerheimia*		21.0			
Synedra	48.1		*Nannochloris*		21.0	**Euglenoids**	**A**	**B**
Tabellaria			*Oocystis*			*Euglena*		
			Pandorina			*Phacus*		
			Pediastrum			*Trachelomonas*	48.1	
Chrysophytes	**A**	**B**	*Phacotus*					
Chromulina	1203.3	335.4	*Scenedesmus*			**Dinoflagellates**	**A**	**B**
Dinobryon		21.0	*Selenastrum*			*Ceratium*		
Mallomonas			*Sphaerocystis*			*Gymnodinium*		
Synura			*Spinoclosterium*			*Tetradinium*		
			Spirogya					
Xanthophytes	**A**	**B**	*Staurastrum*			**Cryptophytes**	**A**	**B**
Isthmochloron			*Teilingia*			*Chroomonas*		
			Tetraedron			*Cryptomonas*		
			Treubaria					
			Ulothrix					
			Zygnema					

Sites:	**A**	**B**	**Comments:**
Cyanobacteria Count	0	63	
Total Count	1,636	524	
Genera Richness	7	8	

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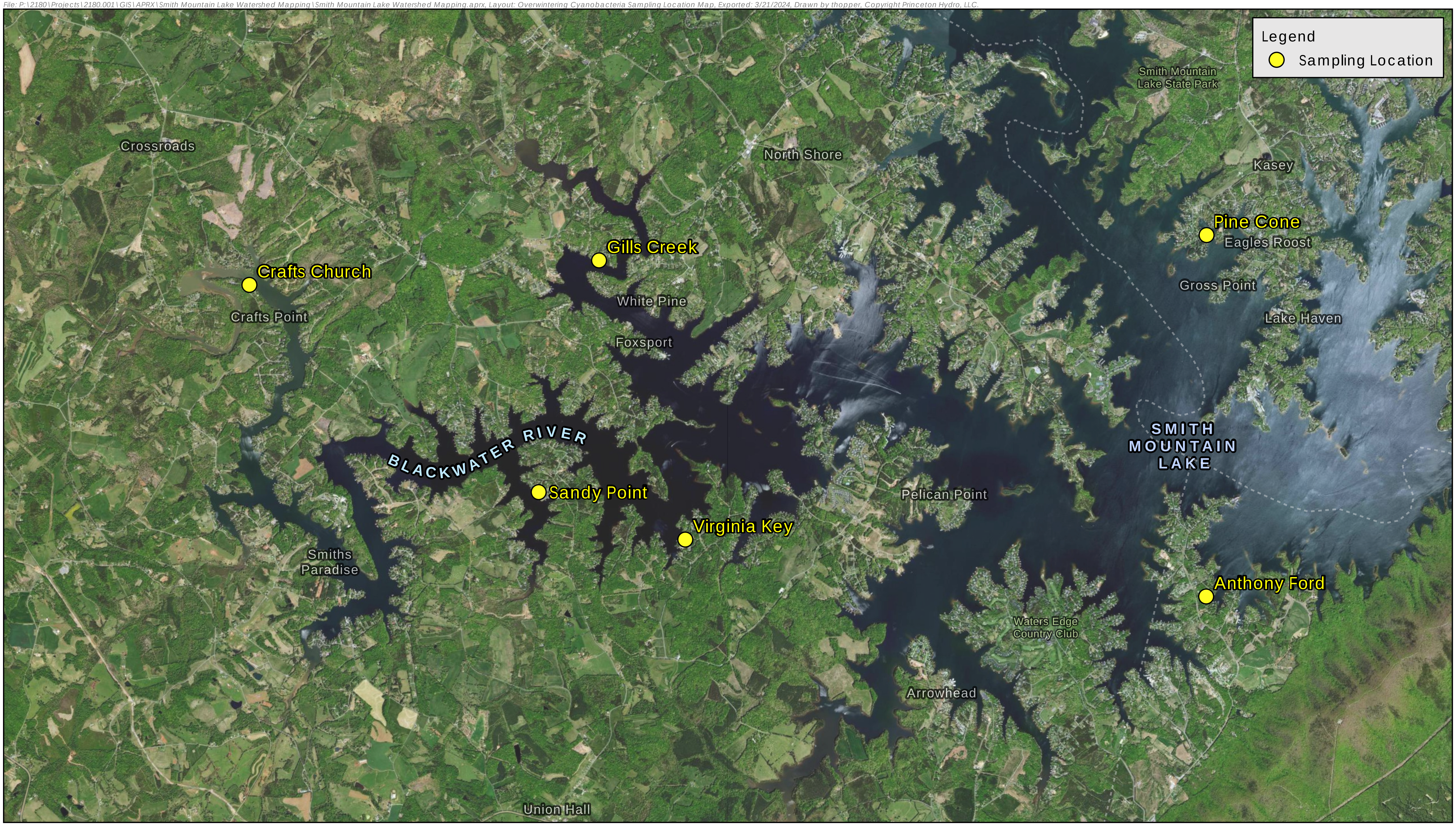
APPENDIX III: SAMPLING MAP



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NOTES:
1. Sampling locations are approximate.
2. Basemap obtained from ESRI basemap services. NAIP Imagery and World Hillshade basemaps.

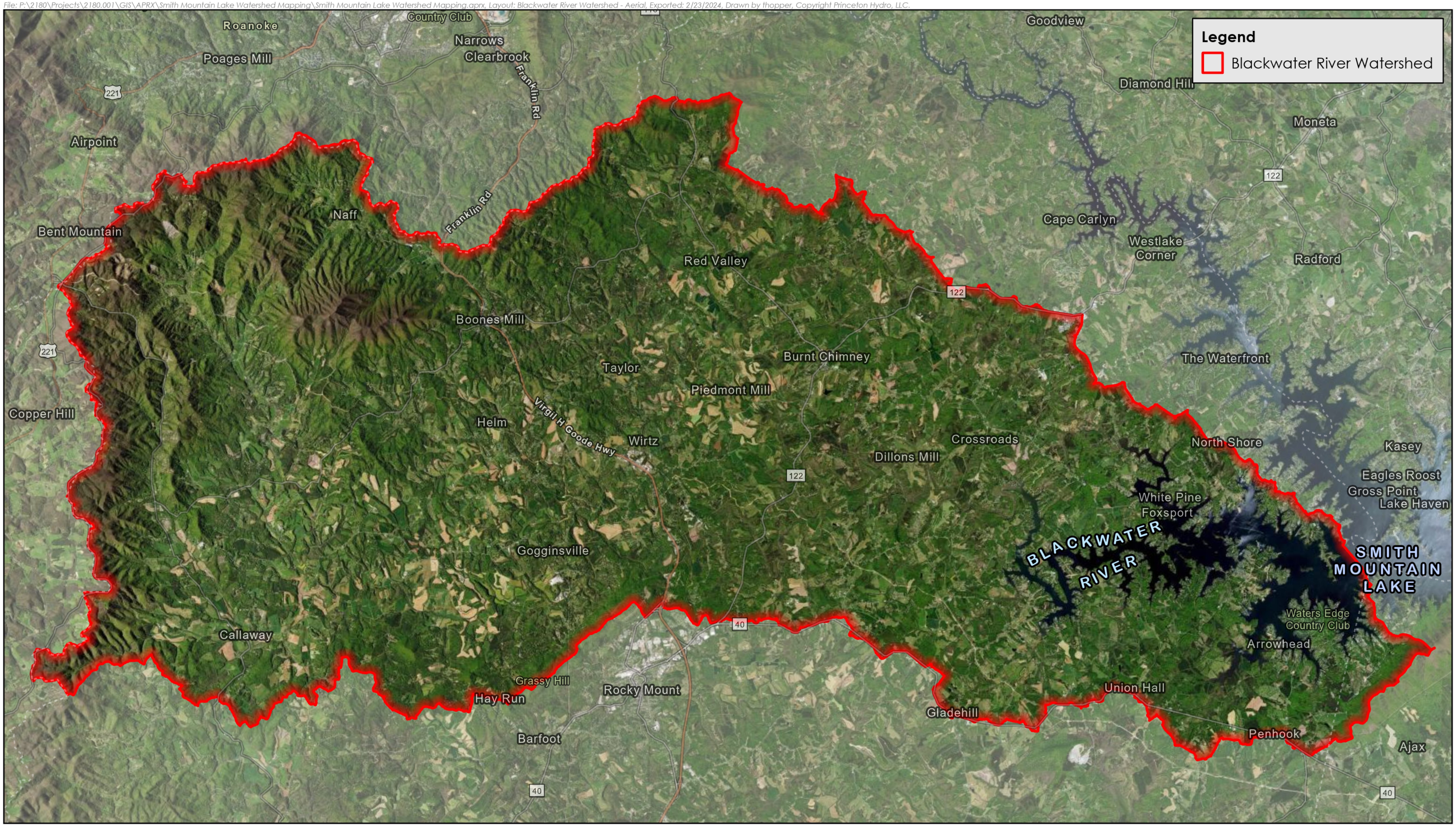
0 ¾ 1½ Miles

Spatial Reference: NAD 1983 2011 StatePlane Virginia South FIPS 4502 Ft US

OVERWINTERING CYANOBACTERIA SAMPLING LOCATION MAP

SMITH MOUNTAIN LAKE
FRANKLIN COUNTY
VIRGINIA

APPENDIX IV: WATERSHED MAPS/NUTRIENT LOADING TABLES



BLACKWATER RIVER WATERSHED

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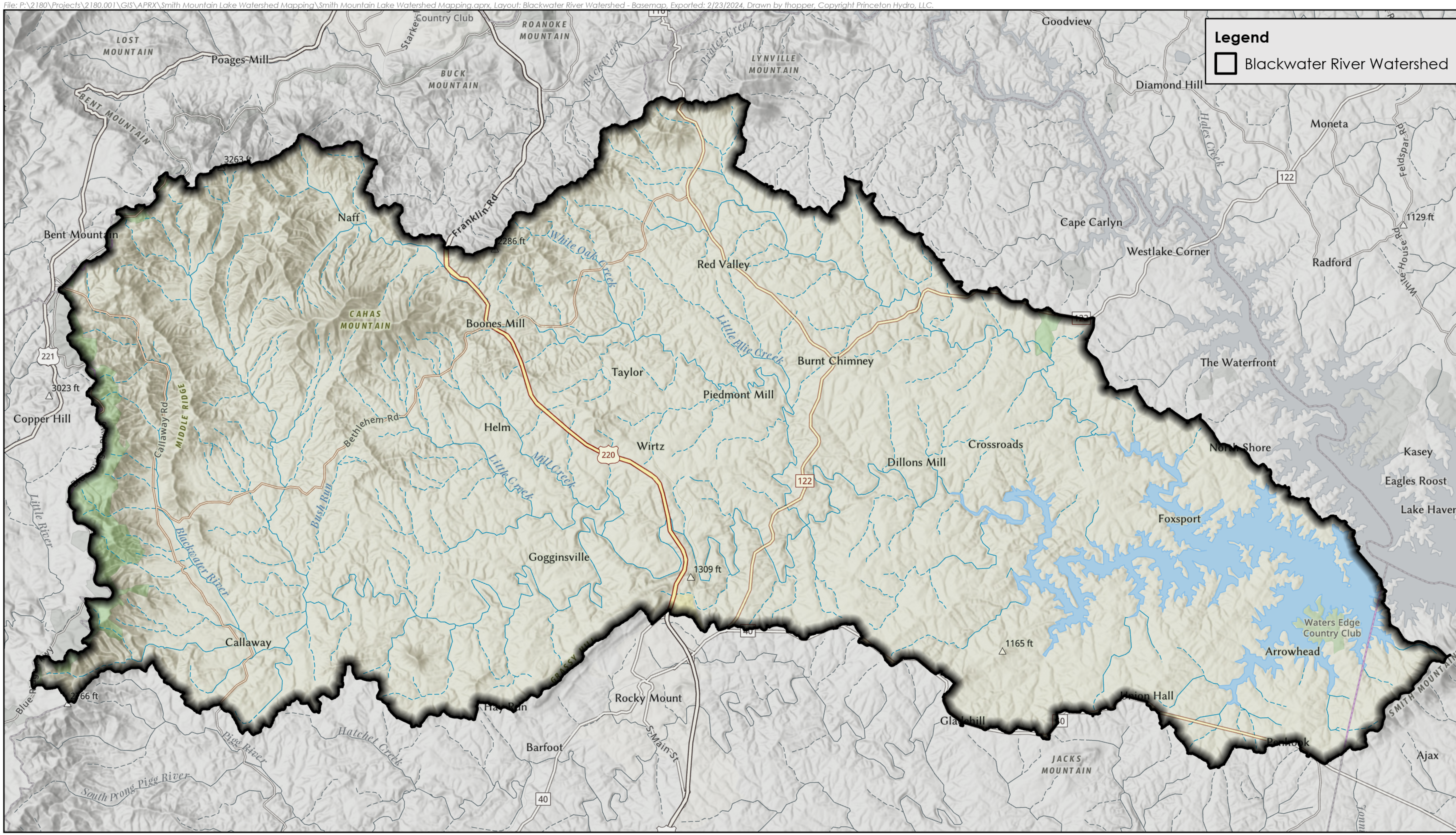
NOTES:
1. Watershed delineated by Princeton Hydro, LLC. using 2018 LiDAR data obtained from the Virginia Geographic Information Network (VGIN) data portal: https://vgin.vdem.virginia.gov/
2. Basemap obtained from ESRI basemap services. NAIP Imagery and World Hillshade basemaps.

0 ½ 1 2 Miles

Spatial Reference: NAD 1983 2011 StatePlane Virginia South FIPS 4502 Ft US

SMITH MOUNTAIN LAKE
FRANKLIN COUNTY
VIRGINIA

File: P:\2180\Projects\2180.001\GIS\APRX\Smith Mountain Lake Watershed Mapping\Smith Mountain Lake Watershed Mapping.aprx, Layout: Blackwater River Watershed - Basemap, Exported: 2/23/2024, Drawn by thopper, Copyright Princeton Hydro, LLC.



BLACKWATER RIVER WATERSHED

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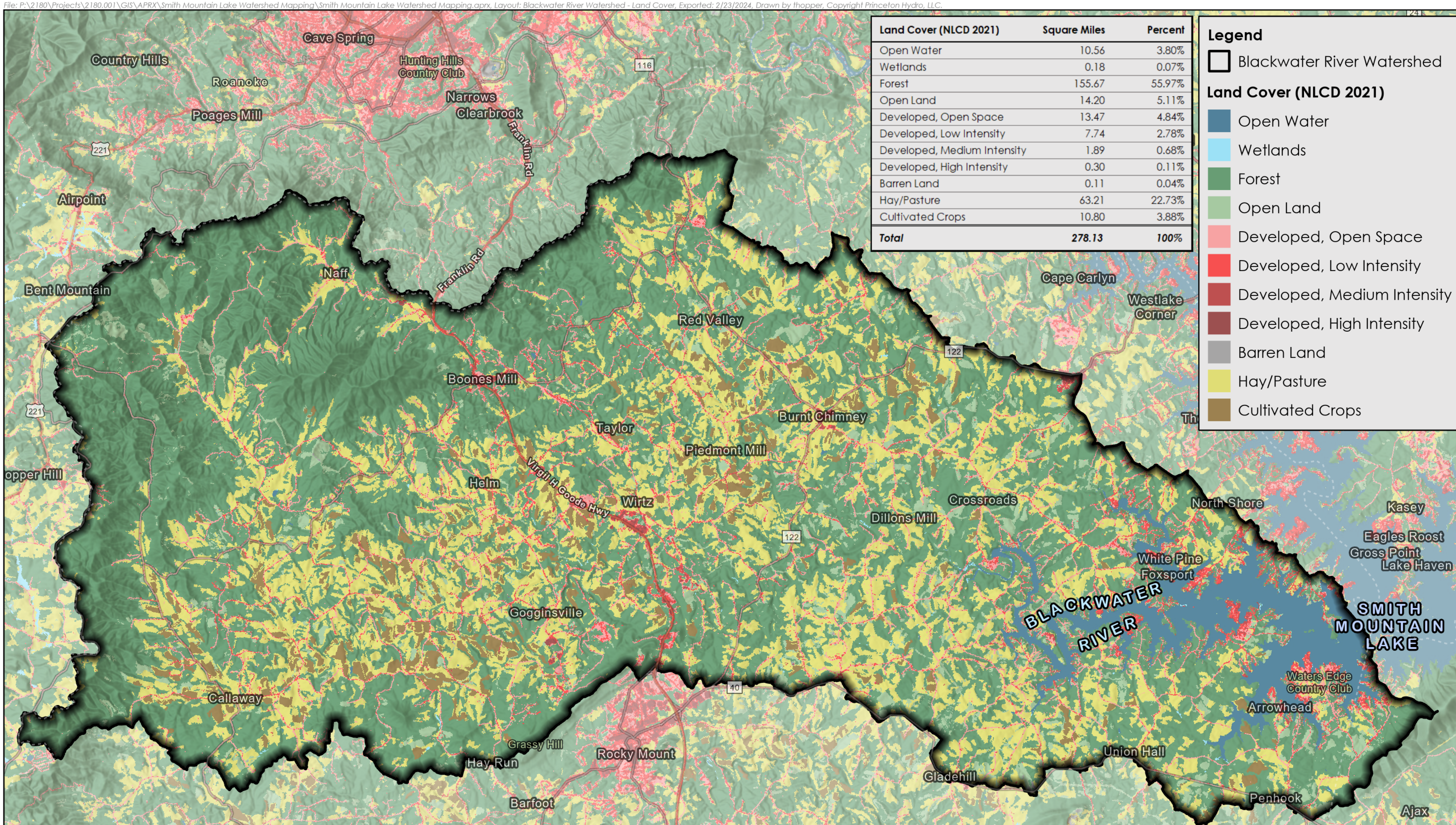
NOTES:
1. Watershed delineated by Princeton Hydro, LLC. using 2018 LiDAR data obtained from the Virginia Geographic Information Network (VGIN) data portal: https://vgin.vdem.virginia.gov/
2. Basemap obtained from ESRI basemap services. National Geographic and World Hillshade basemaps.

0 ½ 1 2 Miles

Spatial Reference: NAD 1983 2011 StatePlane Virginia South FIPS 4502 Ft US

SMITH MOUNTAIN LAKE
FRANKLIN COUNTY
VIRGINIA



Land Cover (NLCD 2021)	Square Miles	Percent
Open Water	10.56	3.80%
Wetlands	0.18	0.07%
Forest	155.67	55.97%
Open Land	14.20	5.11%
Developed, Open Space	13.47	4.84%
Developed, Low Intensity	7.74	2.78%
Developed, Medium Intensity	1.89	0.68%
Developed, High Intensity	0.30	0.11%
Barren Land	0.11	0.04%
Hay/Pasture	63.21	22.73%
Cultivated Crops	10.80	3.88%
Total	***278.13***	***100%***

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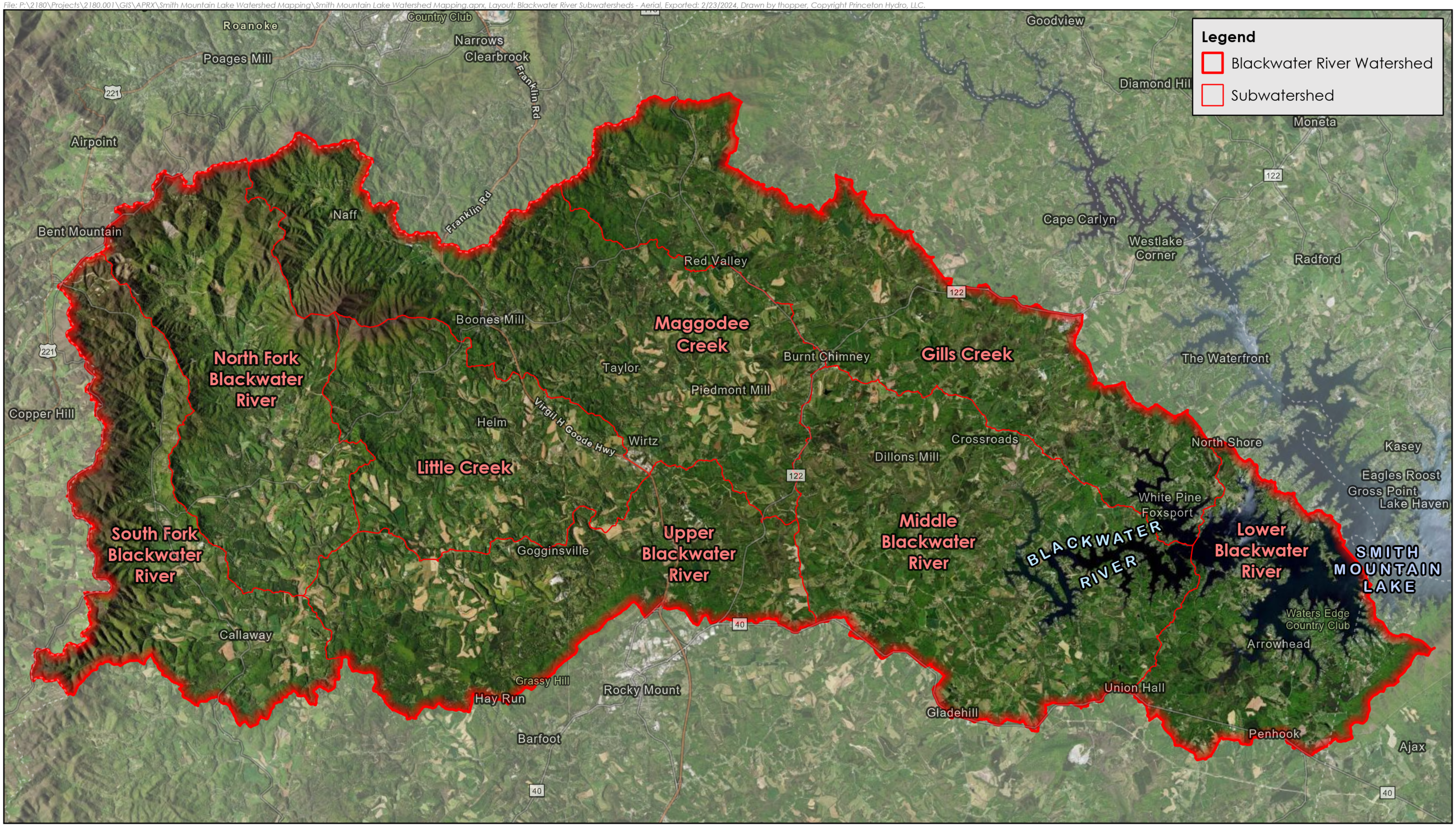
NOTES:
1. Watershed delineated by Princeton Hydro, LLC. using 2018 LiDAR data obtained from the Virginia Geographic Information Network (VGIN) data portal: https://vgin.vdem.virginia.gov/
2. 2021 land cover obtained from the Multi-Resolution Land Characteristics (MRLC) consortium's National Land Cover Database (NLCD).

0 ½ 1 2 Miles

Spatial Reference: NAD 1983 StatePlane Virginia South FIPS 4502 Feet

BLACKWATER RIVER WATERSHED LAND COVER

SMITH MOUNTAIN LAKE
FRANKLIN COUNTY
VIRGINIA



BLACKWATER RIVER WATERSHED

SMITH MOUNTAIN LAKE
FRANKLIN COUNTY
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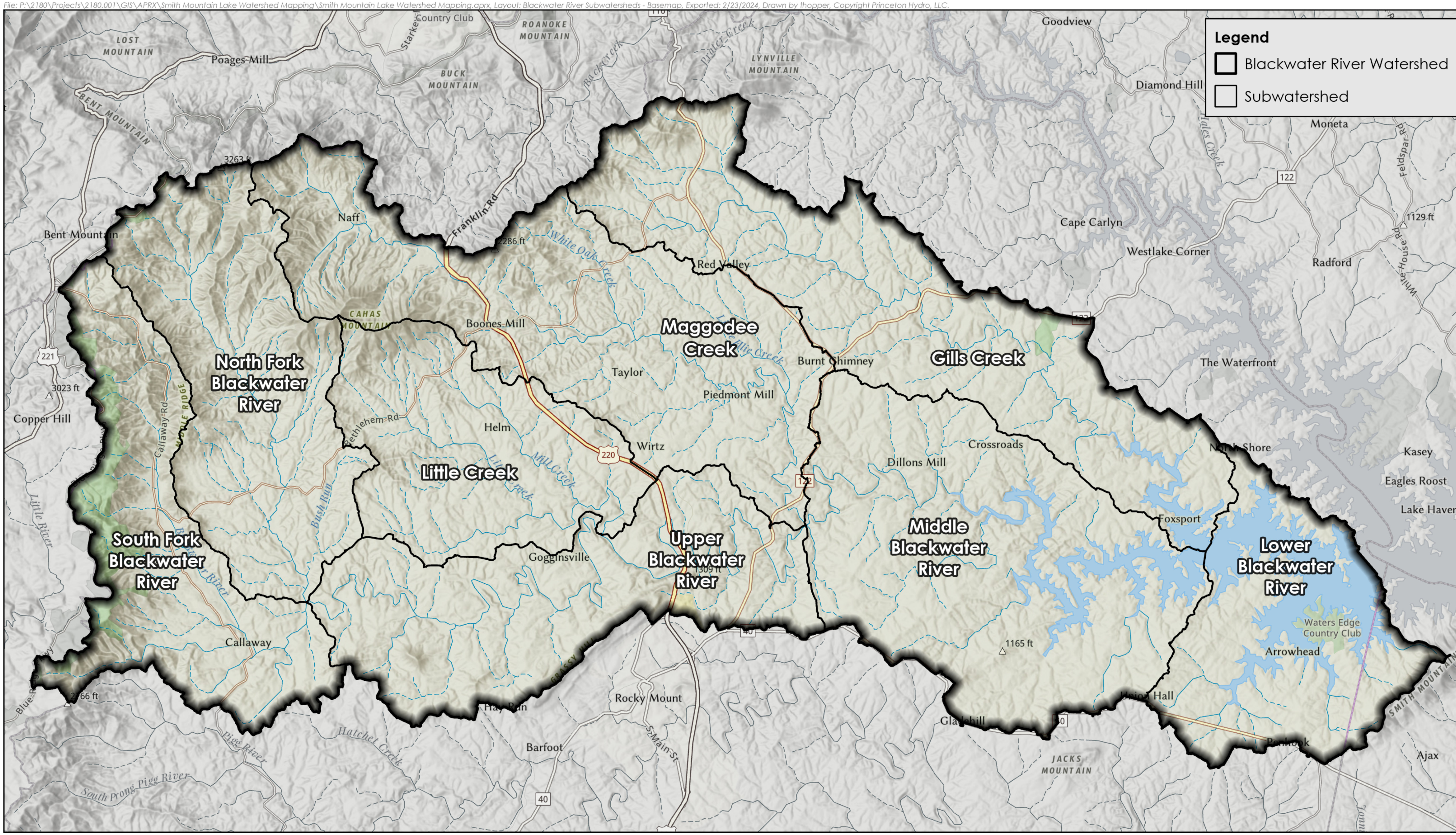
NOTES:
1. Watershed delineated by Princeton Hydro, LLC. using 2018 LiDAR data obtained from the Virginia Geographic Information Network (VGIN) data portal: https://vgin.vdem.virginia.gov/
2. Basemap obtained from ESRI basemap services. NAIP Imagery and World Hillshade basemaps.

0 ½ 1 2 Miles

Spatial Reference: NAD 1983 2011 StatePlane Virginia South FIPS 4502 Ft US

File: P:\2180\Projects\2180.001\GIS\APRX\Smith Mountain Lake Watershed Mapping\Smith Mountain Lake Watershed Mapping.aprx, Layout: Blackwater River Subwatersheds - Basemap, Exported: 2/23/2024, Drawn by thopper, Copyright Princeton Hydro, LLC.



BLACKWATER RIVER WATERSHED

SMITH MOUNTAIN LAKE
FRANKLIN COUNTY
VIRGINIA

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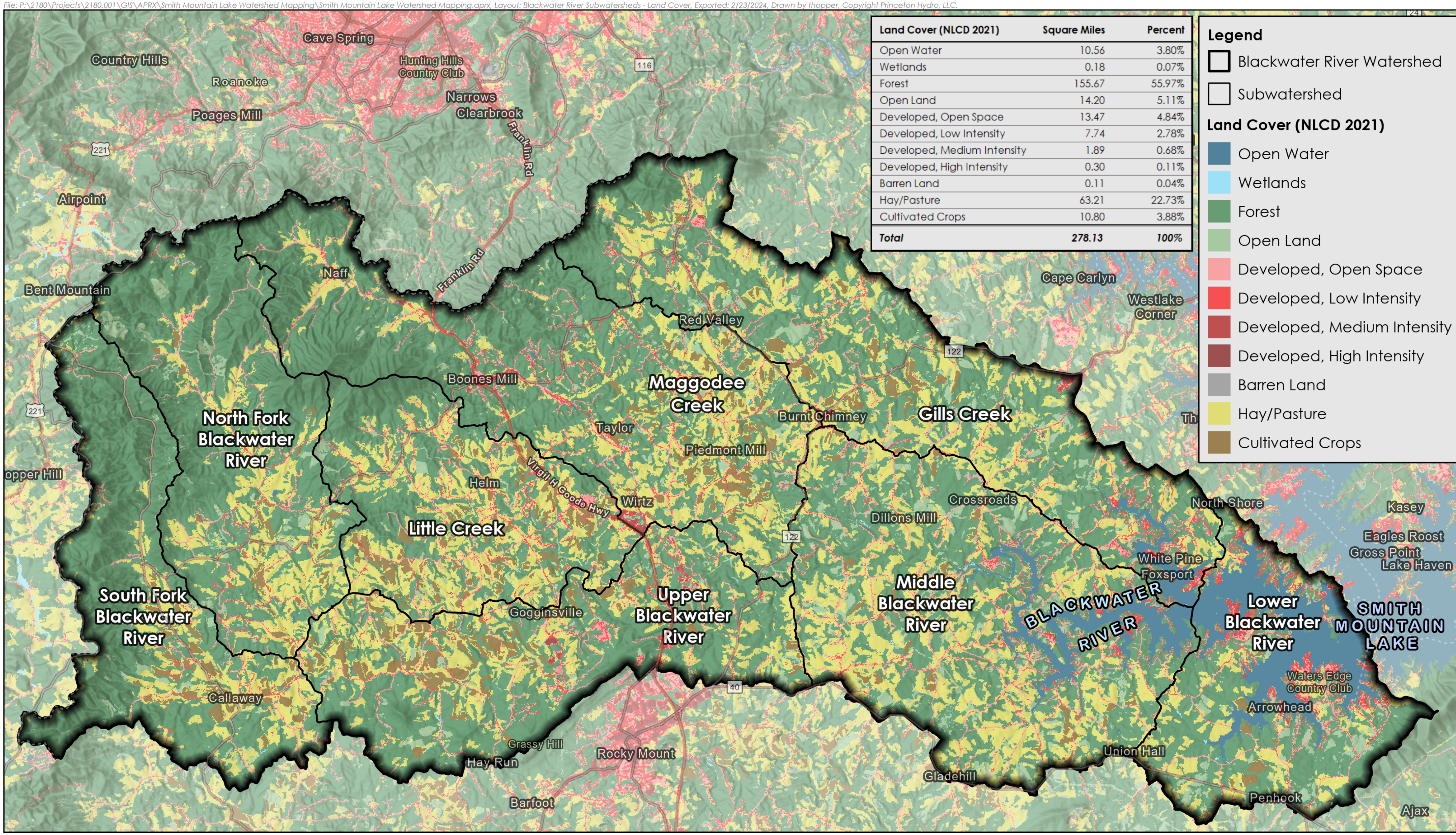
NOTES:
1. Watershed delineated by Princeton Hydro, LLC. using 2018 LiDAR data obtained from the Virginia Geographic Information Network (VGIN) data portal: https://vgin.vdem.virginia.gov/
2. Basemap obtained from ESRI basemap services. National Geographic and World Hillshade basemaps.

0 ½ 1 2 Miles

Spatial Reference: NAD 1983 2011 StatePlane Virginia South FIPS 4502 Ft US

File: P:\2180\Projects\2180.001\GIS\APRX\Smith Mountain Lake Watershed Mapping\Smith Mountain Lake Watershed Mapping.aprx, Layout: Blackwater River Subwatersheds - Land Cover, Exported: 2/23/2024, Drawn by thopper, Copyright Princeton Hydro, LLC.



Land Cover (NLCD 2021)	Square Miles	Percent
Open Water	10.56	3.80%
Wetlands	0.18	0.07%
Forest	155.67	55.97%
Open Land	14.20	5.11%
Developed, Open Space	13.47	4.84%
Developed, Low Intensity	7.74	2.78%
Developed, Medium Intensity	1.89	0.68%
Developed, High Intensity	0.30	0.11%
Barren Land	0.11	0.04%
Hay/Pasture	63.21	22.73%
Cultivated Crops	10.80	3.88%
Total	*278.13*	*100%*

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NOTES:
1. Watershed delineated by Princeton Hydro, LLC. using 2018 LiDAR data obtained from the Virginia Geographic Information Network (VGIN) data portal: https://vgin.vdem.virginia.gov/
2. 2021 land cover obtained from the Multi-Resolution Land Characteristics (MRLC) consortium's National Land Cover Database (NLCD).

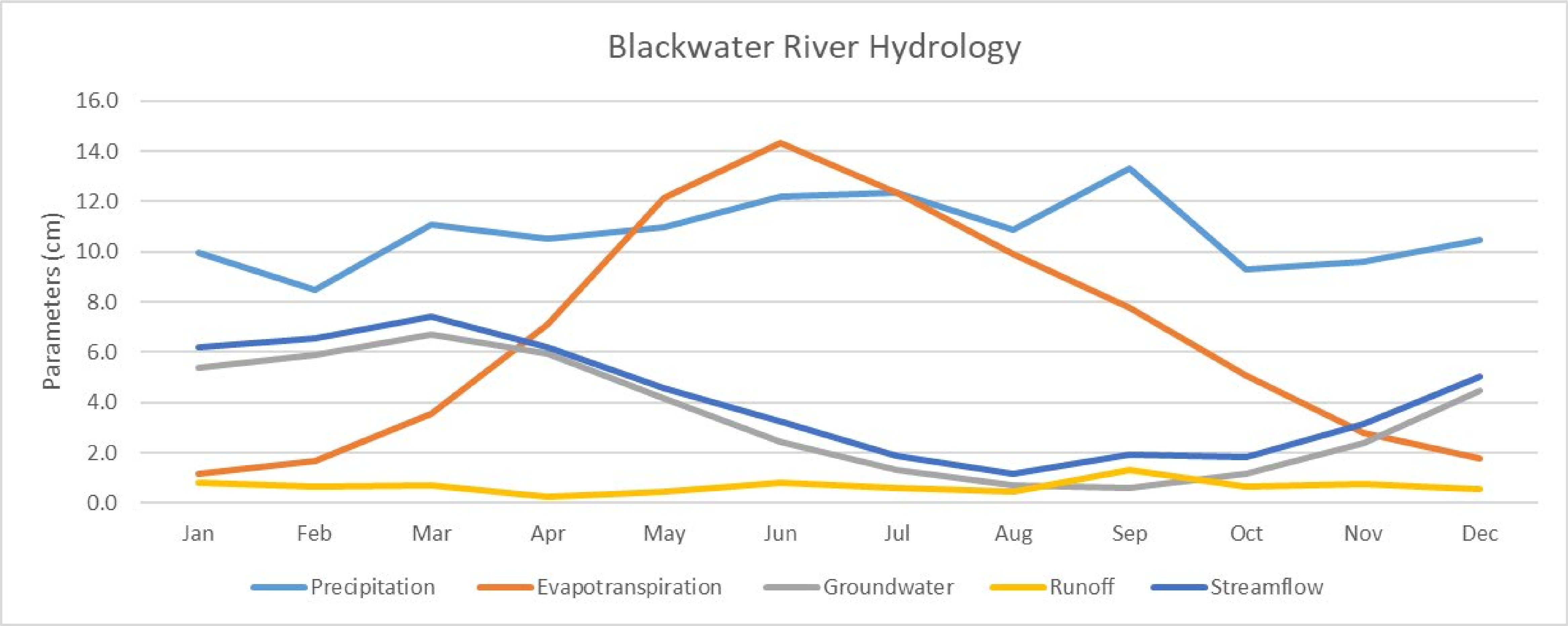
0 ½ 1 2 Miles

Spatial Reference: NAD 1983 StatePlane Virginia South FIPS 4502 Feet

BLACKWATER RIVER WATERSHED LAND COVER

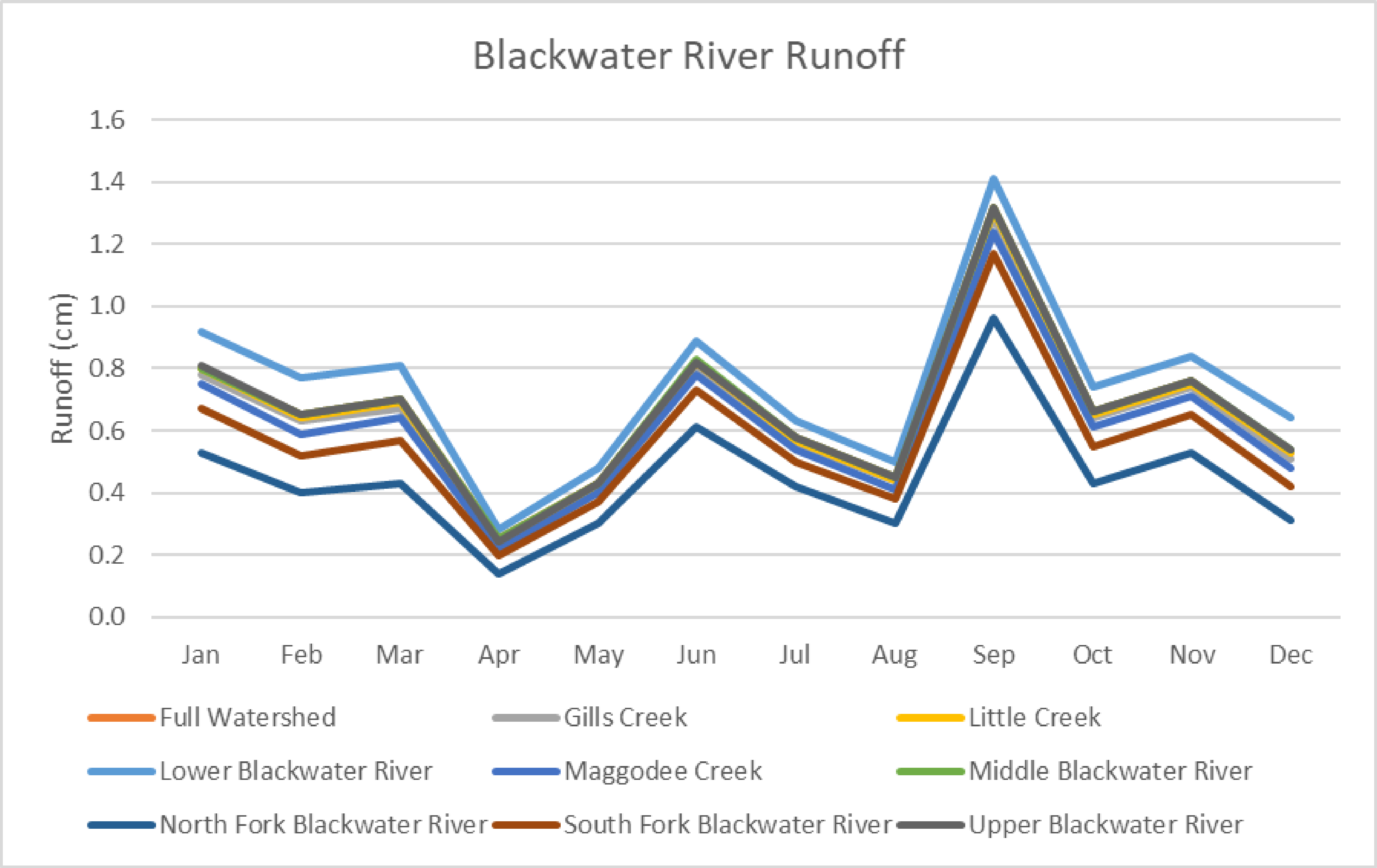
SMITH MOUNTAIN LAKE
FRANKLIN COUNTY
VIRGINIA

Hydrology



Blackwater River Hydrology
16.0
14.0
12.0
10.0
8.0
6.0
4.0
2.0
0.0
Parameters (cm)
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
Precipitation
Evapotranspiration
Groundwater
Runoff
Streamflow

Hydrology



Blackwater River Runoff
Runoff (cm)
1.6
1.4
1.2
1.0
0.8
0.6
0.4
0.2
0.0
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
Full Watershed
Gills Creek
Little Creek
Lower Blackwater River
Maggodee Creek
Middle Blackwater River
North Fork Blackwater River
South Fork Blackwater River
Upper Blackwater River

Land-Use

Source	Full Watershed	Gills Creek	Little Creek	Lower Blackwater River	Maggodee Creek	Middle Blackwater River	North Fork Blackwater River	South Fork Blackwater River	Upper Blackwater River
					Area (acres)				
Open Water	410.3	59.4	17.1	152.6	26.5	123.3	18.7	2.7	10.1
Hay/Pasture	40428.1	6792.4	5268.8	2238.5	6179.8	8676.4	3722.1	2864.2	4688.3
Cropland	6914.0	776.9	1296.3	280.0	1151.8	557.2	427.0	769.5	1655.6
Forest	99265.8	15530.8	7812.7	6689.6	18776.3	14024.7	14800.8	13208.5	12212.2
Wetland	90.9	15.3	13.8	14.3	7.9	22.7	4.0	3.7	20.3
Open Land	9005.0	1082.8	179.4	599.7	556.5	1507.6	380.3	301.2	590.1
Barren Land	69.9	8.9	7.9	4.0	5.2	23.0	4.2	7.9	9.1
Low-Density Mixed	4910.2	854.2	523.6	803.8	802.6	849.1	266.6	189.5	621.0
Medium-Density Mixed	1150.3	170.3	136.9	226.3	227.1	129.0	36.8	43.5	180.1
High-Density Mixed	178.9	33.4	20.5	20.8	43.5	7.2	3.5	7.9	42.5
Low-Density Open Space	8593.8	1306.7	828.5	760.8	1400.3	1833.0	763.3	623.9	1079.6
Total	171017.2	26631.1	16105.5	11790.4	29177.5	27753.2	20427.3	18022.5	21108.9

Source	Full Watershed	Gills Creek	Little Creek	Lower Blackwater River	Maggodee Creek	Middle Blackwater River	North Fork Blackwater River	South Fork Blackwater River	Upper Blackwater River
					Area (%)				
Open Water	0.2	0.2	0.1	1.3	0.1	0.4	0.1	0.0	0.0
Hay/Pasture	23.6	25.5	32.7	19.0	21.2	31.3	18.2	15.9	22.2
Cropland	4.0	2.9	8.0	2.4	3.9	2.0	2.1	4.3	7.8
Forest	58.0	58.3	48.5	56.7	64.4	50.5	72.5	73.3	57.9
Wetland	0.1	0.1	0.1	0.1	0.0	0.1	0.0	0.0	0.1
Open Land	5.3	4.1	1.1	5.1	1.9	5.4	1.9	1.7	2.8
Barren Land	0.0	0.0	0.0	0.0	0.0	0.1	0.0	0.0	0.0
Low-Density Mixed	2.9	3.2	3.3	6.8	2.8	3.1	1.3	1.1	2.9
Medium-Density Mixed	0.7	0.6	0.9	1.9	0.8	0.5	0.2	0.2	0.9
High-Density Mixed	0.1	0.1	0.1	0.2	0.1	0.0	0.0	0.0	0.2
Low-Density Open Space	5.0	4.9	5.1	6.5	4.8	6.6	3.7	3.5	5.1
Total	100	100	100	100	100	100	100	100	100

Phosphorus

Category	Description	Total Phosphorus kg	Total Phosphorus %
Runoff	Hay/Pasture	18221.73	25.0
	Cropland	6965.64	9.6
	Forest	429.24	0.6
	Wetland	0.78	0.0
	Open Land	548.56	0.8
	Barren Land	0.79	0.0
	Low-Density Mixed	89.00	0.1
	Medium-Density Mixed	76.10	0.1
	High-Density Mixed	11.84	0.0
	Low-Density Open Space	155.77	0.2
Other Sources	Farm Animals	23091.69	31.7
	Stream Bank	15908.00	21.8
	Groundwater	5660.22	7.8
	Point Source	0.00	0.0
	Dryfall	138.08	0.2
	Septic Systems	1636.26	2.2
	Total	72933.70	100.0

Phosphorus

Category	Description	Full Watershed kg	Gills Creek kg	Little Creek kg	Lower Blackwater River kg	Maggodee Creek kg	Middle Blackwater River kg	North Fork Blackwater River kg	South Fork Blackwater River kg	Upper Blackwater River kg
Runoff	Hay/Pasture	18221.73	5089.59	4214.11	1506.47	4144.42	6184.21	2594.05	2362.00	3325.54
	Cropland	6965.64	1258.86	2279.17	503.81	1674.24	867.38	677.19	1468.57	2658.47
	Forest	429.24	83.69	46.00	31.54	129.47	62.70	105.43	123.20	66.32
	Wetland	0.78	0.14	0.13	0.12	0.08	0.21	0.04	0.06	0.19
	Open Land	548.56	96.05	17.41	56.09	70.81	90.33	64.38	45.39	49.02
	Barren Land	0.79	0.09	0.09	0.04	0.06	0.24	0.05	0.10	0.00
	Low-Density Mixed	89.00	15.59	9.63	16.07	13.96	14.85	4.04	3.07	10.81
	Medium-Density Mixed	76.10	11.12	9.10	14.40	14.52	8.25	2.20	2.88	11.73
	High-Density Mixed	11.84	2.18	1.36	1.32	2.78	0.46	0.21	0.52	2.77
	Low-Density Open Space	155.77	23.85	15.25	15.21	24.35	32.07	11.56	10.12	18.80
Other Sources	Farm Animals	23091.69	3636.25	2820.61	1199.11	3307.15	4644.72	1992.86	1533.56	2512.04
	Stream Bank	15908.00	863.00	472.00	150.00	1006.00	827.00	360.00	286.00	587.00
	Groundwater	5660.22	857.15	511.61	372.35	931.95	886.24	660.11	604.71	668.99
	Point Sources	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	Dryfall	138.08	.	.	.	.	.	.	.	.
	Septic Systems	1636.26	217.56	132.34	380.12	220.57	354.43	67.26	31.08	179.67
	Total (kg)	72933.70	12155.12	10528.81	4246.64	11540.37	13973.09	6539.37	6471.25	10091.35
	kg/acre	0.43	0.46	0.65	0.36	0.40	0.50	0.32	0.36	0.48

Nitrogen

Category	Description	Total Nitrogen kg	%
Runoff	Hay/Pasture	29490.4	6.13
	Cropland	18633.1	3.87
	Forest	4391.6	0.91
	Wetland	13.3	0.00
	Open Land	4575.6	0.95
	Barren Land	18.5	0.00
	Low-Density Mixed	826.5	0.17
	Medium-Density Mixed	748.4	0.16
	High-Density Mixed	116.4	0.02
	Low-Density Open Space	1446.5	0.30
Other Sources	Farm Animals	104764.0	21.77
	Stream Bank	22400.0	4.66
	Groundwater	221613.6	46.06
	Point Sources	0.0	0.00
	Dryfall	27616.9	5.74
	Septic Systems	44506.8	9.25
	Total	481161.5	100

Nitrogen

Category	Description	Full Watershed kg	Gills Creek kg	Little Creek kg	Lower Blackwater River kg	Maggodee Creek kg	Middle Blackwater River kg	North Fork Blackwater River kg	South Fork Blackwater River kg	Upper Blackwater River kg
Runoff	Hay/Pasture	29490.4	8250.8	6992.8	2016.5	7699.9	8179.0	3913.24	3470.7	5247.2
	Cropland	18633.1	2871.7	5167.2	954.2	4339.3	1742.3	1468.2	2971.2	5942.0
	Forest	4391.6	715.1	367.1	294.8	928.95	615.30	523.17	672.1	559.4
	Wetland	13.3	2.3	2.1	2.1	1.2	3.3	0.6	0.9	3.0
	Open Land	4575.6	601.0	102.6	318.3	357.2	744.6	246.3	188.7	318.5
	Barren Land	18.5	2.3	2.1	1.0	1.4	6.0	1.1	2.1	0.0
	Low-Density Mixed	826.5	147.36	90.0	152.9	134.4	137.00	40.3	28.2	104.13
	Medium-Density Mixed	748.4	111.0	89.9	144.2	147.8	81.1	23.5	28.2	119.3
	High-Density Mixed	116.4	21.7	13.5	13.2	28.3	4.5	2.2	5.1	28.2
	Low-Density Open Space	1446.5	225.4	142.3	144.68	234.5	295.77	115.25	92.8	181.0
Other Sources	Farm Animals	104764.0	16895.8	13105.8	5571.9	15368.4	21582.1	9258.7	7128.0	11670.1
	Stream Bank	22400.0	1307.0	735.00	172.0	1774.0	955.0	486.0	386.0	844.0
	Groundwater	221613.6	24916.1	24492.8	9114.6	36375.3	26144.0	30459.5	31145.6	41778.9
	Point Sources	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	Dryfall	27616.9	.	.	.	.	.	.	.	.
	Septic Systems	44506.8	7663.1	4761.1	7763.1	6417.8	9020.7	1488.6	1173.8	6102.8
	Total (kg)	481161.5	63730.6	56064.2	26663.4	73808.4	69510.9	48026.4	47293.4	72898.4
	kg/acre	2.8	2.4	3.5	2.3	2.5	2.5	2.4	2.6	3.5

Sediment

Category	Description	Sediment kgx1000	%
Runoff	Hay/Pasture	12290.230	16.7
	Cropland	4777.150	6.5
	Forest	188.360	0.3
	Wetland	0.080	0.0
	Open Land	412.540	0.6
	Barren Land	0.170	0.0
	Low-Density Mixed	33.830	0.0
	Medium-Density Mixed	39.220	0.1
	High-Density Mixed	6.100	0.0
	Low-Density Open Space	59.200	0.1
Other Sources	Farm Animals	0.000	0.0
	Stream Bank	55780.801	75.8
	Groundwater	0.000	0.0
	Septic Systems	0.000	0.0
	Total	73587.681	100.0

Sediment

Category	Description	Full Watershed kg x 1000	Gills Creek kg x 1000	Little Creek kg x 1000	Lower Blackwater River kg x 1000	Maggodee Creek kg x 1000	Middle Blackwater River kg x 1000	North Fork Blackwater River kg x 1000	South Fork Blackwater River kg x 1000	Upper Blackwater River kg x 1000
Runoff	Hay/Pasture	12290.230	3543.450	3237.960	1218.320	2934.270	4613.810	1751.970	1772.730	2439.000
	Cropland	4777.150	879.960	1761.590	421.650	1190.890	650.910	462.630	1116.570	1971.090
	Forest	188.360	41.180	25.740	16.360	75.360	28.240	67.010	81.440	34.930
	Wetland	0.080	0.020	0.030	0.020	0.020	0.030	0.010	0.010	0.030
	Open Land	412.540	70.460	13.980	48.050	55.080	67.560	48.020	36.840	37.550
	Barren Land	0.170	0.010	0.020	0.000	0.010	0.040	0.010	0.030	0.000
	Low-Density Mixed	33.830	5.720	3.610	5.620	5.050	5.800	1.440	1.250	3.910
	Medium-Density Mixed	39.220	5.480	4.680	7.580	6.970	4.580	1.060	1.470	5.490
	High-Density Mixed	6.100	1.070	0.700	0.700	1.340	0.250	0.100	0.270	1.300
	Low-Density Open Space	59.200	8.750	5.700	5.320	8.810	12.520	4.130	4.120	6.800
Other Sources	Farm Animals	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
	Stream Bank	55780.801	2800.242	1662.737	565.939	3349.582	2895.034	1125.917	983.828	1998.204
	Groundwater	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
	Septic Systems	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
	Total (kgx1000)	73587.681	7356.342	6716.747	2289.559	7627.382	8278.774	3462.297	3998.558	6498.304
	kg/acre	430.3	276.2	417.0	194.2	261.4	298.3	169.5	221.9	307.8

Bacteria

Category	Description	Fecal Coliform Organisms	%
Fecal Coliform	Farm Animals	3.85E+16	99.9
	Point Sources	0.00E+00	0.0
	Septic Systems	0.00E+00	0.0
	Urban Areas	0.00E+00	0.0
	Wildlife	3.54E+13	0.1
	Total	3.85E+16	100

Category	Description	Full Watershed	Gills Creek	Little Creek	Lower Blackwater River	Maggodee Creek	Middle Blackwater River	North Fork Blackwater River	South Fork Blackwater River	Upper Blackwater River
		%	%	%	%	%	%	%	%	%
Fecal Coliform	Farm Animals	99.9	99.9	99.9	99.8	99.9	99.9	99.8	99.8	99.9
	Point Sources	0.0	0	0	0	0	0	0	0	0
	Septic Systems	0.0	0	0	0	0	0	0	0	0
	Urban Areas	0.0	0	0	0.1	0	0	0	0	0
	Wildlife	0.1	0.1	0.1	0.1	0.1	0.1	0.2	0.2	0.1
	Total (organisms)	3.85E+16	6.13E+15	4.75E+15	2.02E+15	5.58E+15	7.83E+15	3.36E+15	2.59E+15	4.23E+15

APPENDIX V: BMP CUT SHEETS

GLOSSARY OF TERMS

Area BMP - Land based management practices that affect impervious areas, land cover, and pollutant input. (Green Roof, Porous Pavement)

Basin - A stormwater basin is a vegetated depression designed to collect and store runoff as a temporary or permanent pool of water.

Biological uptake - As stormwater flows through a BMP, such as a constructed wetland, vegetation absorbs excess nutrients.

Conveyance - A ditch, or swale that is designed to carry stormwater.

Design Storm - A design storm refers to a specific rainfall event defined by the statistical likelihood of the event occurring in a given year. For example, a 10-year is when the rainfall intensity at which 10% (1/10) of historical rainfall intensities are equal to or greater then, with a 10% likelihood of any storm in one year exceeding that intensity.

Detention storage - The amount of water that temporarily sits on a watershed's surface during a rainfall-runoff event. The volume of detention storage increases gradually as the event progresses and then decreases once it ends.

Filtration - Filtration is a process that removes suspended particles and pollutants through a filter medium that may consist of engineered soils and plants.

Gravitational settling - The primary mechanism of pollutant removal in stormwater treatment systems. Removal occurs downard for solids denser than water like sediment.

Infiltration - The rate at which water enters the soil and permeates the soil. Infiltration is dictated by soil composition (clay, silt, sand) and hydrological group.

Linear BMP - Narrow linear shapes adjacent to stream channels that provide filiration, nutrient uptake, and ancillary benefits of stream shading, wildlife habitat, and aesthetic value. (Vegetated Swale, Vegetated Filter Strip)

Peak Flow - Assumed to occur when the entire watershed is contributing to flow, or the maximum flow of a stream in response to a storm event

Point BMP - Feature that captures upstream drainage at a specific location and may use a combination of detention, infiltration, evaporation, sand settling to manage flow and remove pollutants. (Constructed Wetland, Infiltration Basin, Wet Pond)

Residence time - The amount of water in a reservoir divided by either the rate of addition of water to the reservoir or the rate of loss from it.

Constructed wetland; Pennswood Village, NJ; Designed by Princeton Hydro & Sikora, Wells, Appel

CONSTRUCTED WETLANDS

RELATIVE COST | Range based on complexity

TYPE | Basin

APPLICATION | Commercial - Residential - Agricultural

DEFINITION

Constructed wetlands, sometimes called stormwater wetlands, are shallow, engineered basin systems that mimic natural wetland processes. This practice is utilized for stormwater management, water quality treatment, and habitat creation.

PURPOSE AND FUNCTION

Constructed wetlands are engineered and designed to capture and treat runoff from the design storm, providing a prolonged residence time for stormwater, conducive to multiple pollutant removal processes. Within the constructed wetland environment, gravitational settling, biological uptake, and microbial activity are facilitated, thus enabling effective water purification. Additionally, constructed wetlands contribute to meeting channel and flood protection requirements by employing detention storage to mitigate peak flows, thus reducing overall peak flow volumes from design storm events and providing additional flood protection. Typically positioned as the final element in the roof-to-stream pollutant removal sequence, constructed wetlands do not provide a volume reduction credit and are considered for implementation when a need for further pollutant removal or management of channel and flood protection volume is needed, following the exploration and utilization of all other upland runoff reduction options.

PLANNING CONSIDERATIONS AND FEASBILITY

Constructed wetlands are designed based on three major factors: the contributing hydrology, the desired plant community, and the landscape position, which can be either in-line, meaning along a stream or treatment train, or terminal, meaning the end of a treatment process. These constructed features typically require a footprint that takes up about 3 to 5 percent of the contributing drainage area. Ensuring an adequate water balance is crucial, as the proposed constructed wetland must have enough water supplied from groundwater, surface runoff, and/or baseflow, and equal to the rate of discharge to prevent the wetland micropools from going completely dry in a summer drought. Geotechnical testing should be conducted to determine the infiltration rates and other subsurface properties of the soils underlying the proposed constructed wetland. Soils classified as Hydrologic Soil Group (HSG) C or D are usually adequate to maintain a permanent pool due to their relative impermeability, whereas most group A soils and some group B soils will require a liner to maintain the wetland pool due to their relatively high drainage rates.

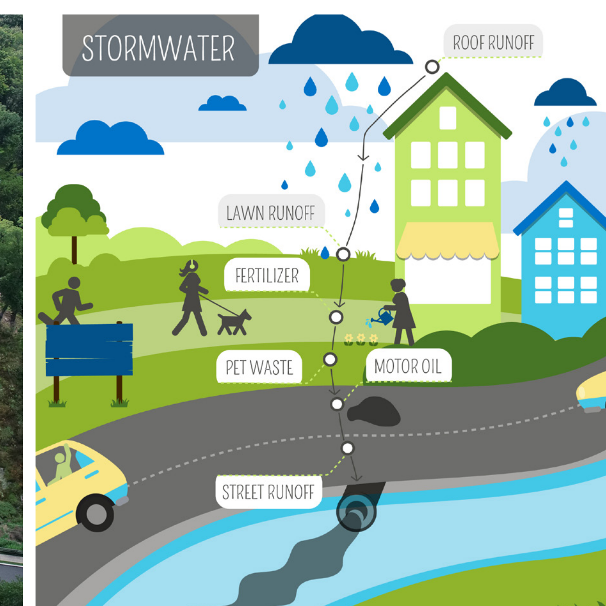
Other planning and cost considerations include the water source as it will impact the overall size of the practice; if stormwater runoff is the only source of flow for the constructed wetland, then a minimum of 10 acres of drainage area is needed to maintain adequate water levels to sustain the practice. Smaller drainage areas of 5 to 10 acres are acceptable if the bottom of the constructed wetland intercepts the groundwater table (ARC 2016). Additional factors include the need for a liner to retain water, ease of access to the proposed area for the constructed wetland, and whether excavated material will need to be disposed of off-property or can be kept on site.

PERFORMANCE

SUMMARY OF STORMWATER FUNCTIONS PROVIDED BY CONSTRUCTED WETLANDS		
STORMWATER FUNCTION	**Level 1 Design**	**Level 2 Design**
Annual Runoff Volume Reduction (RR)	0%	0%
Total Phosphorus (TP) Event Mean Concentration (EMC) Reduction[1] by BMP Treatment Process	50%	75%
TP Mass Load Removal	50%	75%
Total Nitrogen (TN) EMC Reduction[1] by BMP Treatment Process	25%	55%
TN Mass Load Removal	25%	55%
Channel Protection	Yes. Up to 1 foot of detention storage volume can be provided above the normal pool.	
Flood Mitigation	Yes. Flood control storage can be provided above the normal pool.	

[1] Change in event mean concentration (EMC) through the practice
Sources: CWP and CSN 2008; CWP 2007, Virginia Department of Environmental Quality et al., 2024

Constructed wetland; Bloomfield, NJ; Designed by Princeton Hydro



Typical roof to stream runoff
Source: Willmar, Minnesota Stormwater Management; https://www.willmarmn.gov/departments/stormwater_management_same.php

Residential wet pond; Source City of Virginia Beach Public Works

WET POND

RELATIVE COST | Range based on complexity

TYPE | Basin

APPLICATION | Commercial - Residential - Agricultural

DEFINITION
A wet pond is a stormwater facility constructed through filling and/or excavation that provides both permanent and temporary storage of stormwater runoff. It has an outlet structure that is operated to create a permanent pool which detains and attenuates runoff inflows and promotes the settlement of pollutants.

PURPOSE AND FUNCTION
Wet ponds are widely applicable for most land uses and are best suited for larger drainage areas. Wet ponds are not intended to serve as stand-alone stormwater practices due to their poor runoff volume reduction capability. Wet ponds consist of a combination of permanent pools, micro-pools, or shallow marsh that promotes a better environment for gravitational settling, biological uptake, and microbial activity (CWP 2007). Runoff from each new storm enters the pond and partially displaces pool water from previous storms. The pool also acts as a barrier to re-suspension of sediments and other pollutants deposited during prior storms. When sized properly, wet ponds have a residence time that ranges from many days to several weeks depending on the volume of the permanent pool, that allows pollutant removal mechanisms to operate. Wet ponds can also help to meet channel protection requirements by using detention storage above the permanent pool and extended detention storage volumes to reduce peak flows from the 1-year design storm.

PLANNING CONSIDERATIONS AND FEASIBILITY
The surface area of a wet pond will normally be at least 1 to 3 percent of its contributing drainage area, depending on factors such as impervious cover, pond geometry, depth, and other characteristics. A contributing drainage area of at least 10 acres, though 25 acres or more is preferred, is typically recommended for wet ponds to maintain a healthy permanent pool. Soil infiltration tests must be conducted at proposed pond sites to determine the need for a pond liner or other methods to address water level fluctuation. Underlying soils of Hydrologic Soil Group (HSG) C or D should be adequate to maintain a permanent pool. Wet ponds cannot be located within jurisdictional waters, including wetlands, without obtaining a specialized permit from the appropriate state and federal regulatory agencies. Additionally, placing wet ponds on perennial streams is strongly discouraged and will require permits from the appropriate state and/or federal regulatory agencies. Property owners should also consider wet ponds and the associated public safety concerns. Often fences, or similar impediments are required to prevent access which may reduce the aesthetic quality of the stormwater feature.

PERFORMANCE

SUMMARY OF STORMWATER FUNCTIONS PROVIDED BY WET PONDS		
STORMWATER FUNCTION	**Level 1 Design**	**Level 2 Design**
Annual Runoff Volume Reduction (RR)	0%	0%
Total Phosphorus (TP) Event Mean Concentration (EMC) Reduction[1] by BMP Treatment Process	50% (45%)[3]	75%
TP Mass Load Removal	50% (45%)[3]	75%
Total Nitrogen (TN) EMC Reduction[1] by BMP Treatment Process	25% (20%)[3]	55%
TN Mass Load Removal	25% (20%)[3]	55%
Channel Protection	Yes. Up to 1 foot of detention storage volume can be provided above the normal pool.	
Flood Mitigation	Yes. Flood control storage can be provided above the normal pool.	

[1] Runoff Reduction rates for ponds used for year-round irrigation can be determined through a water budget computation.
[2] Change in event mean concentration (EMC) through the practice.
[3] Number in parentheses is slightly lower EMC removal rate in the Coastal Plain (or any location) if the wet pond is influenced by groundwater. See Section 3 of this design specification and CSN Technical Bulletin No. 2. (2009).
Sources: CWP and CSN 2008, CWP 2007

Example of vegetated wet pond; Source: Virginia Waters & Wetlands

A vegetated detention basin, PA; Designed by Princeton Hydro

EXTENDED DETENTION POND

RELATIVE COST | Range based on complexity

TYPE | Basin

APPLICATION | Commercial - Residential - Agricultural

DEFINITION

An extended detention pond is an earthen structure constructed by either excavation of existing soil or impoundment of a natural depression. An extended detention pond temporarily stores stormwater runoff by capturing and holding stormwater after heavy rains to reduce peak runoff and discharge to the downstream receiving waterbody. Water is then gradually released after each rain event to prevent flooding and manage water levels.

PURPOSE AND FUNCTION

An extended detention pond uses gravitational settling to remove pollutants, at removing solid particles but is less effective at removing dissolved pollutants like nitrate and soluble phosphorus. As a standalone solution, it typically has the lowest overall pollutant removal rate compared to other stormwater treatment methods. However, an extended detention pond can help reduce the maximum peak discharge to downstream areas, which in turn, lowers the erosive stress on stream banks caused by flash flooding and high-velocity flows. To meet channel protection or flood control requirements, these ponds are designed to hold water temporarily, usually for just a few minutes or hours. They can also be combined with other stormwater treatment practices, such as wet ponds and constructed wetlands, to improve both performance and appearance.

PLANNING CONSIDERATIONS AND FEASIBILITY

For extended detention ponds, there must be a minimum of 2 feet of separation between the bottom of the basin and the water table. Soil permeability is usually not a design constraint for extended detention ponds, and infiltration through the bottom is encouraged unless it threatens the integrity of the embankment that defines the perimeter of the pond. Initial soil exploration is necessary to determine if infiltration is suitable and to ensure the absence of karst topography. Extended detention ponds should not be constructed within existing natural wetlands or alter their hydroperiods. Constructing extended detention ponds on perennial streams is typically prohibited and requires permits from relevant regulatory agencies. The fluctuating water levels in extended detention ponds can create conditions conducive to mosquito breeding. However, this risk can be minimized by combining extended detention ponds with wet ponds or wetlands by creating mico pools and installing wetland vegetation. This can reduce mosquito populations by providing habitat for their natural predators such as birds, frogs, and other insects.

PERFORMANCE

SUMMARY OF STORMWATER FUNCTIONS PROVIDED BY EXTENDED DETENTION PONDS

STORMWATER FUNCTION	Level 1 Design	Level 2 Design
Annual Runoff Volume Reduction (RR)	0%	15%
Total Phosphorus (TP) Event Mean Concentration (EMC) Reduction[1] by BMP Treatment Process	15%	15%
TP Mass Load Removal	15%	15%
Total Nitrogen (TN) EMC Reduction[1] by BMP Treatment Process	10%	10%
TN Mass Load Removal	10%	24%
Channel Protection	Yes, storage volume can be provided to accommodate the full CPV.	
Flood Mitigation	Yes. Flood protection storage can be provided beyond the maximum extended detention volume.	

[1] Change in EMC through the practice. The actual nutrient mass load removed is the product of the removal rate and the runoff reduction rate.
Source: Virginia Department of Environmental Quality et al., 2024

Example of extended detention basin; Designed by Princeton Hydro

Photo of native Swamp milkweed,water tolerant plant species; Photo by Princeton Hydro

RAINWATER HARVESTING

RELATIVE COST | Range based on complexity

TYPE | Basin

APPLICATION | Commercial - Residential - Agricultural

DEFINITION

Rainwater harvesting functions by intercepting, diverting, slowly releasing, or storing rainwater for future use. Rainwater Harvesting, for the purposes of this description, is limited to rainwater that falls on a rooftop that is collected and conveyed into an above- or below-ground storage tank or chamber where it can be used for non-potable water uses like irrigation, onsite stormwater infiltration, and/or detention.

PURPOSE AND FUNCTION

Rainwater Harvesting systems can be used in a variety of settings and configurations. From a stormwater management perspective, their purpose is to maximize the reduction of runoff volume and the removal of nutrients. These systems are suitable for development projects that include the construction of roof surfaces designed to shed, collect, and direct stormwater to a storage tank, commonly known as a "cistern." They can be implemented in most development sites that include building construction, including highly constrained or urban areas. Rainwater Harvesting is applicable to commercial, residential, industrial, urban, and non-urban sites and can be configured for both indoor and outdoor use. The effectiveness of these systems in reducing annual runoff volume and removing pollutants depends on the size and configuration of the cistern tank, as well as the water demand or use.

PLANNING CONSIDERATIONS AND FEASIBILITY

Rainwater Harvesting systems require adequate space for the storage tank or cistern and any overflow, which is generally not a concern if incorporated into the initial design and layout of residential or commercial developments. The contributing drainage area (CDA) for the cistern is the impervious roof area that directs water into it. Roof areas of any size can be used, following sizing guidelines. Parking lots and other paved surfaces cannot be part of the CDA as they contribute excessive particulates and pollutants, making them unsuitable for storage and distribution in Rainwater Harvesting systems.

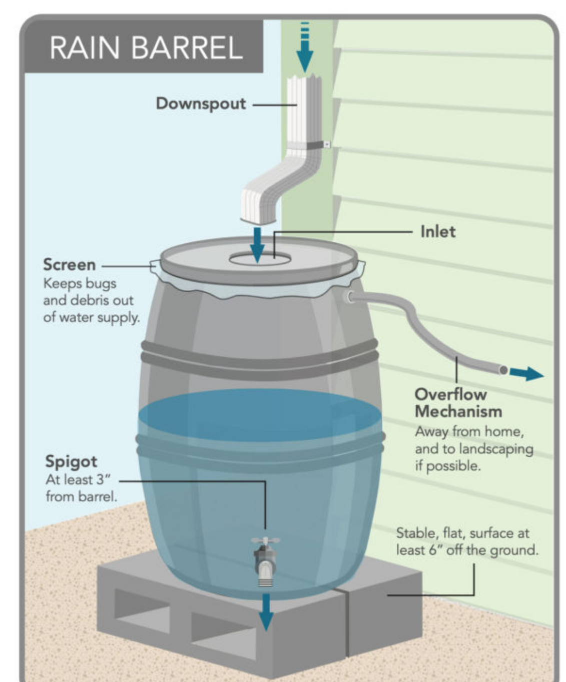
Cisterns should be placed per the manufacturer's guidelines or a structural engineer's recommendations, and in consideration of the soil's bearing capacity since full cisterns can be very heavy and may need an aggregate or concrete base. Designers and plan reviewers must also check local plumbing codes to ensure harvested rainwater can legally be used for toilet flushing, laundry, or urinals. When a municipal backup supply is involved, systems typically require backflow preventers or air gaps to keep harvested rainwater separate from the main water supply.

PERFORMANCE

SUMMARY OF STORMWATER FUNCTIONS PROVIDED BY RAINWATER HARVESTING

STORMWATER FUNCTION	PERFORMANCE
Annual Runoff Volume Reduction (RR)	Variable up to 90%[2]
Total Phosphorus (TP) Event Mean Concentration (EMC) Reduction[1] by BMP Treatment Process	0%
TP Mass Load Removal	Variable up to 90%[2]
Total Nitrogen (TN) EMC Reduction[1] by BMP Treatment Process	0%
TN Mass Load Removal	Variable up to 90%[2]
Channel Protection	Partial: reduced curve numbers and increased time of concentration
Flood Mitigation	Partial: reduced curve numbers and increased time of concentration

[1] Nutrient mass load removal is equal to the runoff volume reduction rate. Zero pollutant removal rate is applied to the rainwater harvesting system only. Nutrient removal rates for secondary practices will be in accordance with the design criteria for those practices.
[2] Credit varies and is determined using the Cistern Design Spreadsheet. Credit up to 90% is possible if all water from storms with rainfall of 1 inch or less is used through demand, and the tank is sized such that no overflow from this size event occurs. The total credit may not exceed 90%.
Source: Virginia Department of Environmental Quality et al., 2024



Small scale rainwater harvesting
Source: City of Palo Alto Stormwater Program

Underground water cisterns for larger scale rainwater harvesting
Source LAIIER; https://www.laiier.io/

Monarch Butterfly in vegetated channel; Photo by Princeton Hydro

VEGETATED CHANNELS

RELATIVE COST | Range based on complexity

TYPE | Conveyance

APPLICATION | Commercial - Residential - Agricultural

DEFINITION

A vegetated channel is a broad and shallow open channel vegetated with grass or other native species, used for water quality treatment and water quantity control, and can be a component of pre-treatment for some best management practices (BMPs).

PURPOSE AND FUNCTION

Vegetated channels are ideal for treating highway runoff, runoff from low- and medium-density residential roads and yards (if there is sufficient right-of-way width and distance between driveways), runoff from small commercial parking areas or driveways, and agricultural fields. They can handle a maximum total contributing drainage area of up to 5 acres. Where development density, topography, and soil conditions allow, vegetated channels are a better alternative to curb and gutter systems and storm drains for stormwater conveyance. They are also effective in treating runoff from managed turf areas, such as sports fields and golf courses, and from areas with a mix of impervious surfaces and turf. Vegetated channels, especially when combined with weeping check dams, can manage water quantity for low-density residential areas and turf-intensive land uses.

PLANNING CONSIDERATIONS AND FEASIBILITY

Vegetated channels are typically more practical in lower-density developments but can still be utilized if certain design standards are met. In higher-density settings, frequent driveway crossings might pose maintenance or construction challenges. While some slope is necessary for proper drainage, vegetated channels are most effective on sites with flat to gently rolling slopes, ideally less than 2%, or up to 4% when incorporating check dams. Vegetated channels can be employed regardless of underlying soil type, though those on Hydrologic Soil Group (HSG) C and D soils can benefit from soil amendments for improved runoff reduction. These channels should have sufficient capacity to handle runoff from a 10-year storm event, maintain a minimum of 6 inches of freeboard, and prevent erosion during a 2-year storm event. Consultation of local ordinances and design criteria is crucial to determine setbacks from property lines, structures, utilities, and wells. Typically, vegetated channels should be offset from the 1H:1V bearing zone or located at least 10 feet from building foundations, 10 feet from residential structures, 35 feet from septic system fields, and 50 feet from private wells (DEQ 2024).

PERFORMANCE

SUMMARY OF STORMWATER FUNCTIONS PROVIDED BY VEGETATED CHANNELS

STORMWATER FUNCTION	HSG SOILS A/B		HSG SOILS C/D	
	NO CA	WITH CA	NO CA	WITH CA
Annual Runoff Volume Reduction (RR)	20%	NA	10%	20%
Total Phosphorus (TP) Event Mean Concentration (EMC) Reduction[1] by BMP Treatment Process	15%		15%	
TP Mass Load Removal	32%		15%	32%
Total Nitrogen (TN) EMC Reduction[1] by BMP Treatment Process	20%		20%	
TN Mass Load Removal	36%		28%	36%
Channel Protection	Use Virginia Runoff Reduction Method (VRRM) Compliance spreadsheet to calculate a curve number (CN) adjustment			

[1] CA= Compost Amended Soils, see P-FIL-08 Soil Compost Amendment.
[2] Compost amendments are generally not applicable for HSG A and B soils, although it may be advisable to incorporate them on mass-graded and/or excavated soils to maintain runoff reduction rates. In these cases, the 30 percent runoff reduction rate may be claimed regardless of the pre-construction HSG.
[3]Change in EMC through the practice. Actual nutrient mass load removed is the product of the pollutant removal rate and the runoff volume reduction rate (see Table 1 in the Introduction to the New Virginia Stormwater Design Specifications).
Source: Virginia Department of Environmental Quality et al., 2024

Example of a vegetated channel; Sewell, New Jersey; Designed by Princeton Hydro

Vegetation parking median; Designed by Princeton Hydro

ROOFTOP/IMPERVIOUS SURFACE DISCONNECTION

RELATIVE COST | Range based on complexity

TYPE | Filtration and Infiltration

APPLICATION | Commercial - Residential - Agricultural

DEFINITION

Impervious areas that directly drain into a stormwater conveyance system or other impervious surfaces are termed "connected impervious" areas, and the stormwater they produce flows untreated into surface water bodies. Disconnection happens when impervious surfaces are redirected and spread out into sheet flow across turf grass or natural vegetation. By directing runoff from impervious areas onto vegetated surfaces as sheet flow, infiltration is enhanced, leading to a direct reduction in runoff and the necessary storage volume.

PURPOSE AND FUNCTION

Disconnecting direct rooftop or impervious surface runoff from the existing conveyance system redirects and disperses the water to designated pervious areas, resulting in reduced runoff volumes and rates. When combined with implementing low-impact practices, peak flow is decreased as a result of extending overland flow time (New York Department of Environmental Conservation [NYDEC], 2015). Vegetated and pervious areas play a crucial role in filtering and infiltrating runoff, thereby enhancing water quality. Ideally, concentrated runoff from impervious surfaces is dispersed as sheet flow over a 40-foot-long path before reaching a natural or manmade stormwater conveyance system.

Alternative disconnection practices that achieve the same runoff reduction rates are available if flow length or slope criteria are not adequate for a simple disconnection practice. In these cases, often found where space is constrained, a rain garden, french drain, or foundation planter designed to capture runoff are a few examples of an alternative practice.

PLANNING CONSIDERATIONS AND FEASIBILITY

Encouraging disconnections on uncompacted, permeable soils [HSGs A and B), requires directing runoff from rooftops to designated areas graded for storage and infiltration, revegetated, and protected from other uses. These areas must be designed for non-erosive conveyance within the site boundary and may utilize splash pads or level spreaders as needed to distribute runoff to designated areas with infiltration capacity. Appropriate pretreatment measures should be applied to dissipate and disperse runoff to designated flow paths.

Yards lacking overall positive drainage should not be used for simple disconnection to avoid risk to property and creating a hazard. In less permeable soils(HSGs C and D or previously impacted HSGs A and B), evaluating permeability and water table depth guides decisions on soil enhancements for designated flow paths.

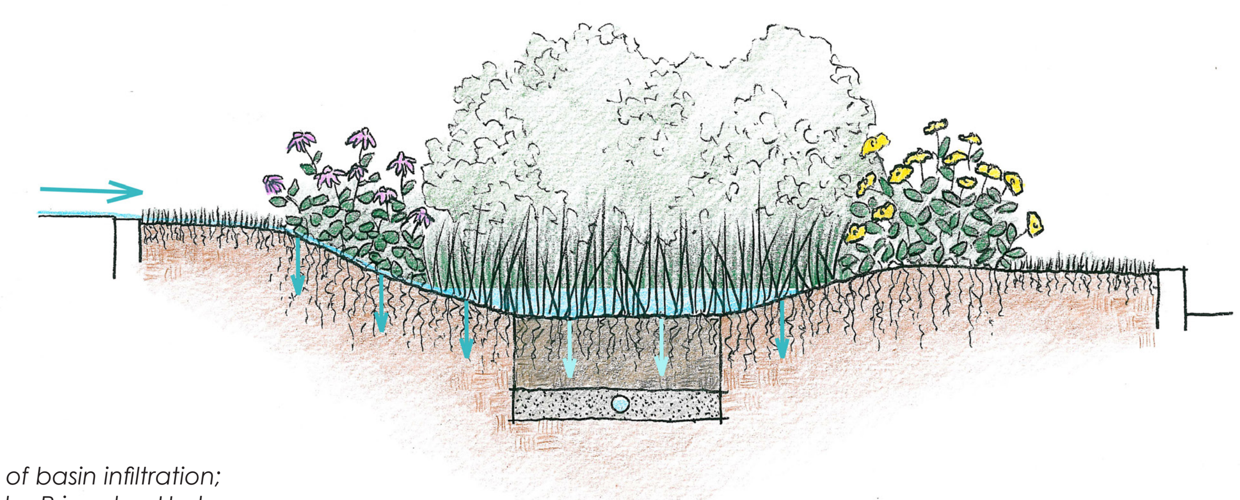
While redirected rooftop runoff may increase the maintenance burden for property owners, alternative mitigation techniques may incur significant installation and additional maintenance costs. Local laws may restrict rooftop disconnection and must always be consulted prior to the design and installation of any practice. Simple disconnection is generally not advisable for residential lots smaller than 6,000 square feet in area, although it may be possible to employ one of the alternate disconnection runoff reduction practices on these lots (e.g., cistern, infiltration).

PERFORMANCE

SUMMARY OF STORMWATER FUNCTIONS PROVIDED BY ROOFTOP/IMPERVIOUS SURFACE DISCONNECTION

STORMWATER FUNCTION	HSG SOILS A & B	HSG SOILS C & D
Annual Runoff Volume Reduction (RR)	50%	25%
Total Phosphorus (TP) Event Mean Concentration (EMC) Reduction[1] by BMP Treatment Process	0%	0%
TP Mass Load Removal	50%	25%
Total Nitrogen (TN) EMC Reduction[1] by BMP Treatment Process	0%	0%
TN Mass Load Removal	50%	25%
Channel and Flood Protection	Partial: Designers can use the VRRM Compliance spreadsheet to adjust curve number for each design storm for the contributing drainage area (CDA) based on the annual runoff reduction achieved.	

[1] When simple disconnection is not possible, alternative practices can be implemented, but no additional runoff reduction is provided beyond 50% unless the design is in accordance with other approved BMP specifications.
[2] Designers should consult the applicable specification for alternative practice design standards.
[3] Compost amendments are not credited with additional volume reduction on HSG A and B soils. Primary use is to improve the volume reduction performance of disconnection in C and D soils.
Source: Virginia Department of Environmental Quality et al., 2024, Center for Watershed Protection (CWP) and Chesapeake Stormwater Network (CSN) 2008; CWP 2007



Sketch of basin infiltration; Drawn by Princeton Hydro

Example of permeable pavement; Photo courtesy: Princeton Hydro

PERMEABLE PAVEMENT

RELATIVE COST | Range based on complexity

TYPE | Filtration and Infiltration

APPLICATION | **Commercial - Residential -** Agricultural

DEFINITION

Permeable pavements offer an alternative paving solution allowing stormwater runoff to filter through voids in the pavement surface into an underlying stone reservoir, where it is temporarily stored and/or infiltrated. Various options exist, such as porous concrete, porous asphalt, permeable grid pavers, interlocking concrete pavers, and even artificial turf as the surface cover. Despite the surface variation, all permeable pavements share a common structure, comprising a permeable surface pavement layer, an underlying stone aggregate reservoir layer, and a filter layer or fabric installed at the bottom.

PURPOSE AND FUNCTION

Permeable pavement has a very high runoff reduction capability and should always be considered as an alternative to conventional pavement, however it is subject to the same feasibility constraints as most infiltration practices.

PLANNING CONSIDERATIONS AND FEASIBILITY

One significant advantage of permeable pavement is its minimal space requirement in comparison to other practices, making it particularly beneficial for small or high-per square foot cost development sites.

Soil conditions influence the need for additional infrastructure, such as underdrains, but do not typically restrict the use of permeable pavement. Impermeable soils in HSG C or D often necessitate underdrains, while HSG A and B soils generally do not. If designed for infiltration without underdrains, the proposed permeable pavement area must demonstrate a field-verified minimum infiltration rate of 0.5 inches per hour. For residential applications, a minimum horizontal distance of 50 feet from any water supply well and 35 feet from any septic system (20 feet if the stone reservoir is lined) is recommended. These setbacks serve as general guidelines and may be subject to adjustment by local authorities depending on specific circumstances, such as the use of underdrains or liners or other precautionary measures.

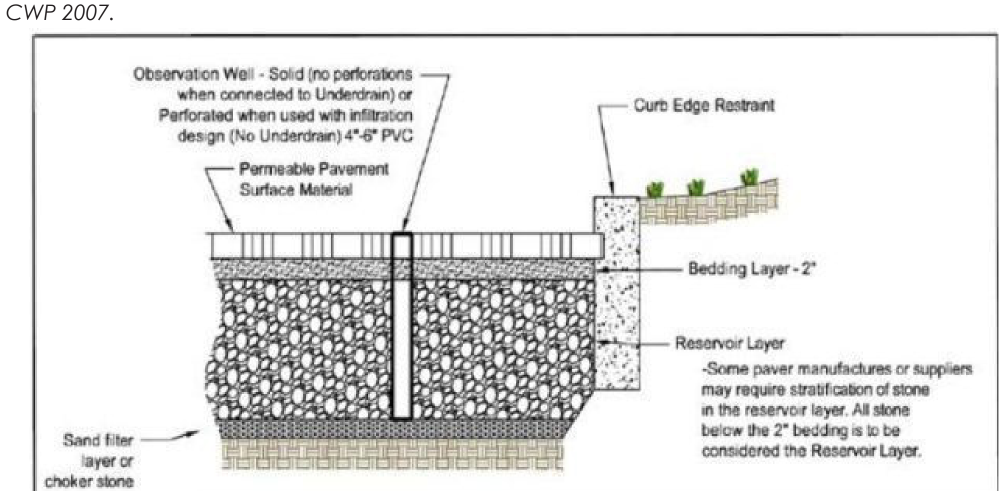
Permeable pavement reduces stormwater runoff volumes, but may also increase the risk that stormwater pollutants might migrate into groundwater aquifers. Designers should avoid the use of infiltration-based permeable pavement in areas known to provide groundwater recharge to aquifers used for water supply or take additional precautions to safeguard groundwater. Permeable pavements require some specialized maintenance to keep the void spaces that allow water to pass through them clear. This may include vacuuming, mowing of grass in grid paver applications, and removal of sediment accumulations. Frequency is dependent on use and certain uses should be avoided to maintain proper function, including sanding, resealing, power washing and storage of sand, soil or mulch and the staging of construction activities on the permeable surfaces.

PERFORMANCE

SUMMARY OF STORMWATER FUNCTIONS PROVIDED BY PERMEABLE PAVEMENT

STORMWATER FUNCTION	Level 1 Design	Level 2 Design
Annual Runoff Volume Reduction (RR)	45%	75%
Total Phosphorus (TP) Event Mean Concentration (EMC) Reduction[1] by BMP Treatment Process	25%	25%
TP Mass Load Removal	25%	75%
Total Nitrogen (TN) EMC Reduction[1] by BMP Treatment Process	25%	25%
TN Mass Load Removal	59%	81%
Channel Protection	Use the Virginia Runoff Reduction Method (VRRM) Compliance spreadsheet to calculate a Curve Number adjustment2; or Design extra storage in the stone underdrain layer and peak rate control structure (optional, as needed) to accommodate detention of larger storm volumes.	
Flood Mitigation	Partial. May be able to design additional storage into the reservoir layer by adding perforated storage pipe or chambers.	

[1] Change in event mean concentration (EMC) through the best management practice (BMP). Actual nutrient mass load removed is the product of the removal rate and the runoff reduction rate.
[2] USDA-NRCS Technical Release 55 Urban Hydrology for Small Watersheds (TR-55) Runoff Equations 2-1 thru 2-5 and Figure 2-1 can be used to compute a curve number adjustment for larger storm events based on the retention storage provided by the practice(s).
Source:Virginia Department of Environmental Quality et al., 2024, Center for Watershed Protection (CWP) and Chesapeake Stormwater Network (CSN) 2008; CWP 2007.



Typical permeable pavement construction; Source: Virginia Stormwater Management Handbook

Example of MTD tree pits; Photo courtesy: Princeton Hydro

BIORETENTION

RELATIVE COST | Range based on complexity

TYPE | Filtration and Infiltration

APPLICATION | Commercial - Residential - Agricultural

DEFINITION

Bioretention involves treating stormwater by collecting it on the surface of a vegetated media system and allowing the suspended solids and sediment to settle at the top mulch layer before the water passes through underlying biofiltration media, where various biogeochemical processes further remove pollutants. Bioretention areas are shallow stormwater basins or landscaped areas equipped with engineered soil media and vegetation to retain and treat stormwater runoff sequentially utilizing a combination of mechanisms before discharging stormwater to local surface water or groundwater.

PURPOSE AND FUNCTION

Bioretention practices are compatible with most land uses. Bioretention offers an array of design alternatives that make it a versatile practice for use primarily within residential commercial and agricultural development sites. Typical locations for bioretention features include but are not limited to the following:

- *Parking Lot Islands* - Parking lots are graded and structured to facilitate sheet flow towards linear and bisecting landscaping areas, and vegetated islands between parking rows and spaces. Utilizing curb-less pavement edges allows water to sheet flow into depressed island landscaping areas, while curbs with curb cuts can provide an alternative option to allow runoff to enter.
- *Parking Lot Edge* - Smaller parking lots can be graded so that flows reach curb-less pavement edges or curb cuts that lead into depressed, landscaped bioretention areas before reaching catch basins or storm drain inlets within the parking lot. A turfgrass strip located at the edge of the parking lot functions as a filter providing pre-treatment for the bioretention practice.
- *Road Medians* - Opposite of standard road cross sections, this method involves sloping the road towards the center median, or center island rather than toward the outer lanes, and using a curb-less edge to allow water to drain to the center median
- *Right of Way or Commercial Setback* - Runoff from the roadway can be directed in sheet flow using a linear configuration. Alternatively, it can be conveyed to the bioretention practice via a grass channel or pipe.
- *Courtyards* - Runoff collected in a storm drain system or roof leaders can be directed to courtyards or other previous areas on site where bioretention can be installed.
- *Dry Extended Detention Basin* - To enhance treatment, a bioretention practice can be situated on the upper shelf of an extended detention basin, after the sediment forebay. Depending on the design of the extended detention basin, the designer may opt to place the bioretention practice at the basin's bottom.
- *Tree Planters and Other Local Landscape Planting Structures* - Tree planting pits or other urban landscape planting structures, like rain gardens, can be designed to accept local curb or sheet flow from roadways, sidewalks, roofs, or other adjacent surfaces with a designed bioretention soil media. Attractive planting can add amenity value to these features if their location makes that desirable.

PLANNING CONSIDERATIONS AND FEASIBILITY

Comprising three primary components - the surface ponding area, soil filter media, and gravel layer with drainage - bioretention systems primarily target treating parking lots and commercial rooftops, typically found in commercial or institutional areas. Inflows can be either sheet flow or concentrated flow. While bioretention practices may also be distributed throughout residential subdivisions, they are ideally located in common areas or within drainage easements to treat a combination of roadway and lot runoff. Space requirements are influenced by the bioretention design level, drainage area size, and land use composition, with dimensions determined based on the treatment volume required. The primary design objective for bioretention is to maximize runoff volume reduction and nutrient removal. Designers may opt for the traditional baseline design (Level 1) or choose an enhanced design (Level 2) to achieve this goal. Level 1 installations focus solely on retention and treatment within the bioretention media, while Level 2 installations incorporate infiltration into the surrounding native soil as part of the treatment process.

Regular maintenance for plantings, mulch replenishment and sediment removal are all tasks associated with bioretention practices. Bioretention areas must be periodically inspected to ensure proper drainage is occurring and take action to replace soil, filters, and drainage components if necessary.

PERFORMANCE

SUMMARY OF STORMWATER FUNCTIONS PROVIDED BY BIORETENTION

STORMWATER FUNCTION	Level 1 Design	Level 2 Design
Annual Runoff Volume Reduction (RR)	40%	80%
Total Phosphorus (TP) Event Mean Concentration (EMC) Reduction[1] by BMP Treatment Process	25%	50%
TP Mass Load Removal	55%	90%
Total Nitrogen (TN) EMC Reduction[1] by BMP Treatment Process	40%	65%
TN Mass Load Removal	64%	90%

[1] Change in event mean concentration (EMC) through the best management practice (BMP).
Source: Virginia Department of Environmental Quality et al., 2024, Hirschman et al 2009.

Examples of bioretention within parking lot islands
Designed by Princeton Hydro

Naturalized basin designed by Princeton Hydro

VEGETATED FILTER STRIPS/ NO MOW AREAS

RELATIVE COST | Range based on complexity ($ $ $ $ $ – 2 of 5)

TYPE | Filtration and Infiltration

APPLICATION | Commercial - Residential - Agricultural

DEFINITION

Filter strips are vegetated zones designed to manage sheet flow from nearby managed turf and impervious surfaces. They accomplish this by reducing runoff speeds, which allows sediment and attached pollutants to settle or be filtered by the vegetation.

PURPOSE AND FUNCTION

Stormwater runoff enters the BMP from paved surfaces uniformly along a linear edge, such as a road or parking lot boundary, flowing parallel to the vegetated filter strip's length. To ensure a smooth transition between the pavement and the filter strip or open space, a gravel diaphragm or other pretreatment method may be employed. If the inflow originates from a pipe or channel, a level spreader is necessary to convert the concentrated flow to sheet flow. There are two main design variants of filter strips: conserved open space and designed vegetated filter strips.

Conserved open space is commonly utilized on sites that are hydrologically connected to protected areas such as stream buffers, wetland buffers, floodplains, or forest conservation zones. They are particularly suitable for integrating into the "outer zone" of a stream buffer, like a Resource Protection Area, which typically receives runoff as sheet flow. It is essential to ensure that all energy dissipators or flow-spreading devices are positioned outside the protected area.

Vegetated filter strips are most effective for treating runoff from small sections of impervious surfaces, usually less than 5,000 square feet that are adjacent to road shoulders, small parking lots, and rooftops. They can also serve as pretreatment for other stormwater practices like dry swales, bioretention areas, or infiltration zones. In cases where sufficient pervious area is available, larger impervious surfaces can be managed by vegetated filter strips using a level spreader to establish sheet flow. Additionally, these strips are well-suited for treating runoff from turf-intensive areas such as sports fields, golf courses, farmland, and parkland.

PLANNING CONSIDERATIONS AND FEASBILITY

Conserved open space and vegetated filter strips have maximum slopes ranging from 6% to 8%. The minimum length of these strips (flow path) depends on the slope of the filter strip itself. The maximum length for a filter strip is 100 feet. Vegetated filter strips are suitable for all soil types except fill soils. However, the effectiveness of runoff reduction depends on the underlying HSGs and whether the soils receive compost amendments. These filter strips are designed to manage small drainage areas, typically spanning several thousand square feet. The primary limiting factor in design is the length of flow directed to the filter, with a recommended maximum upstream contributing length of sheet flow of 100 feet. When flow becomes concentrated, it moves too swiftly to be effectively treated by a vegetated filter strip unless a level spreader or gravel diaphragm is installed upstream. It is advisable to maintain a separation distance of 1 to 2 feet between the bottom of the vegetated filter strip and the elevation of the seasonally high-water table. Consultation of local ordinances and design criteria is necessary to determine minimum setbacks from property lines, structures, utilities, and wells. As a general guideline, filter strips should be positioned at least 10 feet away from building foundations, residential structures, 35 feet from septic system fields, and 50 feet from private wells.

PERFORMANCE

SUMMARY OF STORMWATER FUNCTIONS PROVIDED BY VEGETATED FILTER STRIPS/ NO MOW AREAS

STORMWATER FUNCTION	CONSERVATION AREA		VEGETATED FILTER STRIP	
	HSG SOILS A & B	HSG SOILS C & D	HSG SOILS A	HSG SOILS B[3],C & D
	Assume no CA in Conservation Area		No CA[2]	With CA
Annual Runoff Volume Reduction (RR)	75%	NA	50%	50%
Total Phosphorus (TP) Event Mean Concentration (EMC) Reduction[1] by BMP Treatment Process	0%		0%	
TP Mass Load Removal	75%	50%	50%	50%
Total Nitrogen (TN) EMC Reduction[1] by BMP Treatment Process	0%		0%	
TN Mass Load Removal	75%	50%	50%	50%
Channel Protection & Flood Mitigation	Partial. Use the Virginia Runoff Reduction Method (VRRM) Compliance spreadsheet to adjust curve number for each design storm for the contributing drainage area; and Account for a lengthened time-of-concentration flow path in computing peak discharge.			

[1] Runoff Reduction rates for ponds used for year-round irrigation can be determined through a water budget computation.
[2] Change in event mean concentration (EMC) through the practice.
[3] Number in parentheses is slightly lower EMC removal rate in the Coastal Plain (or any location) if the wet pond is influenced by groundwater. See Section 3 of this design specification and CSN Technical Bulletin No. 2. (2009).
Sources: CWP and CSN 2008, CWP 2007

Volunteer tree planting; Designed and implemented by Princeton Hydro

TREE PLANTING

RELATIVE COST | Range based on complexity

TYPE | FILTRATION AND INFILTRATION

APPLICATION | Commercial - **Residential** - **Agricultural**

DEFINITION

Tree plantings aimed at reducing pollution involve the introduction of new, individually planted trees on developed land. The credited area for pollution reduction is based solely on the precipitation that falls directly on the tree canopy. This practice does not mandate the use of any specific soil media.

PURPOSE AND FUNCTION

Due to their hydrological and biological functions, tree plantings effectively reduce stormwater runoff and enhance local water quality. They achieve these benefits through interception, throughfall, infiltration, transpiration, and absorption. Each new, individually planted tree on developed land contributes to pollution reduction credit. These trees do not need to be planted in a contiguous area and are not intended to create forest-like conditions. However, trees cannot receive credit as a BMP if they are planted to replace trees removed due to land disturbance, planted to meet planning or other local, state, or federal requirements, and financed through local, state, or federal programs. Additionally, they cannot receive credit as a BMP if they're planted to meet water quality requirements via the Virginia Runoff Reduction Method (VRRM) as forest or mixed open land cover, or as part of other BMPs such as urban bioretention, sheet flow to a vegetated filter strip, or manufactured treatment devices.

PLANNING CONSIDERATIONS AND FEASIBILITY

Tree plantings can be used at commercial, institutional, and residential sites. Like bioretention and other post-construction stormwater BMPs, they are typically planted in parking lot islands and edges; road medians, roundabouts, interchanges, and cul-de-sacs; rights-of-way or commercial setbacks; courtyards; and/or residential properties.

In treatment train scenarios, when runoff flows through tree plantings and then into downstream practices within the contributing drainage area (CDA), the canopy area should be entered into the VRRM spreadsheets in the tree planting input fields and excluded from the CDA of the BMP they flow into. Any remaining runoff volume and nutrient loads will be calculated using the treatment train features of the VRRM spreadsheets. Tree plantings cannot be used downstream of other BMPs.

Like all other practices, trees require care and maintenance to provide stormwater treatment. Trees must be watered, pruned and protected from disease and damage to thrive and perform the functions described above.

PERFORMANCE

SUMMARY OF STORMWATER FUNCTIONS PROVIDED BY TREE PLANTING

STORMWATER FUNCTION	TREE CANOPY OVER PERVIOUS		TREE CANOPY OVER IMPERVIOUS
	HSG SOILS A/B	HSG SOILS C/D	
Annual Runoff Volume Reduction (RR)	16%	12%	3.5%
Total Phosphorus (TP) Event Mean Concentration (EMC) Reduction[1] by BMP Treatment Process	0%	0%	0%
TP Mass Load Removal	16%	12%	3.5%
Total Nitrogen (TN) EMC Reduction[1] by BMP Treatment Process	0%	0%	0%
TN Mass Load Removal	16%	12%	3.5%

Source:Virginia Department of Environmental Quality et al., 2024 and Adapted from Hynicka and Divers 2016.

Volunteer tree planting initiative; Photo Courtesy Princeton Hydro

Shoreline stabilization; designed by Princeton Hydro

RIPARIAN AND WETLAND BUFFERS

RELATIVE COST | Range based on complexity

TYPE | Filtration and Infiltration

APPLICATION | Commercial - **Residential** - **Agricultural**

DEFINITION

Riparian and wetland buffers are vegetated areas, typically composed of trees, shrubs, and herbaceous plant species located adjacent to streams, rivers, lakes, or other bodies of water.

PURPOSE AND FUNCTION

In the context of stormwater management and water quality improvements, riparian buffers serve several critical functions. Riparian buffers filter pollutants from stormwater runoff including sediment, nutrients (nitrogen and phosphorus) pesticides and other contaminants before they can reach streams, rivers, and other bodies of water. The root systems of the vegetation in riparian buffers stabilize stream banks and shorelines, reducing erosion and preventing sedimentation in water bodies. These buffers also provide habitat for wildlife, supporting biodiversity and ecological health. By absorbing and slowing down stormwater runoff, riparian buffers can reduce the severity and frequency of flooding events. As an added benefit, riparian buffers also help to shade water bodies, maintaining cooler water temperatures which are crucial for the health of aquatic ecosystems.

PLANNING CONSIDERATIONS AND FEASBILITY

When planning the installation of a riparian buffer, several key considerations must be taken into account to ensure feasibility and effectiveness. The topography and slope of the site should be evaluated to determine the buffer's potential to intercept and slow runoff. Characteristics of the soil should also be considered as the texture, permeability, and fertility, will each play a role in supporting healthy vegetation growth and infiltration. The regulatory width of a riparian buffer is typically determined by a governing body such as the Department of Environmental Protection. Additionally, the appropriate width of the planting is based on the land use and desired ecological benefit. The wider the buffer, the greater water quality and habitat benefits can be realized. It is critical that a diverse and native mix of trees, shrubs, and herbaceous plants are used to provide a range of ecological functions and resilience against pests and diseases. Designers and landowners must review local, state, and federal regulations regarding riparian buffers, water quality standards, and land use to ensure compliance. Easements, setbacks, and right-of-way that may impact the location and design must also be considered.

A newer approach in agricultural riparian buffer practice is the implementation of "Multifunctional Riparian Buffers" which differ from traditional buffers in that they are designed to help the farm produce perennial crops of fruits and nuts, as well as floral trees and shrubs. Some of these products can be kept on the farm for alternate uses, and some can be sold to the public. Multifunctional Riparian Buffers are typically made of three zones. Zone One is located closest to the stream or water body where the goal is to slow down stormwater runoff, lower water temperature, stabilize soil, and provide food and habitat for terrestrial and aquatic organisms. Zone Two is a managed woody zone that absorbs and stores nutrients and slows down floodwater. The fruits and nuts produced in this zone can provide feed for livestock, be eaten by the public, and attract wildlife. Zone Three, known as the working buffer, is located furthest away from the water feature and is the first line of defense in the overall buffer. This zone is the first to intercept excess nutrients and sediment runoff from traditional farming operations and slows down surface water promoting infiltration. This zone also produces the highest amount of harvestable material.

PERFORMANCE

SUMMARY OF STORMWATER FUNCTIONS PROVIDED BY RIPARIAN AND WETLAND BUFFERS

STORMWATER FUNCTION	Buffer designs include herbaceous, shrubs and trees
Annual Runoff Volume Reduction (RR)	68%
TP Mass Load Removal	50-55%
TN Mass Load Removal	76-78%

[1] Runoff Reduction rates for ponds used for year-round irrigation can be determined through a water budget computation.
[2] Change in event mean concentration (EMC) through the practice.
[3] Number in parentheses is slightly lower EMC removal rate in the Coastal Plain (or any location) if the wet pond is influenced by groundwater. See Section 3 of this design specification and CSN Technical Bulletin No. 2. (2009).
Sources: CWP and CSN 2008, CWP 2007

Before, during and after photos documenting riparian buffer installation; Designed by Princeton Hydro

Illustration of hedgerow location in relation to prevailing winds; Source UWM Division of Extension

HEDGEROWS

RELATIVE COST | Range based on complexity

TYPE | Filtration and Infiltration

APPLICATION | Commercial - Residential - **Agricultural**

DEFINITION

A hedgerow is a linear planting of shrubs, trees, and grasses, typically between 3 feet and 15 feet wide, that are strategically established along agricultural field boundaries, slopes, or watercourses

PURPOSE AND FUNCTION

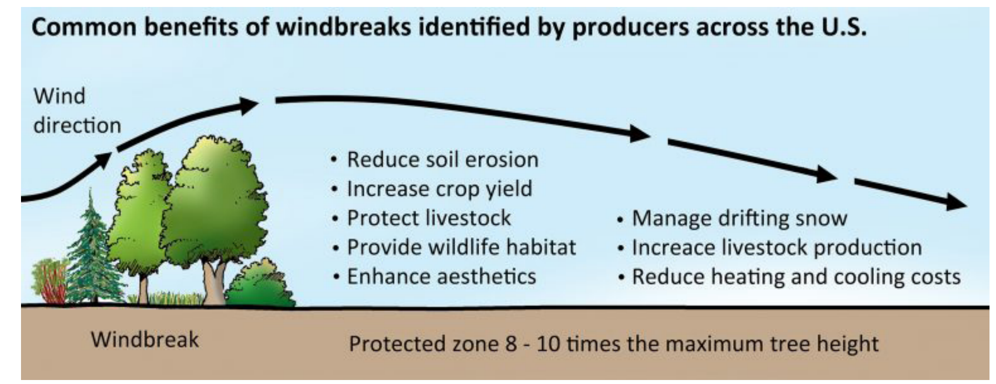
Soil degradation affects between a quarter to a half of the world's agricultural land (Bai et al.,2008; UNCCD, 2017). Hedgerows, as they relate to soil and water quality, are effective BMPs as they help to prevent soil erosion and reduce sediment runoff. These vegetative barriers play a crucial role in conserving soil and maintaining water quality through several different mechanisms. Hedgerows can be thought of as large, natural level spreaders as they slow down the flow of surface runoff, allowing sediments to settle out of the water before it reaches the nearest watercourse. The dense vegetation acts as a physical barrier, capturing soil particles carried by the runoff. By dissipating and slowing moving water the hedgerow also reduces the velocity of runoff, which in turn minimizes the erosive forces of water on the soil surface. Additionally, hedgerows play an important role in promoting water infiltration into the soil, reducing the volume of surface runoff and helping to maintain soil moisture and reducing the transport of sediment.

PLANNING CONSIDERATIONS AND FEASIBILITY

When planning for the installation of hedgerows in agricultural settings, there are several key considerations and feasibility factors that should be taken into account to ensure their effectiveness. Site selection is the first consideration. Reviewing the site's topography, soil type, and hydrology will inform owners and designers on the most suitable location is to implement this BMP. Hedgerows should also be aligned perpendicular to the prevailing wind and water flow directions to maximize their effectiveness in reducing wind and water erosion of soils. The width of the hedgerow is also important as wider hedgerows provide greater environmental benefits but will require more land. A diverse and native mix of trees, shrubs, and herbaceous plants must be used to provide a range of ecological functions and resilience against pests and diseases.

PERFORMANCE

Due to the variability of farm practices, crop type, slope, wind exposure, hedgerow width and many additional site characteristics, the ranges of sediment, phosphorus, and nitrogen reduction are difficult to quantify. However, studies have indicated that when testing soils for nitrogen in near-surface soil paralleled observations for soil organic carbon (SOC) across land cover types, the hedgerow and pasture soils held significantly higher concentrations of nitrogen and phosphorus than the field margins and cultivated areas (Holden, 2019). From these results, the assumption can be made that these elements would have otherwise been discharged into local water bodies.



Benefits of Hedgerows diagram; Source: UWM DIvision of Extension

Autumn hedgerow, Gloucestershire, England, by David P. Howard. Wikimedia Commons

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HELPFUL LINKS

CBLP Sustainable Landscapes Maintenance Manual
https://certified.cblpro.org/product-category/manuals/

Native Plants for Stormwater Best Management Practices
https://certified.cblpro.org/product/plants-for-stormwater-bmps/

Native Plant Center (interactive online version) – http://www.nativeplantcenter.net/

Native Plants for Wildlife Habitat and Conservation Landscaping: Chesapeake Bay Watershed. (available at https://dnr.maryland.gov/criticalarea/Documents/chesapeakenatives.pdf)

Digital Atlas of the Virginia Flora – http://vaplantatlas.org/

Fact Sheets and Brochures: Native Plants for Conservation, Restoration and Landscaping (Coastal Plain, Piedmont Plateau, Mountains, Riparian Forest Buffers, Grasslands) – https://www.dcr.virginia.gov/natural-heritage/factsheets

Native Plants – http://www.dcr.virginia.gov/natural-heritage/nativeplants