



AN ASSESSMENT OF THE LAKES AND WATERSHEDS OF ROCKAWAY TOWNSHIP

TOWNSHIP OF ROCKAWAY, MORRIS COUNTY, NEW JERSEY

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1. INTRODUCTION

The Highlands Water Protection and Planning Council (NJHC) is a regional planning agency that works in partnership with municipalities and counties in the Highlands Region to encourage a comprehensive regional approach to implementing the 2004 Highlands Water Protection and Planning Act (the Highlands Act). The Highlands Act established the Highlands Council and charged it with the creation and adoption of a regional master plan to protect and enhance the natural resources within the New Jersey Highlands. The Highlands Regional Master Plan (RMP) was adopted by the Highlands Council on July 17, 2008 and became effective on September 8, 2008.

Rockaway Township in Morris County has 17,789 acres in the Preservation Area and 11,582 acres in the Planning Area of the Highlands Region. The municipality submitted a Petition for Plan Conformance for both areas, which was approved by the Highlands Council on February 17, 2011. Home to a population of 25,341 people (US Census, April 2020), the township contains a sizeable urban center to the south, surrounding Rt. 80, while the larger northern area of the township is mountainous and features multiple lakes, ponds, and streams, both public and private.

In order to take an active role in the management of these natural resources within multiple watersheds, the Township of Rockaway will be the second municipality in the state of New Jersey to take a regional approach to private lake management through a public-private partnership (PPP) with private lake associations. Although some of these lakes are private, the Township wishes to take an active role in the management of the surrounding watersheds of these lakes, as the private lakes themselves are managed by their respective associations or entities. This regional approach to lake management has recently been informally suggested by staff of both the New Jersey Department of Environmental Protection (NJDEP) and the New Jersey Highlands Council (NJHC).

Given the large number of lakes in the Township, and in an effort to keep this study to a reasonable scope, a selection process occurred with input from the Township Engineering Department, Princeton Hydro and the NJHC. Specifically, the NJHC Master Plan states within Policy 1L2: "to establish tiers of lake management appropriate to management strategies that help protect lake water quality and community value from the impacts of present and future development", and within Objective 1L2a: "Lake management programs shall use the following management tiers around all Highlands Region lakes of greater than 10 acres in size: a Shoreline Protection Tier, a Water Quality Management Tier, a Scenic Resources Tier and a Lake Watershed Tier." Given that both the Policy and Objective use the 10-acre size minimum size in the provision of standards for lake protection, it was determined that lakes greater than 10 acres in size would be selected for the study. Additionally, the Highlands Region Land Use Ordinance, which conforming municipalities pass, include this distinction for waterbodies greater than 10 acres, and the Highlands Region ERIs for each town report out on acres of lakes greater than 10 acres in size.



However, lakes greater than 10-acres in size which are permanently preserved, including state-owned lakes, were eliminated from the study. Reservoirs owned by private water utilities and lakes present on federal facilities were also not included. Finally, lakes less than 10 acres that may possess a swimming beach WERE included due to the potential impacts of harmful algal blooms on the contact recreational use of these lakes. As a result of these criteria, the following list of lakes were selected for this study:

- Green Pond
- Egbert Lake*
- Durham Pond
- Lake Emma
- Camp Lewis Lake
- Lake Telemark
- Lake Ames*
- Mount Hope Pond*
- Mount Hope Lake (AKA Mill Pond)
- White Meadow Lake
- Fox's Pond (AKA Parks Lake)*

Lakes denoted with an asterisk in the list above are largely owned by Rockaway Township and are public parks. The remaining lakes are owned by private lake associations or entities. Despite the private status of many of these lakes, the Township has expressed interest in potentially partnering and managing watersheds in order to limit the amount of sediment and nutrients entering these lakes. In recent years, several lakes in northern NJ suffered from long-lasting harmful algae blooms (HABs), a phenomenon caused by an overpopulation of cyanobacteria ("blue-green algae") in a waterbody. In addition to impacting the aesthetic condition of a lake, cyanobacteria produce toxins that can cause a host of health issues in humans and animals that come in contact with the water. The Township has therefore expressed interest in implementing watershed management measures in order to reduce the impact of watershed nutrient loading, which can influence cyanobacteria growth. The balance of this report details the results of Princeton Hydro's mapping, modeling and monitoring efforts in each waterbody and its respective watershed, along with recommendations for management implementations that may serve to curb the effects of nutrient and sediment loading, both within the lakes and their respective watersheds.



2. HISTORICAL DATA REVIEW

According to the New Jersey Department of Environmental Protection (NJDEP), almost all the above referenced lakes are classified as freshwater non-trout category 1 (FW2-NTC1), with the one exception being Green Pond, which is classified as a trout maintenance lake (FW2-TMC1). Many of the inlet and outlet streams of these water bodies are also classified as Category 1 (C1) waters, varying from non-trout to trout reproduction. C1 waters are afforded the highest-level protection by the NJDEP. As per the NJDEP "Category One (C1) is a type of antidegradation designation that provides additional protection to specific waterbodies. C1 waters are protected from any measurable change in existing water quality because of their exceptional ecological significance, exceptional recreational significance, exceptional water supply significance, or exceptional fisheries resources." As a result, these C1 category waters which feed the lakes of the Township should be afforded the highest levels of protection that can be offered.

Historical water quality data is also available for several of the water bodies in the study, some of which has been collected by Princeton Hydro over the course of many years. Princeton Hydro has also developed a lake and watershed study for Green Pond, which will be discussed in greater detail in its respective subsection. Lastly, the entire township is included in the Passaic River TMDL, although many of the most problematic areas for the Passaic River's watershed are identified as occurring outside of the study area.

2.1 GREEN POND

The NJDEP's Bureau of Freshwater and Biological Monitoring (BFBM) conducted water quality monitoring in three locations in Green Pond (North, Central, and South) between May 2007 and October 2012; it should be noted that none of these sites were located at the Pond's deepest point. Few instances of anoxia were noted, with usually only the very bottom of the water column experiencing substantial oxygen depression. Phosphorus was not listed as being detected at concentrations over 0.02 mg/L, and Secchi depths were generally over 2 meters throughout the dataset.

As mentioned above, Princeton Hydro has been sampling at Green Pond for almost two decades and the collected data has largely matched with that collected by the state. This includes very high Secchi depths and generally low total phosphorus and chlorophyll *a* concentrations. Princeton Hydro's annual sampling includes a station at the Pond's deepest point; this area usually does feature a degree of thermal stratification and bottom anoxia due to its overall depth (15+ meters).

Princeton Hydro also developed a watershed and lake management plan for Green Pond in July of 2008. In this study, Green Pond's watershed was estimated to be largely forested, although approximately a quarter of the area contained urbanized land. Hydraulic modeling was accomplished using Regional Hydraulic Loading Analysis and Corrected Modified Rational Method, and yielded an annual hydraulic budget of approximately 2,900,000 m³. Watershed-based loading of nutrients was calculated using Unit Area Loading (UAL) methodology, and it was estimated that the lake receives 81.3 kg/yr of phosphorus from runoff, while septic systems around the lake yield approximately 65 kg/yr. Runoff was also estimated to yield approximate 925 kg/yr of nitrogen and approximately 108,000 kg/yr of sediment. Septic-based nitrogen loads were estimated to be approximately 1,077 kg/yr. Internal loading of phosphorus was also assessed; this was estimated to contribute approximately 159 kg/yr or



40.3% of the waterbody's annual phosphorus load. It was determined that management efforts should focus on the portion of the internal load originating from anoxic sediments, as well as urban stormwater and non-point source loading from the immediate areas around the waterbody, including that from septic systems.

2.2 CAMP LEWIS LAKE

No available water quality sampling data was found for Camp Lewis Lake. However, the lake was included as part of a TMDL study on several lakes in northern New Jersey for fecal coliform. In this study, Camp Lewis Lake was assessed to require an 89% reduction in bacterial load to meet the TMDL, with these loads originating largely from forested and urban land.

2.3 LAKE TELEMAR

While historical data was not identified for Lake Telemark itself, data has been collected by the BFBM in the former site of Hudsonia Lake, upstream of Lake Telemark, and further upstream in Hibernia Brook. Sampling within Hudsonia Lake between May 2009 and August 2014 yielded relatively low concentrations of phosphorus, with a high of 0.03 mg/L in August 2014. Chlorophyll *a* at this time was also slightly elevated, at approximately 16 µg/L. Total phosphorus obtained upstream of Hudsonia Lake in Hibernia Brook in May of 2018 was the same, at 0.03 mg/L. This stream was also sampled for biological data, and received a Headwaters Index of Biotic Integrity score of 58.9, or "Good". Habitat was ranked as "Suboptimal", however. Additionally, the lake was included in the same TMDL study for fecal coliform in northern NJ lakes as Camp Lewis Lake. Lake Telemark was assessed to require a 94.24% reduction in bacteria load, requiring reductions in loads from several land-cover types.

2.4 LAKE AMES

Lake Ames was sampled by the BFBM between May of 2009 and October of 2014, with sampling occurring at northern and southern stations. Over the course of the program, the northern station occasionally featured decreased amounts of dissolved oxygen, however these were not to anoxic concentrations. The July event of 2009 yielded somewhat elevated chlorophyll *a* concentrations, with a high of 14.77 µg/L at the southern station. Secchi depths were consistently measured over a meter, and phosphorus was detected no higher than 0.03 mg/L.

The lake was given a slightly more detailed survey in 1989 by the NJDEP as part of a statewide assessment of 21 lakes as a requirement for the Clean Water Act. During this survey, dissolved oxygen was found to be sufficient throughout all three sampling events. Total phosphorus ranged from 0.03 – 0.05 mg/L, while chlorophyll *a* ranged from approximately 5.0 to 14.4 µg/L. The report noted the heavy macrophyte growth, which is thought to have largely ended the lake's previous use for swimming. The plankton assemblage was assessed to largely be dominated by green algae and euglenoids.

2.5 MT. HOPE POND

The BFBM sampled Mt. Hope Pond during 2009 and 2014, utilizing a single sampling point in the approximate middle of the waterbody. The pond was found to thermally stratify slightly during the warmer months, with anoxia only occasionally occurring near the very bottom of the water column. Secchi depths were typically over a meter, with the October 2014 event yielding full water column



clarity. Phosphorus concentrations were typically detected at approximately 0.02 mg/L, although the late-September 2009 sample yielded a concentration of approximately 0.05 mg/L.

The Pond was also sampled by the NJDEP in 1989 as part of the same lakes assessment program as Lake Ames. This report notes high growth of milfoil and *Elodea* in the northern portion of the lake, and notes that there may be a high amount of runoff from the surrounding forested areas. Results of Secchi depths and phosphorus concentrations were similar to those obtained later by the BFBM, and mentioned a high chlorophyll *a* value of approximately 19.3 mg/m³ during the fall event. Plankton samples contained a large diversity of organisms, with cyanobacteria only being represented by *Oscillatoria*.

2.6 MT. HOPE LAKE

While the main portion of Mt. Hope Lake has not been sampled by the BFBM, the upper lake did receive sampling in 2011. During each of these three sampling events, dissolved oxygen was measured to be sufficient, chlorophyll *a* concentrations never exceeded 7.0 µg/L, and phosphorus concentrations never exceeded approximately 0.03 mg/L. Secchi depths were not recorded.

2.7 FOX'S POND

The BFBM sampled Fox's Pond via a single mid-pond point in 2008 and 2013, and via the pond's outlet only in 2008. Phosphorus concentrations were detected at somewhat elevated concentrations, with every date yielding a concentration over 0.03 mg/L. Chlorophyll *a* concentrations also ran high, with the November 2013 event yielding a concentration of approximately 43.8 µg/L. The waterbody would occasionally exhibit some dissolved oxygen depression in the bottom of the water column, and Secchi depths were variable, ranging from the full depth of the water column in May of 2008 to 1.0 meter in October of 2008. Phosphorus concentrations in the pond's outlet were consistently measured to be approximately 0.03 mg/L in 2008. Fox's Pond was also included in the above-mentioned regional TMDL study, where it was determined that the watershed would require an overall load reduction of approximately 98% of its bacterial load in order to meet the TMDL.

2.8 WHITE MEADOW LAKE

While White Meadow Lake has not been sampled by the BFBM, Princeton Hydro has sampled the lake multiple times each year for the past two decades. Conditions have varied between different years, but the most recent data indicates that the lake remains relatively well-mixed thermally and well oxygenated, likely due to its aeration system. Total phosphorus concentrations, while not overly high, are at times slightly elevated, and the lake occasionally experiences problems with filamentous green algae and nuisance plant growth. Sampling has also occurred at the lake's inlet at Mt. Hope Creek; these samples have exhibited higher concentrations of phosphorus, suggesting that this subwatershed contributes a relatively large amount of phosphorus to the waterbody. Recent chlorophyll *a* concentrations have been consistently less than 20.0 µg/L. In 2008, chlorophyll *a* concentrations in the lake increased over the course of the year, peaking at 37.1 µg/L in October. The lake was included in the previously-mentioned TMDL study, where it was determined that the watershed would require an overall reduction of approximately 96% of its bacterial load in order to meet the TMDL.



3. HYDROLOGIC AND POLLUTANT LOADING ANALYSIS

3.1 METHODS

Watersheds and sub-watersheds were delineated for each lake using USGS's Streamstats tool, the Stroud Research Center's Model My Watershed tool, and watershed tools on ERI's ArcMAP 10.8.1. Green Pond's watershed was based on a watershed developed for a lake and watershed study in 2008. Sub-watersheds were edited in ESRI's ArcMAP 10.8.1 and QGIS Desktop 3.2.2. Sub-watersheds that were too small for proper analysis with GWLF-E were combined with neighboring sub-watersheds. For the purposes of this study, watershed areas listed exclude the area of the main waterbody itself. Maps displaying watersheds and sub-watersheds for each lake 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. Septic-based phosphorus and nitrogen loads were calculated using Universal Areal Loading (UAL) modeling. For this methodology, houses within 100 meters (330') of the edges of each lake, as well as its tributaries, were counted and multiplied by the US census bureau's estimated number of person's per residence for Rockaway Township between 2015 and 2019 (2.59 persons per household (Census.gov)). This number was again multiplied by a coefficient used for the approximate amount of phosphorus produced by each resident of a watershed each year. The coefficient for annual per capita total nitrogen (TN) loading provided by the EPA (Onsite Wastewater Treatment Systems Manual, 2002) is 4.4 kg TN per year. While the EPA's per capita phosphorus loading coefficient has been 0.115 kg of P per year, studies by Princeton Hydro in the past in West Milford and Jefferson Townships suggest that septic loading is higher than originally anticipated, yielding a coefficient of 0.165 kg of P per year. This higher coefficient was used for UAL modeling for septic-based phosphorus in the Rockaway study. While it was assumed that uses of regular septic systems are year-round, pit-latrines at Boy Scouts of America camps were modeled assuming a 13-week camp season and approximately 12 users per week.

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.

In addition to watershed-based loading, internal loading of phosphorus in each lake was calculated using a loading coefficient of 6 mg TP/m²/day for loading of phosphorus into the water column from sediments under anoxic conditions, whereas minor loading under oxic conditions during the growing season (May-September, 153 days) is represented by a loading coefficient of 0.6 mg TP/m²/day. The number of days each waterbody was estimated to experience bottom anoxia, as well as the area of each waterbody at which anoxic conditions were estimated to occur, were determined based on dissolved oxygen and temperature data collected in the field during water quality sampling events and bathymetric data, when available. It should be noted that a majority of the lakes in this study did not have readily available bathymetric data; as such, the areas of anoxia in these lakes were estimated. Additionally, this analysis was not run for Mt. Hope Lake or Camp Lewis Lake, as in-field measurements and observations could not be collected.

Lastly, in lakes and ponds suspected or known of containing common carp or goldfish, additional modeling was performed to assess the effects of their feeding behaviors on internal phosphorus



loading. These fish can cause additional loading of phosphorus into the water column when feeding via bioturbation, including the uptake of fine sediments from the bed and subsequent discharge through the gills into the water column. As recent fisheries data is not available for these waterbodies, Princeton Hydro estimated a loading rate of 5 mg TP/m²/day based on a loading study conducted by Lamarra (1975).

Table 1: Acres of waterbodies and their watersheds			
Waterbody Name	Surface Area	Watershed Area	Total Area
	Acres		
Lake Ames	14.5	3,178.4	3,192.9
Camp Lewis	1.3	128.0	129.3
Durham Pond	45.7	395.3	441.0
Egbert Lake	14.0	461.4	475.4
Lake Emma	9.6	87.9	97.5
Fox's Pond	12.0	828.3	840.3
Green Pond	506.7	679.4	1,186.1
Mt. Hope Lake	127.3	1,096.4	1,223.7
Mt. Hope Pond	118.1	18.3	136.4
Telemark	9.6	1,669.7	1,679.3
White Meadow Lake	143.1	1,713.7	1,856.8



3.2 RESULTS

GREEN POND

The full watershed of Green Pond covers an area of 679.4 acres (Table 2). It should be noted that, unlike many other waterbodies in NJ, Green Pond's watershed is relatively comparable to the surface area of the waterbody itself (approx. 505 acres). Most other waterbodies in NJ feature watersheds several times larger than their surface area. The watershed largely consists of forested land, with small amounts of development closer to the shoreline of the waterbody. Descriptions of the Pond's sub-watersheds are as follows:

- **Cliffs – North:** The northern cliffs subwatershed is located in the southwest portion of the watershed adjacent to the northern shore. This watershed contains no development, and consists of a steep rocky slope with mostly forested land. For the purposes of this analysis, this subwatershed was assessed by Model My Watershed to consist 100% of forested land.
- **Cliffs – South:** The southern cliffs subwatershed is located in the southwestern-most corner of Green Pond. As with the northern cliffs watershed, this area contains no development and was assessed to be 100% forested.
- **South:** The South watershed contains the peninsula between the two southern coves on Green Pond and the end of Lake End Road. This subwatershed largely consists of wetlands, with approximately a quarter of the area featuring developed space.
- **Lake End – South:** This subwatershed is located in the southeastern corner of the waterbody. A large portion of this area consists of forested land and wetlands, while a small amount of residual development exists along the shoreline, largely following Lake End Road.
- **Lake End – North:** Located in the southeastern portion of Green Pond, this subwatershed largely consists of forested land, with a small amount of wetlands. While some development does exist close to the waterbody along Lake End Road, Model My Watershed does not list this area as developed land-use.
- **Southeast:** This subwatershed is located along the eastern shoreline. As with many of the other subwatersheds, it largely consists of forested land, with some developed land occurring close to the Pond's shoreline.
- **East:** This relatively small subwatershed is located at the approximate middle of the eastern shoreline of Green Pond. As with many of the other subwatersheds, it consists largely of forested land, with a small amount of wetlands and developed land close to the shoreline.
- **Peninsula:** This subwatershed is located along the middle of the eastern shoreline and contains mostly forested land and wetlands. As with the Lake End – North subwatershed, the small amount of developed land in this subwatershed is likely simply classified as part of the forested land-use type in Model My Watershed.
- **Oaklane – South:** This small subwatershed is located in the northeastern portion of green pond. While some development is present, Model My Watershed classifies the entire subwatershed as forested land.
- **Oaklane – North:** This subwatershed is located adjacent to the northeastern corner of Green Pond, containing Oak Lane and parts of Old Lake End Road. The subwatershed consists of approximately three-quarters forested land one-quarter developed land.



- **Northeast:** This subwatershed is located adjacent to the northeastern corner of Green Pond and contains a portion of the Green Pond Corporation's developed area north of the Pond, as well as part of Johnson Road and Green Pond Road (Rt. 513). A majority of this area consists of forested land and wetlands, however approximately a third of the area also contains developed land.
- **North:** This subwatershed encapsulates the central area of Green Pond Corporation's developed area north of Green Pond. Most of this area is classified as forested area or wetlands, however approximately a quarter of the land is developed.
- **Northwest:** This subwatershed contains the northwestern corner of Green Pond, as well as the western portion of Green Pond Corporation's largely developed area. The area is approximately 80% forested with the remaining land being classified as developed.
- **West Shore:** This large subwatershed is located along the middle of the western edge of green pond, and consists entirely of forested land-use type, although a few houses are present within its boundaries.



Table 2. Land-use by sub-watershed in the Green Pond watershed.

Source	Full Watershed		Cliffs - North		Cliffs - South		East		Lake end - South		Lake end - North		Oaklane South		Oakland North		Northeast		Northwest		North		Peninsula		South		Southeast		West Shore		
	Acres	%	Acres	%	Acres	%	Acres	%	Acres	%	Acres	%	Acres	%	Acres	%	Acres	%	Acres	%	Acres	%	Acres	%	Acres	%	Acres	%	Acres	%	
Hay/Pasture	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	
Cropland	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	
Forest	511.3	75.3	19.3	100.0	24.7	100.0	22.7	87.0	55.1	87.5	26.4	97.4	16.8	100.0	31.6	74.9	62.8	58.0	11.6	0	0	0	0	41.3	2.7	0	0	43.7	0	46.2	
Wetland	63.5	9.3	0	0.0	0	0.0	2.2	8.4	4.7	7.5	0.7	2.6	0	0.0	0.5	1.2	0	0.0	0	0	0	0	0	0	0	0	0	0	0	0	
Open Land	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0	0	0	0	0	0	0	0	0	0	0	
Bare Rock	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0	0	0	0	0	0	0	0	0	0	0	
Low-Density Mixed	25.5	3.8	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	1.5	3.6	6.9	6.4	4.2	0	0	0	0	0	0	0	0	0.2	0	0	
Medium-Density Mixed	4	0.6	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0.2	0.5	1	0.9	1	0	2	0	0	0	0	0	0	0	0	0	
High-Density Mixed	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0	0	0	0	0	0	0	0	0	0	0	0
Low-Density Open Space	75.1	11.1	0	0.0	0	0.0	1.2	4.6	3.2	5.1	0	0.0	0	0.0	8.4	19.9	25.9	23.9	3.2	0	0	0	0	0	0	0	0	0	0	0	
Total	679.4	100	19.3	100	24.7	100	26.1	100	63	100	27.1	100	16.8	100	42.2	100	108.2	23.9	41	100	7.8	100	44	100	0	0	13.1	100	47.6	100	46.2

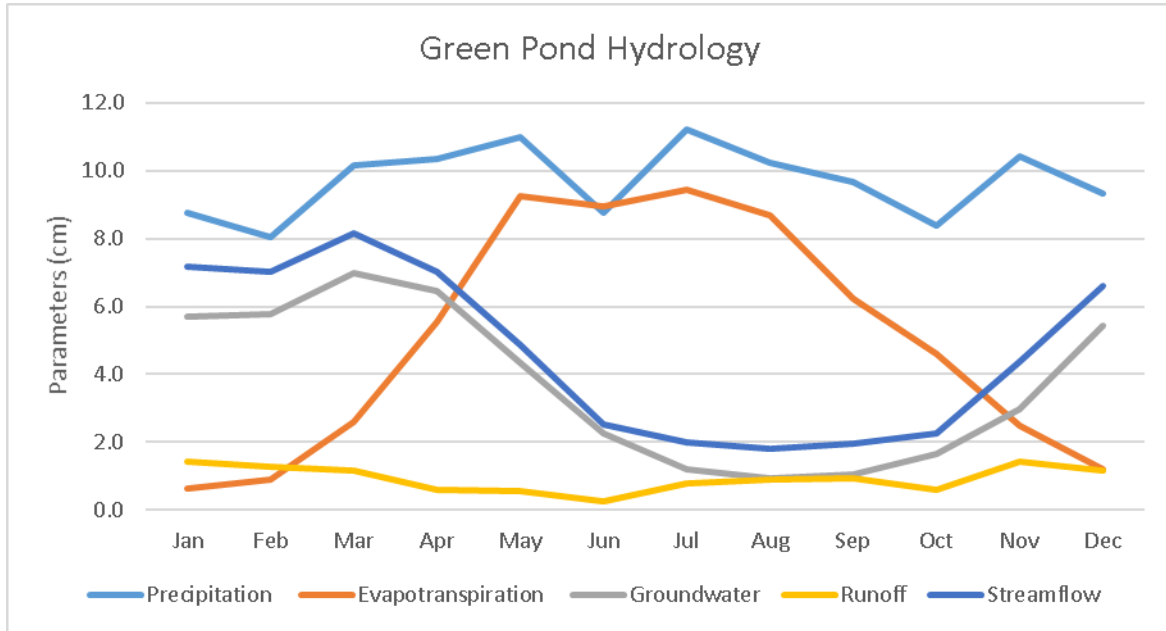


Figure 1. Estimated seasonal changes in hydrology in the Green Pond watershed

Table 3. Total hydrological parameters in the Green Pond watershed

Month	Precipitation	Evapotranspiration	Groundwater	Runoff	Streamflow	
	cm	cm	cm	cm	cm	cfs
Jan	8.8	0.6	5.7	1.4	7.2	2.6
Feb	8.0	0.9	5.8	1.3	7.0	2.8
Mar	10.2	2.6	7.0	1.2	8.2	3.0
Apr	10.4	5.6	6.5	0.6	7.0	2.6
May	11.0	9.3	4.3	0.5	4.9	1.8
Jun	8.8	8.9	2.3	0.3	2.5	0.9
Jul	11.2	9.5	1.2	0.8	2.0	0.7
Aug	10.2	8.7	0.9	0.9	1.8	0.7
Sep	9.7	6.2	1.0	0.9	2.0	0.7
Oct	8.4	4.6	1.7	0.6	2.3	0.8
Nov	10.4	2.5	3.0	1.4	4.4	1.6
Dec	9.3	1.2	5.4	1.2	6.6	2.4
Total	116.4	60.5	44.8	11.0	55.8	1.7

Among most of the subwatersheds surrounding Green Pond, runoff only varies by approximately 0.5 cm (Figure 2). The south subwatershed, however, consistently features the highest rates of runoff throughout the year. This may be due to a relatively high proportion of developed land and the accompanying impervious landcover, as well as the lack of forested area (according to Model My Watershed), which may affect evapotranspiration.



As displayed in Table 3, 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 m³. 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.

When direct precipitation and evapotranspiration to and from the Pond itself are factored in, Green Pond is estimated to receive approximately 2,679,000 m³ or 707.8 million gallons of water a year. This is lower than the estimated hydraulic load calculated in the 2008 lake and watershed study, which totaled approximately 2,900,000 m³, likely in part due to a difference in the methodologies used and in small differences in the delineated watershed area.

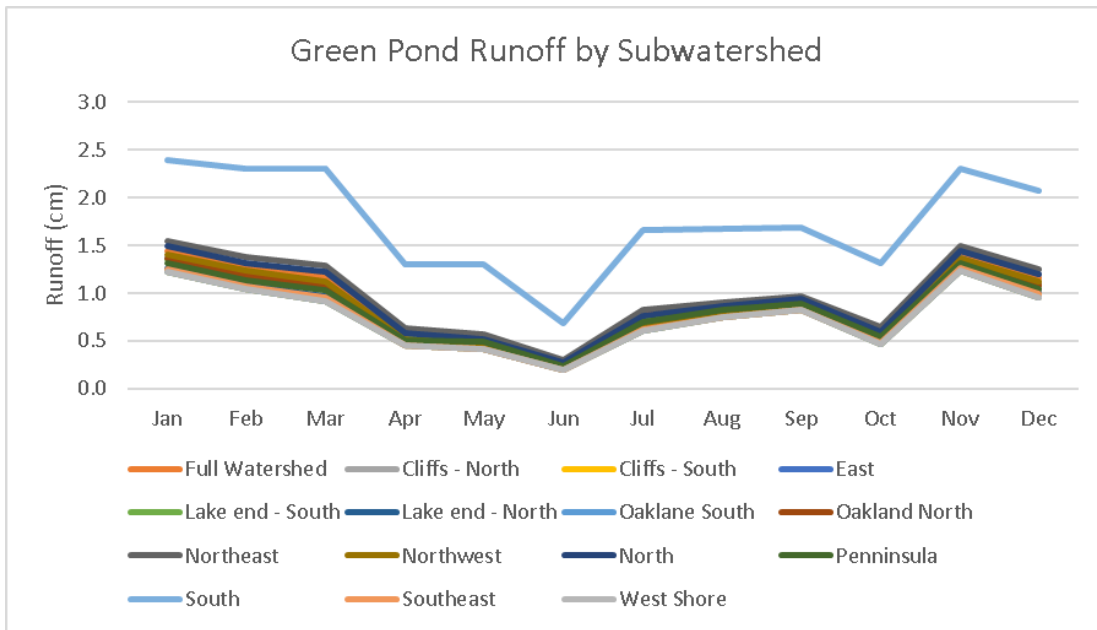


Figure 2. Average monthly runoff occurring by sub-watershed in the Green Pond watershed

Based on a bathymetry performed on Green Pond by Princeton Hydro in August, 2010, Green Pond is estimated to have a volume of approximately 7,870,000 m³ or 2,079 million gallons of water. By using the above estimated annual hydraulic load, the flushing rate and retention period can be estimated. These parameters are important at determining, among other things, how long nutrients and algae populations will remain in the lake after entering from the watershed. Due to its relatively large volume and relatively small watershed, Green Pond is estimated to flush relatively slowly, at approximately once every 3 years. This is similar to the flushing rate of once every 3.1 years calculated in the 2008 lake and watershed study.

Due to variations in monthly precipitation, the annual flushing rate and retention times can be further broken down into monthly annualized estimates. Figure 3 below displays this variation over the course of a hypothetical year. It can be observed that the annualized flushing rate typically decreases during the summer months, allowing water, nutrients, and algae to remain within the lake for even longer. While this pattern is typical, it helps to explain increases in trophic productivity during the growing



season and is also useful in understanding how a large rainstorm may affect smaller lakes during the summer months.

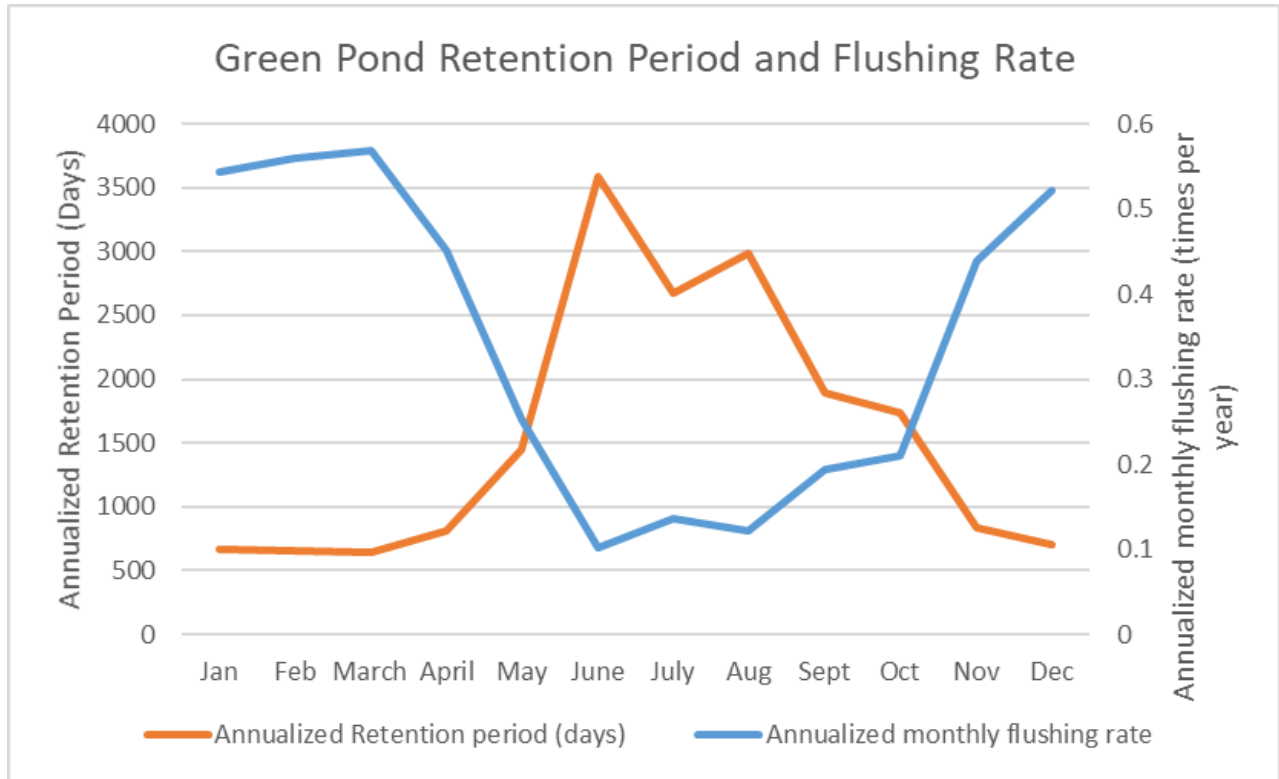


Figure 3. Variations in annualized flushing rates and retention periods over the course of a hypothetical year for Green Pond, based on variations in hydraulic loads.

Table 4: Estimated annual loads of nitrogen in the total Green Pond Watershed

Category	Description	Total Nitrogen	
		kg	%
Runoff	Hay/Pasture	0.0	0.0
	Cropland	0.0	0.0
	Forest	44.3	1.5
	Wetland	12.2	0.4
	Open Land	0.0	0.0
	Bare rock	0.0	0.0
	Low-Density Mixed	3.4	0.1
	Medium-Density Mixed	1.8	0.1
	High-Density Mixed	0.0	0.0
	Low-Density Open Space	10.1	0.3
Other Sources	Farm Animals	0.0	0.0
	Stream Bank	0.0	0.0
	Groundwater	418.2	14.4
	Septic Systems	2,416.0	83.1
Total		2,906.0	100



In many of the Green Pond sub-watersheds, the total nitrogen load was dominated by septic tank effluent (Tables 4, 5). In the two “Cliffs” subwatersheds, septic loads were not present, as no houses exist in these areas. Groundwater-based nitrogen dominated the total load in these subwatersheds, and was usually the second-highest contributor in most of the other subwatersheds. 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. Runoff from forested land yielded a relatively high percentage of nitrogen overall, however this is likely a product of the largely forested nature of this watershed; per unit area, forests have low nitrogen loading rates. When examined on a per-acre basis, the South subwatershed was estimated to yield the highest rate of nitrogen per acre, likely due to the disproportionately high density of septic systems in this subwatershed compared to its relatively small acreage. The overall watershed was estimated to yield approximately 4.28 kg of nitrogen per acre. As stated above, a majority of this nitrogen originates from the many septic systems around Green Pond; without taking these septic systems into account, this number would be much smaller, at only 0.72 kg/acre.

Table 4: Estimated annual loads of phosphorus from various sources in the Green Pond Watershed

Category	Description	Total Phosphorus	
		kg	%
Runoff	Hay/Pasture	0.00	0.0
	Cropland	0.00	0.0
	Forest	7.08	6.4
	Wetland	0.84	0.8
	Open Land	0.00	0.0
	Bare rock	0.00	0.0
	Low-Density Mixed	0.37	0.3
	Medium-Density Mixed	0.18	0.2
	High-Density Mixed	0.00	0.0
	Low-Density Open Space	1.09	1.0
	Other Sources	Farm Animals	0.00
Stream Bank		0.00	0.0
Groundwater		10.95	9.9
Septic Systems		90.60	81.5
Total		111.11	100.0

Influence from septic systems was estimated to contribute to over 80% of the watershed's total phosphorus load (Tables 4,6). While this pattern held true for many of the sub-watersheds, the two “Cliffs” watersheds' individual phosphorus loads were instead dominated by groundwater, as septic tanks are not present in these areas. In terms of surface runoff, urbanized (developed) areas in the watershed as a whole were estimated to yield approximately 1.6 kg of phosphorus per year, while forested areas yielded the highest amount of runoff-based phosphorus at 7.08 kg/year, although this was largely due to the large percentage of the total water watershed that was covered by this land-use type. When examined on a per unit area basis, phosphorus loads largely follow a similar trend to those of nitrogen, with the southern subwatershed yielding a disproportionately high load. This was also estimated to largely be a product of septic systems around the Pond. The total rate of phosphorus loading over the course of a year from the Pond's watershed is 0.16 kg/acre.



As a relatively deep waterbody, bottom anoxia occurs naturally in Green Pond. In 2021, the pond was measured to be anoxic below 9.5 meters in depth during the mid-July event. During a separate water quality event conducted by Princeton Hydro in 2021 for Green Pond's yearly water quality program, anoxia was observed to occur at 9 meters and deeper. During October, when the lake had significantly cooled and had mixed (I assume this is true), the entire water column was well-oxygenated. Based on these observations, it is estimated that the pond is likely anoxic at 9.5 meters and deeper from June to mid-July, covering an area of approximately 45.6 acres, and at 9.0 meters and deeper from mid-July to September, covering an area of approximately 55.7 acres. Using the loading rate of approximately 6 mg phosphorus/m²/day for anoxic areas and a rate of 0.6 mg phosphorus/m²/day for oxygenated areas over the course of a 153-day growing season, Green Pond is estimated to receive a yearly internal load of 326.9 kg of phosphorus. This is approximately 75% of the pond's total annual phosphorus load. If a year without any bottom anoxia were to occur, Green Pond would receive anoxic loading-based internal load of approximately 188.2 kg/year.

The lake and watershed study in 2008 estimated an internal load of approximately 159 kg/yr. The slight difference between the two results may be a product in slight differences in methodology used; the present study estimates a growing season of approximately 153 days, while the TMDL study estimates a critical period of 90 days. Table 5 below displays the external and internal loads of phosphorus for Green Pond, as well as the grand total, which is estimated to be approximately 438 kg/year.

Source	Phosphorus (kg/yr)
External (Runoff, Groundwater, Septic Systems)	111.1
Internal	326.9
Total	438.0

A majority of sediment entering Green Pond was estimated to come from runoff from forested areas (Tables 8,9). Runoff from low-density open space was the next highest contributor to the total yearly sediment load, however this was not estimated to be a particularly high load, at only approximately 440 kg/yr of sediment. The overall sediment load estimated to enter Green Pond is relatively low, at 5,400 kg/yr. When examined on a per-acre basis, the northwest subwatershed was estimated to yield the highest annual amount of sediment per acre, at 7.9 kg/acre. This subwatershed features a very steep slope, which contributes to increased erosion, as well as a higher amount of urbanized landcover. While other subwatersheds, such as the North and South Cliff subwatersheds, also feature steep slopes, they don't feature any urbanized land-cover.

It should be noted that these results differ from those obtained in the 2008 lake and watershed study, which yielded 3,589.7 kg/yr of TN, 393.9 kg/yr of phosphorus, and 109,767.5 kg/y of total suspended solids. This may be a function of the difference in methodologies used between the two studies, as well as differences in estimated hydraulic loads.



Table 6: Estimated annual loads of nitrogen by sub-watershed in the Green Pond Watershed

Category	Description	Full Watershed	Cliffs - North	Cliffs - South	East	Lake End - South	Lake End - North	Oaklane South	Oaklane North	Northeast	Northwest	North	Peninsula	South	Southeast	West Shore
Runoff	Hay/Pasture	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	Cropland	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	Forest	44.3	1.4	2.0	1.7	4.2	2.1	1.3	2.4	4.5	2.7	6.6	3.2	1.9	3.5	3.8
	Wetland	12.2	0.0	0.0	0.4	0.9	0.1	0.0	0.1	2.2	0.0	3.6	0.5	0.0	0.0	0.0
Other Sources	Open Land	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	Barren Land	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	Low-Density Mixed	3.4	0.0	0.0	0.0	0.0	0.0	0.0	0.2	0.8	0.7	1.7	0.0	0.0	0.0	0.0
	Medium-Density Mixed	1.8	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.5	0.6	0.9	0.0	0.0	0.0	0.0
Low-Density Open Space	High-Density Mixed	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	Farm Animals	10.1	0.0	0.0	0.1	0.4	0.0	0.0	0.0	0.0	0.6	3.6	0.0	0.4	0.3	0.0
	Stream Bank	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	Groundwater	418.2	15.1	21.3	14.0	34.1	16.4	9.5	22.6	52.0	29.6	79.3	24.7	3.5	27.5	33.0
Septic Systems	Total (kg)	2,416.0	0.0	0.0	91.2	284.9	227.9	22.8	387.5	159.5	216.5	193.7	239.3	148.1	364.7	79.8
	Total (kg/acre)	4.3	0.9	0.9	4.1	5.2	9.1	2.0	9.8	2.1	6.1	1.8	6.1	11.7	8.3	2.6

Table 7: Estimated annual loads of phosphorus by sub-watershed in the Green Pond Watershed

Category	Description	Full Watershed	Cliffs - North	Cliffs - South	East	Lake end - South	Lake end - North	Oaklane South	Oaklane North	Northeast	Northwest	North	Peninsula	South	Southeast	West Shore
Runoff	Hay/Pasture	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	Cropland	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	Forest	7.08	0.13	0.25	0.14	0.42	0.23	0.11	0.21	0.32	0.39	0.57	0.31	0.00	0.45	0.49
	Wetland	0.84	0.00	0.00	0.03	0.05	0.01	0.00	0.01	0.03	0.10	0.24	0.03	0.10	0.00	0.00
Other Sources	Open Land	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	Barren Rock	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	Low-Density Mixed	0.37	0.00	0.00	0.00	0.00	0.00	0.00	0.02	0.09	0.08	0.19	0.00	0.00	0.00	0.00
	Medium-Density Mixed	0.18	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.06	0.06	0.09	0.00	0.00	0.00	0.00
Low-Density Open Space	High-Density Mixed	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	Farm Animals	1.09	0.00	0.00	0.01	0.05	0.00	0.00	0.11	0.34	0.05	0.39	0.00	0.05	0.03	0.00
	Stream Bank	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	Groundwater	10.95	0.40	0.56	0.37	0.89	0.43	0.25	0.59	1.36	0.78	2.07	0.65	0.09	0.72	0.92
Septic Systems	Total (kg)	90.60	0.00	0.00	3.42	10.68	8.55	0.43	14.53	5.98	8.12	7.26	8.97	5.56	13.68	2.99
	Total (kg/acre)	111.11	0.53	0.81	3.97	12.09	9.22	1.21	15.48	8.28	9.49	10.81	9.96	5.80	14.88	4.40

Table 8: Estimated annual loads of sediment by sub-watershed in the Green Pond Watershed

Category	Description	Full Watershed	Cliffs - North	Cliffs - South	East	Lake end - South	Lake end - North	Oaklane South	Oaklane North	Northeast	Northwest	North	Peninsula	South	Southeast	West Shore
Runoff	Hay/Pasture	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
	Cropland	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
	Forest	4.440	0.050	0.000	0.130	0.050	0.180	0.110	0.040	0.080	0.080	0.230	0.210	0.130	0.000	0.240
	Wetland	0.180	0.000	0.000	0.000	0.000	0.010	0.000	0.000	0.000	0.010	0.000	0.050	0.000	0.000	0.000
Other Sources	Open Land	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
	Barren Land	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
	Low-Density Mixed	0.150	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.010	0.040	0.030	0.070	0.000	0.000	0.000
	Medium-Density Mixed	0.100	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.010	0.030	0.030	0.050	0.000	0.000	0.000
Septic Systems	High-Density Mixed	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
	Low-Density Open Space	0.440	0.000	0.000	0.000	0.020	0.000	0.000	0.000	0.050	0.140	0.020	0.150	0.000	0.020	0.000
Total (kg/acre)	Farm Animals	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
	Stream Bank	0.045	0.001	0.000	0.001	0.003	0.005	0.001	0.001	0.013	0.027	0.014	0.029	0.001	0.005	0.006
Total (kg/acre)	Groundwater	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
	Septic Systems	5.335	0.051	0.131	0.331	0.053	0.215	0.111	0.041	0.163	0.327	0.324	0.559	0.131	0.266	0.270
Total (kg/acre)	Total (kg/acre)	7.882	2.642	5.304	2.031	3.413	4.096	2.440	3.863	3.022	7.902	3.487	2.977	1.908	5.588	5.844



Category	Description	Sediment	
		kgx1000	%
Runoff	Hay/Pasture	0.000	0.0
	Cropland	0.000	0.0
	Forest	4.440	82.9
	Wetland	0.180	3.4
	Open Land	0.000	0.0
	Barren Land	0.000	0.0
	Low-Density Mixed	0.150	2.8
	Medium-Density Mixed	0.100	1.9
	High-Density Mixed	0.000	0.0
	Low-Density Open Space	0.440	8.2
Other Sources	Farm Animals	0.000	0.0
	Stream Bank	0.045	0.8
	Groundwater	0.000	0.0
	Septic Systems	0.000	0.0
Total		5.355	100.0

Due to the largely forested nature of Green Pond's watershed, a majority of bacteria originates from wildlife, while approximately 18% is generated from urban area runoff (Tables 10, 11). The northeastern subwatershed yielded the highest rate of bacteria per year, and also featured a relatively higher rate of urban-based bacteria than many of the other subwatersheds.

Table 10: Estimated annual loads of bacteria from various sources in the total Green Pond Watershed

Category	Description	Fecal Coliform	
		Organisms	%
Fecal Coliform	Farm Animals	0.00E+00	0.0
	Urban Areas	3.91E+10	17.7
	Wildlife	1.82E+11	82.3
	Total	2.21E+11	100



Table 11: Estimated annual loads of bacteria by sub-watershed in the Green Pond Watershed

Category	Description	Full Watershed	Cliffs - North	Cliffs - South	East	Lake end - South	Lake end - North	Oaklane South	Oaklane North	Northeast	Northwest	North	Peninsula	South	Southeast	West Shore
		%	%	%	%	%	%	%	%	%	%	%	%	%	%	%
Fecal Coliform	Farm Animals	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	Urban Areas	17.6	0.0	0.0	1.4	1.7	0.0	0.0	33.4	53.4	30.6	45.4	0.0	100.0	4.2	0.0
	Wildlife	82.4	100.0	100.0	98.6	98.3	100.0	100.0	66.6	46.6	69.4	54.6	100.0	0.0	93.8	100.0
Total (organisms)		2.21E+11	6.87E+09	8.81E+09	8.23E+09	2.00E+10	9.43E+09	5.99E+09	1.69E+10	4.80E+10	1.68E+10	5.79E+10	1.47E+10	1.66E+09	1.63E+10	1.65E+10



EGBERT LAKE

Egbert Lake's watershed covers an area of 461.4 acres (Table 12), while the lake itself has a surface area of approximately 14 acres. The area is mostly forested, although some development exists along Green Pond Road and its smaller side-streets. The main (and only) significant inlet to the lake is Burnt Meadow Brook, a non-trout Category One stream (FW2-NT(C1)). The area immediately surrounding the lake largely consists of low-density open space, with higher elevation areas consisting of forested land in areas farther from the lake. As noted above, the lake and the area surrounding it are owned by Rockaway Township and are used as a public park. Descriptions of the lake's sub-watersheds are as follows:

- **Burnt Meadow:** This approximately 415-acre sub-watershed encompasses a majority of the full Egbert Lake watershed, entering the lake at its northern end but extending south along Green Pond Road. It contains largely forested land and wetlands, with smaller amounts of urbanized area and open water in the form of small ponds along Burnt Meadow Brook.
- **East:** This watershed envelopes the eastern and southern portions of Egbert Lake, and contains mostly forested land, and well as smaller areas of wetlands and developed lands.
- **West:** This very small subwatershed is located along the lake's dam, extending north through the park's parking area up to Green Pond Road. This area is largely forested, with a smaller amount of developed area and low-density developed area.

Table 12. Land-use by sub-watershed in the Egbert Lake watershed.

Source	Full Watershed Acres	Burnt Meadow Acres	East Acres	West Acres
Open Water	3.9	3.9	0.0	0.0
Hay/Pasture	5.7	5.7	0.0	0.0
Cropland	0.0	0.0	0.0	0.0
Forest	337.5	297.0	34.8	5.4
Wetland	75.6	73.1	2.0	0.7
Open Land	0.0	0.0	0.0	0.0
Bare Rock	0.0	0.0	0.0	0.0
Low-Density Mixed	7.4	6.7	0.5	0.2
Medium-Density Mixed	0.2	0.2	0.0	0.0
High-Density Mixed	0.0	0.0	0.0	0.0
Low-Density Open Space	31.1	28.4	1.0	1.5
Total	461.4	415.0	38.3	7.8

Source	Full Watershed %	Burnt Meadow %	East %	West %
Open Water	0.8	0.9	0.0	0.0
Hay/Pasture	1.2	1.4	0.0	0.0
Cropland	0.0	0.0	0.0	0.0
Forest	73.1	71.6	90.9	69.2
Wetland	16.4	17.6	5.2	9.0
Open Land	0.0	0.0	0.0	0.0
Barren Land	0.0	0.0	0.0	0.0
Low-Density Mixed	1.6	1.6	1.3	2.6
Medium-Density Mixed	0.0	0.0	0.0	0.0
High-Density Mixed	0.0	0.0	0.0	0.0
Low-Density Open Space	6.7	6.8	2.6	19.2
Total	100	100	100	100

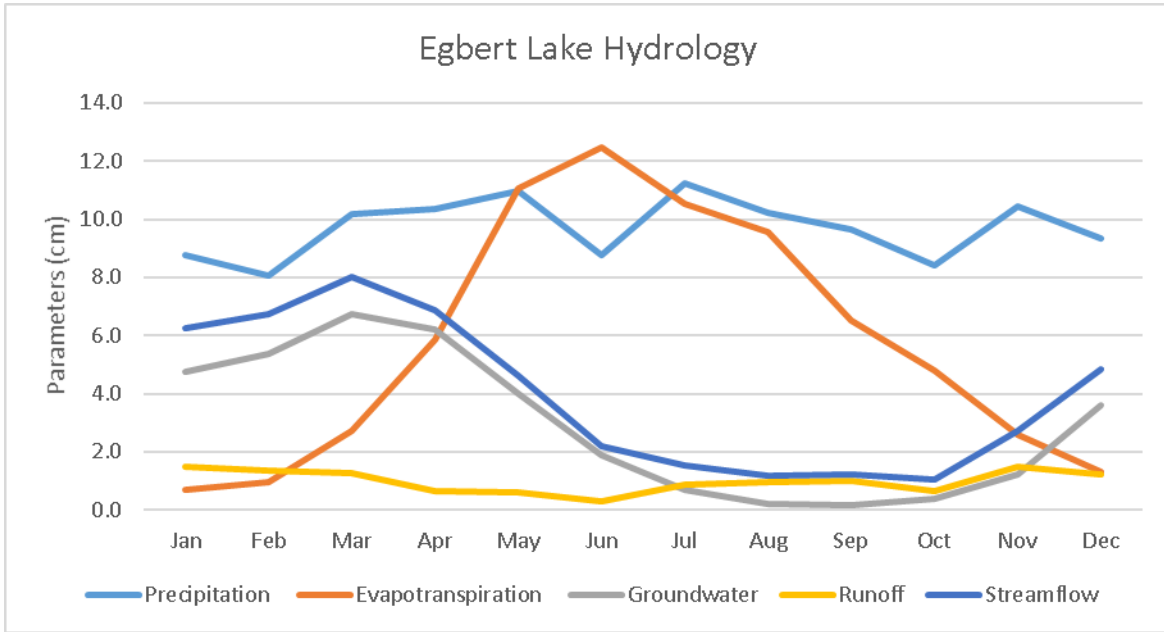


Figure 4. Estimated seasonal changes in hydrology in the Egbert Lake watershed

Table 13: Total hydrological parameters in the full Egbert Lake watershed over the course of a simulated year

Month	Precipitation cm	Evapotranspiration cm	Groundwater cm	Runoff cm	Streamflow cm	cfs
Jan	8.8	0.7	4.8	1.5	6.3	1.5
Feb	8.0	1.0	5.4	1.3	6.7	1.8
Mar	10.2	2.7	6.8	1.3	8.0	2.0
Apr	10.4	5.9	6.2	0.6	6.9	1.7
May	11.0	11.1	4.0	0.6	4.6	1.1
Jun	8.8	12.5	1.9	0.3	2.2	0.6
Jul	11.2	10.5	0.7	0.9	1.5	0.4
Aug	10.2	9.6	0.2	1.0	1.2	0.3
Sep	9.7	6.5	0.2	1.0	1.2	0.3
Oct	8.4	4.8	0.4	0.7	1.1	0.3
Nov	10.4	2.6	1.2	1.5	2.7	0.7
Dec	9.3	1.3	3.6	1.2	4.8	1.2
Total	116.4	69.0	35.3	11.9	47.1	1.0

Runoff varied at most only approximately 25% between subwatersheds, with Burnt Meadow yielding the highest, likely due to its' relatively high percentage of urbanized landcover when compared to the other two subwatersheds. After factoring in direct precipitation and evaporation to the lake itself, Egbert Lake is estimated to receive approximately 906,300 m³ or 239.4 million gallons of water a year.

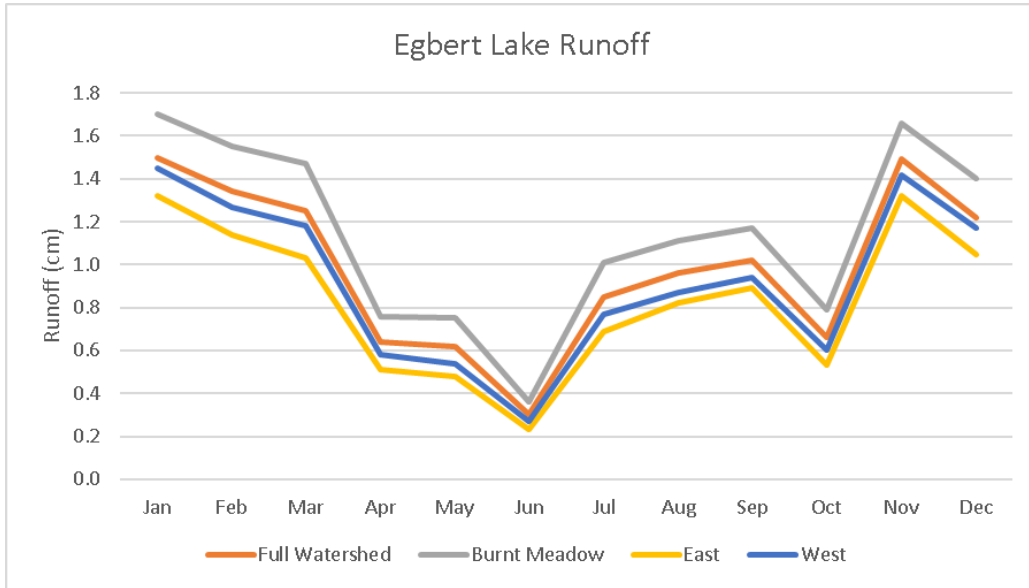


Figure 5. Average monthly runoff within sub-watersheds of the Egbert Lake watershed

No bathymetry data was found to exist for Egbert Lake; as such, the lake's volume is an estimate based on depths of the sample sites. The Lake is estimated to contain approximately 88,994 m³ or 23.5 million gallons of water. As the lake's volume is much smaller than its estimated hydraulic load, the lake flushes relatively quickly, approximately 10.2 times a year. A unit of water is only estimated to stay in the lake for approximately 36 days; this metric is known as the retention period. The lake's annualized monthly flushing rates are estimated to follow a pattern similar to those of Green Pond, although with the period of reduced flushing occurring moreso towards the end of the summer, while Green Pond's lowest annualized monthly flushing rate occurred in June.

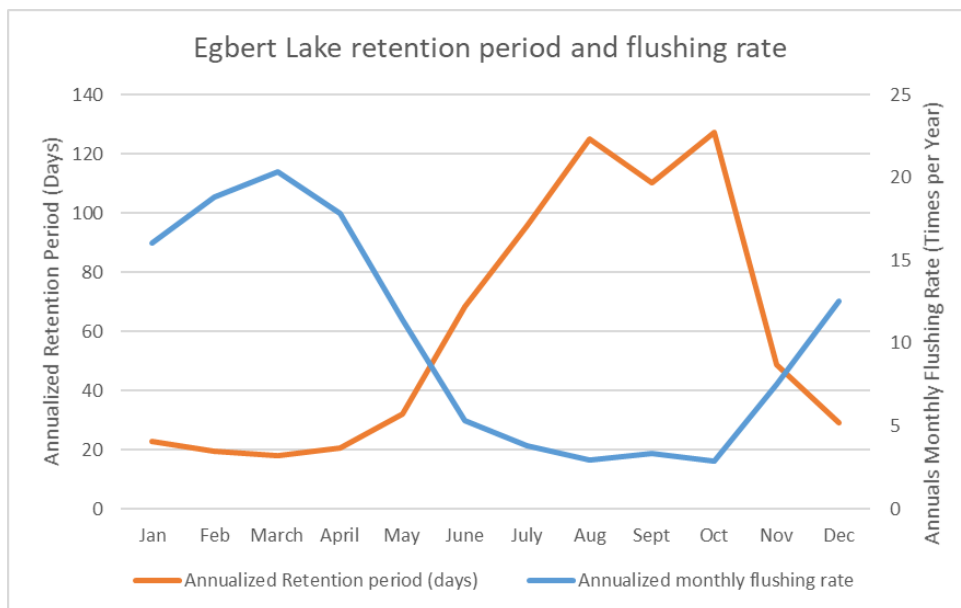


Figure 6. Variations in annualized flushing rates and retention periods over the course of a hypothetical year for Egbert Lake, based on variations in hydraulic loads.



Table 14: Estimated annual loads of nitrogen in the total Egbert Lake Watershed

Category	Description	Total Nitrogen	
		kg	%
Runoff	Hay/Pasture	2.4	0.5
	Cropland	0.0	0.0
	Forest	24.4	4.7
	Wetland	14.2	2.7
	Open Land	0.0	0.0
	Bare rock	0.0	0.0
	Low-Density Mixed	0.9	0.2
	Medium-Density Mixed	0.1	0.0
	High-Density Mixed	0.0	0.0
	Low-Density Open Space	3.7	0.7
Other Sources	Farm Animals	0.0	0.0
	Stream Bank	2.0	0.4
	Groundwater	220.7	42.5
	Septic Systems	250.7	48.3
Total		519.1	100

Table 15: Estimated annual loads of nitrogen by sub-watershed in the Egbert Lake Watershed

Category	Description	Full Watershed	Burnt Meadow	East	West
		kg	kg	kg	kg
Runoff	Hay/Pasture	2.4	2.4	0.0	0.0
	Cropland	0.0	0.0	0.0	0.0
	Forest	24.4	26.9	2.6	0.4
	Wetland	14.2	13.7	0.4	0.1
	Open Land	0.0	0.0	0.0	0.0
	Barren Land	0.0	0.0	0.0	0.0
	Low-Density Mixed	0.9	0.8	0.1	0.0
	Medium-Density Mixed	0.1	0.1	0.0	0.0
	High-Density Mixed	0.0	0.0	0.0	0.0
	Low-Density Open Space	3.7	3.3	0.1	0.1
Other Sources	Farm Animals	0.0	0.0	0.0	0.0
	Stream Bank	2.0	2.0	0.0	0.0
	Groundwater	220.7	185.9	21.1	4.1
	Septic Systems	250.7	227.9	22.8	0.0
Total (kg)		519.1	462.9	47.1	4.8
kg/acre		1.1	1.1	1.2	0.6

As with Green Pond, a majority of Egbert Lake's nitrogen load originates from septic systems and groundwater (Tables 14, 15). In addition, smaller amounts of nitrogen are also contributed by forested land-use types and wetlands. The Burnt Meadow Watershed is estimated to yield the highest amount



of nitrogen because of its size and number of septic systems along a stream corridor. When examined on a per-acre basis, the entire watershed receives an estimated 1.13 kg/acre/year. The eastern subwatershed is estimated to yield a slightly higher per-acre annual rate of nitrogen than the Burnt Meadow subwatershed, while the west subwatershed yielded a considerably lower rate, likely due to its lack of septic systems.

Table 16: Estimated annual loads of phosphorus in the total Egbert Lake Watershed

Category	Description	Total Phosphorus	
		kg	%
Runoff	Hay/Pasture	0.98	4.2
	Cropland	0.00	0.0
	Forest	1.75	7.5
	Wetland	0.84	3.6
	Open Land	0.00	0.0
	Bare rock	0.00	0.0
	Low-Density Mixed	0.10	0.4
	Medium-Density Mixed	0.01	0.0
	High-Density Mixed	0.00	0.0
	Low-Density Open Space	0.40	1.7
Other Sources	Farm Animals	0.00	0.0
	Stream Bank	1.00	4.3
	Groundwater	8.88	38.0
	Septic Systems	9.40	40.2
Total		23.36	100.0



Table 17: Estimated annual loads of phosphorus by sub-watershed for Egbert Lake Watershed

Category	Description	Full Watershed kg	Burnt Meadow kg	East kg	West kg
Runoff	Hay/Pasture	0.98	0.97	0.00	0.00
	Cropland	0.00	0.00	0.00	0.00
	Forest	1.75	1.94	0.22	0.03
	Wetland	0.84	0.80	0.02	0.01
	Open Land	0.00	0.00	0.00	0.00
	Bare Rock	0.00	0.00	0.00	0.00
	Low-Density Mixed	0.10	0.08	0.01	0.00
	Medium-Density Mixed	0.01	0.01	0.00	0.00
	High-Density Mixed	0.00	0.00	0.00	0.00
	Low-Density Open Space	0.40	0.35	0.01	0.01
Other Sources	Farm Animals	0.00	0.00	0.00	0.00
	Stream Bank	1.00	1.00	0.00	0.00
	Groundwater	8.88	7.42	0.55	0.11
	Septic Systems	9.40	8.55	0.85	0.00
Total (kg)		23.4	21.1	1.7	0.2
kg/acre		0.05	0.05	0.04	0.02

Septic systems and groundwater were also the overall largest source of phosphorus in the Egbert Lake watershed, contributing approximately 40% and 38% of the total annual load, respectively (Tables 16, 17). The West and East sub-watersheds were estimated to produce relatively low loading rate of phosphorus compared to Burnt Meadow, which, as mentioned above, featured the largest area and the highest number of septic systems. While runoff contributed a small amount of phosphorus to the lake (mostly from forested areas), this was not particularly high.

During lake sampling events in 2021, Egbert Lake was only observed to exhibit bottom anoxia immediately above the lake bed during July at the south end station, however it was not anoxic at the deeper Dam station, perhaps due to better circulation near the outlet. Based on these observations, it was estimated that approximately 50% of the waterbody area became anoxic for one month over the course of the growing season. After loading from oxygenated sediment is accounted for, Egbert Lake is estimated to receive approximately 9.93 kg/yr of phosphorus from internal loading. If a year were to occur with no instances of anoxia, Egbert Lake's internal load would be an estimated 5.2 kg.

Table 18 below displays the external and internal loads of phosphorus for Egbert Lake, as well as the grand total, which is estimated to be approximately 33.3 kg/year. External loading is estimated to be the primary source of phosphorus loading in Egbert Lake, representing approximately 70% of the entire annual load.



Table 18. Total estimated annual phosphorus load for Egbert Lake from external and internal sources

Source	Phosphorus (kg/yr)
External (Runoff, Groundwater, Septic Systems)	23.4
Internal	9.9
Total	33.3

Table 19: Estimated annual loads of sediment in the Egbert Lake Watershed

Category	Description	Sediment	
		kgx1000	%
Runoff	Hay/Pasture	0.030	0.6
	Cropland	0.000	0.0
	Forest	0.440	9.2
	Wetland	0.090	1.9
	Open Land	0.000	0.0
	Barren Land	0.000	0.0
	Low-Density Mixed	0.040	0.8
	Medium-Density Mixed	0.010	0.2
	High-Density Mixed	0.000	0.0
	Low-Density Open Space	0.160	3.4
Other Sources	Farm Animals	0.000	0.0
	Stream Bank	3.993	83.8
	Groundwater	0.000	0.0
	Septic Systems	0.000	0.0
Total		4.763	100.0

A majority of Egbert Lake's incoming sediment load is estimated to come from stream bank erosion in Burnt Meadow Brook (Tables 19, 20). Most of the runoff-based sediment originates from forested areas; this is likely simply due to the large percentage of forest cover. For the overall watershed, this is not particularly high, at only 440 kg/yr, or 10.32 kg/acre.



Table 20: Estimated annual loads of sediment by sub-watershed in the Egbert Lake Watershed

Category	Description	Full Watershed kg x 1000	Burnt Meadow kg x 1000	East kg x 1000	West kg x 1000
Runoff	Hay/Pasture	0.030	0.030	0.000	0.000
	Cropland	0.000	0.000	0.000	0.000
	Forest	0.440	0.490	0.080	0.010
	Wetland	0.090	0.080	0.000	0.000
	Open Land	0.000	0.000	0.000	0.000
	Barren Land	0.000	0.000	0.000	0.000
	Low-Density Mixed	0.040	0.030	0.000	0.000
	Medium-Density Mixed	0.010	0.010	0.000	0.000
	High-Density Mixed	0.000	0.000	0.000	0.000
	Low-Density Open Space	0.160	0.140	0.010	0.010
Other Sources	Farm Animals	0.000	0.000	0.000	0.000
	Stream Bank	3.993	3.637	0.003	0.006
	Groundwater	0.000	0.000	0.000	0.000
	Septic Systems	0.000	0.000	0.000	0.000
	Total (kgx1000)	4.763	4.417	0.093	0.026
	kg/acre	10.323	10.643	2.428	3.333

Table 19: Estimated annual loads of bacteria from various sources in the total Egbert Lake Watershed

Category	Description	Fecal Coliform Organisms	%
Fecal Coliform	Farm Animals	0.00E+00	0.0
	Urban Areas	7.36E+09	5.8
	Wildlife	1.20E+11	94.2
	Total	1.27E+11	100

Table 20: Estimated annual loads of bacteria by sub-watershed in the Egbert Lake Watershed

Category	Description	Full Watershed %	Burnt Meadow %	East %	West %
Fecal Coliform	Farm Animals	0.0	0.0	0.0	0.0
	Urban Areas	5.8	6.0	1.1	30.2
	Wildlife	94.2	94.0	98.9	69.8
	Total (organisms)	1.27E+11	1.13E+11	1.26E+10	2.78E+09

As with Green Pond, a majority of the total bacteria load for Egbert Lake is estimated to originate with wildlife, likely due to the large portion of the total watershed that consists of forested land. The Burnt Meadow subwatershed is estimated to yield the largest amount of bacteria, again because of its large area.



DURHAM POND

Durham pond is located in the northern portion of the township and is part of the Boy Scouts of America's Camp Winnebago. The pond has a surface area of approximately 45.7 acres, while the pond's watershed covers an area of approximately 395 acres, and consists almost entirely of forested land, as well as almost 70 acres of wetland to the north. The pond's inlets include two small streams draining the wetlands from the north, as well as a stream entering the western side of the lake. The pond drains eastward towards Splitrock Reservoir. Descriptions of the pond's subwatersheds are as follows:

- **East:** This 13-acre subwatershed contains the lake's dam, as well as the forested area along the eastern shoreline of the pond. The area is almost entirely forested.
- **Northeast:** This approximately 78-acres subwatershed contains one of the large wetlands that drains into Durham pond. This wetland area covers an area of approximately 12 acres, while the remainder of the subwatershed is forested.
- **Northwest:** This 97.3-acre subwatershed drains the second large wetland to the north of the pond, and also contains some of the camp's campsites, buildings, and swimming area. The wetland covers an area of approximately 15 acres, while the rest of the area is classified as forested land.
- **Southeast:** This 14.6-acre subwatershed is almost entirely forested and contains a part of the southern-most campsite on Winnebago's property.
- **South:** This narrow, 10-acre watershed is classified as entirely forested and contains part of the southern-most campsite on Winnebago's property.
- **Southwest:** This 27.9-acre subwatershed is entirely forested and contains part of the camp's main trail.
- **Camp Road:** This approximately 20-acre subwatershed is located along the western edge of the pond and is classified as entirely forested. It contains several campsites and camp facilities.
- **West:** This is the largest of Durham Pond's subwatersheds at 133.6 acres. The area is almost entirely covered in forests and wetlands, with the exception of a small amount of developed open space to the south.



Table 21. Land-use by sub-watershed in the Durham Pond watershed.

Source	Full Watershed Acres	East Acres	Northeast Acres	Northwest Acres	Southeast Acres	South Acres	Southwest Acres	Camp Road Acres	West Acres
Open Water	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Hay/Pasture	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Cropland	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Forest	326.4	12.8	66.0	82.5	12.6	10.1	27.9	20.3	94.1
Wetland	68.7	0.2	12.1	14.8	2.0	0.0	0.0	0.0	39.3
Open Land	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Bare Rock	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Low-Density Mixed	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Medium-Density Mixed	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
High-Density Mixed	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Low-Density Open Space	0.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.2
Total	395.3	13.0	78.1	97.3	14.6	10.1	27.9	20.3	133.6

Source	Full Watershed %	East %	Northeast %	Northwest %	Southeast %	South %	Southwest %	Camp Road %	West %
Open Water	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Hay/Pasture	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Cropland	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Forest	82.6	98.5	84.5	84.8	86.3	100.0	100.0	100.0	70.4
Wetland	17.4	1.5	15.5	15.2	13.7	0.0	0.0	0.0	29.4
Open Land	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Barren Land	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Low-Density Mixed	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Medium-Density Mixed	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
High-Density Mixed	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Low-Density Open Space	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1
Total	100	100	100	100	100	100	100	100	100

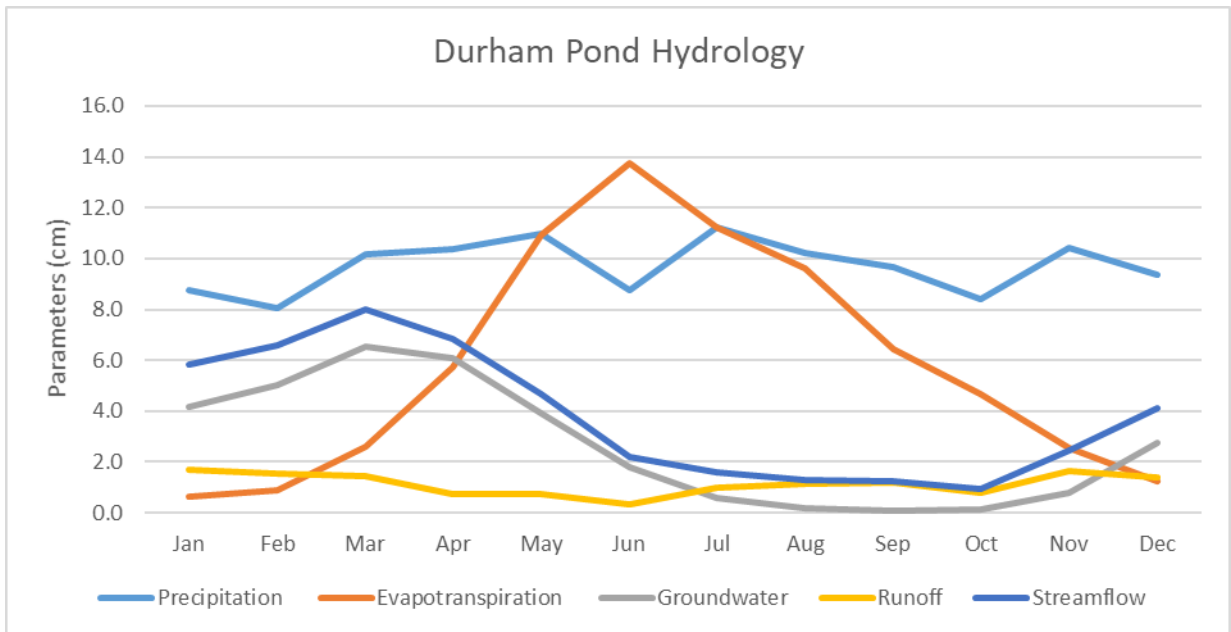


Figure 7. Estimated seasonal changes in hydrology in the Durham Pond watershed



Table 22: Total hydrological parameters in the full Durham Pond watershed

Month	Precipitation cm	Evapotranspiration cm	Groundwater cm	Runoff cm	Streamflow cm	cfs
Jan	8.8	0.7	4.2	1.7	5.8	1.2
Feb	8.0	0.9	5.0	1.5	6.6	1.5
Mar	10.2	2.6	6.6	1.5	8.0	1.7
Apr	10.4	5.7	6.1	0.8	6.9	1.5
May	11.0	10.9	3.9	0.8	4.7	1.0
Jun	8.8	13.7	1.8	0.4	2.2	0.5
Jul	11.2	11.2	0.6	1.0	1.6	0.3
Aug	10.2	9.6	0.2	1.1	1.3	0.3
Sep	9.7	6.4	0.1	1.2	1.3	0.3
Oct	8.4	4.7	0.1	0.8	0.9	0.2
Nov	10.4	2.5	0.8	1.7	2.4	0.5
Dec	9.3	1.2	2.7	1.4	4.1	0.9
Total	116.4	70.3	32.1	13.7	45.8	0.8

Runoff into Durham Pond is estimated to be largely similar between the different sub-watersheds, as most of them are largely forested. It should be noted that most of the soils within the watershed are classified as being in the "Slow Infiltration" soil group, suggesting that, during heavy rain events, water begins to runoff from the land relatively quickly. When direct precipitation and evapotranspiration in the waterbody itself is factored in, Durham Pond is estimated to receive an annual hydrologic load of approximately 817,556 m³ or 216 million gallons of water.

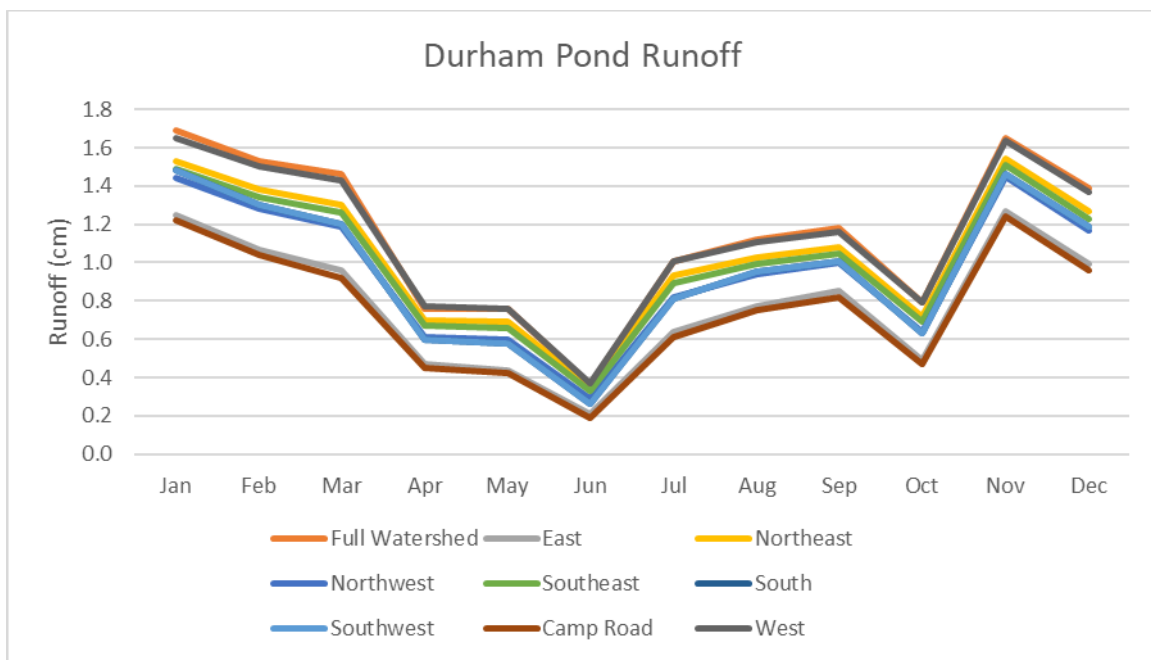


Figure 8. Average monthly runoff within each sub-watershed in the Durham Pond watershed



As with Egbert Lake, bathymetric survey data was not available for Durham Pond, and the pond's volume was estimated at 471,000 m³ or 124.6 million gallons of water. The Pond's flushing rate is accordingly calculated to be approximately 1.7 times a year, with for a retention period of approximately 211 days. When examined on a monthly basis, the pond has a much lower annualized flushing rate and higher retention period from June through October, contributing to elevated productivity at that time.

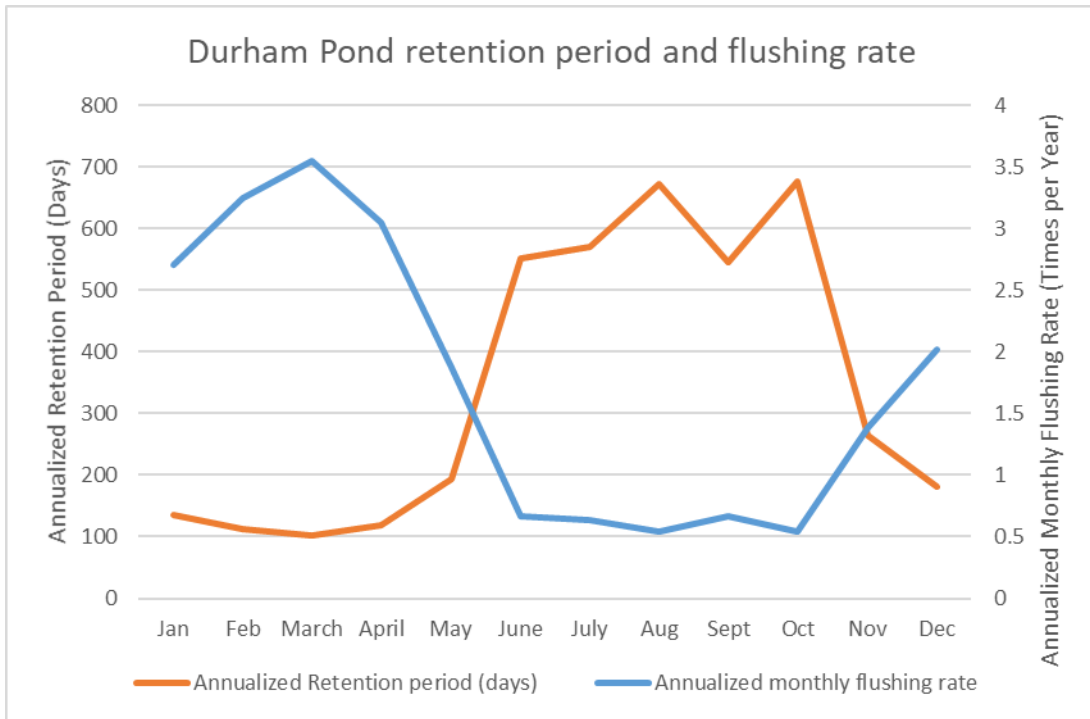


Figure 9. Variations in annualized flushing rates and retention periods over the course of a hypothetical year for Durham Pond, based on variations in hydraulic loads.



Table 23: Estimated annual loads of nitrogen in the total Durham Pond Watershed

Category	Description	Total Nitrogen	
		kg	%
Runoff	Hay/Pasture	0.0	0.0
	Cropland	0.0	0.0
	Forest	30.6	10.0
	Wetland	12.8	4.2
	Open Land	0.0	0.0
	Bare rock	0.0	0.0
	Low-Density Mixed	0.0	0.0
	Medium-Density Mixed	0.0	0.0
	High-Density Mixed	0.0	0.0
	Low-Density Open Space	0.02	0.0
Other Sources	Farm Animals	0.0	0.0
	Stream Bank	0.0	0.0
	Groundwater	171.3	55.8
	Septic Systems	92.4	30.1
Total		307.1	100

Table 24: Estimated annual loads of nitrogen by subwatershed in the Durham Pond Watershed

Category	Description	Full Watershed	East	Northeast	Northwest	Southeast	South	Southwest	Camp Road	West
		kg	kg	kg	kg	kg	kg	kg	kg	kg
Runoff	Hay/Pasture	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	Cropland	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	Forest	30.6	1.0	4.5	6.0	0.9	0.9	2.6	1.5	6.9
	Wetland	12.8	0.1	2.6	2.8	0.5	0.0	0.0	0.0	7.4
	Open Land	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	Barren Land	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	Low-Density Mixed	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	Medium-Density Mixed	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	High-Density Mixed	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	Low-Density Open Space	0.02	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.02
Other Sources	Farm Animals	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	Stream Bank	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	Groundwater	171.3	7.7	32.9	44.4	7.5	5.6	15.1	11.6	52.6
	Septic Systems	92.4	0.0	0.0	52.8	13.2	0.0	0.0	13.2	13.2
Total (kg)		307.1	8.7	40.0	106.0	22.1	6.5	17.7	26.3	80.1
kg/acre		0.8	0.7	0.5	1.1	1.5	0.6	0.6	1.3	0.6

Nitrogen loads in the Durham Pond watershed were largely contributed by groundwater sources. While not a particularly high percentage of the watershed's overall nitrogen load, forested land wetland areas contributed the majority of the runoff-based nitrogen load. While septic systems are generally not present within the 300' buffer of Durham Pond and its inlets, there are approximately 7 pit latrines at campsites located in this area. As these are only used during the summer months, these yield overall less nitrogen than septic systems do in year-round lake house septic systems. While not as much of a contributing source as groundwater flows, these latrines are estimated to contribute a significant amount of nitrogen to Durham Pond, most of which originates in the Northwest subwatershed.



Table 25: Estimated annual loads of phosphorus in the total Durham Pond Watershed

Category	Description	Total Phosphorus	
		kg	%
Runoff	Hay/Pasture	0.00	0.00
	Cropland	0.00	0.00
	Forest	2.80	24.62
	Wetland	0.74	6.51
	Open Land	0.00	0.00
	Bare rock	0.00	0.00
	Low-Density Mixed	0.00	0.00
	Medium-Density Mixed	0.00	0.00
	High-Density Mixed	0.00	0.00
	Low-Density Open Space	0.00	0.00
Other Sources	Farm Animals	0.00	0.00
	Stream Bank	0.00	0.00
	Groundwater	4.37	38.42
	Septic Systems	3.47	30.46
Total		11.38	100.0

Table 26: Estimated annual load of phosphorus by subwatershed in the Durham Pond Watershed

Category	Description	Full Watershed	East	Northeast	Northwest	Southeast	South	Southwest	Camp Road	West
		kg	kg	kg	kg	kg	kg	kg	kg	kg
Runoff	Hay/Pasture	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	Cropland	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	Forest	2.80	0.08	0.36	0.48	0.07	0.07	0.23	0.11	0.50
	Wetland	0.74	0.00	0.12	0.15	0.03	0.00	0.00	0.00	0.42
	Open Land	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	Bare Rock	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	Low-Density Mixed	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	Medium-Density Mixed	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	High-Density Mixed	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	Low-Density Open Space	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Other Sources	Farm Animals	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	Stream Bank	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	Groundwater	4.37	0.20	0.71	1.14	0.20	0.15	0.39	0.30	1.38
	Septic Systems	3.47	0.00	0.00	1.98	0.50	0.00	0.00	0.50	0.50
Total (kg)		11.38	0.28	1.19	3.75	0.80	0.22	0.62	0.91	2.80
kg/acre		0.03	0.02	0.02	0.04	0.05	0.02	0.02	0.04	0.02

As with nitrogen loads, phosphorus loads in the Durham Pond watershed are estimated to originate largely from groundwater and latrines, particularly in the Northwest subwatershed. Runoff from forested areas and wetlands also contributes to phosphorus loading, however not to a large extent.

During field surveys conducted in 2021, bottom anoxia was not detected at Durham Pond. As such, the Pond's internal phosphorus load was estimated solely based on oxic loading and was estimated to be approximately 17 kg/year.

Table 27 below displays the external and internal loads of phosphorus for Durham Pond, as well as the grand total, which is estimated to be approximately 28.4 kg/year. The internal load is estimated to represent the majority of the total phosphorus load (approximately 60%), however the external load should not be ignored as a phosphorus source, as it makes up approximately 40% of the total load.



Table 27. Total estimated annual phosphorus load for Durham Pond from external and internal sources

Source	Phosphorus (kg/yr)
External (Runoff, Groundwater, Septic Systems)	11.4
Internal	17
Total	28.4

Table 28: Estimated annual loads of sediment in the total Durham Pond Watershed

Category	Description	Sediment	
		kgx1000	%
Runoff	Hay/Pasture	0.000	0.0
	Cropland	0.000	0.0
	Forest	1.070	92.4
	Wetland	0.080	6.9
	Open Land	0.000	0.0
	Barren Land	0.000	0.0
	Low-Density Mixed	0.000	0.0
	Medium-Density Mixed	0.000	0.0
	High-Density Mixed	0.000	0.0
	Low-Density Open Space	0.000	0.0
Other Sources	Farm Animals	0.000	0.0
	Stream Bank	0.008	0.7
	Groundwater	0.000	0.0
	Septic Systems	0.000	0.0
Total		1.158	100.0

Table 29: Estimated annual loads of sediment by subwatershed in the Durham Pond Watershed

Category	Description	Full Watershed kg x 1000	East kg x 1000	Northeast kg x 1000	Northwest kg x 1000	Southeast kg x 1000	South kg x 1000	Southwest kg x 1000	Camp Road kg x 1000	West kg x 1000
Runoff	Hay/Pasture	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
	Cropland	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
	Forest	1.070	0.030	0.050	0.150	0.020	0.020	0.090	0.030	0.140
	Wetland	0.080	0.000	0.000	0.010	0.000	0.000	0.000	0.000	0.030
	Open Land	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
	Barren Land	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
	Low-Density Mixed	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
	Medium-Density Mixed	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
	High-Density Mixed	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
	Low-Density Open Space	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Other Sources	Farm Animals	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
	Stream Bank	0.008	0.001	0.000	0.001	0.001	0.001	0.001	0.001	0.002
	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)		1.158	0.031	0.050	0.161	0.021	0.021	0.091	0.031	0.172
kg/acre		2.929	2.385	0.640	1.655	1.438	2.079	3.262	1.527	1.287



Almost the entirety of Durham Pond's estimated annual sediment load is estimated to run off from forested land and wetlands. The Northwest and West subwatersheds contribute the largest annual loads. Overall, the sediment loading rates, on a unit area basis, are very low and reflect the forested watershed.

Table 30: Estimated annual loads of bacteria from various sources in the total Durham Pond Watershed

Category	Description	Fecal Coliform Organisms	%
Fecal Coliform	Farm Animals	0.00E+00	0.0
	Urban Areas	0.00E+00	0.0
	Wildlife	1.16E+11	100.0
	Total	1.16E+11	100.0

Table 31: Estimated annual loads of bacteria by sub-watershed in the Durham Pond Watershed

Category	Description	Full Watershed %	East %	Northeast %	Northwest %	Southeast %	South %	Southwest %	Camp Road %	West %
Fecal Coliform	Farm Animals	0	0	0	0	0	0	0	0	0
	Urban Areas	0	0	0	0	0	0	0	0	0
	Wildlife	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
Total (organisms)		1.16E+11	4.58E+09	2.35E+10	2.94E+10	4.49E+09	3.61E+09	9.96E+09	7.23E+09	3.36E+10

Due to the largely forested nature of Durham Pond's watershed, the entirety of the pond's bacterial load is estimated to originate from wildlife. The West and Northeast subwatersheds were estimated to yield the largest amount of bacteria of the 8 subwatersheds.

LAKE EMMA

Lake Emma's watershed covers an area of approximately 87.9 acres (Table 32), while the lake itself features a surface area of approximately 9.6 acres. Much of the watershed (approx. 69%) is forested, with another 18% covered in wetlands. Developed land makes up a relatively small (12.3%) portion of the total watershed. The lake does not feature any significant inlets, but features two outlets: one of which drains to a small pond on the eastern side of Green Pond Road, and another which drains south into Hibernia Brook. Descriptions of Lake Emma's subwatersheds are as follows:

- **West:** This 6.3-acre subwatershed is located along the western edge of the waterbody and features development in the form of lake house, as well as some wetlands. It also includes parts of Green Pond Rd.
- **Northeast:** This 5.1-acre subwatershed is located along the shallower northern portion of Lake Emma and is almost entirely forested, with the exception of a very small (0.2 acre) area of developed land.
- **East:** This is the largest of Lake Emma's subwatersheds at 54.6 acres. While the area is mostly forested, it also encompasses some developed areas along Upper Hibernia Road.
- **South:** This 14.1-acre subwatershed is entirely forested. While one homeowner property does exist in this subwatershed, this area is still classified as forested land by Map My Watershed.



- **Southwest:** This 5.7-acre watershed is located adjacent to the south dam. Similar to the south subwatershed, while a single property exists in this area the entire subwatershed is considered to be forested.

Table 32: Land-use by sub-watershed in the Lake Emma watershed

Source	Full Watershed Acres	East Acres	Northeast Acres	South Acres	Southwest Acres	West Acres
Open Water	0.0	0.0	0.0	0.0	0.0	0.0
Hay/Pasture	0.2	0.0	0.0	0.0	0.0	0.2
Cropland	0.0	0.0	0.0	0.0	0.0	0.0
Forest	60.8	34.3	4.9	14.1	5.7	0.5
Wetland	16.1	13.1	0.0	0.0	0.0	2.2
Open Land	0.0	0.0	0.0	0.0	0.0	0.0
Bare Rock	0.0	0.0	0.0	0.0	0.0	0.0
Low-Density Mixed	2.2	1.0	0.0	0.0	0.0	1.2
Medium-Density Mixed	0.0	0.0	0.0	0.0	0.0	0.0
High-Density Mixed	0.0	0.0	0.0	0.0	0.0	0.0
Low-Density Open Space	8.6	6.2	0.2	0.0	0.0	2.2
Total	87.9	54.6	5.1	14.1	5.7	6.3

Table 32 cont'd: Land-use by sub-watershed in the Lake Emma watershed

Source	Full Watershed %	East %	Northeast %	South %	Southwest %	West %
Open Water	0.0	0.0	0.0	0.0	0.0	0.0
Hay/Pasture	0.2	0.0	0.0	0.0	0.0	3.2
Cropland	0.0	0.0	0.0	0.0	0.0	0.0
Forest	69.2	62.8	96.1	100.0	100.0	7.9
Wetland	18.3	24.0	0.0	0.0	0.0	34.9
Open Land	0.0	0.0	0.0	0.0	0.0	0.0
Barren Land	0.0	0.0	0.0	0.0	0.0	0.0
Low-Density Mixed	2.5	1.8	0.0	0.0	0.0	19.0
Medium-Density Mixed	0.0	0.0	0.0	0.0	0.0	0.0
High-Density Mixed	0.0	0.0	0.0	0.0	0.0	0.0
Low-Density Open Space	9.8	11.4	3.9	0.0	0.0	34.9
Total	100	100	100	100	100	100

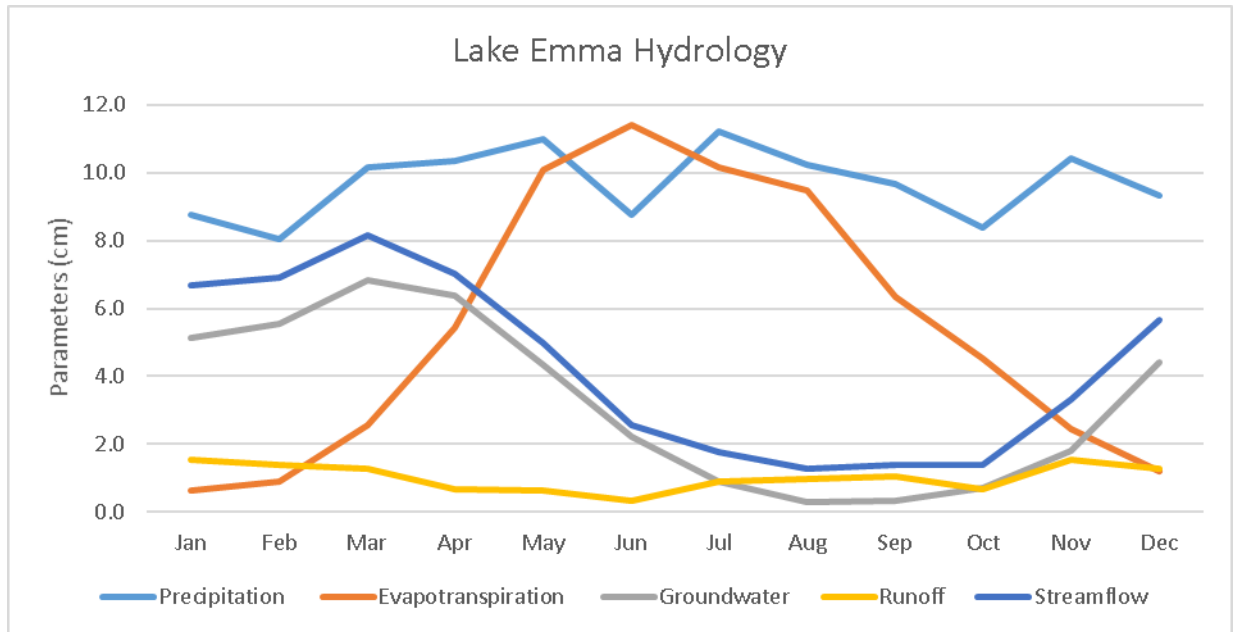


Figure 10. Estimated seasonal changes in hydrology in the Lake Emma watershed

Table 33: Total hydrological parameters in the full Lake Emma watershed

Month	Precipitation	Evapotranspiration	Groundwater	Runoff	Streamflow	
	cm	cm	cm	cm	cm	cfs
Jan	8.8	0.6	5.1	1.5	6.7	0.3
Feb	8.0	0.9	5.5	1.4	6.9	0.4
Mar	10.2	2.6	6.9	1.3	8.1	0.4
Apr	10.4	5.4	6.4	0.7	7.0	0.3
May	11.0	10.1	4.3	0.6	5.0	0.2
Jun	8.8	11.4	2.2	0.3	2.5	0.1
Jul	11.2	10.2	0.9	0.9	1.8	0.1
Aug	10.2	9.5	0.3	1.0	1.3	0.1
Sep	9.7	6.3	0.3	1.0	1.4	0.1
Oct	8.4	4.5	0.7	0.7	1.4	0.1
Nov	10.4	2.4	1.8	1.5	3.3	0.2
Dec	9.3	1.2	4.4	1.3	5.7	0.3
Total	116.4	65.1	38.9	12.2	51.1	0.2

Some variability exists between the Lake Emma subwatersheds in regard to runoff (Figure 11). In particular, the West subwatershed yields higher rates of runoff throughout the year than other subwatersheds, likely due to its increased coverage by developed land, which is more likely to include impervious landcover such as pavement. The south and southwest subwatersheds feature the least runoff, likely due to their estimated 100% coverage with forested area. This land-use type typically allows for greater infiltration of precipitation into the water table than developed land does. When direct precipitation and evaporation to and from the lake itself are factored in, Lake Emma is estimated to receive approximately 201,600 m³ or 53.3 million gallons of water a year.

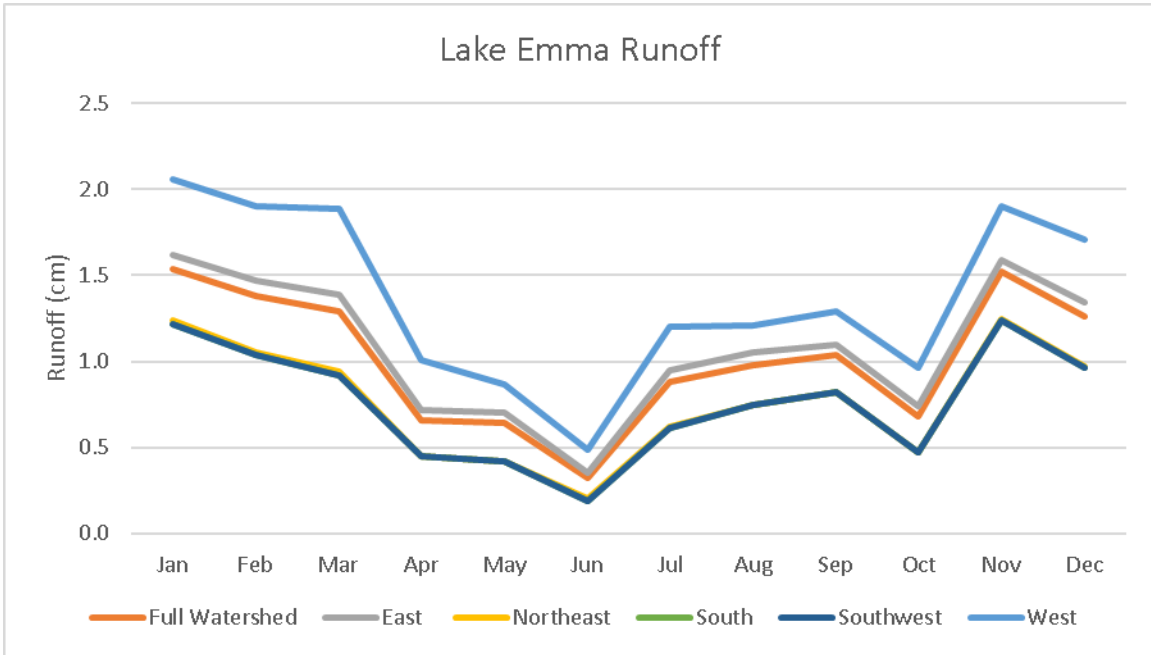


Figure 11. Average monthly runoff occurring within the Lake Emma watershed

Bathymetric data is not available for Lake Emma; as such, only an estimation of the lake's volume could be obtained. The estimated volume of the lake is approximately 45,539 m³ or 12 million gallons of water. Due to its small size, lake Emma is estimated to have a relatively high flushing rate, at approximately 4.4 times per year. When examined on a monthly basis, the lake experiences a summer period of a lower annualized flushing rate and an increased retention period.

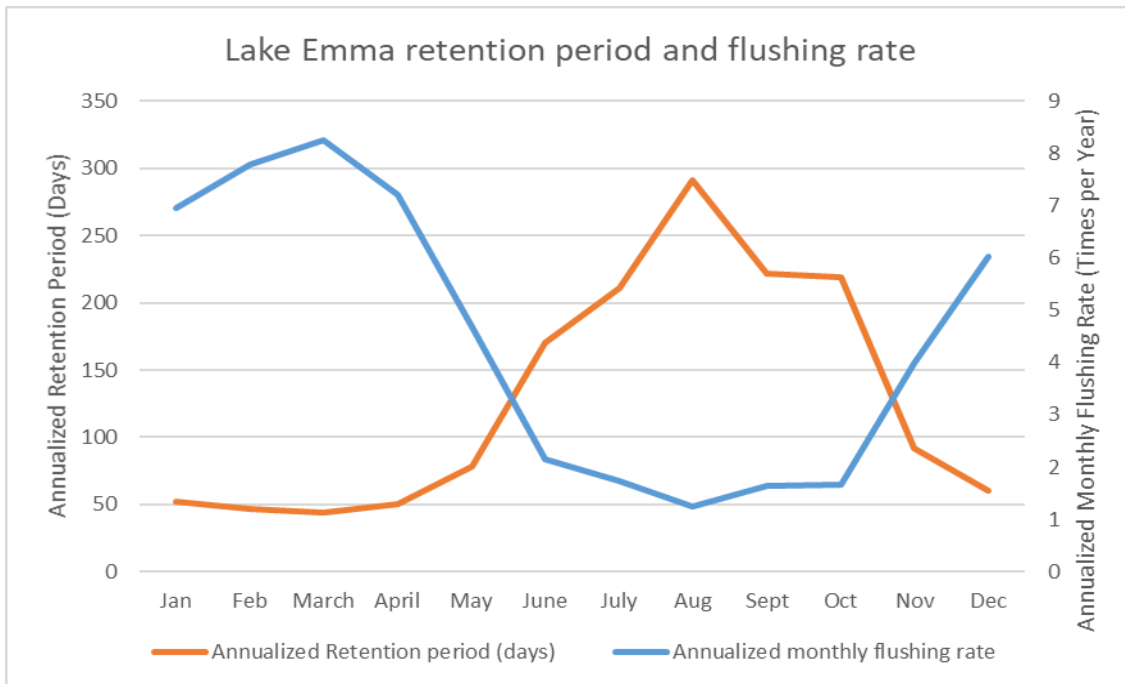


Figure 12. Variations in annualized flushing rates and retention periods over the course of a hypothetical year for Lake Emma, based on variations in hydraulic loads.



Table 34: Estimated annual loads of nitrogen in the total Lake Emma Watershed

Category	Description	Total Nitrogen	
		kg	%
Runoff	Hay/Pasture	0.1	0.1
	Cropland	0.0	0.0
	Forest	4.4	2.8
	Wetland	3.0	1.9
	Open Land	0.0	0.0
	Bare rock	0.0	0.0
	Low-Density Mixed	0.3	0.2
	Medium-Density Mixed	0.0	0.0
	High-Density Mixed	0.0	0.0
	Low-Density Open Space	1.0	0.6
Other Sources	Farm Animals	0.0	0.0
	Stream Bank	0.0	0.0
	Groundwater	47.1	29.7
	Septic Systems	102.6	64.7
Total		158.4	100

Table 35: Estimated annual loads of nitrogen by sub-watershed in the Lake Emma Watershed

Category	Description	Full Watershed	East	Northeast	South	Southwest	West
		kg	kg	kg	kg	kg	kg
Runoff	Hay/Pasture	0.1	0.0	0.0	0.0	0.0	0.1
	Cropland	0.0	0.0	0.0	0.0	0.0	0.0
	Forest	4.4	2.5	0.4	1.0	0.4	0.0
	Wetland	3.0	2.5	0.0	0.0	0.0	0.4
	Open Land	0.0	0.0	0.0	0.0	0.0	0.0
	Barren Land	0.0	0.0	0.0	0.0	0.0	0.0
	Low-Density Mixed	0.3	0.1	0.0	0.0	0.0	0.1
	Medium-Density Mixed	0.0	0.0	0.0	0.0	0.0	0.0
	High-Density Mixed	0.0	0.0	0.0	0.0	0.0	0.0
	Low-Density Open Space	1.0	0.7	0.0	0.0	0.0	0.2
Other Sources	Farm Animals	0.0	0.0	0.0	0.0	0.0	0.0
	Stream Bank	0.0	0.0	0.0	0.0	0.0	0.0
	Groundwater	47.1	25.3	2.9	8.3	3.3	2.6
	Septic Systems	102.6	11.4	34.2	0.0	11.4	45.6
Total (kg)		158.4	42.5	37.5	9.3	15.1	49.1
kg/acre		1.8	0.8	7.3	0.7	2.7	7.8

Most of the Lake Emma external nitrogen load originates from septic systems and, as a result, groundwater flows (Tables 34, 35). Runoff from forested areas and wetlands also yields a portion of the yearly load of nitrogen, particularly in the east subwatershed, however these are relatively low. The West subwatershed is estimated to yield the largest annual nitrogen load due to the higher number of houses here close to the waterbody than in other subwatersheds.



Table 36: Estimated annual loads of phosphorus in the total Lake Emma Watershed

Category	Description	Total Phosphorus	
		kg	%
Runoff	Hay/Pasture	0.04	0.7
	Cropland	0.00	0.0
	Forest	0.33	5.7
	Wetland	0.18	3.1
	Open Land	0.00	0.0
	Bare rock	0.00	0.0
	Low-Density Mixed	0.03	0.5
	Medium-Density Mixed	0.00	0.0
	High-Density Mixed	0.00	0.0
	Low-Density Open Space	0.10	1.7
Other Sources	Farm Animals	0.00	0.0
	Stream Bank	0.00	0.0
	Groundwater	1.23	21.4
	Septic Systems	3.85	66.8
Total		5.76	100.0

Table 37: Estimated annual loads of phosphorus/sub-watershed in the Lake Emma Watershed

Category	Description	Full Watershed	East	Northeast	South	Southwest	West
		kg	kg	kg	kg	kg	kg
Runoff	Hay/Pasture	0.04	0.00	0.00	0.00	0.00	0.04
	Cropland	0.00	0.00	0.00	0.00	0.00	0.00
	Forest	0.33	0.18	0.03	0.08	0.03	0.00
	Wetland	0.18	0.15	0.00	0.00	0.00	0.02
	Open Land	0.00	0.00	0.00	0.00	0.00	0.00
	Bare Rock	0.00	0.00	0.00	0.00	0.00	0.00
	Low-Density Mixed	0.03	0.01	0.00	0.00	0.00	0.01
	Medium-Density Mixed	0.00	0.00	0.00	0.00	0.00	0.00
	High-Density Mixed	0.00	0.00	0.00	0.00	0.00	0.00
	Low-Density Open Space	0.10	0.08	0.00	0.00	0.00	0.02
Other Sources	Farm Animals	0.00	0.00	0.00	0.00	0.00	0.00
	Stream Bank	0.00	0.00	0.00	0.00	0.00	0.00
	Groundwater	1.23	0.66	0.08	0.22	0.09	0.07
	Septic Systems	3.85	0.43	1.28	0.00	0.43	1.71
Total (kg)		5.76	1.51	1.39	0.30	0.55	1.87
kg/acre		0.07	0.03	0.27	0.02	0.10	0.30

As with nitrogen concentrations, phosphorus in the Lake Emma watershed largely originates from groundwater and septic systems (Tables 29, 30). The West Subwatershed is estimated to yield the highest amount of phosphorus, again due to the higher number of houses present than in other subwatersheds. Phosphorus inputs due to runoff are relatively small; these mostly originate from forested land and wetlands.



As a relatively small and shallow waterbody with an apparent abundance of organic material, Lake Emma was anoxic during the July event from as shallow as half a meter deep to the bottom, covering an estimated area of approximately 8.6 acres or 90% of the waterbody's area. Additionally, the October sampling event saw an unusual pattern of anoxia that is the "inverse" of what is typically observed in most waterbodies. Generally, anoxia primarily occurs in the deepest reaches of a waterbody. In October, the deep area near the dam showed some oxygen depression, but the shallow northern portions were fully anoxic. This is likely a product of decreased mixing occurring in this area due to dense floating vegetation coverage, combined with the senescence and decomposition of other vegetation that was beginning to occur at that time. Anoxia was estimated to impact approximately 60% of the lake, or approximately 5.75 acres, at that time. Due to this event and the estimated deep anoxia from July, as well as oxic loading that likely occurs in other areas of the waterbody and at other times of the growing season, Lake Emma's annual internal load was estimated to be approximately 24.28 kg/yr. Should the entire waterbody experience a year without any occurrence of bottom anoxia, this load is estimated to be approximately 3.56 kg/yr. This suggests that anoxic loading is a very large driver of the yearly phosphorus load in Lake Emma.

Table 38 below displays the external and internal loads of phosphorus for Lake Emma, as well as the grand total, which is estimated to be approximately 30.1 kg/year. As stated above, internal loading appears to be a very large source of phosphorus within Lake Emma (at approximately 81% of the total load) compared to watershed-based sources.

Source	Phosphorus (kg/yr)
External (Runoff, Groundwater, Septic Systems)	5.8
Internal	24.3
Total	30.1

Table 39: Estimated annual loads of sediment in the total Lake Emma Watershed

Category	Description	Sediment	
		kgx1000	%
Runoff	Hay/Pasture	0.000	0.0
	Cropland	0.000	0.0
	Forest	0.090	16.3
	Wetland	0.020	3.6
	Open Land	0.000	0.0
	Barren Land	0.000	0.0
	Low-Density Mixed	0.010	1.8
	Medium-Density Mixed	0.000	0.0
	High-Density Mixed	0.000	0.0
	Low-Density Open Space	0.040	7.3
Other Sources	Farm Animals	0.000	0.0
	Stream Bank	0.391	71.0
	Groundwater	0.000	0.0
	Septic Systems	0.000	0.0
Total		0.551	100.0



Table 40: Estimated annual loads of sediment by sub-watershed in the Lake Emma Watershed

Category	Description	Full Watershed kg x 1000	East kg x 1000	Northeast kg x 1000	South kg x 1000	Southwest kg x 1000	West kg x 1000
Runoff	Hay/Pasture	0.000	0.000	0.000	0.000	0.000	0.000
	Cropland	0.000	0.000	0.000	0.000	0.000	0.000
	Forest	0.090	0.040	0.010	0.030	0.010	0.000
	Wetland	0.020	0.020	0.000	0.000	0.000	0.000
	Open Land	0.000	0.000	0.000	0.000	0.000	0.000
	Barren Land	0.000	0.000	0.000	0.000	0.000	0.000
	Low-Density Mixed	0.010	0.010	0.000	0.000	0.000	0.010
	Medium-Density Mixed	0.000	0.000	0.000	0.000	0.000	0.000
	High-Density Mixed	0.000	0.000	0.000	0.000	0.000	0.000
	Low-Density Open Space	0.040	0.030	0.000	0.000	0.000	0.010
Other Sources	Farm Animals	0.000	0.000	0.000	0.000	0.000	0.000
	Stream Bank	0.391	0.008	0.001	0.001	0.000	0.001
	Groundwater	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
	Total (kgx1000)	0.551	0.108	0.011	0.031	0.010	0.021
	kg/acre	6.268	1.978	2.157	2.199	1.754	3.333

The overall sediment load for Lake Emma is relatively low, at only an estimated 551 kg/yr, likely due to its watershed containing mostly forested land and wetlands. A majority of sediment is estimated to originate from streambank erosion. Some runoff occurs from developed and forested land, as well as wetlands, however these are all relatively small yearly loads. The west subwatershed yields the highest amount of sediment per acre, likely due to its larger proportion of urbanized landcover.

A majority of the bacterial load in the Lake Emma watershed is estimated to originate from wildlife, likely due to the high amount of forested land within the watershed. A significant amount is also contributed by runoff from developed areas.

Table 41: Estimated annual loads of bacteria for the full Lake Emma Watershed

Category	Description	Fecal Coliform	
		Organisms	%
Fecal Coliform	Farm Animals	0.00E+00	0.0
	Urban Areas	3.01E+09	12.2
	Wildlife	2.17E+10	87.8
	Total	2.47E+10	100

Table 42: Estimated annual loads of bacteria by sub-watershed in the Lake Emma Watershed

Category	Description	Full Watershed %	East %	Northeast %	South %	Southwest %	West %
Fecal Coliform	Farm Animals	0.0	0.0	0.0	0.0	0.0	0.0
	Urban Areas	12.2	14.4	1.3	0.0	0.0	96.4
	Wildlife	87.8	85.6	98.7	100.0	100.0	3.6
	Total (organisms)	2.47E+10	1.43E+10	1.79E+09	5.02E+09	2.03E+09	4.86E+09



Camp Lewis Lake

Camp Lewis Lake's watershed covers an area of approximately 128 acres (Table 43), while the lake itself has a surface area of approximately 1.3 acres. This watershed is largely forested but contains some urbanized landcover to the west along Upper Hibernia Road. The lake's main inlet is an unnamed tributary, classified as a Category 1 non-trout stream. Downstream of the lake's dam, this tributary continues downstream to other small waterbodies, eventually draining into Splitrock Reservoir. Descriptions of Camp Lewis Lake's subwatersheds are as follows:

- **West:** This is the largest subwatershed to Camp Lewis Lake at 102.8 acres. This subwatershed contains the lake's single inlet tributary, and consists largely of forest land, although there is a significant amount of urbanized area to the west.
- **North:** This 18.8-acre subwatershed is entirely forested.
- **East:** This 6.4-acre subwatershed is classified as entirely forested, however some facilities for Camp Lewis are present.

Table 43. Land-use by sub-watershed in the Camp Lewis Lake watershed.

Source	Full Watershed Acres	East Acres	North Acres	West Acres
Open Water	0.0	0.0	0.0	0.0
Hay/Pasture	0.0	0.0	0.0	0.0
Cropland	0.0	0.0	0.0	0.0
Forest	110.7	6.4	18.8	85.5
Wetland	7.7	0.0	0.0	7.7
Open Land	0.0	0.0	0.0	0.0
Bare Rock	0.0	0.0	0.0	0.0
Low-Density Mixed	1.2	0.0	0.0	1.2
Medium-Density Mixed	0.0	0.0	0.0	0.0
High-Density Mixed	0.2	0.0	0.0	0.2
Low-Density Open Space	8.2	0.0	0.0	8.2
Total	128.0	6.4	18.8	102.8
Source	Full Watershed %	East %	North %	West %
Open Water	0.0	0.0	0.0	0.0
Hay/Pasture	0.0	0.0	0.0	0.0
Cropland	0.0	0.0	0.0	0.0
Forest	86.5	100.0	100.0	83.2
Wetland	6.0	0.0	0.0	7.5
Open Land	0.0	0.0	0.0	0.0
Barren Land	0.0	0.0	0.0	0.0
Low-Density Mixed	0.9	0.0	0.0	1.2
Medium-Density Mixed	0.0	0.0	0.0	0.0
High-Density Mixed	0.2	0.0	0.0	0.2
Low-Density Open Space	6.4	0.0	0.0	8.0
Total	100.0	100.0	100.0	100.0

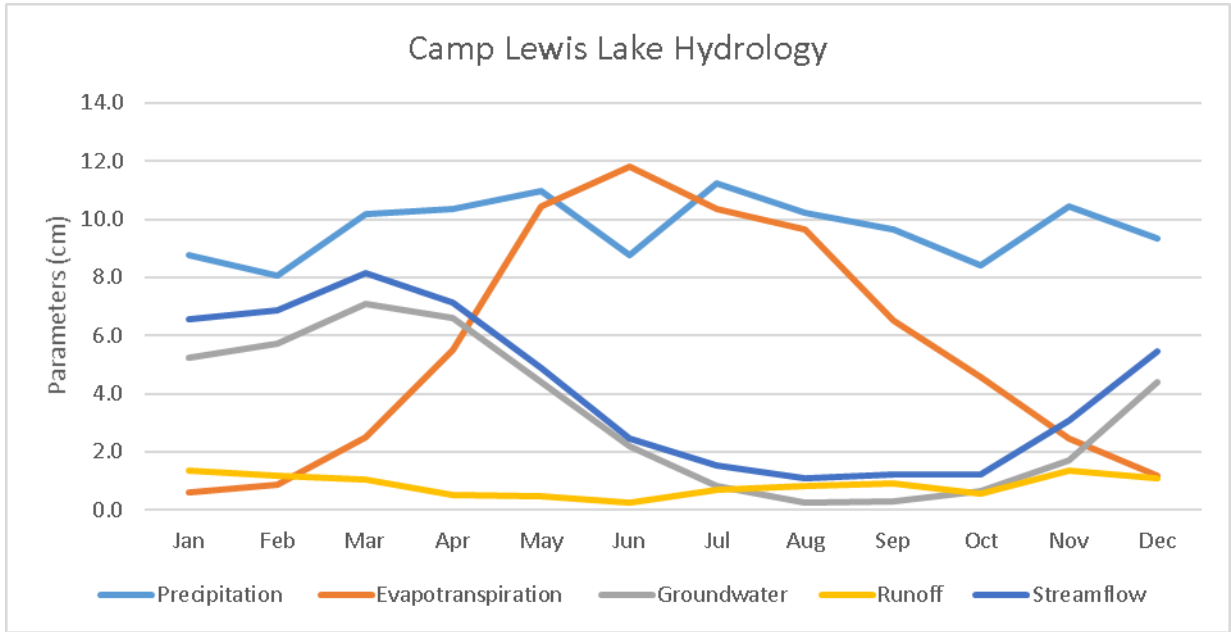


Figure 6. Estimated seasonal changes in hydrology in the Camp Lewis Lake watershed

Table 44: Total hydrological parameters in the full Camp Lewis Lake watershed

Month	Precipitation cm	Evapotranspiration cm	Groundwater cm	Runoff cm	Streamflow cm	cfs
Jan	8.8	0.6	5.2	1.3	6.6	0.4
Feb	8.0	0.9	5.7	1.2	6.9	0.5
Mar	10.2	2.5	7.1	1.1	8.2	0.6
Apr	10.4	5.5	6.6	0.5	7.1	0.5
May	11.0	10.5	4.4	0.5	4.9	0.3
Jun	8.8	11.8	2.2	0.2	2.4	0.2
Jul	11.2	10.4	0.8	0.7	1.6	0.1
Aug	10.2	9.7	0.3	0.8	1.1	0.1
Sep	9.7	6.5	0.3	0.9	1.2	0.1
Oct	8.4	4.6	0.7	0.6	1.2	0.1
Nov	10.4	2.5	1.7	1.3	3.1	0.2
Dec	9.3	1.2	4.4	1.1	5.5	0.4
Total	116.4	66.5	39.5	10.2	49.7	0.3

Little variation exists among Camp Lewis Lake's subwatersheds in regard to runoff, likely due to their largely forested nature (Figure 14). The west watershed, which accounts for about 80% of the total, is estimated to yield slightly higher runoff, likely due to the presence of developed areas along the western edge of the watershed. Once precipitation and evapotranspiration to and from the lake directly are accounted, Camp Lewis Lake is estimated to receive approximately 259,914.1 m³ or 68.7 million gallons of water a year.

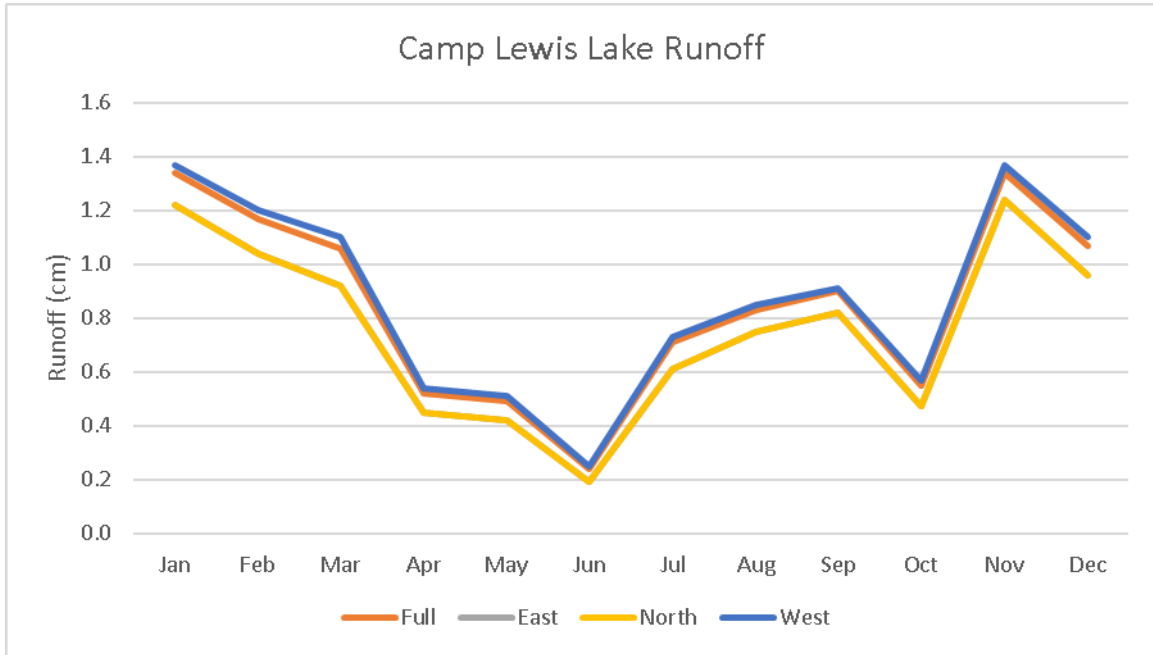


Figure 14. Average monthly runoff within each sub-watershed in the Lower Skyline Lake watershed

Table 45: Estimated annual loads of nitrogen in the total Camp Lewis Lake Watershed

Category	Description	Total Nitrogen	
		kg	%
Runoff	Hay/Pasture	0.0	0.0
	Cropland	0.0	0.0
	Forest	8.6	7.1
	Wetland	1.5	1.2
	Open Land	0.0	0.0
	Bare rock	0.0	0.0
	Low-Density Mixed	0.1	0.1
	Medium-Density Mixed	0.0	0.0
	High-Density Mixed	0.2	0.2
	Low-Density Open Space	0.9	0.7
	Other Sources	Farm Animals	0.0
Stream Bank		0.0	0.0
Groundwater		69.5	57.7
Septic Systems		39.6	32.9
Total		120.4	100



Table 46: Estimated annual loads of nitrogen by subwatershed in the Camp Lewis Lake Watershed

Category	Description	Full Watershed	East	North	West
		kg	kg	kg	kg
Runoff	Hay/Pasture	0.0	0.0	0.0	0.0
	Cropland	0.0	0.0	0.0	0.0
	Forest	8.6	0.5	1.5	6.5
	Wetland	1.5	0.0	0.0	1.5
	Open Land	0.0	0.0	0.0	0.0
	Barren Land	0.0	0.0	0.0	0.0
	Low-Density Mixed	0.1	0.0	0.0	0.1
	Medium-Density Mixed	0.0	0.0	0.0	0.0
	High-Density Mixed	0.2	0.0	0.0	0.2
	Low-Density Open Space	0.9	0.0	0.0	0.9
Other Sources	Farm Animals	0.0	0.0	0.0	0.0
	Stream Bank	0.0	0.0	0.0	0.0
	Groundwater	69.5	3.7	10.9	55.0
	Septic Systems	39.6	26.4	0.0	13.2
	Total (kg)	120.4	30.6	12.3	77.4
	kg/acre	0.9	4.8	0.7	0.8

Camp Lewis Lake's watershed features latrines rather than septic systems, and these were modeled using the same methodology as those at Durham Pond. These latrines and groundwater were estimated to yield the majority of the nitrogen entering Camp Lewis Lake. Runoff from forested land and wetlands is estimated to yield a smaller annual amount of nitrogen.

Table 47: Estimated annual loads of phosphorus in the total Camp Lewis Lake Watershed

Category	Description	Total Phosphorus	
		kg	%
Runoff	Hay/Pasture	0.00	0.0
	Cropland	0.00	0.0
	Forest	0.89	20.1
	Wetland	0.10	2.3
	Open Land	0.00	0.0
	Bare rock	0.00	0.0
	Low-Density Mixed	0.01	0.2
	Medium-Density Mixed	0.00	0.0
	High-Density Mixed	0.02	0.5
	Low-Density Open Space	0.10	2.3
Other Sources	Farm Animals	0.00	0.0
	Stream Bank	0.00	0.0
	Groundwater	1.82	41.1
	Septic Systems	1.49	33.6
	Total	4.43	100.0



Table 48: Estimated annual loads of phosphorus by subwatershed in the Camp Lewis Lake Watershed

Category	Description	Full Watershed	East	North	West
		kg	kg	kg	kg
Runoff	Hay/Pasture	0.00	0.00	0.00	0.00
	Cropland	0.00	0.00	0.00	0.00
	Forest	0.89	0.03	0.15	0.64
	Wetland	0.10	0.00	0.00	0.10
	Open Land	0.00	0.00	0.00	0.00
	Bare Rock	0.00	0.00	0.00	0.00
	Low-Density Mixed	0.01	0.00	0.00	0.01
	Medium-Density Mixed	0.00	0.00	0.00	0.00
	High-Density Mixed	0.02	0.00	0.00	0.02
	Low-Density Open Space	0.10	0.00	0.00	0.10
Other Sources	Farm Animals	0.00	0.00	0.00	0.00
	Stream Bank	0.00	0.00	0.00	0.00
	Groundwater	1.82	0.10	0.28	1.44
	Septic Systems	1.49	0.99	0.00	0.50
Total (kg)		4.43	1.12	0.43	2.81
kg/acre		0.03	0.18	0.02	0.03

Most of Camp Lewis Lake's annual phosphorus load is estimated to originate from groundwater and latrines. While the Western subwatershed yielded the most phosphorus of the three subwatersheds, the eastern subwatershed yielded the highest estimated load per acre, likely due to the disproportionately high load contributed by latrines. Small amounts of runoff-based phosphorus from forested land, wetlands, and low-density open space are also estimated to enter Camp Lewis Lake.

Table 49: Estimated annual loads of sediment in the total Camp Lewis Lake Watershed

Category	Description	Sediment	
		kgx1000	%
Runoff	Hay/Pasture	0.000	0.0
	Cropland	0.000	0.0
	Forest	0.420	82.5
	Wetland	0.020	3.9
	Open Land	0.000	0.0
	Barren Land	0.000	0.0
	Low-Density Mixed	0.010	2.0
	Medium-Density Mixed	0.000	0.0
	High-Density Mixed	0.010	2.0
	Low-Density Open Space	0.040	7.9
Other Sources	Farm Animals	0.000	0.0
	Stream Bank	0.009	1.8
	Groundwater	0.000	0.0
	Septic Systems	0.000	0.0
Total		0.509	100.0



Table 50: Estimated annual loads of sediment by sub-watershed in the Camp Lewis Lake Watershed

Category	Description	Full Watershed kg x 1000	East kg x 1000	North kg x 1000	West kg x 1000
Runoff	Hay/Pasture	0.000	0.000	0.000	0.000
	Cropland	0.000	0.000	0.000	0.000
	Forest	0.420	0.010	0.070	0.280
	Wetland	0.020	0.000	0.000	0.020
	Open Land	0.000	0.000	0.000	0.000
	Barren Land	0.000	0.000	0.000	0.000
	Low-Density Mixed	0.010	0.000	0.000	0.010
	Medium-Density Mixed	0.000	0.000	0.000	0.000
	High-Density Mixed	0.010	0.000	0.000	0.010
	Low-Density Open Space	0.040	0.000	0.000	0.040
Other Sources	Farm Animals	0.000	0.000	0.000	0.000
	Stream Bank	0.009	0.000	0.001	0.009
	Groundwater	0.000	0.000	0.000	0.000
	Septic Systems	0.000	0.000	0.000	0.000
	Total (kgx1000)	0.509	0.010	0.071	0.369
	kg/acre	3.977	1.563	3.777	3.589

Given Camp Lewis Lake's largely forested watershed, the estimated annual sediment load for the lake is relatively low, at 509 kg/yr. A majority of this sediment is estimated to enter the lake in runoff from forested areas. As with Durham Pond, a majority of the soils in this watershed are classified as "Slow Infiltration", suggesting that rain events may produce runoff somewhat quickly, transferring sediment downhill into the lake.

Table 51: Estimated annual loads of bacteria for the full Camp Lewis Lake Watershed

Category	Description	Fecal Coliform Organisms	%
Fecal Coliform	Farm Animals	0.00E+00	0.0
	Urban Areas	1.67E+09	4.1
	Wildlife	3.95E+10	95.9
	Total	4.12E+10	100

Due to the largely forested nature of Camp Lewis Lake's watershed, most of the lake's annual bacterial load is estimated to originate from wildlife within the watershed. A small amount (approx. 4%) of bacteria is estimated to originate in the small amount of urbanized areas in the western subwatershed; as a result, this subwatershed is estimated to produce the highest bacterial load of the three subwatersheds.



Table 52: Estimated annual loads of bacteria by sub-watershed in the Camp Lewis Watershed

Category	Description	Full Watershed	East	North	West
		%	%	%	%
Fecal Coliform	Farm Animals	0.0	0.0	0.0	0.0
	WWTP	0.0	0.0	0.0	0.0
	Septic Systems	0.0	0.0	0.0	0.0
	Urban Areas	4.0	0.0	0.0	6.4
	Wildlife	96.0	1.0	1.0	93.6
	Total (organisms)	4.12E+10	2.29E+09	6.70E+09	3.26E+10

LAKE TELEMAR

Lake Telemark's full watershed spans an area of approximately 1,670 acres, while the lake itself has a surface area of approximately 9.6 acres. The area includes Lake Emma and its full watershed, as well as a length of Green Pond Road and the Rolling Ridge Drive development. The western portion of the watershed contains part of the Picatinny Arsenal property. The watershed is over 75% forested and almost 10% urbanized landcover, with the remaining portions consisting of wetlands and a very small amount of hay/pasture landcover. The lake features three inlets, and the outlet drains south to Hibernia Brook and Lake Ames. Descriptions of the lake's subwatersheds are as follows:

- **East:** This approximately 292-acre subwatershed contains a tributary of Hibernia Brook, as well as Norway Field, the Telemark Hill development, and the developed area along the lake's eastern shore. The area contains mostly forested land and wetlands, with about approximately 19% of the land being developed.
- **Hibernia:** As its name indicates, this watershed contains the mainstem of Hibernia Brook upstream of Lake Telemark and all of its smaller tributaries. This large subwatershed also contains part of Green Pond Road, several small developed areas to the north, and Lake Emma. Over 90% of the area consists of forests and wetlands, while the remainder of the area is classified as urbanized land, including a single acre of high-density mixed urban land cover.
- **North:** This 12.4-acre subwatershed contains the developed area around the intersection of Oslo Dr. and Lakeview Rd., as well as some forested areas to the north. This subwatershed is about 66% urbanized, with the rest of the area covered in forested land.
- **Northwest:** This 14.5-acre subwatershed contains developed areas along Oslo Dr. and Hallvard Terrace, as well as forested area to the north. The area is classified as over 95% forested, with the remaining land classified as urbanized.
- **West:** This watershed has an area of over 1,000 acres, including a tributary to Hibernia Brook that enters the southwestern corner of the lake. This watershed contains a length of Denmark Road and part of the Picatinny Arsenal property. While the areas consists largely of forests and wetlands, there is also approximately 97 acres of developed land.
- **Hallvard:** This small watershed consists of a small area between the West and Northwest subwatersheds. The area largely consists of developed open space.



Table 53. Land-use by sub-watershed in the Lake Telemark watershed.

Source	Full Watershed Acres	East Acres	Hibernia Acres	North Acres	Northwest Acres	West Acres	Hallvard Acres
Open Water	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Hay/Pasture	0.2	0.0	0.2	0.0	0.0	0.2	0.0
Cropland	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Forest	1,272.1	201.9	829.3	4.2	13.8	831.8	0.2
Wetland	232.8	34.6	152.7	0.0	0.0	152.7	0.0
Open Land	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Bare Rock	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Low-Density Mixed	27.7	9.1	16.3	1.0	0.2	16.3	0.7
Medium-Density Mixed	5.4	1.2	3.5	0.0	0.0	3.5	0.5
High-Density Mixed	1.0	0.0	1.0	0.0	0.0	1.0	0.0
Low-Density Open Space	130.5	44.7	74.6	7.2	0.5	76.4	2.0
Total	1,669.7	291.5	1,077.6	12.4	14.5	1,081.9	3.4
Source	Full Watershed %	East %	Hibernia %	North %	Northwest %	West %	Hallvard %
Open Water	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Hay/Pasture	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Cropland	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Forest	76.2	69.3	77.0	33.9	95.2	76.9	5.9
Wetland	13.9	11.9	14.2	0.0	0.0	14.1	0.0
Open Land	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Barren Land	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Low-Density Mixed	1.7	3.1	1.5	8.1	1.4	1.5	20.6
Medium-Density Mixed	0.3	0.4	0.3	0.0	0.0	0.3	14.7
High-Density Mixed	0.1	0.0	0.1	0.0	0.0	0.1	0.0
Low-Density Open Space	7.8	15.3	6.9	58.1	3.4	7.1	58.8
Total	100	100	100	100	100	100	100

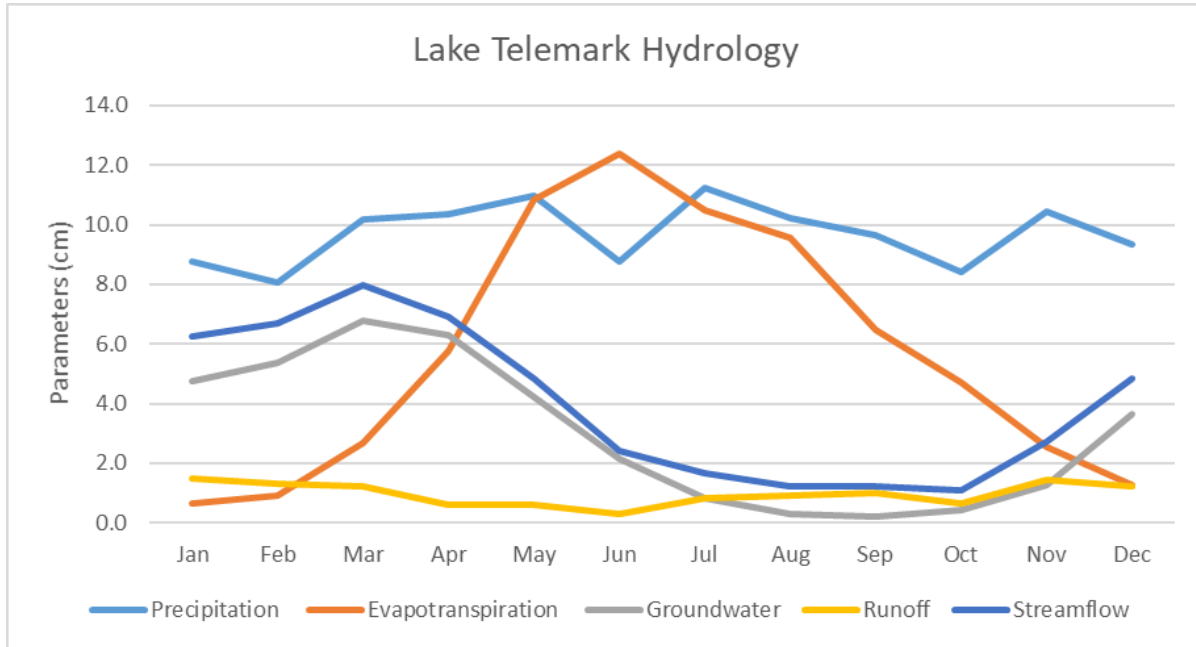


Figure 75. Estimated seasonal changes in hydrology in the Lake Telemark watershed

Table 54. Total hydrological parameters in the full Lake Telemark watershed

Month	Precipitation	Evapotranspiration	Groundwater	Runoff	Streamflow	
	cm	cm	cm	cm	cm	cfs
Jan	8.8	0.7	4.8	1.5	6.2	5.6
Feb	8.0	0.9	5.4	1.3	6.7	6.5
Mar	10.2	2.7	6.8	1.2	8.0	7.1
Apr	10.4	5.8	6.3	0.6	6.9	6.4
May	11.0	10.9	4.2	0.6	4.8	4.3
Jun	8.8	12.4	2.1	0.3	2.4	2.2
Jul	11.2	10.5	0.8	0.8	1.7	1.5
Aug	10.2	9.6	0.3	0.9	1.2	1.1
Sep	9.7	6.5	0.2	1.0	1.2	1.1
Oct	8.4	4.7	0.4	0.6	1.1	1.0
Nov	10.4	2.6	1.3	1.5	2.7	2.5
Dec	9.3	1.3	3.7	1.2	4.9	4.3
Total	116.4	68.3	36.3	11.5	47.8	3.6

There is little difference between most of the individual subwatersheds in regards to runoff, with the only outlier being Hallvard. While this is the smallest subwatershed for Lake Telemark, it contains mostly urbanized areas, with little forested land or wetlands to allow rainwater to infiltrate the soil or otherwise be detained. Taking into account direct precipitation and evapotranspiration to and from the lake itself, Lake Telemark is estimated to receive approximately 3,247,800.0 m³ or 858 million gallons of water a year.

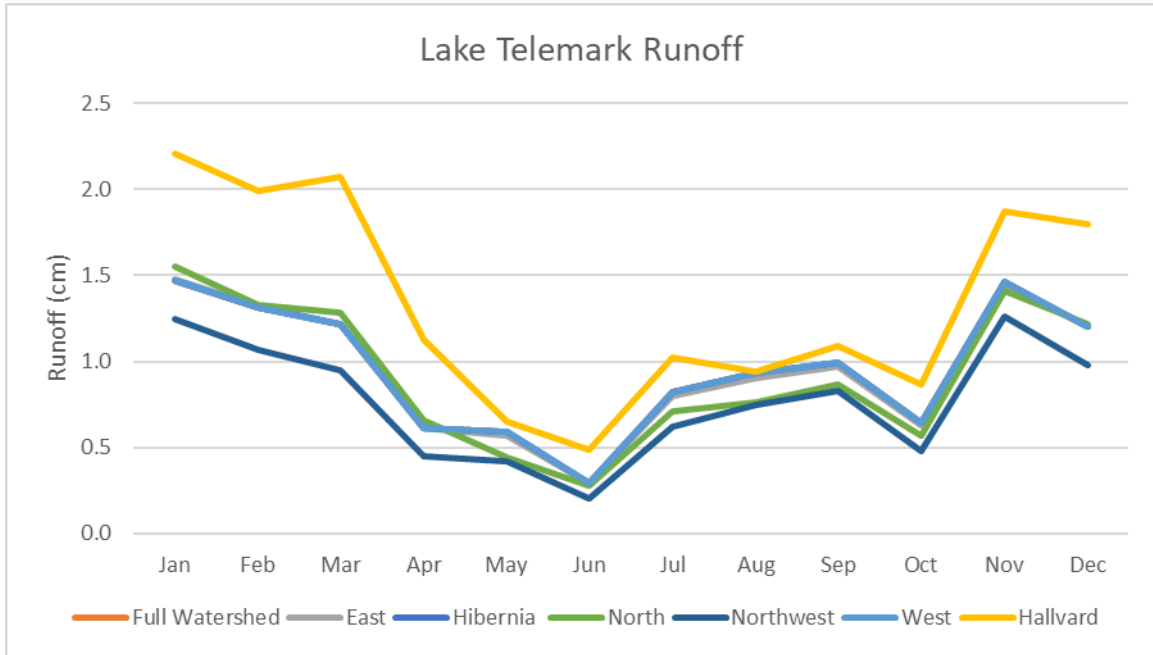


Figure 8. Average monthly runoff occurring in each sub-watershed in the Lake Telemark watershed

As no bathymetry data was available for Lake Telemark, the lake’s estimated volume is 57,189 m³ or 15.3 million gallons of water. Due to its relatively small size and large watershed, which contains two major inlet streams, the lake flushes very quickly, at an estimated 56.2 times a year. This means that, upon entering, a unit of water in Lake Telemark only remains for approximately 6.5 days before it is flushed from the system. When examined on a monthly basis, the period of the lowest annualized flushing rate occurs from approximately August through October, although even at that point the retention period is minimal and flushing relatively high.

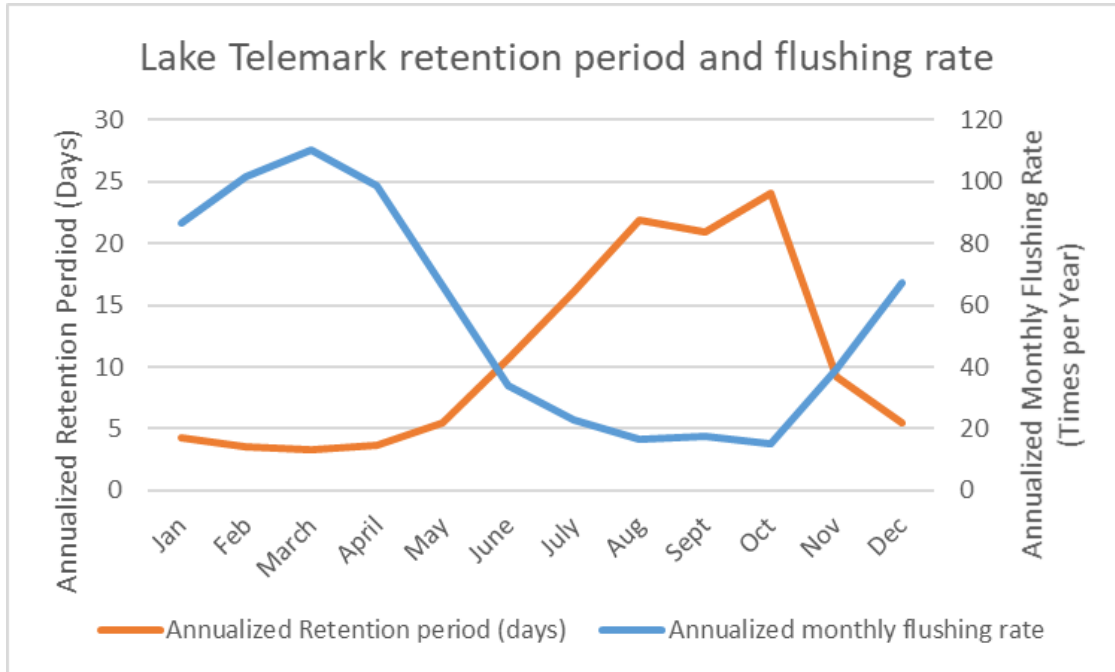


Figure 17. Variations in annualized flushing rates and retention periods over the course of a hypothetical year for Lake Emma, based on variations in hydraulic loads.

Table 55: Estimated annual loads of nitrogen in the total Lake Telemark Watershed

Category	Description	Total Nitrogen	
		kg	%
Runoff	Hay/Pasture	0.1	0.0
	Cropland	0.0	0.0
	Forest	86.7	3.7
	Wetland	40.8	1.7
	Open Land	0.0	0.0
	Bare rock	0.0	0.0
	Low-Density Mixed	3.1	0.1
	Medium-Density Mixed	3.9	0.2
	High-Density Mixed	0.7	0.0
	Low-Density Open Space	14.6	0.6
Other Sources	Farm Animals	21.5	0.9
	Stream Bank	14.0	0.6
	Groundwater	767.9	32.9
	Septic Systems	1,378.9	59.1
Total		2,332.2	100



Table 56: Estimated annual loads of nitrogen by sub-watershed in the Lake Telemark Watershed

Category	Description	Full Watershed kg	East kg	Hibernia kg	North kg	Northwest kg	West kg	Hallvard kg
Runoff	Hay/Pasture	0.1	0.0	0.1	0.0	0.0	0.1	0.0
	Cropland	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	Forest	86.7	16.0	55.0	0.3	1.1	61.0	0.0
	Wetland	40.8	6.7	26.2	0.0	0.0	28.9	0.0
	Open Land	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	Barren Land	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	Low-Density Mixed	3.1	1.1	1.8	0.1	0.1	2.0	0.1
	Medium-Density Mixed	3.9	0.3	3.5	0.0	0.0	3.8	0.3
	High-Density Mixed	0.7	0.0	1.0	0.0	0.0	1.1	0.0
	Low-Density Open Space	14.6	5.4	8.2	0.9	0.1	9.2	0.3
Other Sources	Farm Animals	21.5	0.0	21.5	0.0	0.0	0.0	0.0
	Stream Bank	14.0	0.0	0.0	0.0	0.0	0.0	0.0
	Groundwater	767.9	145.0	484.4	6.1	8.3	538.0	1.6
	Septic Systems	1,378.9	501.4	444.4	193.7	22.8	114.0	102.6
	Total (kg)	2,332.2	675.9	1,046.1	201.1	32.3	758.1	104.9
	kg/acre	1.4	2.3	1.0	16.2	2.2	0.7	30.8

A large majority of the nitrogen entering Lake Telemark is due to septic systems and groundwater. Forested land contributed the largest runoff-based nitrogen load in the watershed. As the largest subwatershed, the Hibernia subwatershed was estimated to yield the largest amount of nitrogen per year, with a majority of this coming from septic systems and groundwater. Proportionate to acreage, however, the Hibernia nitrogen load is actually somewhat low. The Hallvard subwatershed, however, yields over 30 kg/acre/year of nitrogen, due to both the presence of septic systems and runoff from urbanized areas. As discussed above, this subwatershed features a disproportionately high percentage of urbanized areas, compared to many of the other subwatersheds, which have high percentages of forested land. The northern subwatershed also features a similar, although slightly less severe, loading regime.

Table 57: Estimated annual loads of phosphorus in the total Lake Telemark Watershed

Category	Description	Total Phosphorus	
		kg	%
Runoff	Hay/Pasture	0.03	0.0
	Cropland	0.00	0.0
	Forest	5.83	5.8
	Wetland	2.16	2.1
	Open Land	0.00	0.0
	Bare rock	0.00	0.0
	Low-Density Mixed	0.30	0.3
	Medium-Density Mixed	0.35	0.3
	High-Density Mixed	0.06	0.1
	Low-Density Open Space	1.41	1.4
Other Sources	Farm Animals	5.75	5.7
	Stream Bank	6.00	5.9
	Groundwater	27.43	27.2
	Septic Systems	51.71	51.2
	Total	101.03	100.0



Table 58: Estimated annual loads of phosphorus by sub-watershed in the Lake Telemark Watershed

Category	Description	Full Watershed kg	East kg	Hibernia kg	North kg	Northwest kg	West kg	Hallvard kg
Runoff	Hay/Pasture	0.03	0.00	0.03	0.00	0.00	0.04	0.00
	Cropland	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	Forest	5.83	1.65	3.49	0.03	0.10	4.55	0.00
	Wetland	2.16	0.45	1.32	0.00	0.00	1.72	0.00
	Open Land	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	Bare Rock	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	Low-Density Mixed	0.30	0.12	0.17	0.01	0.01	0.21	0.01
	Medium-Density Mixed	0.35	0.03	0.30	0.00	0.00	0.39	0.03
	High-Density Mixed	0.06	0.00	0.09	0.00	0.00	0.11	0.00
	Low-Density Open Space	1.41	0.59	0.76	0.10	0.01	1.00	0.03
Other Sources	Farm Animals	5.75	0.00	5.75	0.00	0.00	0.00	0.00
	Stream Bank	6.00	0.00	4.00	0.00	0.00	5.00	0.00
	Groundwater	27.43	5.88	16.70	0.16	0.22	21.84	0.04
	Septic Systems	51.71	18.80	16.67	7.26	0.85	4.27	3.85
Total (kg)		101.0	27.5	49.3	7.6	1.2	39.1	4.0
kg/acre		0.06	0.09	0.05	0.61	0.08	0.04	1.16

Similar to its nitrogen load, a large majority of the phosphorus entering Lake Telemark is estimated to originate from septic systems throughout the watershed. Groundwater was also estimated to be a large influence, with forested land contributing the most runoff-based phosphorus. Hibernia was estimated to contribute the largest yearly load of phosphorus of all the subwatersheds, mainly from septic systems and groundwater. The western subwatershed also yields a relatively high annual load, however this originates largely from groundwater. As with nitrogen, the Hallvard subwatershed yields the highest load of phosphorus per acre, largely due to this subwatershed occurring almost entirely within urbanized areas, whereas many of the other subwatersheds have a large proportion of forested land.

Anoxia in Lake Telemark was not observed during in-lake sampling efforts of 2021. As such, its yearly internal phosphorus load estimate considers only oxic loading, occurring at the reduced rate of 0.6 mg/m²/day, however it may be considerably higher if the lake goes anoxic. The total annual internal load for Lake Telemark is estimated to be approximately 3.6 kg/yr, but potentially may be an order of magnitude higher.

Table 59 below displays the external and internal loads of phosphorus for Lake Telemark, as well as the grand total, which is estimated to be approximately 104.6 kg/year. External loading is estimated to dominate the total load, representing approximately 97%. Even if the lake experiences anoxia and a larger internal load, external loading from the watershed would still dominate loading processes.

Source	Phosphorus (kg/yr)
External (Runoff, Groundwater, Septic Systems)	101
Internal	3.6
Total	104.6



Table 60: Estimated annual loads of sediment in the total Lake Telemark Watershed

Category	Description	Sediment	
		kgx1000	%
Runoff	Hay/Pasture	0.000	0.0
	Cropland	0.000	0.0
	Forest	0.980	7.3
	Wetland	0.150	1.1
	Open Land	0.000	0.0
	Barren Land	0.000	0.0
	Low-Density Mixed	0.070	0.5
	Medium-Density Mixed	0.100	0.7
	High-Density Mixed	0.020	0.1
	Low-Density Open Space	0.330	2.5
Other Sources	Farm Animals	0.000	0.0
	Stream Bank	11.746	87.7
	Groundwater	0.000	0.0
	Septic Systems	0.000	0.0
Total		13.396	100.0

Table 61: Estimated annual loads of sediment by sub-watershed in the Lake Telemark Watershed

Category	Description	Full Watershed kg x 1000	East kg x 1000	Hibernia kg x 1000	North kg x 1000	Northwest kg x 1000	West kg x 1000	Hallvard kg x 1000
Runoff	Hay/Pasture	0.000	0.000	0.000	0.000	0.000	0.000	0.000
	Cropland	0.000	0.000	0.000	0.000	0.000	0.000	0.000
	Forest	0.980	0.780	0.420	0.010	0.040	1.280	0.000
	Wetland	0.150	0.090	0.060	0.000	0.000	0.190	0.000
	Open Land	0.000	0.000	0.000	0.000	0.000	0.000	0.000
	Barren Land	0.000	0.000	0.000	0.000	0.000	0.000	0.000
	Low-Density Mixed	0.070	0.050	0.030	0.010	0.000	0.090	0.000
	Medium-Density Mixed	0.100	0.020	0.060	0.000	0.000	0.190	0.020
	High-Density Mixed	0.020	0.000	0.020	0.000	0.000	0.050	0.000
	Low-Density Open Space	0.330	0.240	0.130	0.040	0.000	0.410	0.010
Other Sources	Farm Animals	0.000	0.000	0.000	0.000	0.000	0.000	0.000
	Stream Bank	11.746	0.077	5.932	0.017	0.002	18.256	0.013
	Groundwater	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
Total (kgx1000)		13.396	1.257	6.652	0.077	0.042	20.466	0.043
kg/acre		8.023	4.312	6.173	6.210	2.897	18.917	12.647

A very large percentage of Lake Telemark’s sediment load is estimated to originate from stream bank erosion. In particular, the West subwatershed yields a very large estimated yearly load almost entirely from stream bank erosion. This subwatershed has a higher percentage of soils classified as “D - Very Slow Infiltration” than many of the other subwatersheds, which likely results in moderate runoff and increased erosion (most of the other subwatersheds around Lake Telemark and in Rockaway Township as a whole largely feature soils classified as “C – Slow Infiltration”). High sediment loads are typical of lake systems with high watershed to lake area ratios.



Table 62: Estimated annual loads of bacteria in the total Lake Telemark Watershed

Category	Description	Fecal Coliform	
		Organisms	%
Fecal Coliform	Farm Animals	2.10E+11	29.9
	Urban Areas	3.83E+10	5.5
	Wildlife	4.54E+11	64.6
	Total	7.02E+11	100

Table 63: Estimated annual loads of bacteria by sub-watershed in the Lake Telemark Watershed

Category	Description	Full Watershed	East	Hibernia	North	Northwest	West	Hallvard
		%	%	%	%	%	%	%
Fecal Coliform	Farm Animals	29.9	0.0	39.9	0.0	0.0	0.0	0.0
	WWTP	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	Septic Systems	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	Urban Areas	5.5	25.1	3.8	89.4	1.7	6.6	99.1
	Wildlife	64.6	74.9	56.2	10.6	98.3	93.4	0.9
Total (organisms)		7.02E+11	9.61E+10	5.26E+11	1.41E+10	5.02E+09	3.17E+11	9.75E+09

Due to its largely forested watershed, a majority of the bacteria in Lake Telemark's watershed originates from wildlife. Farm animals were also a large contributor in the Hibernia watershed, while urban areas were a large source in the Hallvard and North subwatersheds.

LAKE AMES

Lake Ames's full watershed covers a large area relative to the lake's surface area (14.5 acres), with the watershed encompassing 3,177 acres (Table 64). While this area contains largely forested areas and wetlands, at least 6% of the total watershed consists of low-density developed open space. The lake has two major inlets: A southwestern tributary to Hibernia Brook, listed as a Category 1 Trout-production stream (FW2-TP(C-1)), and the mainstem of Hibernia Brook entering from the north, listed as a Category 1 Trout-maintenance stream (FW2-TM(C-1)). Hibernia Brook continues south past the lake's dam. Descriptions of the Lake's subwatersheds are as follows:

- **Dam:** This small subwatershed is located along the southernmost edge of Lake Ames and contains a short length of Snake Hill Road, as well as part of the parking area for the Lake Ames Park. The 2.2-acre area is almost evenly split between developed open land and forested land.
- **East:** This 5.9-acre subwatershed contains a length of Green Pond Road on the eastern edge of the lake, as well as a forested area and a small area of development along Sunset Trail.
- **L. Erikson Rd.:** As the name suggests, this 11.8-acre subwatershed contains part of the developed area around Leif Erikson Road, as well as the southern portion of Whippoorwill Lane. The area is classified as mostly forested with approximately 3 acres of developed land.
- **Hibernia:** This is Lake Ames's largest watershed, and contains the mainstem of Hibernia Brook and all upstream tributaries, as well as Lake Telemark and its respective watershed. The majority of the area is forested, although approximately 188 acres of developed land exist in this subwatershed as well.
- **North:** This 17.1-acre subwatershed contains a length of Green Pond Road and surrounding developed area, as well as part of the Sunset Trail development. The area is almost entirely classified as developed land.



- **Snake Hill Rd.:** This relatively large watershed contains almost the entire length of Snake Hill Road, as well as the forested area surrounding it and some of Picatinny Arsenal's facilities to the northwest and part of the Tilcon quarry facility to the southwest. The area is classified mostly as forested land and wetlands.
- **South:** This 36.3-acre subwatershed contains a short length of Snake Hill Road and is almost entirely forested.
- **Southwest:** This small subwatershed is located along the southern edge of the lake, and contains an old camp parking lot. The area is classified as mostly forested land and wetlands.
- **West:** This 5.9-acres subwatershed is located immediately west of the lake's western inlet, and entirely consists of wetlands and forested land.

Table 64. Land-use by sub-watershed in the Lake Ames watershed.

Source	Full Watershed Acres	Dam Acres	East Acres	Erikson Acres	Hibernia Acres	North Acres	Snakehill Acres	South Acres	Southwest Acres	West Acres
Open Water	32.7	0.0	0.0	0.0	19.2	0.0	13.5	0.0	0.0	0.0
Hay/Pasture	0.2	0.0	0.0	0.0	0.2	0.5	0.0	0.0	0.0	0.0
Cropland	10.4	0.0	0.0	0.0	0.0	0.0	10.4	0.0	0.0	0.0
Forest	2,404.3	1.0	0.2	8.6	1,358.6	0.0	992.6	36.1	2.5	4.4
Wetland	450.0	0.0	0.0	0.0	245.4	0.0	202.4	0.0	1.0	1.5
Open Land	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Bare Rock	27.2	0.0	0.0	0.0	0.0	0.0	27.2	0.0	0.0	0.0
Low-Density Mixed	40.3	0.0	0.0	0.5	29.9	2.0	7.7	0.0	0.0	0.0
Medium-Density Mixed	11.9	0.0	0.0	0.0	5.4	0.0	6.4	0.0	0.0	0.0
High-Density Mixed	1.0	0.0	0.0	0.0	1.0	0.0	0.2	0.0	0.0	0.0
Low-Density Open Space	200.4	1.2	5.7	2.7	151.7	14.6	23.5	0.2	0.5	0.0
Total	3,178.4	2.2	5.9	11.8	1,811.4	17.1	1,283.9	36.3	4.0	5.9

Source	Full Watershed %	Dam %	East %	Erikson %	Hibernia %	North %	Snakehill %	South %	Southwest %	West %
Open Water	1.0	0.0	0.0	0.0	1.1	0.0	1.1	0.0	0.0	0.0
Hay/Pasture	0.0	0.0	0.0	0.0	0.0	2.9	0.0	0.0	0.0	0.0
Cropland	0.3	0.0	0.0	0.0	0.0	0.0	0.8	0.0	0.0	0.0
Forest	75.6	45.5	3.4	72.9	75.0	0.0	77.3	99.4	62.5	74.6
Wetland	14.2	0.0	0.0	0.0	13.5	0.0	15.8	0.0	25.0	25.4
Open Land	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Barren Land	0.9	0.0	0.0	0.0	0.0	0.0	2.1	0.0	0.0	0.0
Low-Density Mixed	1.3	0.0	0.0	4.2	1.7	11.7	0.6	0.0	0.0	0.0
Medium-Density Mixed	0.4	0.0	0.0	0.0	0.3	0.0	0.5	0.0	0.0	0.0
High-Density Mixed	0.0	0.0	0.0	0.0	0.1	0.0	0.0	0.0	0.0	0.0
Low-Density Open Space	6.3	54.5	96.6	22.9	8.4	85.4	1.8	0.6	12.5	0.0
Total	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0

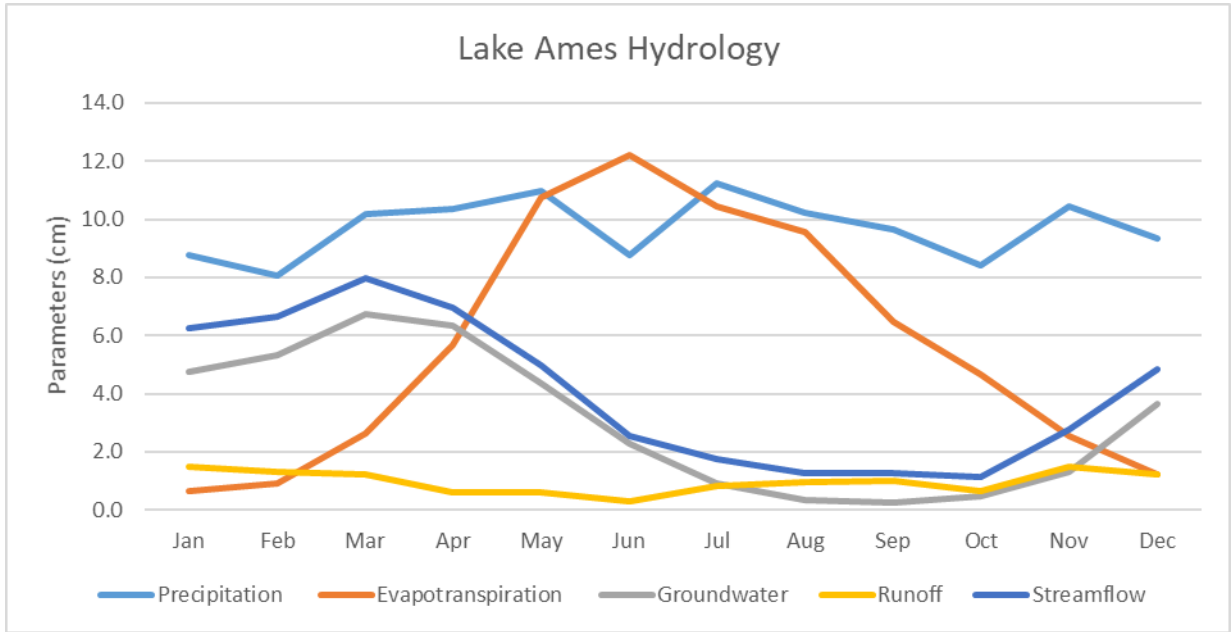


Figure 189. Estimated seasonal changes in hydrology in the Lake Ames watershed

Table 65. Total hydrological parameters in the full Lake Ames watershed

Month	Precipitation cm	Evapotranspiration cm	Groundwater cm	Runoff cm	Streamflow cm	cfs
Jan	8.8	0.7	4.7	1.5	6.2	10.6
Feb	8.0	0.9	5.3	1.3	6.7	12.4
Mar	10.2	2.6	6.7	1.2	8.0	13.5
Apr	10.4	5.7	6.3	0.6	7.0	12.2
May	11.0	10.7	4.4	0.6	5.0	8.4
Jun	8.8	12.2	2.3	0.3	2.6	4.5
Jul	11.2	10.5	0.9	0.8	1.8	3.0
Aug	10.2	9.6	0.3	0.9	1.3	2.2
Sep	9.7	6.5	0.3	1.0	1.3	2.2
Oct	8.4	4.7	0.5	0.7	1.1	1.9
Nov	10.4	2.5	1.3	1.5	2.8	4.9
Dec	9.3	1.2	3.7	1.2	4.9	8.2
Total	116.4	67.8	36.6	11.7	48.3	7.0

The subwatersheds of Lake Ames all experience similar estimated runoff rates, especially during October and November. The north and east subwatersheds feature the highest runoff early in the year due to their high coverage by urban landcover; however, the north subwatershed features less runoff than the East or Hibernia subwatersheds during the summer months. When direct precipitation and evaporation to and from the lake itself is factored in, Lake Ames is estimated to receive approximately 6,245,000 m³ or 1,649.7 million gallons of water a year.

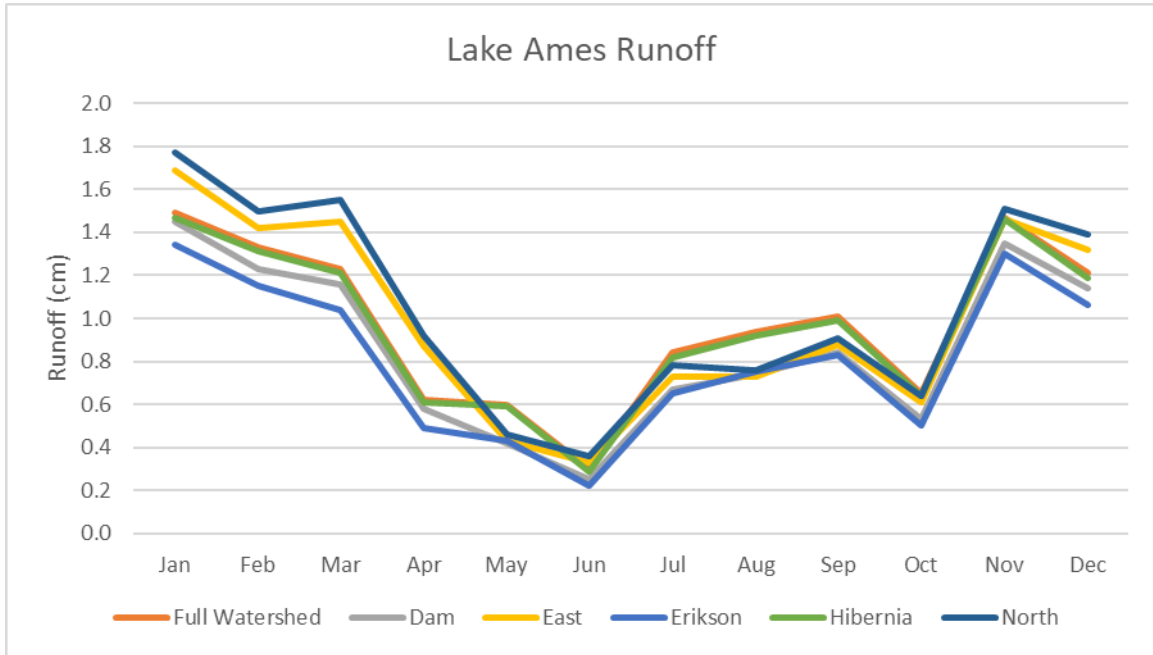


Figure 19. Average monthly runoff occurring in each sub-watershed in the Lake Ames watershed

No bathymetric data could be obtained for Lake Ames; the estimated volume is approximately 66,610 m³ or 17.6 million gallons. As with Lake Telemark, Lake Ames has a very large watershed relative to its volume, and as such, is estimated to flush as fast at approximately 94 times per year. Water entering Lake Ames is estimated to pass through the waterbody within 4 days. When examined on a monthly basis, the annualized monthly flushing rate is estimated to be at its lowest between August and October. At its very lowest, the lake's annualized retention period is estimated to be approximately 14 days. This is still very short, especially when compared to a deeper waterbody such as Green Pond. To an extent high rates of flushing limit efficient nutrient utilization and may also favor the development of plants over algal productivity.

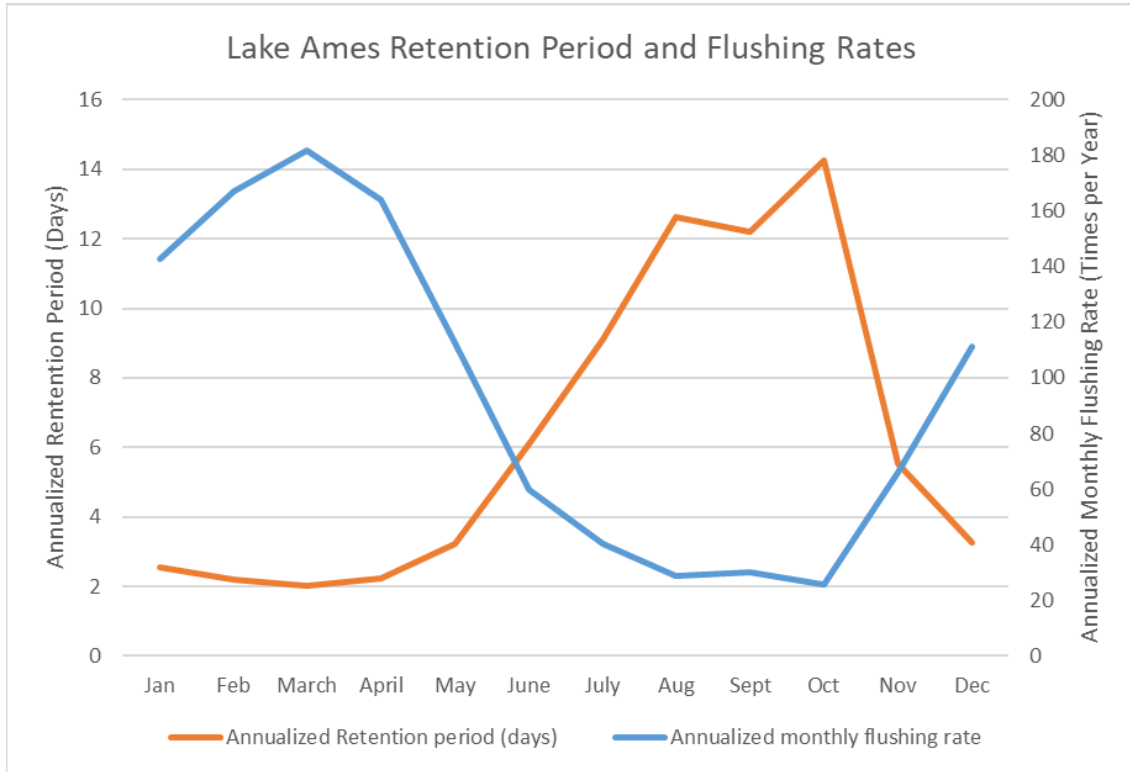


Figure 20. Variations in annualized flushing rates and retention periods over the course of a hypothetical year for Lake Ames, based on variations in hydraulic loads.

Table 66: Estimated annual loads of nitrogen in the total Lake Ames Watershed

Category	Description	Total Nitrogen	
		kg	%
Runoff	Hay/Pasture	0.1	0.0
	Cropland	24.8	0.9
	Forest	167.2	6.1
	Wetland	79.0	2.9
	Open Land	0.0	0.0
	Bare rock	7.6	0.3
	Low-Density Mixed	4.6	0.2
	Medium-Density Mixed	6.7	0.2
	High-Density Mixed	0.6	0.0
	Low-Density Open Space	22.8	0.8
Other Sources	Farm Animals	21.5	0.8
	Stream Bank	28.0	1.0
	Groundwater	1490.9	54.4
	Septic Systems	888.9	32.4
Total		2742.8	100



A majority of the nitrogen in the Lake Ames watershed originates in groundwater, with a significant quantity also originating from septic tanks. Most of the runoff in the watershed originates in forested land. The Hibernia subwatershed is estimated to yield the highest amount of nitrogen among all of the Lake Ames watershed, due to its size and number of septic systems. The eastern subwatershed is estimated to yield the largest amount of nitrogen per acre, likely due to the relatively high amount of septic systems present relative to the subwatershed's size, as well as the relatively high amount of urbanized land-use.



Table 67: Estimated annual loads of nitrogen by sub-watershed in the Lake Ames Watershed

Category	Description	Full Watershed Kg	Dam kg	East kg	Erikson kg	Hibernia kg	North kg	Snakehill kg	South kg	Southwest kg	West kg
Runoff	Hay/Pasture	0.1	0.0	0.0	0.0	0.1	0.0	0.0	0.0	0.0	0.0
	Cropland	24.8	0.0	0.0	0.0	0.0	0.0	26.7	0.0	0.0	0.0
	Forest	167.2	0.1	0.0	0.7	90.7	0.0	85.0	3.1	0.2	0.3
	Wetland	79.0	0.0	0.0	0.0	41.4	0.0	38.2	0.0	0.2	0.3
	Open Land	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	Barren Land	7.6	0.0	0.0	0.0	0.0	0.0	8.0	0.0	0.0	0.0
	Low-Density Mixed	4.6	0.0	0.0	0.1	3.3	0.2	1.0	0.0	0.0	0.0
	Medium-Density Mixed	6.7	0.0	0.0	0.0	3.8	0.0	3.3	0.0	0.0	0.0
	High-Density Mixed	0.6	0.0	0.0	0.0	0.7	0.0	0.1	0.0	0.0	0.0
	Low-Density Open Space	22.8	0.1	0.6	0.4	16.6	1.6	3.0	0.0	0.1	0.0
Other Sources	Farm Animals	21.5	0.0	0.0	0.0	21.5	0.0	0.0	0.0	0.0	0.0
	Stream Bank	28.0	0.0	0.0	0.0	17.0	0.0	0.0	0.0	0.0	0.0
	Groundwater	1,490.9	1.1	2.8	6.3	811.7	7.7	619.5	21.0	1.9	2.9
	Septic Systems	888.9	0.0	57.0	57.0	763.5	11.4	0.0	0.0	0.0	0.0
	Total (kg)	2,742.8	1.2	60.4	64.5	1,770.3	20.9	784.8	24.1	2.3	3.5
	kg/acre	0.9	0.6	10.2	5.5	1.0	1.2	0.6	0.7	0.6	0.6

Table 68: Estimated annual loads of phosphorus by sub-watershed in the Lake Ames Watershed

Category	Description	Full Watershed kg	Dam kg	East kg	Erikson kg	Hibernia kg	North kg	Snakehill kg	South kg	Southwest kg	West kg
Runoff	Hay/Pasture	0.04	0.00	0.00	0.00	0.03	0.00	0.00	0.00	0.00	0.00
	Cropland	5.23	0.00	0.00	0.00	0.00	0.00	6.11	0.00	0.00	0.00
	Forest	11.76	0.00	0.00	0.05	5.88	0.00	6.55	0.32	0.01	0.02
	Wetland	3.78	0.00	0.00	0.00	1.85	0.00	2.32	0.00	0.01	0.01
Other Sources	Open Land	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	Barren Rock	0.26	0.00	0.00	0.00	0.00	0.00	0.29	0.00	0.00	0.00
	Low-Density Mixed	0.46	0.00	0.00	0.01	0.30	0.02	0.10	0.00	0.00	0.00
	Medium-Density Mixed	0.62	0.00	0.00	0.00	0.33	0.00	0.33	0.00	0.00	0.00
	High-Density Mixed	0.05	0.00	0.00	0.00	0.06	0.00	0.01	0.00	0.00	0.00
	Low-Density Open Space	2.27	0.01	0.07	0.05	1.54	0.17	0.31	0.00	0.01	0.00
	Farm Animals	5.75	0.00	0.00	0.00	5.75	0.00	0.00	0.00	0.00	0.00
	Stream Bank	13.00	0.00	0.00	0.00	8.00	0.00	1.00	0.00	0.00	0.00
	Groundwater	55.33	0.03	0.07	0.17	27.99	0.20	25.10	0.85	0.05	0.08
	Septic Systems	33.33	0.00	2.14	2.14	28.63	0.43	0.00	0.00	0.00	0.00
	Total (kg)	131.9	0.04	2.28	2.42	80.36	0.82	42.12	1.17	0.08	0.11
	kg/acre	0.04	0.02	0.39	0.20	0.04	0.05	0.03	0.03	0.02	0.02



Table 69: Estimated annual loads of phosphorus in the total Lake Ames Watershed

Category	Description	Total Phosphorus	
		kg	%
Runoff	Hay/Pasture	0.04	0.0
	Cropland	5.23	4.0
	Forest	11.76	8.9
	Wetland	3.78	2.9
	Open Land	0.00	0.0
	Bare rock	0.26	0.2
	Low-Density Mixed	0.46	0.3
	Medium-Density Mixed	0.62	0.5
	High-Density Mixed	0.05	0.0
	Low-Density Open Space	2.27	1.7
Other Sources	Farm Animals	5.75	4.4
	Stream Bank	13.00	9.9
	Groundwater	55.33	42.0
	Septic Systems	33.33	25.3
Total		131.88	100.0

Most of Lake Ames's annual estimated phosphorus load originates in groundwater, with septic systems also yielding a significant load. The Hibernia subwatershed yields the greatest amount of phosphorus, most of which originates in groundwater or septic systems. Most runoff-based phosphorus in the Lake Ames watershed originates from forested land. As with nitrogen loads, the East subwatershed is estimated to yield the highest yearly load of phosphorus per acre.

Through field sampling, the small deep area near the lake's dam was shown to exhibit minor anoxia only once in 2021, during the October sampling event. The affected area was estimated to be approximately 1.45 acres and to only stay anoxic (and experience anoxic loading) for approximately one month (31 days). When oxic loading in other areas of the lake and during other points in the growing season were taken into account, the total annual internal load was estimated to be approximately 6.37 kg/yr. Without the small amount of anoxia that occurred, it is estimated that this yearly load would instead be approximately 5.34 kg/yr.

Table 70 below displays the external and internal loads of phosphorus for Lake Ames, as well as the grand total, which is estimated to be approximately 138.27 kg/year. As with Lake Telemark, Lake Ames's total phosphorus load is dominated by that contributed by external sources, which represent approximately 95% of the total.

Source	Phosphorus (kg/yr)
External (Runoff, Groundwater, Septic Systems)	131.9
Internal	6.4
Total	138.3



Table 71: Estimated annual loads of sediment in the total Lake Ames Watershed

Category	Description	Sediment	
		kgx1000	%
Runoff	Hay/Pasture	0.000	0.0
	Cropland	1.650	4.6
	Forest	2.450	6.8
	Wetland	0.000	0.0
	Open Land	0.000	0.0
	Barren Land	0.020	0.1
	Low-Density Mixed	0.130	0.4
	Medium-Density Mixed	0.230	0.6
	High-Density Mixed	0.020	0.1
	Low-Density Open Space	0.640	1.8
Other Sources	Farm Animals	0.000	0.0
	Stream Bank	30.782	85.7
	Groundwater	0.000	0.0
	Septic Systems	0.000	0.0
Total		35.922	100.0

A large majority of sediment entering Lake Ames originates from stream bank erosion within the watershed. As with phosphorus and nitrogen, the Hibernia subwatershed contributes most of the lake's sediment load. The north subwatershed, however, is estimated to yield the highest annual load of sediment per acre, most originating from low-density open urban space.

Over 75% of the total bacterial load in the Lake Ames watershed is estimated to originate from wildlife, likely due to the high percentage of forested land. Farm Animals or livestock in the Hibernia subwatershed are also estimated to contribute to approximately 19% amount of the total bacterial load.

Table 72: Estimated annual loads of bacteria in the total Lake Ames Watershed

Category	Description	Fecal Coliform	
		Organisms	%
Fecal Coliform	Farm Animals	2.10E+11	18.8
	Urban Areas	4.88E+10	4.4
	Wildlife	8.58E+11	76.8
Total		1.12E+12	100



Table 73: Estimated annual loads of sediment by sub-watershed in the Lake Ames Watershed

Category	Description	Full Watershed kg x 1000	Dam kg x 1000	East kg x 1000	Erikson kg x 1000	Hibernia kg x 1000	North kg x 1000	Snakehill kg x 1000	South kg x 1000	Southwest kg x 1000	West kg x 1000
Runoff	Hay/Pasture	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
	Cropland	1.650	0.000	0.000	0.000	0.000	0.000	2.750	0.000	0.000	0.000
	Forest	2.450	0.000	0.000	0.020	0.750	0.040	1.960	0.160	0.000	0.000
	Wetland	0.000	0.000	0.000	0.000	0.000	0.000	0.310	0.000	0.000	0.000
	Open Land	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
	Barren Land	0.020	0.000	0.000	0.000	0.000	0.000	0.030	0.000	0.000	0.000
	Low-Density Mixed	0.130	0.000	0.000	0.000	0.050	0.220	0.040	0.000	0.000	0.000
	Medium-Density Mixed	0.230	0.000	0.000	0.000	0.070	0.000	0.170	0.000	0.000	0.000
	High-Density Mixed	0.020	0.000	0.000	0.000	0.010	0.000	0.010	0.000	0.000	0.000
	Low-Density Open Space	0.640	0.000	0.030	0.020	0.270	1.590	0.120	0.000	0.000	0.000
Other Sources	Farm Animals	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
	Stream Bank	30.782	0.001	0.020	0.007	11.131	0.000	3.876	0.001	0.011	0.000
	Groundwater	0.000	0.000	0.000	0.000	0.000	0.039	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	0.000
Total (kgx1000)		35.922	0.001	0.050	0.047	12.281	1.889	9.266	0.161	0.011	0.000
kg/acre		11.302	0.455	8.475	3.983	6.780	110.468	7.217	4.435	2.750	0.000

Table 74: Estimated annual loads of bacteria by sub-watershed in the Lake Ames Watershed

Category	Description	Full Watershed %	Dam %	East %	Erikson %	Hibernia %	North %	Snakehill %	South %	Southwest %	West %
Fecal Coliform	Farm Animals	18.8	0	0	0	28.3	0	0	0	0	0
	Urban Areas	4.4	81.1	99.3	38.8	6.2	99.6	0.9	0.0	12.7	0
	Wildlife	76.8	18.9	0.7	61.2	65.4	0.4	99.1	100.0	87.3	100
Total (organisms)		1.12E+12	1.87E+09	1.29E+10	5.04E+09	7.41E+11	3.97E+10	3.57E+11	1.29E+10	1.01E+09	1.59E+09



MT. HOPE POND

The watershed for Mt. Hope Pond covers an area of approximately 118 acres, while the lake itself has a surface area of approximately 18.3 acres. As with many other of the watersheds in Rockaway Township, this area is largely forested, with small amounts of developed land present in the form of transportation corridors. The watershed contains a small part of the pond's beach parking lot, as well as Mt. Hope Road (Rt. 664). Additionally, a small amount of bare-rock land cover is present in the far northern reaches of the watershed. The pond is largely fed by groundwater, with the only surface inlet being a very small spring-fed stream entering at the northern end. The pond's outlet stream flows under Mt. Hope Road and east into Mt. Hope Lake. Descriptions of the pond's subwatersheds are as follows:

- **Dam:** This subwatershed is located along the northeastern edge of Mt. Hope Pond. While it contains the portion of the pond's dam north of the outlet, it also contains part of Mt. Hope Road and the forested area above. The subwatershed is largely forested.
- **Northeast:** As with the Dam subwatershed, this area contains a small portion of Mt. Hope Road and a forested area to the north, as well as a few acres of bare rock near the far northern portion of the subwatershed.
- **Rt. 644:** As the name suggests, this watershed contains a portion of Mt. Hope Road/Rt. 644, as well as forested land to the north that is traversed by a powerline cut.
- **North:** This watershed contains a portion of Mt. Hope Road, as well as forested land to the north.
- **Camp Road:** This subwatershed is situated along the northwestern corner of the pond, and consists almost entirely of forested land, part of which is property of the Picatinny Arsenal. The pond's tiny inlet is also present in this subwatershed.
- **Camp:** As the name suggests, this subwatershed contains part of a hunting camp located on the northwest end of the pond, as well as some of the Picatinny Arsenal's property. This area is almost entirely forested.
- **West:** This subwatershed covers an area of approximately 7.6 acres and is almost entirely forested.
- **Southwest:** This subwatershed covers an area of approximately 23.2 acres and is entirely covered by forested land.
- **South:** This subwatershed consists mainly of the forested area on the southeastern edge of the pond, as well as the pond's swimming beach and a small part of the beach's parking lot. The area is categorized as entirely forested.



Table 75. Land-use by sub-watershed in the Mt. Hope Pond watershed.

Source	Full Watershed Acres	Camp Acres	Camproad Acres	Dam Acres	North Acres	Northeast Acres	Rt 664 Acres	South Acres	Southwest Acres	West Acres
Open Water	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Hay/Pasture	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Cropland	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Forest	109.7	18.8	11.4	8.6	11.4	15.1	6.7	6.7	23.2	7.4
Wetland	1.5	1.0	0.2	0.0	0.2	0.0	0.0	0.0	0.0	0.2
Open Land	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Bare Rock	5.4	0.0	0.0	0.0	0.0	5.7	0.0	0.0	0.0	0.0
Low-Density Mixed	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Medium-Density Mixed	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
High-Density Mixed	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Low-Density Open Space	1.5	0.0	0.2	1.0	0.5	0.0	0.0	0.0	0.0	0.0
Total	118.1	19.8	11.8	9.6	12.1	20.8	6.7	6.7	23.2	7.6

Source	Full Watershed %	Camp %	Camproad %	Dam %	North %	Northeast %	Rt 664 %	South %	Southwest %	West %
Open Water	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Hay/Pasture	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Cropland	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Forest	92.9	94.9	96.6	89.6	94.2	72.6	100.0	100.0	100.0	97.4
Wetland	1.3	5.1	1.7	0.0	1.7	0.0	0.0	0.0	0.0	2.6
Open Land	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Barren Land	4.6	0.0	0.0	0.0	0.0	27.4	0.0	0.0	0.0	0.0
Low-Density Mixed	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Medium-Density Mixed	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
High-Density Mixed	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Low-Density Open Space	1.3	0.0	1.7	10.4	4.1	0.0	0.0	0.0	0.0	0.0
Total	100	100	100	100	100	100	100	100	100	100

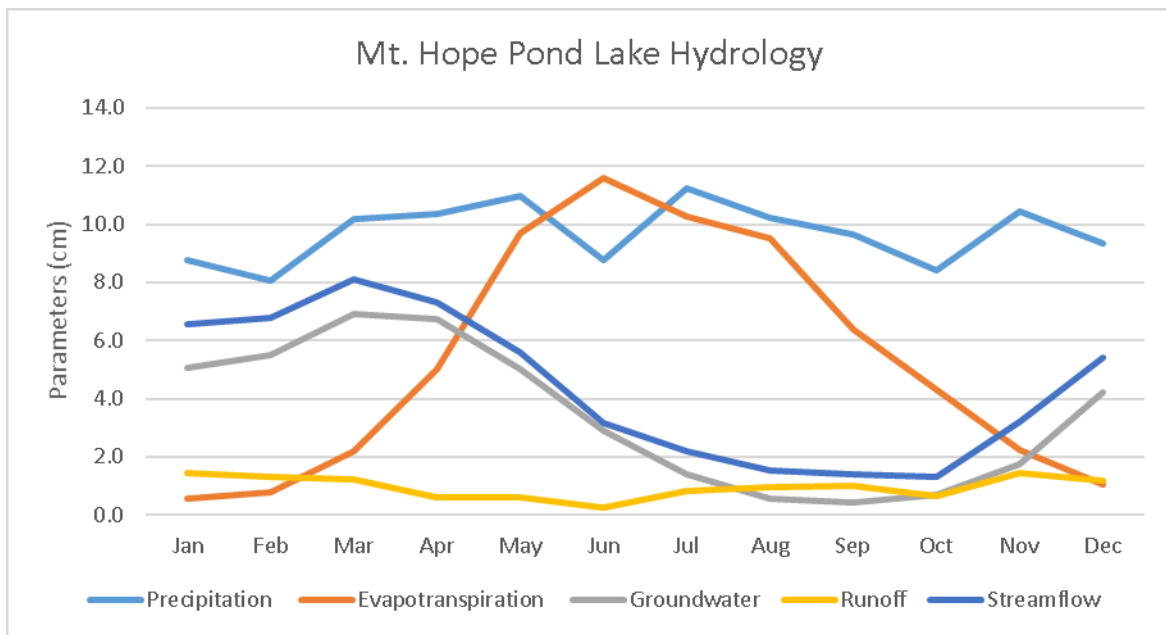


Figure 21. Estimated seasonal changes in hydrology in the Mt. Hope Pond watershed



Table 76. Total hydrological parameters in the full Mt. Hope Pond watershed

Month	Precipitation cm	Evapotranspiration cm	Groundwater cm	Runoff cm	Streamflow cm	cfs
Jan	8.8	0.5	5.1	1.5	6.5	0.4
Feb	8.0	0.8	5.5	1.3	6.8	0.5
Mar	10.2	2.2	6.9	1.2	8.1	0.5
Apr	10.4	5.0	6.7	0.6	7.3	0.5
May	11.0	9.7	5.0	0.6	5.6	0.4
Jun	8.8	11.6	2.9	0.3	3.2	0.2
Jul	11.2	10.3	1.4	0.8	2.2	0.1
Aug	10.2	9.5	0.6	0.9	1.5	0.1
Sep	9.7	6.4	0.4	1.0	1.4	0.1
Oct	8.4	4.3	0.7	0.6	1.3	0.1
Nov	10.4	2.2	1.8	1.5	3.2	0.2
Dec	9.3	1.1	4.2	1.2	5.4	0.3
Total	116.4	63.5	41.2	11.4	52.6	0.3

Due to the largely forested nature of most of the Mt. Hope Pond watershed, there is, for the most part, only minor variation between its subwatersheds in regards to runoff. The northeast subwatershed, however, features the highest overall runoff, and this is likely a product of the area of bare rock it contains. This land-type is estimated to contain largely impervious cover, meaning most rainfall immediately continues downhill rather than infiltrating into groundwater. When direct precipitation and evapotranspiration to the pond itself are considered, Mt. Hope Pond is estimated to receive approximately 290,629.6 m³ or approximately 76.8 million gallons of water a year.

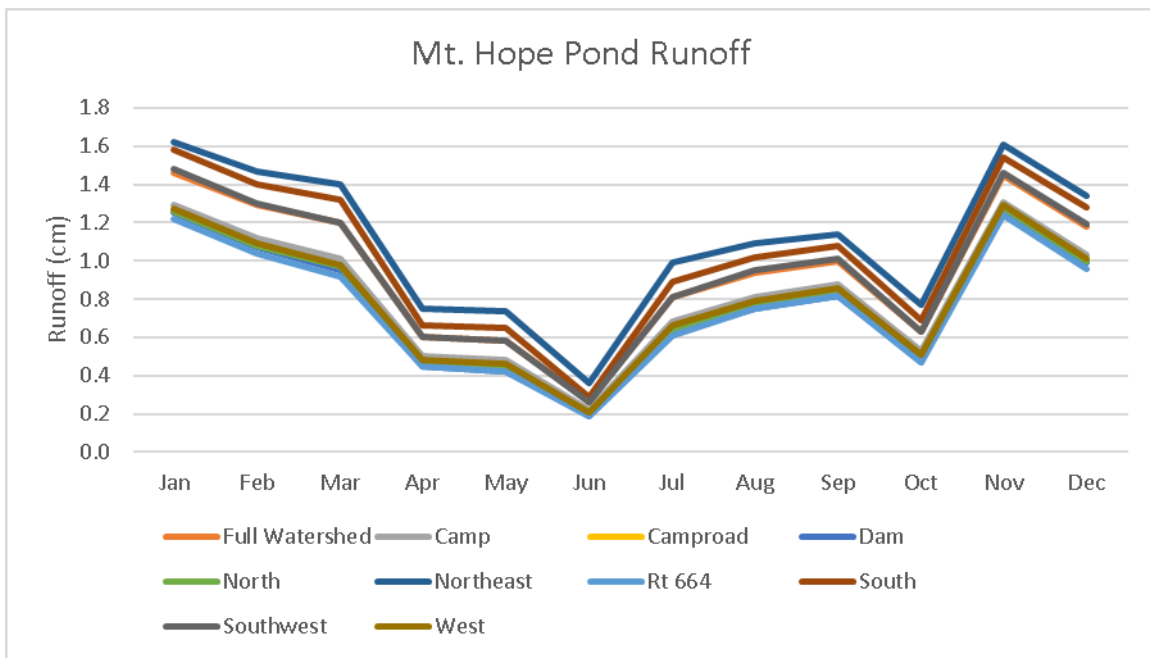


Figure 22. Average monthly runoff occurring in each sub-watershed in the Mt. Hope Pond watershed



As with several of the other waterbodies in this study, recent bathymetric data was not available for Mt. Hope Pond. An estimate of the pond's volume yielded approximately 132,100 m³ or 34.9 million gallons of water. The pond is accordingly estimated to flush approximately 2.2 times a year, with a water retention period of approximately 166 days. On a monthly basis, Mt. Hope Pond features a similar pattern of variation as the other waterbodies assessed, with the lowest annualized flushing rate occurring in August. This is relatively slow flushing, especially for a waterbody of its size and may indicate increased susceptibility to algal issues and more efficient utilization of nutrient loads.

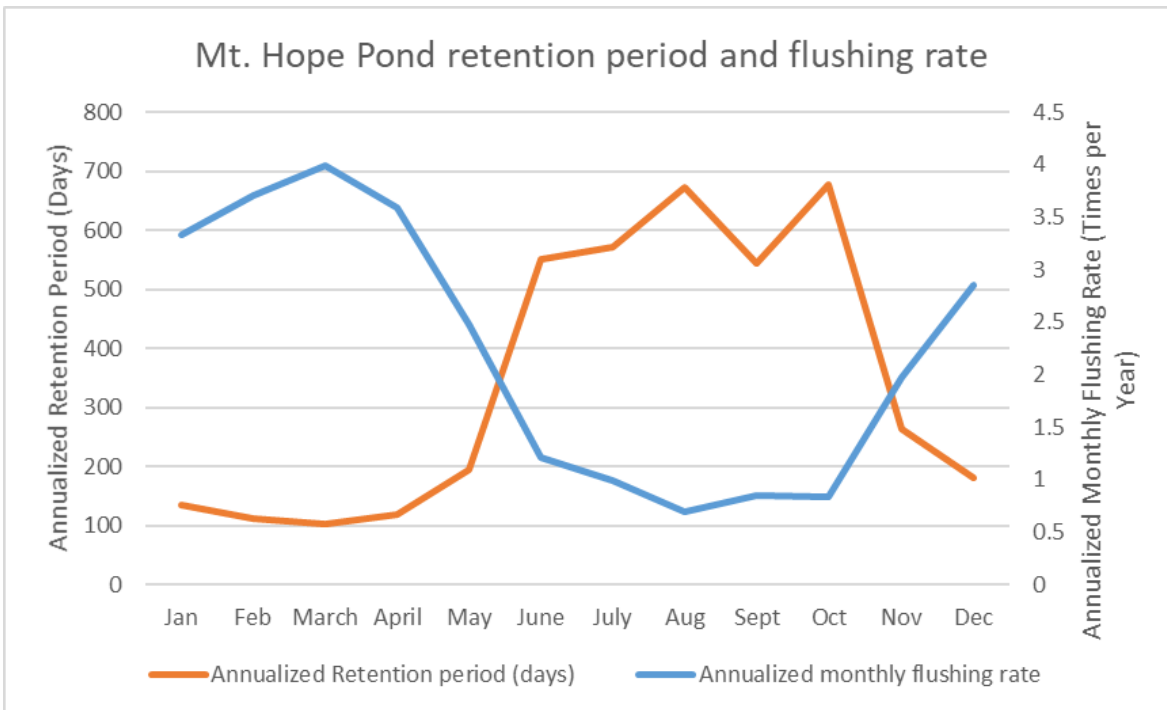


Figure 23. Variations in annualized flushing rates and retention periods over the course of a hypothetical year for Mt. Hope Pond, based on variations in hydraulic loads.



Table 77: Estimated annual loads of nitrogen in the total Mt. Hope Pond Watershed

Category	Description	Total Nitrogen	
		kg	%
Runoff	Hay/Pasture	0.0	0.0
	Cropland	0.0	0.0
	Forest	12.8	13.9
	Wetland	0.3	0.3
	Open Land	0.0	0.0
	Bare rock	1.6	1.7
	Low-Density Mixed	0.0	0.0
	Medium-Density Mixed	0.0	0.0
	High-Density Mixed	0.0	0.0
	Low-Density Open Space	0.1	0.1
Other Sources	Farm Animals	0.0	0.0
	Stream Bank	0.0	0.0
	Groundwater	66.1	71.7
	Septic Systems	11.4	12.4
Total		92.3	100.0

Table 78: Estimated annual loads of nitrogen by sub-watershed in the Mt. Hope Pond Watershed

Category	Description	Full Watershed kg	Camp kg	Camproad kg	Dam kg	North kg	Northeast kg	Rt 664 kg	South kg	Southwest kg	West kg
Runoff	Hay/Pasture	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	Cropland	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	Forest	12.8	1.5	0.9	0.7	0.9	1.2	0.5	0.7	2.2	0.5
	Wetland	0.3	0.2	0.1	0.0	0.1	0.0	0.0	0.0	0.0	0.1
	Open Land	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	Barren Land	1.6	0.0	0.0	0.0	0.0	1.7	0.0	0.0	0.0	0.0
	Low-Density Mixed	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	Medium-Density Mixed	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	High-Density Mixed	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	Low-Density Open Space	0.1	0.0	0.0	0.1	0.1	0.0	0.0	0.0	0.0	0.0
Other Sources	Farm Animals	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	Stream Bank	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	Groundwater	66.1	11.1	6.5	5.5	6.9	13.1	3.9	4.1	12.7	4.4
	Septic Systems	11.4	11.4	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Total (kg)		92.3	24.2	7.5	6.3	7.9	15.9	4.4	4.8	14.8	5.0
kg/acre		0.8	1.2	0.6	0.7	0.7	0.8	0.7	0.7	0.6	0.7

Unlike many of the other lakes in this study, Mt. Hope Pond features only a single septic system within 300' of the waterbody. As such, estimated annual loading rates of phosphorus and nitrogen are generally lower. A majority of Mt. Hope Pond's nitrogen load is estimated to occur from groundwater sources, as well as from runoff from forested areas. The single septic system is located in the camp subwatershed, and contributed approximately 11.40 kg of nitrogen per year.



Table 79: Estimated annual loads of phosphorus in the total Mt. Hope Pond Watershed

Category	Description	Total Phosphorus	
		kg	%
Runoff	Hay/Pasture	0.00	0.0
	Cropland	0.00	0.0
	Forest	1.38	38.5
	Wetland	0.01	0.3
	Open Land	0.00	0.0
	Bare rock	0.06	1.7
	Low-Density Mixed	0.00	0.0
	Medium-Density Mixed	0.00	0.0
	High-Density Mixed	0.00	0.0
	Low-Density Open Space	0.01	0.3
Other Sources	Farm Animals	0.00	0.0
	Stream Bank	0.00	0.0
	Groundwater	1.70	47.4
	Septic Systems	0.43	11.9
Total		3.59	100.0

Table 80: Estimated annual loads of phosphorus by sub-watershed in the Mt. Hope Pond Watershed

Category	Description	Full Watershed kg	Camp kg	Camproad kg	Dam kg	North kg	Northeast kg	Rt 664 kg	South kg	Southwest kg	West kg
Runoff	Hay/Pasture	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	Cropland	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	Forest	1.38	0.12	0.06	0.05	0.07	0.08	0.04	0.05	0.13	0.03
	Wetland	0.01	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	Open Land	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	Bare Rock	0.06	0.00	0.00	0.00	0.00	0.06	0.00	0.00	0.00	0.00
	Low-Density Mixed	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	Medium-Density Mixed	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	High-Density Mixed	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	Low-Density Open Space	0.01	0.00	0.00	0.01	0.01	0.00	0.00	0.00	0.00	0.00
Other Sources	Farm Animals	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	Stream Bank	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	Groundwater	1.70	0.29	0.16	0.14	0.18	0.34	0.10	0.11	0.33	0.12
	Septic Systems	0.43	0.45	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Total (kg)		3.59	0.87	0.22	0.20	0.26	0.48	0.14	0.16	0.46	0.15
kg/acre		0.03	0.04	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02

Very little phosphorus (3.59 kg/yr) was estimated to enter Mt. Hope Pond from the watershed when compared to the loads estimated for the other lakes in this study. As with nitrogen, a small amount (less than a kg) of this load is estimated to originate from septic systems. A majority of the yearly phosphorus load is estimated to run off from forested land, particularly in the camp and southwest subwatersheds. Groundwater-based phosphorus is estimated to be the dominant external source for Mt. Hope Pond.

Bottom anoxia was detected in Mt. Hope Pond during the July field event within the approximately bottom most 0.5-1.0 meter of the water column; however, deep water samples did not indicate a significantly higher amount of phosphorus from the bottom of the water than at the top. As such, it was estimated that significant anoxic loading occurred from August to September, covering an area of



approximately 60% of the total waterbody (approximately 11 acres). This is of limited duration and develops relatively late in the growing season. During the October event, bottom phosphorus levels were somewhat high compared to those at the surface; however, bottom anoxia was not observed. Given the relatively high concentration of chlorophyll *a* at the bottom during this event, this may be due to a high biomass of algae at the bottom of the water column at this time, rather than anoxic loading. Using the estimated time period of August and September, Mt. Hope Pond was estimated to receive approximately 21.47 kg/yr of phosphorus via internal loading. In a hypothetical year during which anoxia does not occur at all, the internal load is estimated to be 6.81 kg/yr. Because this watershed is largely forested, small, and with low nutrient loads, it may have lower phosphorus reserves in the sediments than many of the other lakes.

Table 81 below displays the external and internal loads of phosphorus for Mt. Hope Pond, as well as the grand total, which is estimated to be approximately 25.06 kg/year. According to modeled loads, the pond is estimated to receive a majority of phosphorus (approximately 86%) from internal loads.

Source	Phosphorus (kg/yr)
External (Runoff, Groundwater, Septic Systems)	3.6
Internal	21.5
Total	25.1

Table 82: Estimated annual loads of sediment in the total Mt. Hope Pond Watershed

Category	Description	Sediment	
		kgx1000	%
Runoff	Hay/Pasture	0.000	0.0
	Cropland	0.000	0.0
	Forest	0.760	99.2
	Wetland	0.000	0.0
	Open Land	0.000	0.0
	Barren Land	0.000	0.0
	Low-Density Mixed	0.000	0.0
	Medium-Density Mixed	0.000	0.0
	High-Density Mixed	0.000	0.0
	Low-Density Open Space	0.000	0.0
Other Sources	Farm Animals	0.000	0.0
	Stream Bank	0.006	0.8
	Groundwater	0.000	0.0
	Septic Systems	0.000	0.0
Total		0.766	100.0



Table 83: Estimated annual loads of sediment by sub-watershed in the Mt. Hope Pond Watershed

Category	Description	Full Watershed kg x 1000	Camp kg x 1000	Camproad kg x 1000	Dam kg x 1000	North kg x 1000	Northeast kg x 1000	Rt 664 kg x 1000	South kg x 1000	Southwest kg x 1000	West kg x 1000
Runoff	Hay/Pasture	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
	Cropland	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
	Forest	0.760	0.040	0.020	0.010	0.020	0.030	0.010	0.020	0.020	0.000
	Wetland	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
	Open Land	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
	Barren Land	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
	Low-Density Mixed	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
	Medium-Density Mixed	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
	High-Density Mixed	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
	Low-Density Open Space	0.000	0.000	0.000	0.010	0.000	0.000	0.000	0.000	0.000	0.000
Other Sources	Farm Animals	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
	Stream Bank	0.006	0.001	0.001	0.001	0.002	0.001	0.000	0.001	0.001	0.000
	Groundwater	0.000	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	0.000
Total (kgx1000)		0.766	0.041	0.021	0.021	0.022	0.031	0.010	0.021	0.021	0.000
kg/acre		6.486	2.071	1.780	2.188	1.818	1.490	1.493	3.134	0.905	0.000

As with phosphorus, very little (766 kg/yr) sediment is estimated to enter Mt. Hope Pond from the watershed (Tables 47, 48). Almost the entirety of the yearly sediment load is estimated to originate as runoff from forested areas, with a very small amount (6 kg/yr) originating from stream bank erosion. The South subwatershed is estimated to yield the highest annual load of sediment per acre. This subwatershed is estimated to contain a much higher percentage of “very slow infiltrating soils” than many of the other subwatersheds around the pond, and as such is estimated to feature a relatively high amount of runoff.

Table 84: Estimated annual loads of bacteria for the full Mt. Hope Pond Watershed

Description	Fecal Coliform	
	Organisms	%
Farm Animals	0.00E+00	0.0
Urban Areas	3.79E+07	0.1
Wildlife	3.91E+10	99.9
Total	3.91E+10	100

Table 85: Estimated annual loads of bacteria by subwatershed for the Mt. Hope Pond Watershed

Description	Full Watershed %	Camp %	Camproad %	Dam %	North %	Northeast %	Rt 664 %	South %	Southwest %	West %
Farm Animals	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Urban Areas	0.1	0.0	0.3	6.3	1.0	0.0	0.0	0.0	0.0	0.0
Wildlife	99.9	100	99.7	93.7	99	100	100	100.0	100.0	100
Total (organisms)	3.91E+10	6.70E+09	4.06E+09	3.29E+09	4.10E+09	5.38E+09	2.38E+09	2.38E+09	8.28E+09	2.64E+09

Similar to other lakes in this study with largely forested watersheds, most of the bacteria estimated to enter Mt. Hope Lake originates from Wildlife, with a very small amount estimated to originate from urban areas. The southwest subwatershed was estimated to yield the highest yearly bacterial load, likely due to its surface area.



MT. HOPE LAKE/MILL POND

The watershed for Mount Hope Lake covers an area of approximately 1,096.4 acres, while the lake itself features a surface area of 127.3 acres. While forested land dominates the land-use type in this watershed, there is a diversity of other land use types throughout, including a significant portion of bare rock, urbanized area, wetlands, and open water. The northern portion of the watershed covers a majority of Tilcon's quarry operations, while the western portion includes urbanized land around the Mt. Hope Road corridor and forested land around Mt. Hope Pond. The main portion of the lake receives inflow from the upper portion to the north, as well as the outlet flow from Mt. Hope Pond. Mt. Hope Lake's outlet flows southeast into White Meadow Lake. Descriptions of Mt. Hope Lake's subwatersheds are as follows:

- **Mt. Hope Pond:** This 323-acre subwatershed is situated along the eastern shoreline of Mt. Hope Lake and contains Mt. Hope Pond and its entire watershed, as well as a portion of Mt. Hope Road and the urbanized areas along it. The subwatershed is largely forested, but also contains approximately 30.6 acres of urbanized area, as well as a significant acreage of wetlands, a small amount of barren rock, and open water.
- **Garden Ave.:** This smaller subwatershed (8.6 acres) is located by the intersection of Garden Avenue and another Tilcon driveway. It consists mostly of forested land, and also contains barren rock and urbanized areas.
- **Northwest:** This 11.3-acre subwatershed is located south of Tilcon's quarry operations and contains mostly bare rock and forested land, as well as smaller amounts of wetlands and urbanized areas.
- **Tilcon Entrance:** This 7.1-acre subwatershed contains several driveways, and as such is largely classified as barren rock and urbanized land, while approximately 2.5 acres of forest are also present.
- **Silos:** This subwatershed covers a 13-acre area within the quarry and is largely classified as urbanized area and bare rock, although some forested areas and wetlands do exist closer to the lake.
- **North:** This small 5.2-acre subwatershed comprises a swath of wetlands along the lake's northern edge, as well as a portion of the quarry. It is classified as wetlands and barren rock.
- **Storage – West:** This 20-acre subwatershed consists approximately half of Tilcon's quarry operations and half of the wetlands along the northern edge of the waterbody.
- **Storage – East:** This 23-acre subwatershed consists largely of a part of Tilcon's quarry operations, as well as a smaller portion of near-lake wetlands.
- **Upper:** This is the largest of Mt. Hope Lake's subwatersheds at approximately 573 acres. This area contains most of the quarry, as well as the upper portion of Mt. Hope Lake and the surrounding forested land and wetlands.
- **Northeast:** This small area southeast of upper Mt. Hope lake is largely forested with approximately half-an-acre of wetlands.
- **East:** This 35.4-acre subwatershed encapsulates the entire eastern edge of Mt. Hope Pond, as well as a portion of the developed area along Cayuga Avenue.
- **South:** This small 8.6-acre area is located adjacent to the lake's outlet and contains forested land and wetlands.
- **Southeast:** This 17.2-acre subwatershed contains largely forested land and wetlands, as well as a small portion of urbanized land near Beaverdam Road.



- **West:** This 38.8-acre subwatershed contains the urbanized areas just south of the intersection of Mt. Hope Road and Mt. Hope Avenue (Rt. 661), as well as some wetlands and forested areas closer to the lake.
- **Mill Pond Rd.:** This small, 4.9-acre subwatershed contains the developed areas along Mill Pond Road as well as some of the surrounding forested areas.

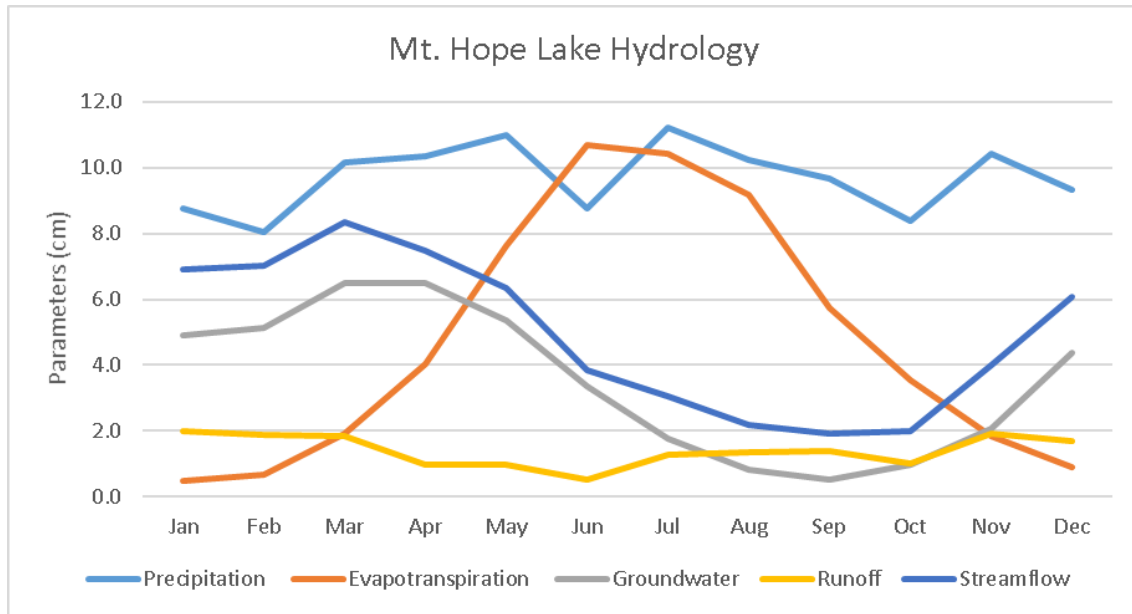


Figure 24. Estimated seasonal changes in hydrology in the Mt. Hope Lake watershed

Table 86. Total hydrological parameters in the full Mt. Hope Lake watershed

Month	Precipitation	Evapotranspiration	Groundwater	Runoff	Streamflow	
	cm	cm	cm	cm	cm	cfs
Jan	8.8	0.5	4.9	2.0	6.9	4.0
Feb	8.0	0.7	5.1	1.9	7.0	4.5
Mar	10.2	1.9	6.5	1.8	8.3	4.9
Apr	10.4	4.1	6.5	1.0	7.5	4.5
May	11.0	7.6	5.3	1.0	6.3	3.7
Jun	8.8	10.7	3.4	0.5	3.9	2.3
Jul	11.2	10.4	1.8	1.3	3.1	1.8
Aug	10.2	9.2	0.8	1.4	2.2	1.3
Sep	9.7	5.7	0.5	1.4	1.9	1.2
Oct	8.4	3.6	1.0	1.0	2.0	1.2
Nov	10.4	1.8	2.1	1.9	4.0	2.4
Dec	9.3	0.9	4.4	1.7	6.1	3.6
Total	116.4	57.0	42.3	16.8	59.1	2.9



Table 87: Land-use by subwatershed in the Mt. Hope Lake watershed.

Source	Full Watershed Acres	East Acres	Garden Ave Acres	Mill Pond Road Acres	Mt Hope Pond Acres	North Acres	Northeast Acres	Northwest Acres	Silos Acres	South Acres	Southeast Acres	Storage East Acres	Storage West Acres	Tikon Entrance Acres	Upper Acres	West Acres
Open Water	67.7	0.0	0.0	0.0	18.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Hay/Pasture	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Cropland	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Forest	495.2	26.7	5.2	1.7	221.4	6.7	4.2	1.7	1.7	4.9	9.6	0.0	0.0	2.5	205.1	1.2
Wetland	122.6	1.5	0.0	0.2	45.7	3.5	0.5	0.5	1.2	3.7	5.4	5.7	7.7	0.0	40.5	5.7
Open Land	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.0	0.0
Bare Rock	311.8	0.0	1.2	0.0	7.2	1.7	0.0	4.4	6.2	0.0	0.0	17.3	7.9	2.7	262.7	0.0
Low-Density Mixed	27.7	3.0	0.5	0.5	7.7	0.0	0.7	2.2	2.2	0.0	0.0	0.0	0.2	1.0	4.4	7.7
Medium-Density Mixed	12.4	0.0	1.5	0.0	3.2	0.0	1.5	1.0	0.0	0.0	0.0	0.0	0.2	0.7	2.2	2.0
High-Density Mixed	1.7	0.0	0.0	0.0	1.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.5
Low-Density Open Space	57.3	4.2	0.2	2.5	18.5	0.0	0.0	0.0	0.7	0.0	2.2	0.0	0.0	0.2	7.7	21.7
Total	1096.4	35.4	8.6	4.9	323.2	5.2	7.2	11.3	13.0	8.6	17.2	23.0	20.0	7.1	573.0	38.8

Source	Full Watershed %	East %	Garden Ave %	Mill Pond Road %	Mt Hope Pond %	North %	Northeast %	Northwest %	Silos %	South %	Southeast %	Storage East %	Storage West %	Tikon Entrance %	Upper %	West %
Open Water	6.2	0.0	0.0	0.0	5.7	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Hay/Pasture	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Cropland	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Forest	45.2	75.4	60.5	34.7	68.5	0.0	93.1	37.2	13.1	57.0	55.8	0.0	20.0	35.2	35.8	3.1
Wetland	11.2	4.2	0.0	4.1	14.1	67.3	6.9	4.4	9.2	43.0	31.4	24.8	38.5	0.0	7.1	14.7
Open Land	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.2	0.0
Barren Land	28.4	0.0	14.0	0.0	2.2	32.7	0.0	38.9	47.7	0.0	0.0	75.2	39.5	38.0	45.8	0.0
Low-Density Mixed	2.5	8.5	5.8	10.2	2.4	0.0	0.0	6.2	16.9	0.0	0.0	0.0	1.0	14.1	0.8	19.8
Medium-Density Mixed	1.1	0.0	17.4	0.0	1.0	0.0	0.0	13.3	7.7	0.0	0.0	0.0	1.0	9.9	5.2	5.2
High-Density Mixed	0.2	0.0	0.0	0.0	0.4	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.3
Low-Density Open Space	5.2	11.9	2.3	51.0	5.7	0.0	0.0	0.0	5.4	0.0	12.8	0.0	0.0	2.8	1.3	55.9
Total	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0

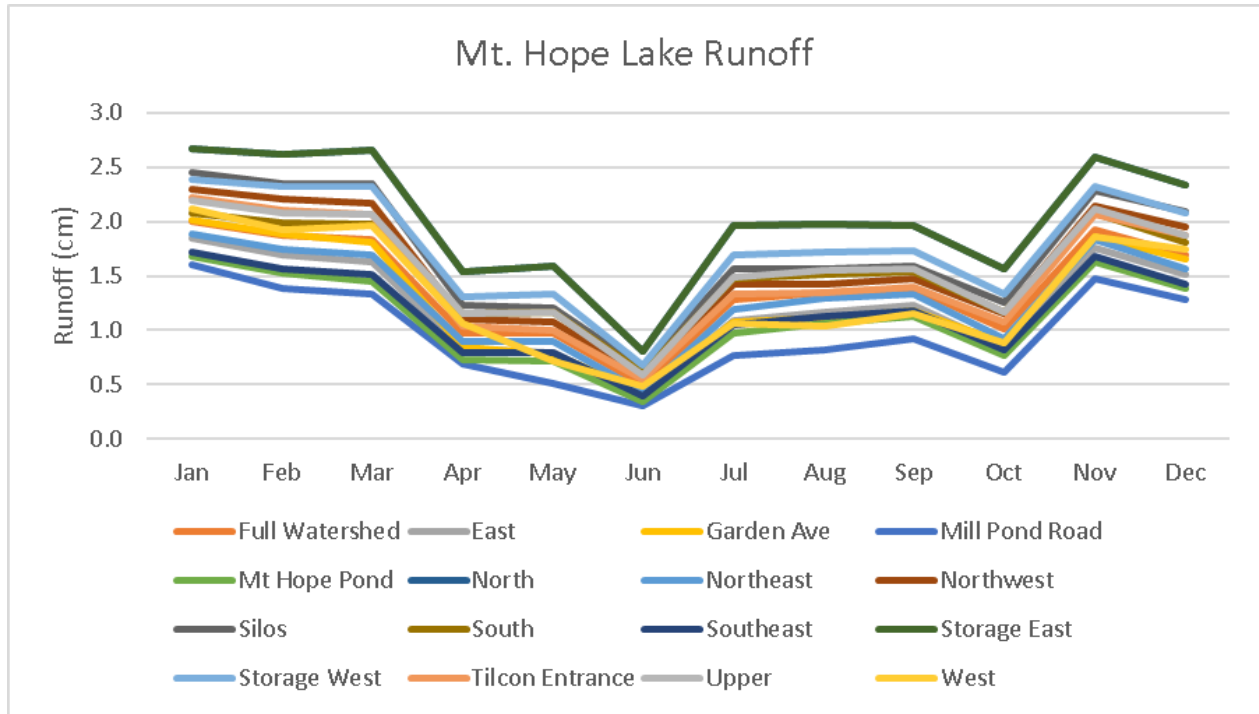


Figure 2510. Average monthly runoff occurring in each sub-watershed in the Mt. Hope Lake watershed

A maximum of 50% difference in runoff exists between all of Mount Hope Lake's subwatersheds (Figure 12). Many of the subwatersheds yielding the highest runoff rates are those which contain parts of the quarry; this is because these areas likely contain a large amount of impervious landcover. When direct precipitation and evapotranspiration to the lake itself are accounted for, Mt. Hope Lake is estimated to receive approximately 2,927,000 m³ or 773.3 million gallons of water a year.

Table 88: Estimated annual loads of nitrogen in the total Mt. Hope Lake Watershed

Category	Description	Total Nitrogen	
		kg	%
Runoff	Hay/Pasture	0.0	0.0
	Cropland	0.0	0.0
	Forest	39.9	4.7
	Wetland	21.8	2.6
	Open Land	0.6	0.1
	Bare rock	86.0	10.1
	Low-Density Mixed	3.6	0.4
	Medium-Density Mixed	6.4	0.7
	High-Density Mixed	0.9	0.1
	Low-Density Open Space	7.5	0.9
	Other Sources	Farm Animals	0.0
Stream Bank		0.0	0.0
Groundwater		548.8	64.4
Septic Systems		136.8	16.0
Total		852.2	100.0



Table 89: Estimated annual loads of nitrogen by sub-watershed in the Mt. Hope Lake Watershed

Category	Description	Full Watershed																			UAL (Quarry) kg
		kg	kg	kg	kg	kg	kg	kg	kg	kg	kg	kg	kg	kg	kg	kg	kg	kg	kg	kg	
Runoff	Hay/Pasture	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	Cropland	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	Forest	399.9	2.9	0.4	0.1	18.8	0.7	0.8	0.4	0.1	0.4	0.7	0.8	0.4	0.1	0.4	0.7	0.8	0.4	0.1	18.0
	Wetland	21.8	0.3	0.0	0.1	8.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	7.0
	Open Land	0.6	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.5
	Bare Rock	86.0	0.0	0.4	0.0	0.0	0.0	2.0	0.0	0.5	0.0	0.0	1.4	1.8	0.5	0.0	0.0	0.0	0.0	0.0	70.6
	Low-Density Mixed	3.6	0.4	0.1	0.1	0.1	0.1	0.2	0.0	0.2	0.5	0.0	0.6	0.6	0.0	0.0	0.0	0.0	0.1	0.2	0.6
	Medium-Density Mixed	6.4	0.0	0.5	0.0	1.7	0.0	0.0	0.0	0.0	0.0	0.5	0.6	0.0	0.0	0.0	0.0	0.0	0.1	0.2	1.0
	High-Density Mixed	0.9	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.2
	Low-Density Open Space	7.3	0.6	0.0	0.0	0.4	0.0	0.4	0.0	0.0	0.0	0.0	0.0	0.0	0.2	0.0	0.0	0.0	0.0	0.0	2.9
Other Sources	Farm Animals	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	Stream Bank	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	Groundwater	548.8	16.2	4.9	2.5	136.6	1.9	3.5	7.1	7.7	3.6	7.6	15.1	9.6	6.6	4.4	334.0	15.8	0.0	0.0	15.8
	Septic Systems	136.8	0.0	0.0	0.0	91.2	0.0	22.8	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	22.8
Total (kg)		852.2	20.5	6.3	94.2	193.7	3.0	4.4	9.6	11.2	4.9	9.6	20.7	13.8	6.1	432.7	45.1	0.0	0.0	0.0	394.2
kg/acre		0.8	0.6	0.7	19.2	0.6	0.6	0.6	0.8	0.9	0.6	0.6	0.9	0.7	0.9	0.9	4.2	0.8	0.0	0.0	1.2

Table 90: Estimated annual loads of phosphorus by sub-watershed in the Mt. Hope Lake Watershed

Category	Description	Full Watershed																			UAL (Quarry) kg
		kg	kg	kg	kg	kg	kg	kg	kg	kg	kg	kg	kg	kg	kg	kg	kg	kg	kg	kg	
Runoff	Hay/Pasture	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	Cropland	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	Forest	2.59	0.18	0.03	0.01	1.21	0.03	0.03	0.03	0.01	0.03	0.03	0.03	0.01	0.05	0.06	0.04	0.08	0.07	0.01	0.37
	Wetland	0.00	0.02	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.02
	Open Land	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	Bare Rock	2.97	0.00	0.01	0.00	0.06	0.02	0.00	0.05	0.00	0.02	0.06	0.00	0.13	0.08	0.00	0.03	2.42	0.00	0.00	2.42
	Low-Density Mixed	0.34	0.04	0.01	0.01	0.09	0.00	0.01	0.00	0.02	0.06	0.00	0.00	0.12	0.01	0.02	0.05	0.05	0.11	0.08	0.11
	Medium-Density Mixed	0.57	0.00	0.05	0.00	0.15	0.00	0.00	0.00	0.05	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.12
	High-Density Mixed	0.08	0.00	0.00	0.00	0.06	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.03
	Low-Density Open Space	0.71	0.06	0.00	0.00	0.04	0.00	0.21	0.00	0.00	0.00	0.00	0.00	0.02	0.00	0.00	0.00	0.00	0.00	0.00	0.09
Other Sources	Farm Animals	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	Stream Bank	1.00	0.00	0.00	0.00	1.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	Groundwater	19.44	0.59	0.20	0.10	4.87	0.08	0.88	0.14	0.14	0.29	0.31	0.53	0.39	0.18	0.18	11.29	0.64	0.00	0.00	0.64
	Septic Systems	5.13	0.00	0.00	0.00	3.42	0.85	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.85	0.00	0.00	0.85
Total (kg)		34.07	0.89	0.30	0.30	3.58	0.73	8.91	0.13	0.20	0.20	0.44	0.53	0.23	0.44	0.44	23.03	0.03	0.03	0.03	23.65
kg/acre		0.03	0.03	0.03	0.03	0.73	0.03	0.03	0.03	0.03	0.03	0.04	0.04	0.03	0.03	0.03	0.31	0.04	0.04	0.03	0.06

Table 91: Estimated annual loads of sediment by sub-watershed in the Mt. Hope Lake Watershed

Category	Description	Full Watershed																			UAL (Quarry) kg
		kg	kg	kg	kg	kg	kg	kg	kg	kg	kg	kg	kg	kg	kg	kg	kg	kg	kg	kg	
Runoff	Hay/Pasture	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
	Cropland	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
	Forest	0.400	0.030	0.010	0.000	0.000	0.020	0.210	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.190
	Wetland	0.120	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.010
	Open Land	0.010	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
	Bare Rock	0.240	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.150
	Low-Density Mixed	0.070	0.010	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.040
	Medium-Density Mixed	0.150	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.060
	High-Density Mixed	0.020	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.020
	Low-Density Open Space	0.140	0.010	0.000	0.000	0.000	0.000	0.050	0.000	0.000	0.000	0.000	0.000	0.000	0.010	0.000	0.000	0.000	0.000	0.000	0.120
Other Sources	Farm Animals	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
	Stream Bank	2.138	0.004	0.006	0.000	0.009	1.021	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.039
	Groundwater	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	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	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Total (kg)		3.288	0.054	0.066	0.029	0.029	1.371	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.289
kg/acre		2.999	1.525	5.349	5.918	4.242	1.371	0.000	1.399	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.755



The estimated yearly external nitrogen load for Mt. Hope Lake is estimated to be largely dominated by nitrogen originating from septic systems and groundwater. Runoff from barren rock is also a significant source, particularly in the Upper subwatershed. The Mill Pond road subwatershed was also estimated to yield a relatively high amount of nitrogen via septic tank influence.

Table 92: Estimated annual loads of phosphorus in the total Mt. Hope Lake Watershed

Category	Description	Total Phosphorus	
		kg	%
Runoff	Hay/Pasture	0.00	0.0
	Cropland	0.00	0.0
	Forest	2.59	6.1
	Wetland	1.22	2.9
	Open Land	0.02	0.0
	Bare rock	2.97	7.0
	Low-Density Mixed	0.34	0.8
	Medium-Density Mixed	0.57	1.3
	High-Density Mixed	0.08	0.2
	Low-Density Open Space	0.71	1.7
Other Sources	Farm Animals	0.00	0.0
	Stream Bank	1.00	2.3
	Groundwater	19.44	45.6
	Septic Systems	13.68	32.1
	Total	42.62	100.0

The majority of the yearly external phosphorus load for Mt. Hope Lake is estimated to originate in septic systems and groundwater, although runoff from forested lands and barren rock also contributes significantly. Similar to the annual nitrogen load, the Mt. Hope Pond and Upper watershed yielded the highest annual loads, while the Mill Pond Road subwatershed yielded the highest amount of phosphorus relative to its size.



Table 93: Estimated annual loads of sediment in the total Mt. Hope Lake Watershed

Category	Description	Sediment	
		kgx1000	%
Runoff	Hay/Pasture	0.00	0.0
	Cropland	0.00	0.0
	Forest	0.40	12.2
	Wetland	0.12	3.6
	Open Land	0.01	0.3
	Barren Land	0.24	7.3
	Low-Density Mixed	0.07	2.1
	Medium-Density Mixed	0.15	4.6
	High-Density Mixed	0.02	0.6
	Low-Density Open Space	0.14	4.3
Other Sources	Farm Animals	0.00	0.0
	Stream Bank	2.14	65.0
	Groundwater	0.00	0.0
	Septic Systems	0.00	0.0
Total		3.29	100.0

The annual sediment load for Mount Hope Lake is estimated to largely originate from eroded stream banks, with runoff contributing relatively minor amounts. The Mount Hope Pond subwatershed is estimated to be the single largest contributor of sediment to Mount Hope Lake, with stream bank erosion from this area contributing as much as an estimated 1,000 kg per year.

The area north of the lake is dominated by the quarry. While the main parts of this quarry are contained in a bowl-like pit that is likely self-contained, an area of quarry operations (appearing from aerial imagery to be a largely paved storage area) of approximately 97.4 acres is located between the quarry pit and the lake. Model My Watershed classifies this land, as well as the rest of the quarry, as barren rock, which yields minimal amounts of sediment. This area was assessed using UAL methodology using the more specific land-use classification of "Extractive Mining", a classification used for this area in the NJ 2015 land-use/land-cover GIS layer. Using this methodology, this 97.4-acre area is estimated to yield approximately 394.2 kg of nitrogen, 23.6 kg of phosphorus, and 157,665.5 kg of sediment per year. Note that the results of these calculations are listed under a separate column in Tables 89-91, however these are not included in the listed totals. Additionally, it should be noted that the UAL analysis does not take into account any BMPs or controls that may currently be in place to mitigate the load. Some of the wetlands between this area and the lake may also capture portions of that load.



Table 94: Estimated annual loads of bacteria for the full Mt. Hope Lake Watershed

Category	Description	Fecal Coliform Organisms	%
	Farm Animals	0.00E+00	0.0
Fecal Coliform	Urban Areas	2.74E+10	13.4
	Wildlife	1.77E+11	86.6
	Total	2.04E+11	100

Most of the bacteria estimated to enter Mt. Hope Lake originates from Wildlife, with a small percentage (approx. 13%) estimated to originate from urban areas. The Mount Hope Pond subwatershed was estimated to be the largest contributor to the total annual bacterial load, likely due to its relatively high surface area.



Table 95: Estimated annual loads of bacteria by subwatershed in the Mt. Hope Pond Watershed

Category	Description	Full Watershed	East	Garden Ave	Millpond Road	Mt.Hope Pond	North	Northeast	Northwest	Slips	South	Southeast	Storage East	Storage West	Ticon Entrance	Upper	West
		%	%	%	%	%	%	%	%	%	%	%	%	%	%	%	%
Fecal Coliform	Farm Animals	0.0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	Urban Areas	13.4	27.1	60.6	87.2	10.1	0	0	59.4	87.5	0	14.7	0	3.7	71.5	1.5	99.4
	Wildlife	86.6	72.9	39.4	12.8	89.9	0	100	40.6	12.5	100	85.3	0	96.3	28.5	98.5	0.6
Total (organisms)	2.04E+11	1.31E+10	4.70E+09	4.83E+09	8.79E+10	0.00E+00	2.38E+09	3.69E+09	4.93E+09	1.76E+09	4.03E+09	0.00E+00	0.00E+00	1.46E+09	3.09E+09	7.43E+10	7.59E+10



FOX'S POND/PARKS LAKE

The watershed for Fox's Pond covers an area of approximately 828.3 acres, while the pond itself features a surface area of approximately 12 acres. The watershed differs from those of many of the other waterbodies in this project in that it is largely urbanized. The area contains a length of Mt. Hope Road, as well as a length of Rt. 80. The pond's inlet is Fox's Brook, which enters at the northern end of the pond. The pond's outlet drains south to the Rockaway River. The watershed consists almost 75% of urbanized land, with the remaining land classified as forested land and wetlands. Descriptions of the pond's subwatersheds are as follows:

- **Chestnut Tr.:** This subwatershed is located along the northwestern edge of the waterbody and contains short lengths of Lakeside Drive and Chestnut Terrace. This subwatershed consists over 80% of urbanized landcover.
- **Fox's Brook:** As its name suggests, this subwatershed contains the inlet for Fox's Pond and is the pond's largest subwatershed, at approximately 750 acres. The area is approximately 73% urbanized, with the remaining land being classified as forest or wetland.
- **Northeast:** This 24-acre watershed contains the intersection of Mt. Hope Road, Academy Street, Caruso Road, and Seminole Avenue, as well as the development north of this intersection. This subwatershed is almost 80% urbanized, with the remainder of the land being forested.
- **North:** This small subwatershed contains the intersection of Chestnut Terrace and Mt. Hope Road and the surrounding urbanized area. The subwatershed is classified as mostly urbanized, with a single acre of forested land to the northeast.
- **Northwest:** This approximately 13-acre subwatershed contains the intersection of Chestnut Terrace and Lakeside Drive, expanding southwest to Legion Court. The area is largely urbanized with 4 acres of forested land.
- **Southeast:** This 9.1-acre subwatershed contains a length of Academy Street, as well as the beach. Like many of the other Fox's Pond subwatersheds, it is largely urbanized with sparse amounts of forest.
- **Southwest:** This subwatershed contains the southern portions of Lakeside Drive and Chestnut Terrace, stretching west to the intersection of Hickory Plaza and Duncan Lane. The area is almost entirely urbanized.
- **West:** This narrow subwatershed contains short lengths of Chestnut Terrace and Lakeside Drive, as well as the area adjacent to Legion Court. The area is largely forested with approximately 2.7 acres of forested land.



Table 96. Land-use by sub-watershed in the Fox's Pond watershed.

Source	Full Watershed Acres	Chestnut Acres	Fox's Brook Acres	Northeast Acres	North Acres	Northwest Acres	Southeast Acres	Southwest Acres	West Acres
Open Water	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Hay/Pasture	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Cropland	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Forest	163.8	1.0	147.0	4.9	1.0	4.0	2.5	0.7	2.7
Wetland	54.1	0.0	54.1	0.0	0.0	0.0	0.0	0.0	0.0
Open Land	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Bare Rock	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Low-Density Mixed	242.9	0.7	226.3	3.5	1.2	3.5	2.5	3.7	1.5
Medium-Density Mixed	48.2	0.5	46.2	0.0	0.2	0.7	0.7	0.0	0.0
High-Density Mixed	3.7	0.0	3.5	0.0	0.0	0.0	0.2	0.0	0.0
Low-Density Open Space	315.6	3.5	273.1	15.6	4.9	4.9	3.2	7.9	2.7
Total	828.3	5.7	750.2	24.0	7.3	13.1	9.1	12.3	6.9

Source	Full Watershed %	Chestnut %	Fox's Brook %	Northeast %	North %	Northwest %	Southeast %	Southwest %	West %
Open Water	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Hay/Pasture	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Cropland	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Forest	19.8	17.5	19.6	20.4	13.7	30.5	27.5	5.7	39.1
Wetland	6.5	0.0	7.2	0.0	0.0	0.0	0.0	0.0	0.0
Open Land	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Barren Land	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Low-Density Mixed	29.3	12.3	30.2	14.6	16.4	26.7	27.5	30.1	21.7
Medium-Density Mixed	5.8	8.8	6.2	0.0	2.7	5.3	7.7	0.0	0.0
High-Density Mixed	0.4	0.0	0.5	0.0	0.0	0.0	2.2	0.0	0.0
Low-Density Open Space	38.1	61.4	36.4	65.0	67.1	37.4	35.2	64.2	39.1
Total	100	100	100	100	100	100	100	100	100

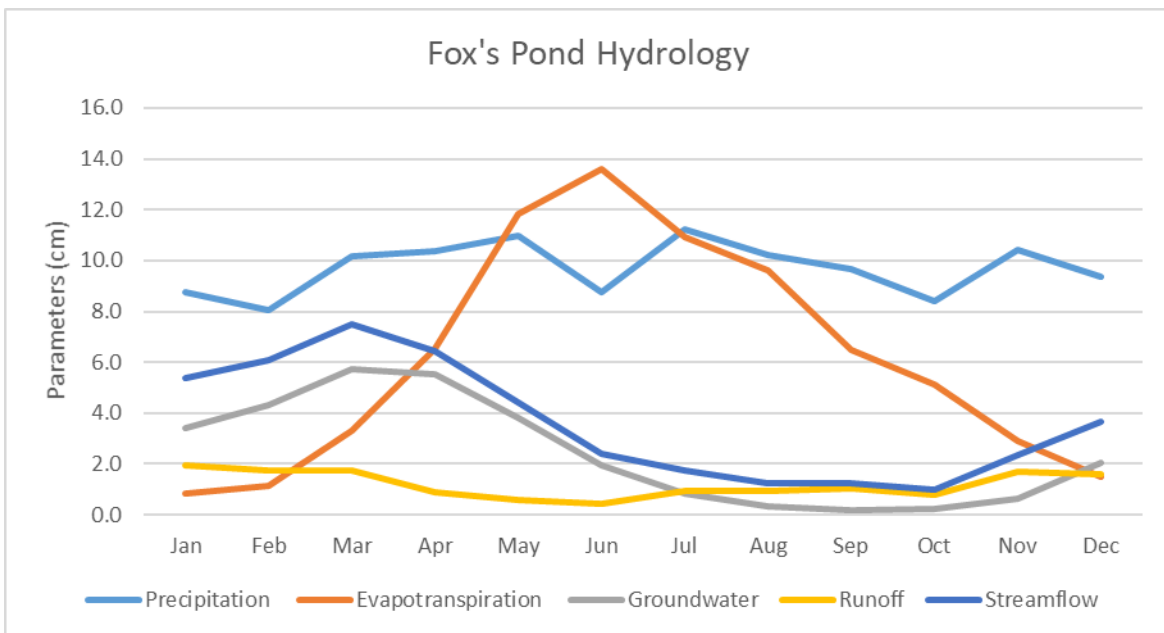


Figure 26. Estimated seasonal changes in hydrology in the Fox's Pond watershed



Table 97. Total hydrological parameters in the full Fox's Pond watershed

Month	Precipitation cm	Evapotranspiration cm	Groundwater cm	Runoff cm	Streamflow cm	cfs
Jan	8.8	0.8	3.4	2.0	5.4	2.4
Feb	8.0	1.2	4.3	1.8	6.1	2.9
Mar	10.2	3.3	5.8	1.8	7.5	3.3
Apr	10.4	6.5	5.5	0.9	6.4	2.9
May	11.0	11.8	3.8	0.6	4.4	1.9
Jun	8.8	13.6	2.0	0.4	2.4	1.1
Jul	11.2	11.0	0.8	0.9	1.8	0.8
Aug	10.2	9.6	0.3	0.9	1.2	0.5
Sep	9.7	6.5	0.2	1.0	1.2	0.6
Oct	8.4	5.1	0.2	0.8	1.0	0.4
Nov	10.4	2.9	0.6	1.7	2.4	1.1
Dec	9.3	1.5	2.1	1.6	3.6	1.6
Total	116.4	73.9	29.0	14.4	43.4	1.6

Due to the higher percentage of urbanized landcover, the Fox's Pond watershed develops higher runoff rates than most of the other watersheds described. The southeast subwatershed yields the highest runoff throughout most of the year, whereas the West subwatershed, which has a higher percentage of forested land than the other subwatersheds, features the lowest annual runoff. When direct precipitation and evapotranspiration of the pond itself are considered, Fox's Pond is estimated to receive approximately 1,475,727.6 m³ or 389.8 million gallons of water each year.

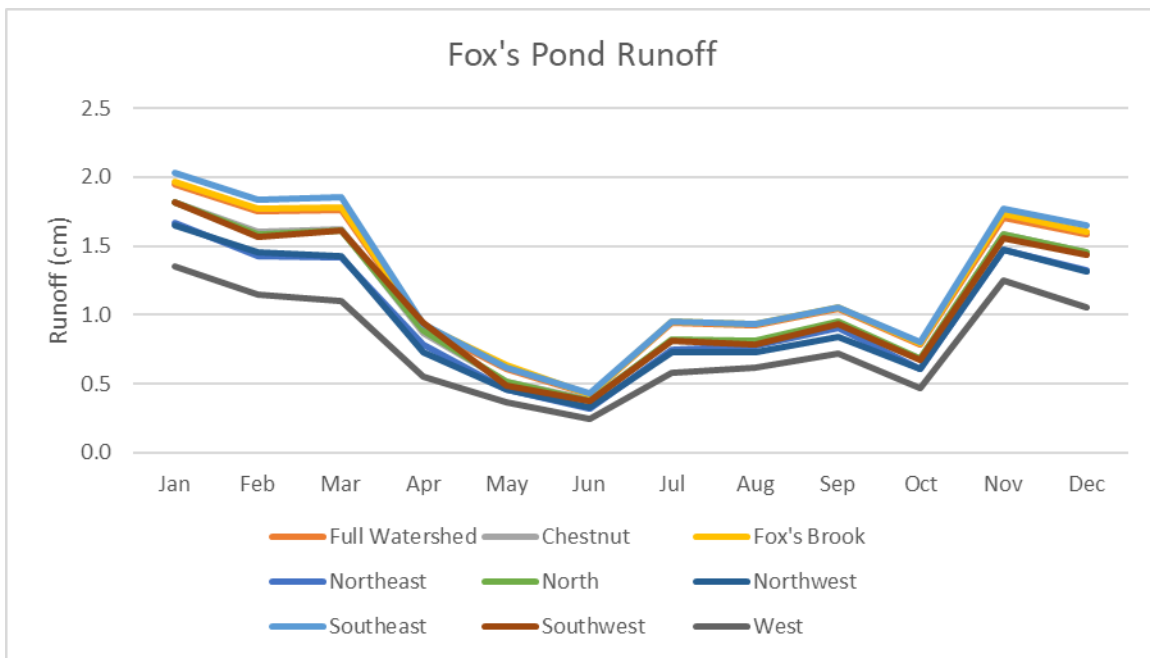


Figure 27. Average monthly runoff occurring in each sub-watershed in the Fox's Pond watershed



Using an older bathymetric survey by the NJDEP, Fox's Pond was determined to have a volume of approximately 69,568.4 m³, or 18.4 million gallons of water. Given that the annual hydraulic load is much higher than this, the pond is estimated to have a relatively high flushing rate of approximately 21.2 times a year, with water in the pond being replaced approximately every 17.2 days. When assessed on a monthly basis, Fox's Pond features a pattern of annualized monthly retention similar to that of some of the other waterbodies in this study with the highest annualized retention period occurring in October.

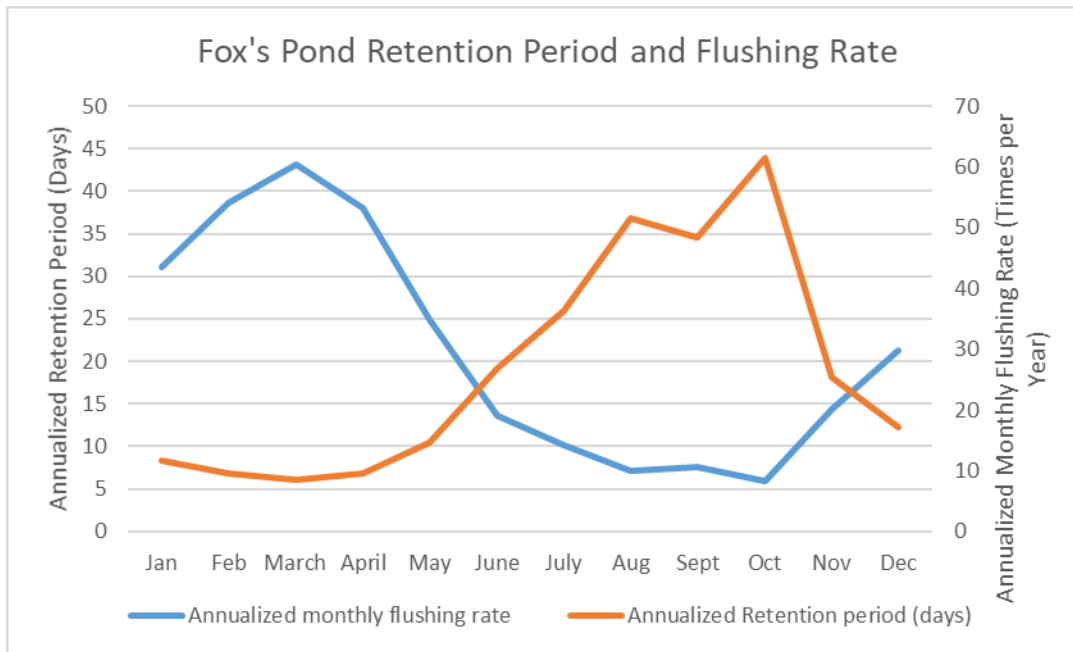


Figure 28. Variations in annualized flushing rates and retention periods over the course of a hypothetical year for Mt. Hope Pond, based on variations in hydraulic loads.

Table 98: Estimated annual loads of nitrogen in the total Fox's Pond Watershed

Category	Description	Total Nitrogen	
		kg	%
Runoff	Hay/Pasture	0.0	0.0
	Cropland	0.0	0.0
	Forest	9.8	2.1
	Wetland	10.3	2.3
	Open Land	0.0	0.0
	Bare rock	0.0	0.0
	Low-Density Mixed	37.2	8.1
	Medium-Density Mixed	26.2	5.7
	High-Density Mixed	2.0	0.4
	Low-Density Open Space	48.3	10.5
Other Sources	Farm Animals	0.0	0.0
	Stream Bank	0.0	0.0
	Groundwater	324.6	70.8
	Septic Systems	0.0	0.0
Total		458.4	100



Table 99: Estimated annual loads of nitrogen by sub-watershed in the Fox's Pond Watershed

Category	Description	Full Watershed	Chestnut	Fox's Brook	Northeast	North	Northwest	Southeast	Southwest	West
		kg	kg	kg	kg	kg	kg	kg	kg	kg
Runoff	Hay/Pasture	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	Cropland	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	Forest	9.8	0.0	8.6	0.4	0.1	0.1	0.2	0.0	0.1
	Wetland	10.3	0.0	10.2	0.0	0.0	0.0	0.0	0.0	0.0
	Open Land	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	Barren Land	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	Low-Density Mixed	37.2	0.2	34.6	0.5	0.1	0.6	0.4	0.5	0.2
	Medium-Density Mixed	26.2	0.3	26.1	0.0	0.1	0.4	0.4	0.0	0.0
	High-Density Mixed	2.0	0.0	2.0	0.0	0.0	0.0	0.2	0.0	0.0
	Low-Density Open Space	48.3	0.7	41.8	2.1	0.5	0.9	0.6	1.1	0.3
Other Sources	Farm Animals	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	Stream Bank	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	Groundwater	324.6	2.7	289.1	11.1	3.4	6.3	4.3	5.5	3.5
	Septic Systems	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	Total (kg)	458.4	3.9	412.3	14.1	4.2	8.4	6.1	7.0	4.1
	kg/acre	0.6	0.7	0.5	0.6	0.6	0.6	0.7	0.6	0.6

Fox's Pond's watershed is entirely serviced by a sewer system, and as such, annual phosphorus and nitrogen loads originate mostly from groundwater and runoff. A majority of Mt. Hope Pond's runoff-based nitrogen load is estimated to originate from urbanized land. The Fox's Brook subwatershed is estimated to yield the highest annual load of nitrogen, mostly originating from groundwater.

Table 100: Estimated annual loads of phosphorus in the total Fox's Pond Watershed

Category	Description	Total Phosphorus	
		kg	%
Runoff	Hay/Pasture	0.00	0.0
	Cropland	0.00	0.0
	Forest	0.79	2.9
	Wetland	0.62	2.3
	Open Land	0.00	0.0
	Bare rock	0.00	0.0
	Low-Density Mixed	3.88	14.4
	Medium-Density Mixed	2.59	9.6
	High-Density Mixed	0.20	0.7
	Low-Density Open Space	5.04	18.7
Other Sources	Farm Animals	0.00	0.0
	Stream Bank	0.00	0.0
	Groundwater	13.86	51.4
	Septic Systems	0.00	0.0
	Total	26.98	100.0



Table 101: Estimated annual loads of phosphorus by sub-watershed in the Fox's Pond Watershed

Category	Description	Full Watershed kg	Chestnut kg	Fox's Brook kg	Northeast kg	North kg	Northwest kg	Southeast kg	Southwest kg	West kg
Runoff	Hay/Pasture	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	Cropland	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	Forest	0.79	0.00	0.66	0.03	0.01	0.01	0.01	0.00	0.01
	Wetland	0.62	0.00	0.59	0.00	0.00	0.00	0.00	0.00	0.00
	Open Land	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	Bare Rock	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	Low-Density Mixed	3.88	0.02	3.55	0.05	0.01	0.06	0.05	0.05	0.02
	Medium-Density Mixed	2.59	0.03	2.54	0.00	0.01	0.04	0.04	0.00	0.00
	High-Density Mixed	0.20	0.00	0.19	0.00	0.00	0.00	0.02	0.00	0.00
	Low-Density Open Space	5.04	0.08	4.28	0.23	0.06	0.09	0.06	0.11	0.04
	Other Sources	Farm Animals	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Stream Bank		0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Groundwater		13.86	0.11	12.23	0.46	0.14	0.26	0.18	0.22	0.14
Septic Systems		0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Total (kg)		27.0	0.24	24.04	0.77	0.23	0.46	0.36	0.38	0.21
	kg/acre	0.03	0.04	0.03	0.03	0.03	0.04	0.04	0.03	0.03

As with nitrogen, groundwater was estimated to be the dominant source of phosphorus for Fox's Pond. Runoff from urbanized areas was also estimated to yield a significant amount of phosphorus, at approximately 11.71 kg per year. Fox's Brook is estimated to contribute the largest annual load of phosphorus among the subwatersheds, most of which originates from groundwater.

During the two field events conducted on Fox's Pond in 2021, the pond was not observed to be anoxic. As such, internal phosphorus loading was limited to that produced by oxic loading, which is estimated to yield a lower rate. This resulted in an estimated internal phosphorus load of 4.46 kg/yr. Table () below compares the external and internal phosphorus loads, as well as a total estimated annual load, estimated to be approximately 31.46 kg/yr. A majority (approx. 86%) of the pond's total estimated annual phosphorus load originates in the watershed, rather than by internal loading.

Table 102. Total estimated annual phosphorus load for Fox's Pond from external and internal sources

Source	Phosphorus (kg/yr)
External (Runoff, Groundwater, Septic Systems)	27.0
Internal	4.5
Total	31.5



Table 103: Estimated annual loads of sediment in the total Fox's Pond Watershed

Category	Description	Sediment	
		kgx1000	%
Runoff	Hay/Pasture	0.000	0.0
	Cropland	0.000	0.0
	Forest	0.280	5.7
	Wetland	0.090	1.8
	Open Land	0.000	0.0
	Barren Land	0.000	0.0
	Low-Density Mixed	1.290	26.3
	Medium-Density Mixed	1.280	26.1
	High-Density Mixed	0.100	2.0
	Low-Density Open Space	1.680	34.2
Other Sources	Farm Animals	0.000	0.0
	Stream Bank	0.188	3.8
	Groundwater	0.000	0.0
	Septic Systems	0.000	0.0
Total		4.908	100.0

Table 104: Estimated annual loads of sediment by sub-watershed in the Fox's Pond Watershed

Category	Description	Full Watershed kg x 1000	Chestnut kg x 1000	Fox's Brook kg x 1000	Northeast kg x 1000	North kg x 1000	Northwest kg x 1000	Southeast kg x 1000	Southwest kg x 1000	West kg x 1000
Runoff	Hay/Pasture	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
	Cropland	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
	Forest	0.280	0.000	0.210	0.010	0.000	0.000	0.000	0.000	0.000
	Wetland	0.090	0.000	0.070	0.000	0.000	0.000	0.000	0.000	0.000
	Open Land	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
	Barren Land	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
	Low-Density Mixed	1.290	0.010	1.100	0.020	0.010	0.020	0.020	0.020	0.010
	Medium-Density Mixed	1.280	0.020	1.180	0.000	0.010	0.020	0.020	0.000	0.000
	High-Density Mixed	0.100	0.000	0.090	0.000	0.000	0.000	0.010	0.000	0.000
	Low-Density Open Space	1.680	0.030	1.330	0.090	0.020	0.030	0.020	0.040	0.010
Other Sources	Farm Animals	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
	Stream Bank	0.188	0.015	0.160	0.031	0.019	0.021	0.017	0.023	0.010
	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)		4.908	0.075	4.140	0.151	0.059	0.091	0.087	0.083	0.030
kg/acre		5.925	13.158	5.519	6.292	8.082	6.947	9.560	6.748	4.348

A majority of Fox's Pond's annual sediment load originates from runoff, particularly from urbanized areas. As with phosphorus and nitrogen, Fox's Brook is the largest overall conveyor of sediment, with the largest amount estimated to originate from low-density open space. The Chestnut subwatershed, however, is estimated to yield the highest annual amount of sediment per acre.



Table 105: Estimated annual loads of bacteria for the full Mt. Hope Pond Watershed

Description	Fecal Coliform Organisms	%
Farm Animals	0.00E+00	0.0
Urban Areas	1.35E+12	95.9
Wildlife	5.84E+10	4.1
Total	1.41E+12	100

Table 106: Estimated annual loads of bacteria by subwatershed for the Fox's Pond Watershed

Description	Full Watershed %	Chestnut %	Fox's Brook %	Northeast %	North %	Northwest %	Southeast %	Southwest %	West %
Farm Animals	0	0	0	0	0	0	0	0	0
Urban Areas	95.9	97	95.9	95.5	97.7	93	94.8	99.1	87.0
Wildlife	4.1	3	4.1	4.5	2.3	7	5.2	0.9	13.0
Total (organisms)	1.41E+12	1.16E+10	1.27E+12	3.88E+10	1.52E+10	2.02E+10	1.69E+10	2.90E+10	7.44E+09

Most of the annual bacterial load in the Fox's Pond watershed is estimated to originate from urbanized areas, while wildlife contributes a relatively small percentage. As with the above parameters, Fox's Brook yields the highest bacterial load of any of the subwatersheds.

WHITE MEADOW LAKE

White Meadow Lake's watershed covers an area of approximately 1,713.72 acres, while the lake features a surface area of approximately 143.1 acres. The watershed consists of the developed areas immediately around the lake, as well as the full watersheds of Mt. Hope Lake and Mt. Hope Pond. The area consists mostly of forested land, with barren rock and developed areas also covering a significant portion of the watershed. Descriptions of the lake's subwatersheds are as follows:

- **Beach 3:** This subwatershed is located in the northeast corner of the waterbody, containing the developed areas around the northern intersection of North Lake Shore Drive and White Meadow Road, as well as parts of Cherokee Avenue and Erie Avenue. The area is approximately 67% Urbanized and 33% forested.
- **Clubhouse:** As its name suggests, this subwatershed contains the White Meadow Lake community clubhouse near the lake's dam, as well as a length of White Meadow Road. The area is largely urbanized with approximately 1 acres of forested land also present.
- **East:** This small subwatershed is located immediately north of the clubhouse subwatershed and contains the community pool, as well as a small length of White Meadow Road. The area is mostly urbanized with a small amount of forested land.
- **Northeast:** This subwatershed contains a majority of North Lake Shore Drive and the urban areas immediately surrounding it. The area is mostly urbanized with the remaining land containing forests and wetlands.
- **Forest Shore:** This 35.1-acre subwatershed is located along the northern edge of the lake, containing a small portion of West Lake Shore Drive. The area is largely forested with a small amount of urbanized land.
- **Hillside:** This subwatershed consists of a largely forested area along the lake's northern-most shoreline. The area is classified as entirely forested.



- **Lakeview:** This subwatershed is located along the southern-most tip of the lake, containing Lakeview Ct. and a length of West Lake Shore Drive. The area is largely urbanized with a small amount of forest and wetland also present.
- **Miami:** This subwatershed is located along the northwestern shoreline, and contains the Miami Trail development. The area is almost evenly divided between undeveloped areas classified as forest and wetland and developed areas.
- **Mt. Hope:** This is the largest of White Meadow Lake's subwatersheds, containing both the full watersheds for Mt. Hope Lake and Mt. Hope Pond. Most of this subwatershed is forested; however, significant amounts of urbanized land and barren rock, sited at the quarry, are also present.
- **North:** This small subwatershed is located immediately east of the Hillside subwatershed and contains a short length of West Lake Shore Drive. Its land-cover is classified as mostly forested.
- **Northwest:** This small subwatershed is located immediately west of the North subwatershed, containing a short length of West Lake Shore Drive. It is classified as largely forested.
- **Oswego:** This subwatershed is located in the southeast corner of the waterbody and contains the swimming area near the dam, as well as portions of Oswego Ave. and Lake Shore Drive. This area is approximately half urbanized and half consisting of forested area and wetlands.
- **South:** This subwatershed is located southwest of the Oswego subwatershed and contains portions of Lake Shore Drive and Wenonah Avenue. The area is dominated by low-density open space (urbanized open land).
- **Wenonah:** This subwatershed is located immediately southwest of the South subwatershed, and contains parts of Lake Shore Drive, Wenonah Avenue, and Hibernia Road. A majority of this subwatershed is urbanized.
- **West:** This 27.4-acre subwatershed is located between the Miami and Forest Shore subwatersheds. The area is largely forested.
- **Brookside:** This watershed is located along the southwestern portion of the lake's shoreline, immediately north of the lake's inlet. This subwatershed is almost evenly split between forested land and urbanized areas.



Table 107: Land-use by subwatershed in the White Meadow Lake watershed.

Source	Full Watershed Acres	Beach 3 Acres	Clubhouse Acres	East Acres	Forest Shore Acres	Hillside Acres	Lakeview Acres	Miami Acres	Mt. Hope Acres	North Acres	Northeast Acres	Northwest Acres	Oswego Acres	South Acres	Wenonah Acres	West Acres	Brookside Acres
Open Water	195.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	195.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Hay/Pasture	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Cropland	1.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Forest	698.8	11.1	1.2	1.7	29.9	11.4	1.5	27.7	548.1	6.9	1.2	7.2	8.9	2.2	3.7	25.7	10.4
Wetland	174.5	0.0	0.0	0.0	0.0	0.0	1.0	4.2	164.6	0.0	1.2	0.0	1.2	0.0	0.0	0.0	2.0
Open Land	1.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Bare Rock	311.8	0.0	0.0	0.0	0.0	0.0	0.0	0.0	311.8	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Low-Density Mixed	99.1	5.7	1.2	1.0	1.5	0.0	4.9	12.1	54.6	0.5	1.2	1.5	3.5	3.0	6.7	0.7	1.0
Medium-Density Mixed	20.8	0.0	0.0	0.0	0.0	0.0	0.7	0.0	18.3	0.0	0.0	0.0	1.5	0.0	0.2	0.0	0.0
High-Density Mixed	2.7	0.0	0.0	0.0	0.0	0.0	0.0	0.2	2.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Low-Density Open Space	208.8	16.6	6.7	4.4	3.7	0.0	13.1	18.5	103.5	2.0	3.0	0.5	4.4	6.4	14.6	1.0	10.4
Total	1713.7	33.4	9.1	7.1	35.1	11.4	21.2	62.7	1400.6	9.4	6.6	9.2	19.5	11.6	25.2	27.4	23.8
Source	Full Watershed %	Beach 3 %	Clubhouse %	East %	Forest Shore %	Hillside %	Lakeview %	Miami %	Mt. Hope %	North %	Northeast %	Northwest %	Oswego %	South %	Wenonah %	West %	Brookside %
Open Water	11.4	0.0	0.0	0.0	0.0	0.0	0.0	0.0	13.9	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Hay/Pasture	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Cropland	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Forest	40.8	33.2	13.2	23.9	85.2	100.0	7.1	44.2	39.1	73.4	18.2	78.3	45.6	19.0	14.7	93.8	43.7
Wetland	10.2	0.0	0.0	0.0	0.0	0.0	4.7	6.7	11.8	0.0	1.82	0.0	6.2	0.0	0.0	0.0	8.4
Open Land	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Barren Land	18.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	22.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Low-Density Mixed	5.8	17.1	13.2	14.1	4.3	0.0	23.1	19.3	3.9	5.3	18.2	16.3	17.9	25.9	26.6	2.6	4.2
Medium-Density Mixed	1.2	0.0	0.0	0.0	0.0	0.0	3.3	0.0	1.3	0.0	0.0	0.0	7.7	0.0	0.8	0.0	0.0
High-Density Mixed	0.2	0.0	0.0	0.0	0.0	0.0	0.0	0.3	0.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Low-Density Open Space	12.2	49.7	73.6	62.0	10.5	0.0	61.8	29.5	7.4	21.3	45.5	5.4	22.6	55.2	57.9	3.6	43.7
Total	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0

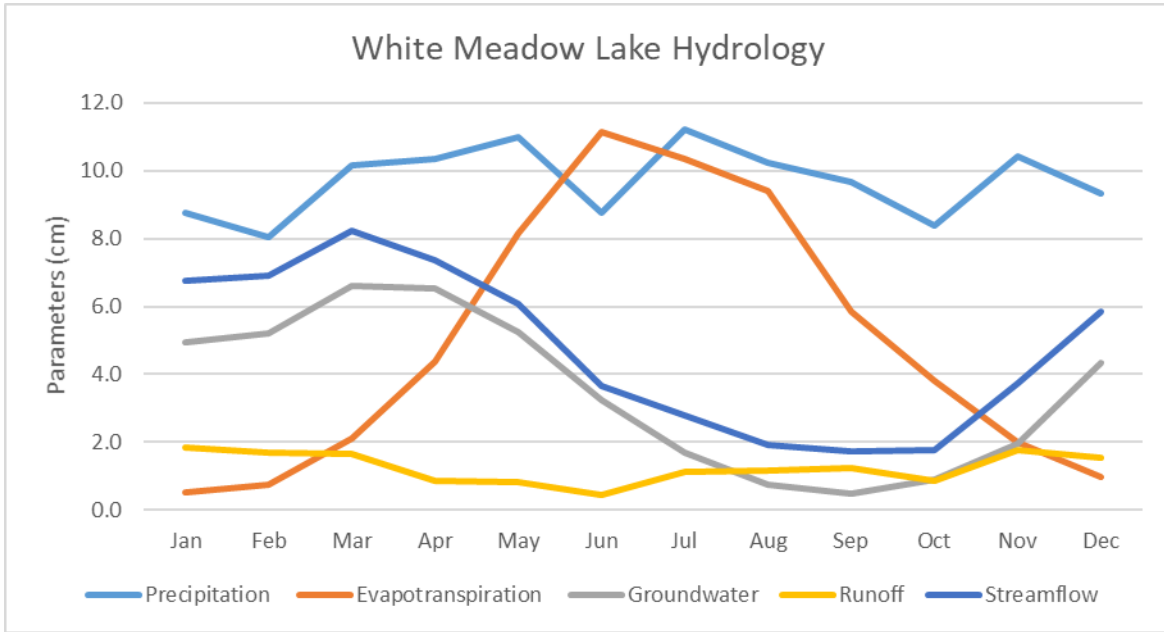


Figure 29. Estimated seasonal changes in hydrology in the White Meadow Lake watershed

Table 108. Total hydrological parameters in the full White Meadow Lake watershed

Month	Precipitation cm	Evapotranspiration cm	Groundwater cm	Runoff cm	Streamflow cm	cfs
Jan	8.8	0.5	4.9	1.8	6.8	6.2
Feb	8.0	0.7	5.2	1.7	6.9	6.9
Mar	10.2	2.1	6.6	1.6	8.2	7.5
Apr	10.4	4.4	6.5	0.9	7.4	7.0
May	11.0	8.2	5.2	0.8	6.1	5.5
Jun	8.8	11.2	3.2	0.4	3.7	3.4
Jul	11.2	10.4	1.7	1.1	2.8	2.5
Aug	10.2	9.4	0.7	1.2	1.9	1.7
Sep	9.7	5.9	0.5	1.2	1.7	1.6
Oct	8.4	3.8	0.9	0.9	1.8	1.6
Nov	10.4	2.0	2.0	1.8	3.7	3.5
Dec	9.3	1.0	4.3	1.5	5.9	5.4
Total	116.4	59.4	41.8	15.0	56.8	4.4

Runoff for the majority of White Meadow Lake’s subwatersheds was relatively high due to the prevalence of urbanized land-use and associated impervious groundcover. The Mt. Hope subwatershed yielded the highest estimated annual runoff, likely due to it featuring more bare rock land cover than other subwatersheds. Much like urban impervious landcover, bare rock similarly allows for almost all water to run off rather than infiltrate into groundwater. When direct participation and evapotranspiration to the lake itself are considered, White Meadow Lake is estimated to receive approximately 4,264,762.9 m³ or 1,126.6 million gallons of water each year.

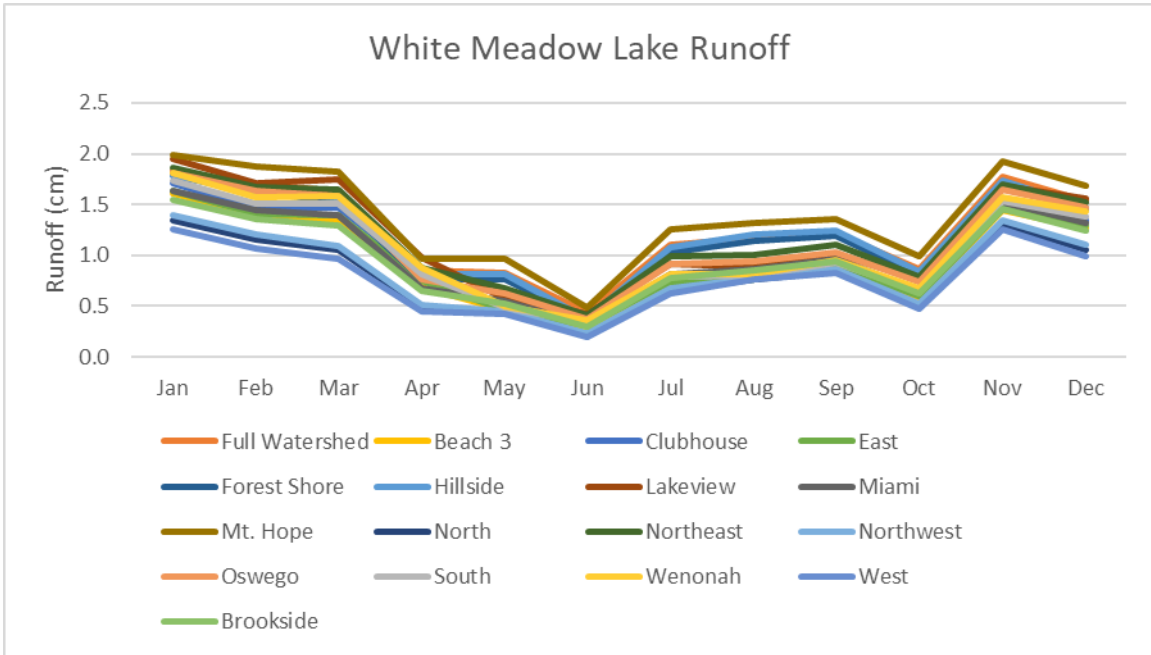


Figure 11. Average monthly runoff occurring in the sub-watersheds of White Meadow Lake watershed

Based on a bathymetric survey of White Meadow Lake conducted in 2008 by Princeton Hydro, White Meadow Lake has an estimated volume of approximately 1,049,200 m³ or 277.7 million gallons of water. The lake is estimated to have a flushing rate of approximately 4.1 times a year, with water entering the lake taking approximately 90 days to leave the system. Examined on a monthly basis, White Meadow Lake's annualized flushing rates and retention periods follow a similar pattern to those of other waterbodies in this study, with the flushing rate being at its lowest between August and October.

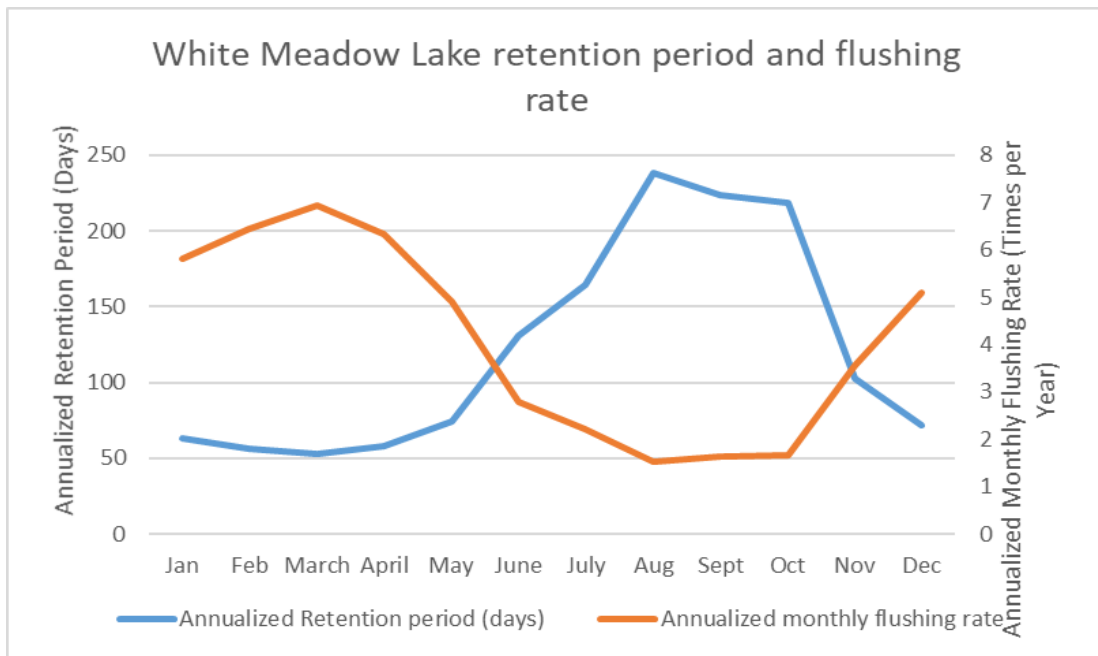


Figure 121. Variations in annualized flushing rates and retention periods over the course of a hypothetical year for White Meadow Lake, based on variations in hydraulic loads.



Table 109: Estimated annual loads of nitrogen by sub-watershed in the White Meadow Lake Watershed

Category	Description	Full Watershed	Beach 3	Clubhouse	East	Forest Shore	Hillside	Lakeview	Miami	Mt. Hope	North	Northeast	Northwest	Oswego	South	Wenonah	West	Brookside
		kg x 1000	kg	kg x 1000	kg x 1000	kg	kg	kg	kg	kg	kg	kg	kg	kg	kg	kg	kg	kg
Runoff	Hay/Pasture	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	Cropland	4.1	0.0	0.0	0.0	0.0	0.0	0.0	3.9	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	Forest	50.2	0.9	0.1	0.1	3.7	1.3	0.1	2.0	42.7	0.5	0.1	0.5	0.2	0.0	0.2	2.0	0.8
	Wetland	31.2	0.0	0.0	0.0	0.0	0.0	0.0	28.0	0.8	0.0	0.2	0.0	0.2	0.0	0.0	0.0	0.4
	Open Land	0.6	0.0	0.0	0.0	0.0	0.0	0.0	0.6	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Low-Density Mixed	Barren Land	88.1	0.0	0.0	0.0	0.0	0.0	0.0	83.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	Low-Density Mixed	13.1	0.8	0.1	0.1	0.1	0.0	0.7	1.7	7.0	0.1	0.1	0.2	0.2	0.4	0.9	0.2	0.1
	Medium-Density Mixed	12.1	0.0	0.0	0.0	0.0	0.0	0.4	0.0	10.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	High-Density Mixed	1.6	0.0	0.0	0.0	0.0	0.0	0.0	0.2	1.4	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	Low-Density Open Space	27.6	2.2	0.6	0.6	0.4	0.0	0.0	13.3	0.3	0.3	0.4	0.1	0.1	0.7	2.0	0.1	1.3
Other Sources	Farm Animals	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	Stream Bank	26.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	Groundwater	1,262.4	81.5	20.6	16.7	88.9	29.5	9.8	24.9	638.6	25.1	14.0	24.6	50.3	26.7	42.4	39.4	11.5
Sewer Systems	Sewer Systems	238.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	238.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	Total (kg)	1,755.6	85.3	21.5	17.6	93.1	30.8	13.1	32.3	1,067.5	26.0	2.8	2.3	25.5	28.2	45.6	41.7	14.1
	kg/acre	1.0	2.6	2.4	2.5	2.7	2.7	0.6	0.5	0.8	2.8	2.3	2.8	2.7	2.4	1.8	1.5	0.6

Table 110: Estimated annual loads of phosphorus by sub-watershed in the White Meadow Lake Watershed

Category	Description	Full Watershed	Beach 3	Clubhouse	East	Forest Shore	Hillside	Lakeview	Miami	Mt. Hope	North	Northeast	Northwest	Oswego	South	Wenonah	West	Brookside
		kg	kg	kg	kg	kg	kg	kg	kg	kg	kg	kg	kg	kg	kg	kg	kg	kg
Runoff	Hay/Pasture	0.85	0.00	0.00	0.00	0.00	0.00	0.00	0.74	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	Cropland	3.48	0.08	0.01	0.01	0.37	0.11	0.01	2.90	0.04	0.01	0.01	0.05	0.05	0.01	0.02	0.18	0.02
	Forest	1.65	0.00	0.00	0.00	0.00	0.00	0.00	1.34	0.00	0.01	0.00	0.00	0.01	0.00	0.00	0.00	0.06
	Wetland	0.02	0.00	0.00	0.00	0.00	0.00	0.00	0.02	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	Open Land	3.12	0.00	0.00	0.00	0.00	0.00	0.00	2.67	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Low-Density Mixed	Barren Land	1.29	0.08	0.01	0.01	0.02	0.00	0.08	0.63	0.01	0.02	0.02	0.02	0.05	0.04	0.10	0.02	0.01
	Low-Density Mixed	1.13	0.00	0.00	0.00	0.00	0.00	0.04	0.00	0.00	0.00	0.00	0.00	0.05	0.00	0.01	0.00	
	Medium-Density Mixed	0.15	0.00	0.00	0.00	0.00	0.00	0.02	0.12	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	
	High-Density Mixed	2.71	0.24	0.07	0.04	0.04	0.00	0.20	1.19	0.03	0.04	0.04	0.01	0.08	0.09	0.21	0.01	
	Low-Density Open Space	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	
Other Sources	Farm Animals	8.00	0.00	0.00	0.00	0.00	0.00	0.00	4.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	
	Stream Bank	353.94	1.13	0.29	0.23	1.23	0.41	0.43	21.52	0.53	0.19	0.34	0.70	0.37	0.70	0.84	0.30	
	Groundwater	8.94	0.00	0.00	0.00	0.00	0.00	0.00	8.94	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	
Sewer Systems	Total (kg)	67.28	1.53	0.38	0.32	1.66	0.52	0.77	44.53	0.43	0.27	0.42	0.42	0.95	0.51	1.04	1.05	
	kg/acre	0.04	0.05	0.04	0.05	0.05	0.05	0.04	0.03	0.05	0.04	0.05	0.05	0.05	0.04	0.04	0.04	

Table 111: Estimated annual loads of sediment by sub-watershed in the White Meadow Lake Watershed

Category	Description	Full Watershed	Beach 3	Clubhouse	East	Forest Shore	Hillside	Lakeview	Miami	Mt. Hope	North	Northeast	Northwest	Oswego	South	Wenonah	West	Brookside
		kg x 1000	kg x 1000	kg x 1000	kg x 1000	kg x 1000	kg x 1000	kg x 1000	kg x 1000	kg x 1000	kg x 1000	kg x 1000	kg x 1000	kg x 1000	kg x 1000	kg x 1000	kg x 1000	kg x 1000
Runoff	Hay/Pasture	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
	Cropland	0.330	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.140	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
	Forest	0.760	0.030	0.000	0.000	0.170	0.030	0.000	0.000	0.04	0.220	0.01	0.000	0.020	0.010	0.000	0.080	0.020
	Wetland	0.110	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.040	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
	Open Land	0.010	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Low-Density Mixed	Barren Land	0.300	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.120	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
	Low-Density Mixed	0.340	0.030	0.010	0.010	0.080	0.010	0.000	0.030	0.070	0.000	0.010	0.010	0.020	0.020	0.040	0.010	0.010
	Medium-Density Mixed	0.400	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.150	0.000	0.000	0.000	0.000	0.000	0.010	0.000	0.000
	High-Density Mixed	0.050	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.020	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
	Low-Density Open Space	0.710	0.090	0.030	0.030	0.790	0.010	0.000	0.080	0.110	0.150	0.01	0.010	0.000	0.000	0.040	0.080	0.010
Other Sources	Farm Animals	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
	Stream Bank	18.624	0.031	0.020	0.014	0.008	0.000	0.000	0.306	0.028	4.877	0.006	0.010	0.005	0.021	0.042	0.003	0.017
	Groundwater	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	
Sewer Systems	Sewer Systems	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
	Total (kg/1000)	21.634	0.181	0.060	0.054	0.198	0.030	0.030	0.436	0.248	5.797	0.026	0.030	0.035	0.081	0.172	0.103	0.107
	kg/acre	12.624	5.419	6.593	7.606	5.641	2.632	2.632	20.566	3.955	2.766	4.545	3.804	4.769	6.983	3.759	4.496	



Table 112: Estimated annual loads of nitrogen in the total White Meadow Lake Watershed

Category	Description	Total Nitrogen	
		kg	%
Runoff	Hay/Pasture	0.0	0.0
	Cropland	4.1	0.2
	Forest	50.2	2.9
	Wetland	31.2	1.8
	Open Land	0.6	0.0
	Bare rock	88.1	5.0
	Low-Density Mixed	13.1	0.7
	Medium-Density Mixed	12.1	0.7
	High-Density Mixed	1.6	0.1
	Low-Density Open Space	27.6	1.6
Other Sources	Farm Animals	0.0	0.0
	Stream Bank	26.0	1.5
	Groundwater	1262.4	71.9
	Septic Systems	238.5	13.6
Total		1755.6	100

The estimated annual nitrogen load for White Meadow Lake is dominated by nitrogen originating from groundwater, with the few septic systems in the watershed also contributing a significant load. It should be noted that a large portion of the lake's watershed is on a sewer system rather than septic, including the areas immediately around the lake's shoreline. The only houses with septic systems within the 300' buffer of the lake or any inlets were in the Mt. Hope subwatershed, which yielded a majority of that lake's total load.

Table 113: Estimated annual loads of Phosphorus in the total White Meadow Lake Watershed

Category	Description	Total Phosphorus	
		kg	%
Runoff	Hay/Pasture	0.00	0.0
	Cropland	0.85	1.3
	Forest	3.48	5.2
	Wetland	1.65	2.5
	Open Land	0.02	0.0
	Bare rock	3.12	4.6
	Low-Density Mixed	1.29	1.9
	Medium-Density Mixed	1.13	1.7
	High-Density Mixed	0.15	0.2
	Low-Density Open Space	2.71	4.0
Other Sources	Farm Animals	0.00	0.0
	Stream Bank	8.00	11.9
	Groundwater	35.94	53.4
	Septic Systems	8.94	13.3
Total		67.28	100.0



The estimated yearly external phosphorus load in White Meadow Lake featured a similar pattern to that of nitrogen, with groundwater yielding the largest majority of the load, and septic systems also producing a significant amount. Stream bank erosion was also a significant source of phosphorus, and largely originated from the Mt. Hope subwatershed. Forested land, bare rock, and low-density open space yielded the highest runoff-based annual loads.

During field events in 2021, White Meadow Lake was not observed to become anoxic. As such, oxic loading over the course of the growing season is estimated to be approximately 53.16 kg/yr. Additionally, the lake features a population of common carp, which may also be contributing to internal phosphorus loading via bioturbation. The current density of this population is not presently known; as such, Princeton Hydro utilized a loading rate of 5 mg/m²/day, as per Lamarra (1975) and assumed that approximately half of the load would shortly settle to the lake bottom. This resulted in an estimated of approximately 354.7 kg/yr. It should be stressed that, with more accurate recent fisheries data, this estimated load can be better refined.

Table 114 below displays the external and internal loads of phosphorus for White Meadow Lake, as well as the grand total, which is estimated to be approximately 475.14 kg/year. According to the models, feeding actions by carp are estimated to be a disproportionately high driver (approximately 75%) of phosphorus loading in White Meadow Lake. It should be noted, however, that these models do not take into account some of the management practices that have already been implemented on the lake, such as the lake's alum injection system.

Table 114. Total estimated annual phosphorus load for White Meadow Lake from external and internal sources	
Source	Phosphorus (kg/yr)
External (Runoff, Groundwater, Septic Systems)	67.3
Internal	53.2
Carp	354.7
Total	475.1



Table 115: Estimated annual loads of sediment in the total White Meadow Lake Watershed

Category	Description	Sediment	
		kgx1000	%
Runoff	Hay/Pasture	0.000	0.0
	Cropland	0.330	1.5
	Forest	0.760	3.5
	Wetland	0.110	0.5
	Open Land	0.010	0.0
	Barren Land	0.300	1.4
	Low-Density Mixed	0.340	1.6
	Medium-Density Mixed	0.400	1.8
	High-Density Mixed	0.050	0.2
	Low-Density Open Space	0.710	3.3
Other Sources	Farm Animals	0.000	0.0
	Stream Bank	18.624	86.1
	Groundwater	0.000	0.0
	Septic Systems	0.000	0.0
Total		21.634	100.0

The total estimated yearly sediment load for White Meadow Lake largely originated from eroded stream banks, again, mostly from the Mt. Hope subwatershed. It is likely however that a large portion of this load remains in Mt. Hope Lake and does not continue downstream to White Meadow Lake. Forested and urbanized landcover did yield small amounts of sediment, however these were several orders of magnitude less than the yearly load estimated to originate from stream banks. When examined on a per-acre basis, the Lakeview subwatershed yielded the highest estimated annual load of sediment per acre. This is likely due to the subwatershed's lower proportion of forested land and wetlands relative to urbanized landcover. While urbanized landcover is prevalent throughout the lake's watershed, many of the other subwatersheds have more forested land and wetlands as part of their total area.

Table 116: Estimated annual loads of bacteria in the total White Meadow Lake Watershed

Category	Description	Fecal Coliform Organisms	%
Fecal Coliform	Farm Animals	0.00E+00	0.0
	Urban Areas	1.91E+11	43.4
	Wildlife	2.49E+11	56.6
	Total	4.40E+11	100

While a majority of the total bacterial load for White Meadow Lake is estimated to originate from wildlife, a significant amount is also estimated to originate urban areas. The Mt. Hope subwatershed was estimated to yield the highest annual load of bacteria, most of which originates from Wildlife.



Table 117: Estimated annual bacterial loads by sub-watershed in the White Meadow Lake Watershed

Category	Description	Full Watershed	Beach 3	Clubhouse	East	Forest Shore	Hillside	Lakeview	Miami	Mt. Hope	North	Northeast	Northwest	Oswego	South	Wenonah	West	Brookside	
		%	%	%	%	%	%	%	%	%	%	%	%	%	%	%	%	%	
C Fecal Coliform	Farm Animals	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	Urban Areas	43.4	90.2	97.4	94.2	14.3	0.0	98.8	79.8	27.6	37.5	93.7	31.3	81.8	96.1	97.3	2.8	76.8	0.0
	Wildlife	56.6	9.8	2.6	5.8	85.7	100	1.2	20.2	72.4	62.5	6.3	68.7	18.2	3.9	2.7	97.2	23.2	0.0
	Total (organisms) volume	4.40E+11	4.06E+10	1.72E+10	1.07E+10	1.24E+10	4.05E+09	4.59E+10	4.90E+10	2.70E+11	3.95E+09	7.03E+09	3.72E+09	1.74E+10	2.04E+10	4.98E+10	4.98E+10	1.6E+10	1.6E+10
	Total (organisms)	4.40E+11	4.06E+10	1.72E+10	1.07E+10	1.24E+10	4.05E+09	4.59E+10	4.90E+10	2.70E+11	3.95E+09	7.03E+09	3.72E+09	1.74E+10	2.04E+10	4.98E+10	4.98E+10	1.6E+10	1.6E+10



4. LAKE-BASED WATER QUALITY DATA

4.1 METHODS

Sampling events were conducted at each of the lakes three (3) different times over the course of 2021 in order to collect data during Spring, Summer, and Autumn conditions. Lake sampling was not conducted at Camp Lewis Lake or Mt. Hope Lake, as permission to access these waterbodies was not granted by landowners. Additionally, Fox's Pond was not sampled during the spring event only, as the water level was lowered at this time due to work occurring on the Pond's dam.

At each lake, *In-situ* water quality data was collected at two locations using a calibrated multi-probe water quality meter. Princeton Hydro is certified by the State of New Jersey for the analysis of *In-situ* water quality data (Certification #10006). This data was collected throughout the water column in half-meter to one-meter increments in order to generate full profiles of the entirety of the water column. The parameters sampled as part of *In-situ* water quality sampling are water temperature (°C), dissolved oxygen (mg/L), specific conductivity (mS/cm), and pH (standard units). Additionally, water clarity was measured using a Secchi disk.

At a sampling point located at the deepest area of each lake, discrete water quality samples were collected at the surface of the water column by hand and half a meter above the bottom sediments using a Van Dorn sampler. At the end of each sampling event, these samples were delivered to the laboratory Environmental Compliance Monitoring (#18630) in HillsTownship Township, NJ for analysis. Samples were analyzed for the following parameters:

- Total Phosphorus (TP)
- Soluble Reactive Phosphorus (SRP)
- Chlorophyll *a* (Chl. *a*)
- Nitrate Nitrogen (NO₃-N)
- Nitrite Nitrogen (NO₂-N)
- Ammonia Nitrogen (NH₃-N)
- Total Suspended Solids (TSS)

In addition, plankton samples were collected at the discrete water quality sampling location. These were sampled using a tow-net pulled vertically from a depth within the lake's thermocline (the sharpest change in temperature along the water column). If a lake was not stratified and featured no thermocline, the net was pulled from a depth equal to twice the Secchi depth. Samples were taken to Princeton Hydro's in-house laboratory, preserved with Lugol's solution, and assessed for community composition.

Additionally, notes were taken regarding pertinent observations, such as weather, submerged aquatic vegetation (SAV) or algae growth, and water color. Maps displaying the sampling locations on each lake are provided in Appendix II.



4.2 RESULTS

GREEN POND

In-situ water quality

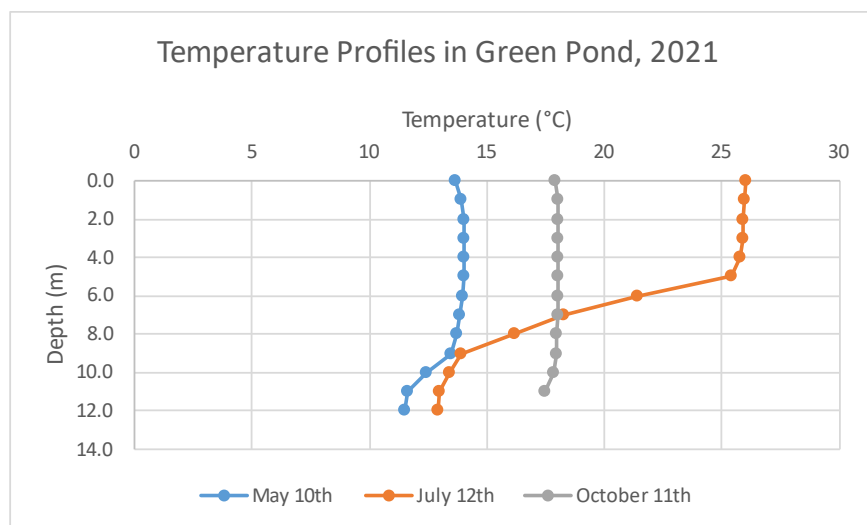


Figure 32. Temperature profiles collected during dates in 2021 at the north station at Green Pond

Green pond featured a minor degree of thermal stratification during the early-May event, with the thermocline occurring between 9 and 11 meters. This stratification became more pronounced during the July event, with a thermocline occurring between 6 and 8 meters in depth. By October, the water column had become thermally well-mixed. Thermal stratification is a common phenomenon that occurs in lakes typically towards the middle of the summer season. As surface water temperatures rise, this water becomes less dense and rises above a layer of colder water situated in the bottom of the water column. As the difference in temperature between these two layers increases, they become less able to mix. The sharpest change in water temperature between two adjacent depths under these conditions is typically referred to as the thermocline. *In-situ* water quality data for all lakes studied is provided in Appendix III.

Dissolved oxygen concentrations during the May sampling event were sufficient throughout the entirety of the water column, although a small decrease was measured in the bottom 2 meters. By July, these bottom few meters had become anoxic (DO <1 mg/L). Bottom dissolved oxygen concentrations recovered by October. The reduction of dissolved oxygen at the bottom of the lake is a common occurrence associated with thermal stratification. As the warm, upper layer of the water column separates from the cooler, deeper layer, atmospheric oxygen that normally mixes into the water column at the surface is less able to mix to the lower reaches of the water column. As a result, dissolved oxygen concentrations at the bottom of a stratified lake will typically become reduced through respiration of bacteria and other organisms. This both reduces available habitat for fish and other organisms and can potentially lead to the loading of phosphorus into the water column from the bottom sediments, which will be described in greater detail below.

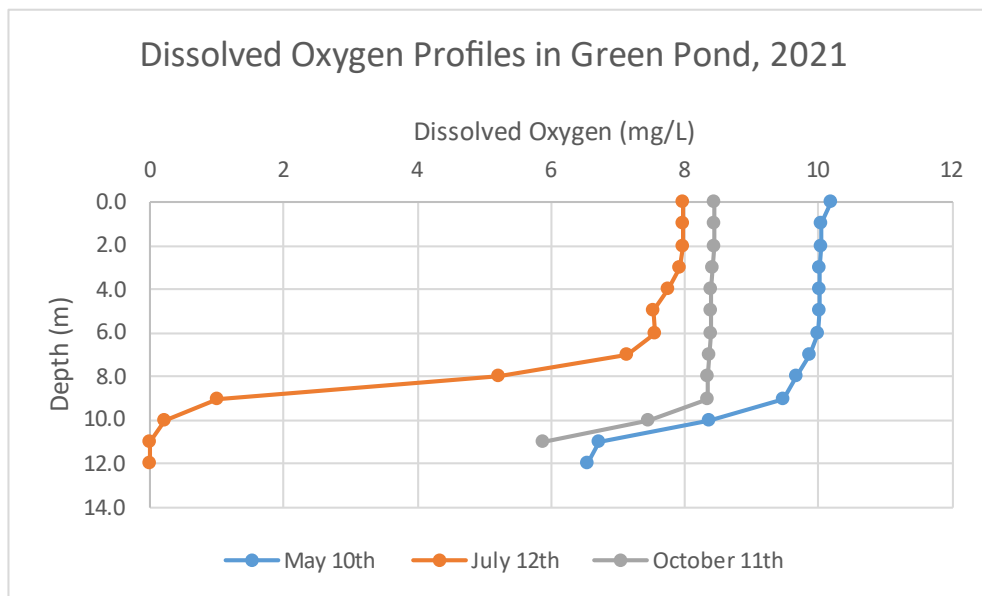


Figure 33. Dissolved oxygen profiles collected 2021 at the North Station at Green Pond

In the past, Princeton Hydro has typically measured high water clarities by Secchi depth in Green Pond. The 2021 growing season continued this trend, with clarities of almost 5 meters measured during the May event. These dropped slightly in July to approximately 3-3.5 meters before increasing to approximately 4.5 meters in October.

Discrete water quality

The parameters analyzed in a typical suite of discrete water quality samples in a recreational lake in New Jersey consist largely of nutrients that are used by plants, algae, and cyanobacteria. Of these nutrients, one of the most important for many lakes in the region is phosphorus. Phosphorus is often a limiting nutrient in a lake, meaning that even a relatively small increase in the nutrient will result in a large increase in algae productivity. Very high spikes of phosphorus are usually associated with large algae and/or cyanobacteria blooms. In this study, two variations of phosphorus were assessed: total phosphorus (TP) and soluble reactive phosphorus (SRP). Total phosphorus is all phosphorus present in the water sample, including that which is locked in organic matter or algae cells and not present available for assimilation by other algae or cyanobacteria. Soluble reactive phosphorus is the portion of phosphorus in the sample that is freely available for assimilation by photosynthetic organisms. SRP is typically detected at very low concentrations, and any significant increases usually result in an excess of algae and/or cyanobacteria.

While phosphorus can enter a waterbody through the watershed, it can also enter the water column through a process known as internal loading. In instances where bottom dissolved oxygen levels go completely anoxic (DO <1 mg/L), redox reactions at the sediment-water interface allow phosphorus normally bound to solid substances in the sediment to precipitate back into the water column. During a mixing event (such as fall turnover) where the surface and deep waters mix, this released phosphorus is mixed to the top of the water column, where it is available for assimilation by algae and cyanobacteria. The NJ Surface Water Quality Standards list 0.05 mg/L of total phosphorus as the maximum concentration that should be measured in any standing body of water with the FW2 classification.



In addition to phosphorus, water samples were analyzed for nitrate-N and ammonia. While the nitrogen is not typically the limiting nutrient in most northeastern lakes, it can be assimilated by plants and algae once it has been reduced to ammonia. Nitrogen often enters the waterbody during storm events as organic debris and fertilizers are washed into the waterbody, as well as through the atmosphere. Additionally, groundwater inputs usually naturally contain relatively high nitrogen concentrations compared to surface water. Ammonia enters the water column through a variety of processes, such as the fixation of nitrogen by bacteria, or by the decomposition of organic matter.

Water samples were also analyzed for total suspended solids (TSS), a measure of organic debris and suspended sediments in the water column. A high TSS results in water that appears muddy and features poor water clarity and may explain these conditions in the absence of high chlorophyll a concentrations or plankton counts. Often, TSS will increase following a rain event as sediment washes into the waterbody.

Lastly, water samples were also analyzed for chlorophyll a, a compound utilized during photosynthesis by most plants, algae, and cyanobacteria. Chlorophyll a is typically used as a proxy for overall algae and cyanobacteria growth and is usually positively correlated with phosphorus concentrations and negatively correlated with Secchi depths.

Discrete water quality monitoring data for all lakes in this study is provided in Appendix IV.

For both the May and July events, both the surface and deep samples at Green Pond measured minimal total phosphorus concentrations of 0.01 mg/L (Figure 34). This increased to 0.04 mg/L and 0.03 mg/L for the surface and deep respectively during the October event. While a concentration of 0.04 mg/L is relatively elevated for Green Pond, this is still below the NJ Surface Water Quality Standard of 0.05 mg/L. Samples from Green Pond did not yield measurable amounts of SRP over the course of the entire year.

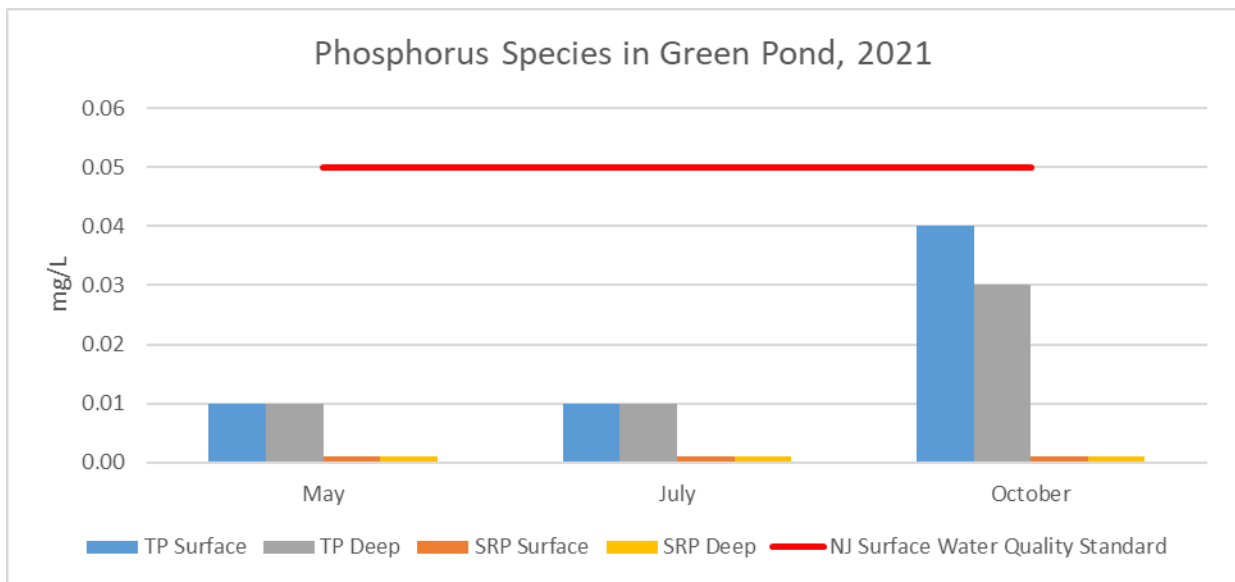


Figure 34. Concentrations of total phosphorus (TP) and soluble reactive phosphorus (SRP) measured from surface and deep samples in 2021 from the North station at Green Pond



Nitrate-N concentrations were relatively low throughout the year, particularly during the Spring, when the surface sample was measured to be 0.01 mg/L and the deep sample was below the detection limit. By July, concentrations had increased slightly to 0.03 and 0.06 mg/L at the surface and deep, respectively. Concentrations dropped slightly in September, with the surface sample yielding 0.02 mg/L and the deep sample yielding 0.01 mg/L. Ammonia-nitrogen concentrations were low throughout the year, measuring only between 0.01 – 0.02 mg/L throughout May and July, and being below the measurable concentration in September. TSS was not measured at measurable concentrations from surface samples at all throughout the year, and was not measured in bottom samples during May and September. The July bottom sample, however, yielded a relatively high concentration of 11 mg/L.

Surface and deep chlorophyll *a* concentrations were overall relatively low throughout the season, reaching a seasonal high of only 5.3 µg/L at the surface in July. It should be noted that the deep sample collected in May was slightly higher in concentration than the surface sample on the same date, suggesting a presence of deep-water algae.

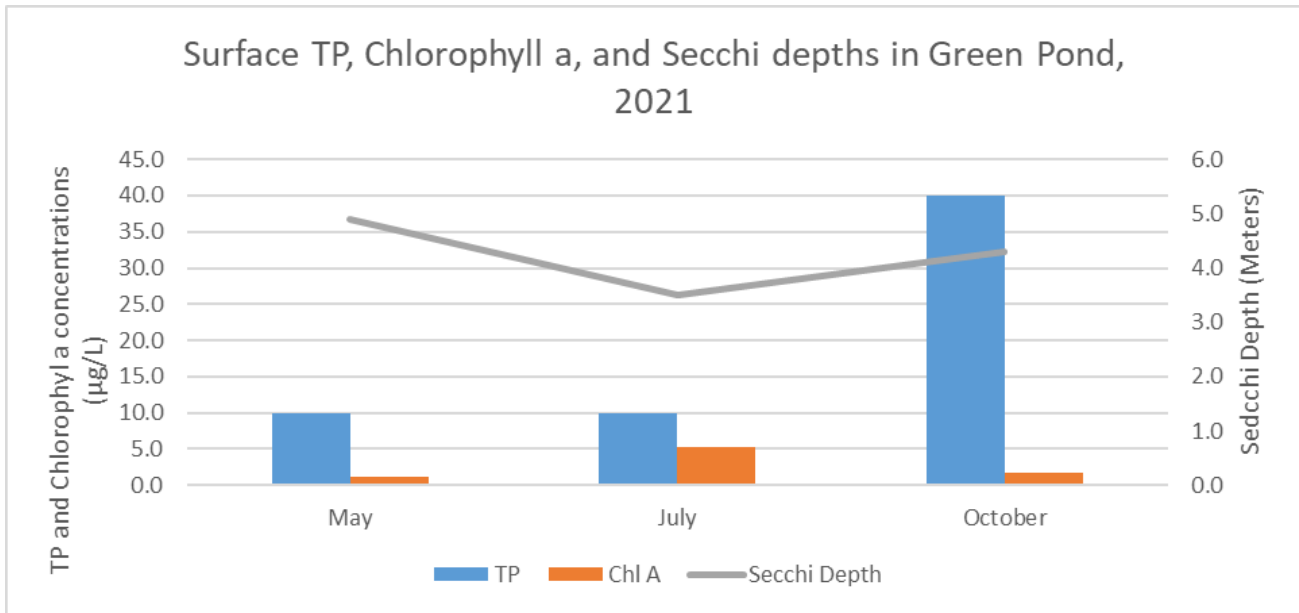


Figure 13. Concentrations of chlorophyll *a* (Chlorophyll *a*) and total phosphorus (TP), as well as Secchi depths, measured from the surface of the North station at Green Pond on three dates in 2021.

Plankton and macrophytes

Plankton data for each lake in this study is provided in Appendix V.

During the May event, Green Pond featured an abundance of the diatom *Asterionella*, as well as common densities of the diatom *Fragilaria*, the golden algae *Dinobryon*, the cyanobacteria *Aphanocapsa*, and the dinoflagellate *Ceratium*. In many northern NJ lakes, the abundance of diatoms and golden algae is common during the earlier, cooler portion of the growing season. The zooplankton community in May was dominated by the copepod genus *Microcyclops* and the rotifer *Keratella*. The cyanobacteria *Microcystis* was relatively common in the sample from July, with *Dinobryon* also featuring as a secondary presence. The zooplankton community at this time was largely dominated by the cladoceran *Bosmina*. Phytoplankton and zooplankton densities in Green Pond had overall



dropped during by the October event, with the phytoplankton community being largely represented by *Dinobryon* and the zooplankton community being dominated by *Keratella*.

Due to Green Pond's depth, the only macrophytes observed during the Rockaway lakes surveys were those around the docks on the lake's northern end. This area featured a moderate-density assemblage of tape grass (*Vallisneria americana*) and pondweeds (*Potamogeton* sp.). Occasional Eurasian watermilfoil (*Myriophyllum spicatum*) plants were also observed in this area.

EGBERT LAKE

In-situ Water Quality

Egbert Lake featured a thermally well-mixed water column during the May sampling event. Dissolved oxygen at this time was sufficient throughout the water column. During the July event, the water column was observed to feature a slight thermal gradient of approximately 2-3°C. Reductions in dissolved oxygen were also measured during this event within the bottom-most half-meter of the water column. The dam station featured a slight increase in dissolved oxygen at the very bottom of the water column, however. This may have been a product of plant or algae growth occurring just over the bottom sediments. Water clarity as measured with a Secchi disk was measured to be at least 1.5 meters during this event; plants obscured the disk before it disappeared from view due to turbidity. By September, the water column had become thermally mixed, and dissolved oxygen concentrations, while not particularly high, were sufficient for aquatic life. Secchi depths also increased during this time, measured at 1.9 – 2 meters.

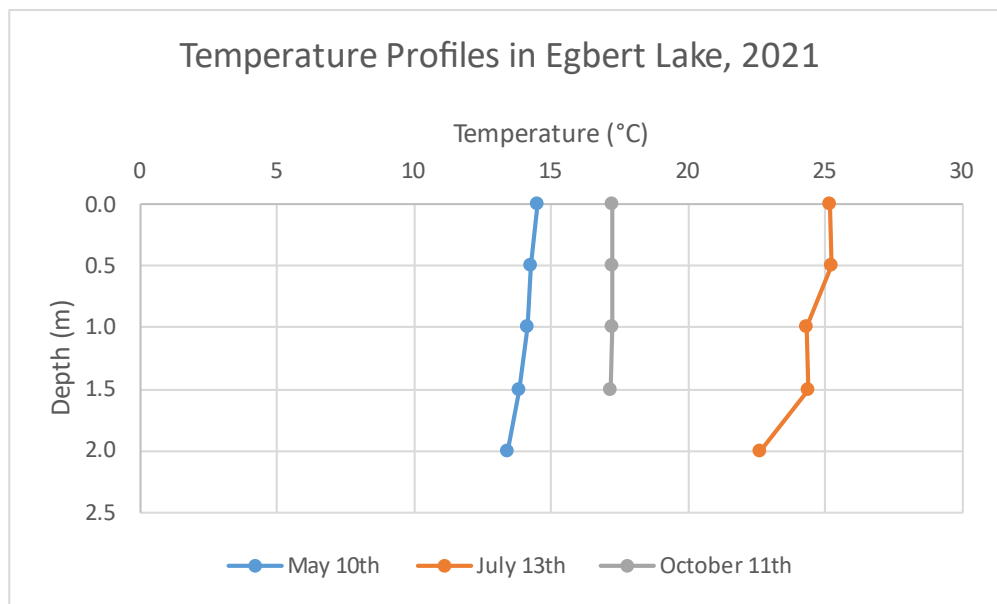


Figure 14. Temperature profiles collected during 2021 at the Dam station at Egbert Lake

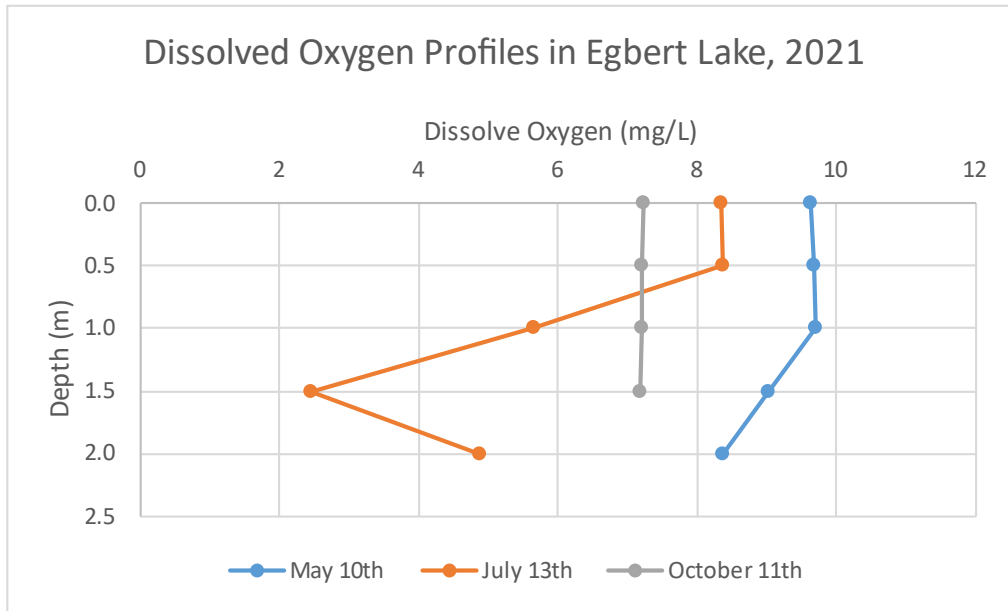


Figure 15. Dissolved oxygen profiles collected during 2021 at the Dam station at Egbert Lake

Discrete Water Quality

Total phosphorus concentrations were relatively low in May, with both the surface and deep sample yielding 0.02 mg/L (Figure 19). SRP for both surface and deep samples during this date were below the detectable concentration (0.002 mg/L). July featured a surface TP concentration of 0.02 mg/L and no detectable SRP; however, the deep sample yielded 0.06 mg/L, as well as an SRP concentration of 0.003 mg/L. This suggests that a degree of internal phosphorus loading is occurring in Egbert Lake. The deep concentration for this date also exceeds the NJ Surface Water Quality Standard for phosphorus of 0.05 mg/L. By September, surface concentrations of TP had increased to 0.04 mg/L, while deep concentrations decreased to 0.03 mg/L. SRP was below detectable concentrations at the surface during this date, while the deep sample yielded a concentration of 0.002 mg/L.

Egbert Lake typically yielded moderate concentrations of nitrogen, with both the surface and deep samples yielding concentrations of 0.05 mg/L. By July, the surface concentration had increased to 0.07 mg/L, while the deep concentration at increased further to 0.09 mg/L. October saw a slight decrease in both surface and deep samples to 0.05 and 0.04 mg/L, respectively. Ammonia-N concentrations were relatively low throughout the season, measuring at only 0.01 mg/L for both surface and deep samples in May and July, and being below the measurable concentration in September.

Surface TSS concentrations were generally low, with a maximum of 3 mg/L in September. In May and July, however, deep samples were slightly higher, with the July deep sample yielding 11 mg/L. Chlorophyll *a* concentrations were low-to-moderate for most of the season, with surface samples reaching a maximum of 8.3 µg/L. Deep samples were consistently higher, however, particularly during the October event, which yielded a deep chlorophyll concentration of 24.0 µg/L. This may be a product of epiphytial algae growing on macrophytes, or due to benthic algae at the bottom of the water column.

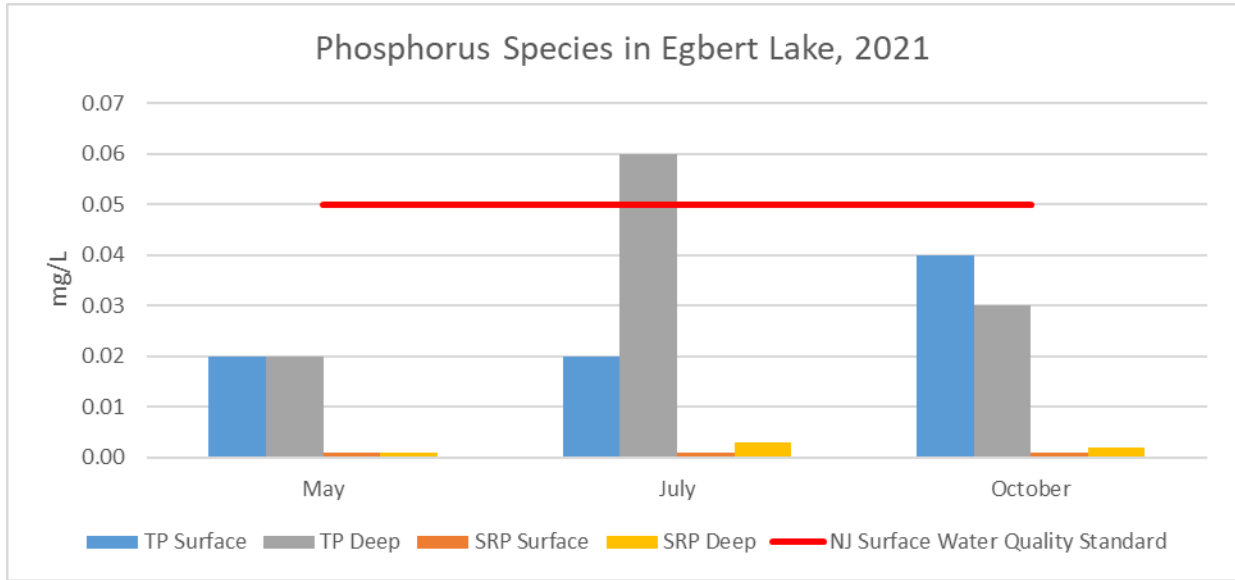


Figure 16. Concentrations of total phosphorus (TP) and soluble reactive phosphorus (SRP) measured from surface and deep samples collected in 2021 from the Dam station in Egbert Lake

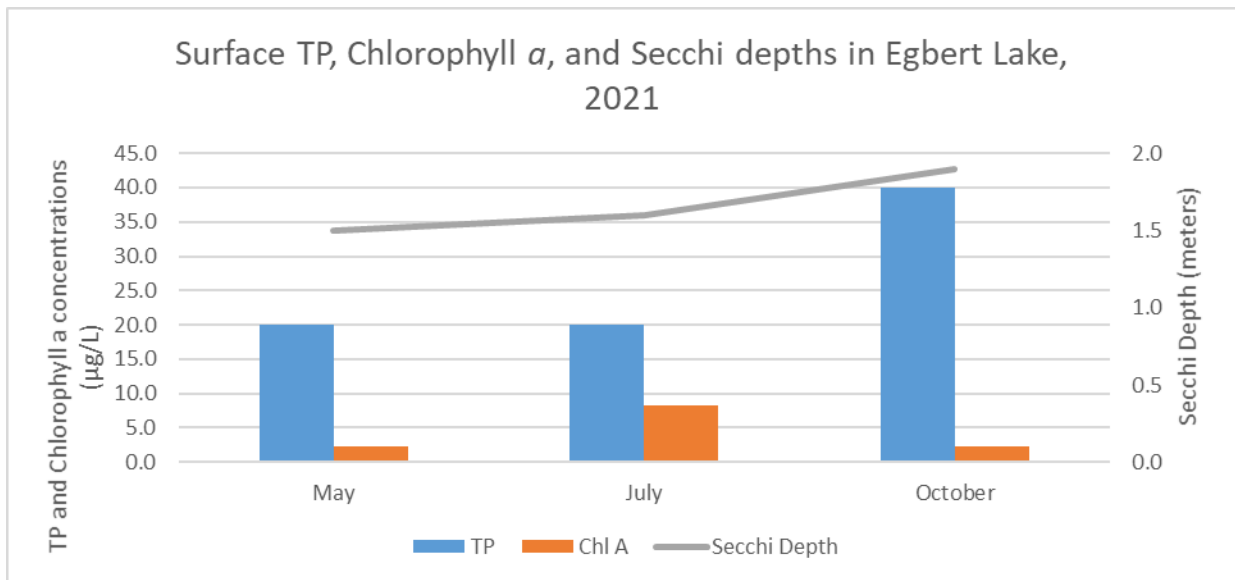


Figure 17. Concentrations of chlorophyll a (Chlorophyll a) and total phosphorus (TP), as well as Secchi depths, measured from the surface of the Dam station Egbert Lake in 2021.



Plankton and Macrophytes

In May, Egbert Lake's phytoplankton assemblage was dominated by the diatom *Fragilaria*. Also common in the sample were the diatom *Tabellaria* and the green algae genera *Dictyosphaerium* and *Mougeotia*. The zooplankton assemblage featured an abundance of copepod nauplii, as well as common densities of the cladoceran *Chydorus*, the copepod *Microcyclops* (as well as an unidentifiable calanoid copepod), and three genera of rotifers. By July, the lake featured an abundance of the dinoflagellate *Ceratium*, with the euglenoid *Trachelomonas* also being observed at common densities. Zooplankton densities had dropped overall at this time, with no one genus showing a high prevalence. *Dinobryon* and *Trachelomonas* were common in the October sample, as the water temperature had begun to cool. The zooplankton community was dominated by copepod nauplii at this time.

During the May event, Egbert Lake was observed to feature large densities of the invasive plant Eurasian watermilfoil in the northern areas of the lake, as well as another invasive plant curlyleaf pondweed in the middle and southern portions of the lake. The edges of the waterbody also contained the floating-leaved plants spatterdock and watershield. By July, curlyleaf populations had senesced in favor of additional densities of Eurasian watermilfoil. The northern portion of the lake was also observed to contain coontail, water crowfoot, and common bladderwort. *Elodea* was also present in the southern portion of the lake. Some of these plants were observed to still be present during the October event.

DURHAM POND

In-situ Water Quality

During the May event, the northern station at Durham Pond featured a slight temperature gradient, however this was not true stratification. This station also featured a slight decrease in dissolved oxygen above the bottom sediments; however, concentrations were still sufficient at this time. July saw the north station become increasingly thermally stratified, with the thermocline occurring between 2 and 2.5 meters in depth. The bottom-most half-meter at this station had also become hypoxic, with a dissolved oxygen concentration of 1.49 mg/L at 2.5 meters. By October, the water column had become well-mixed thermally and generally well oxygenated, with only a minor decrease in dissolved oxygen in the bottom-most depths. Secchi depths in May and July measured approximately 1 meter, before increasing slightly to approximately 1.4 meters in October.

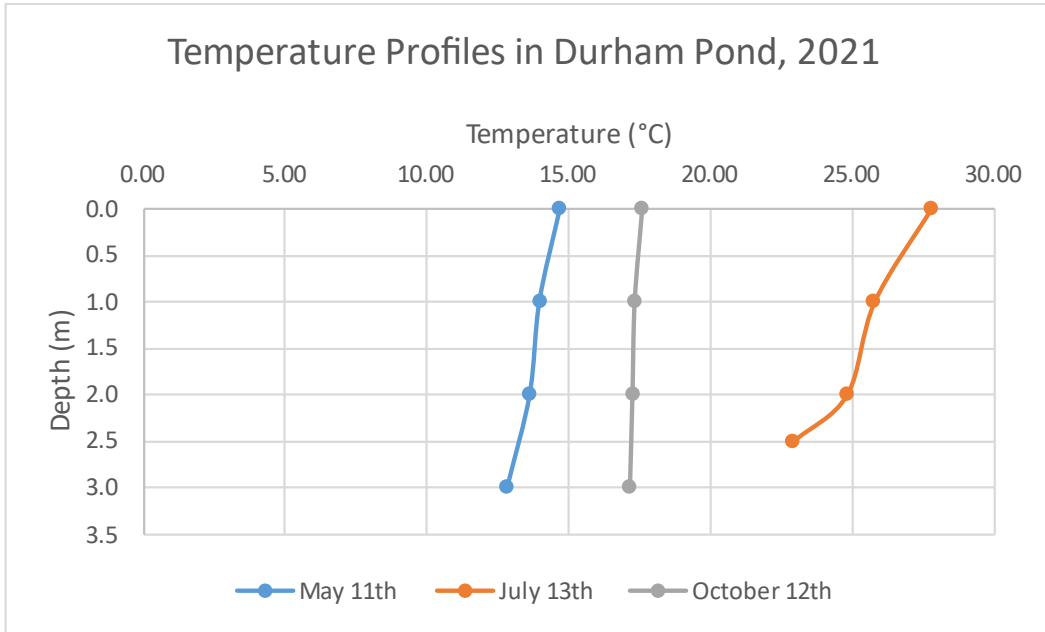


Figure 18. Temperature profiles collected during 2021 at the North station in Durham Pond

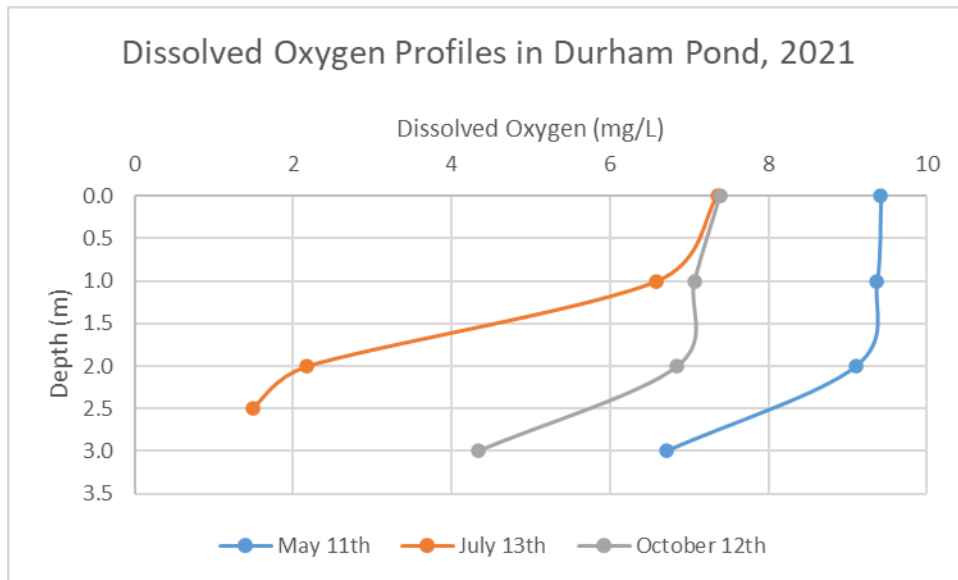


Figure 19. Dissolved oxygen profiles collected during 2021 at the North station at Durham Pond

Discrete Water Quality

Surface phosphorus concentrations were relatively low during May, with surface and deep samples yielding concentrations of 0.02 and 0.03 mg/L, respectively. Concentrations were measured to increase slightly by July, with both the surface and deep samples yielding 0.04 mg/L. Surface concentrations dropped to 0.02 mg/L in September; however, the deep sample yielded a concentration of 0.06 mg/L, above the NJ Surface Water Quality Standard of 0.05 mg/L. SRP



concentrations were consistently below the detectable concentration for both surface and deep samples throughout the year.

The May event yielded a surface nitrogen concentration of 0.05 mg/L, while the deep sample yielded a concentration of twice this. Both surface and deep samples yielded concentrations of 0.05 mg/L in July, before concentrations increased in October to 0.12 mg/L at the surface and 0.15 mg/L towards the bottom of the water column. Ammonia-N was only detected at very low concentrations during the July event, whereas May and October did not yield detectable concentrations.

Total suspended solids were generally low throughout the season, with a seasonal high of 4 mg/L at the surface and 7 mg/L at the bottom of the water column in September. Chlorophyll a concentrations were moderate throughout the season, with surface concentrations ranging from 10.0 µg/L in May to 15.0 µg/L in September, and the deep sample in October yielding a concentration of 17.0 µg/L.

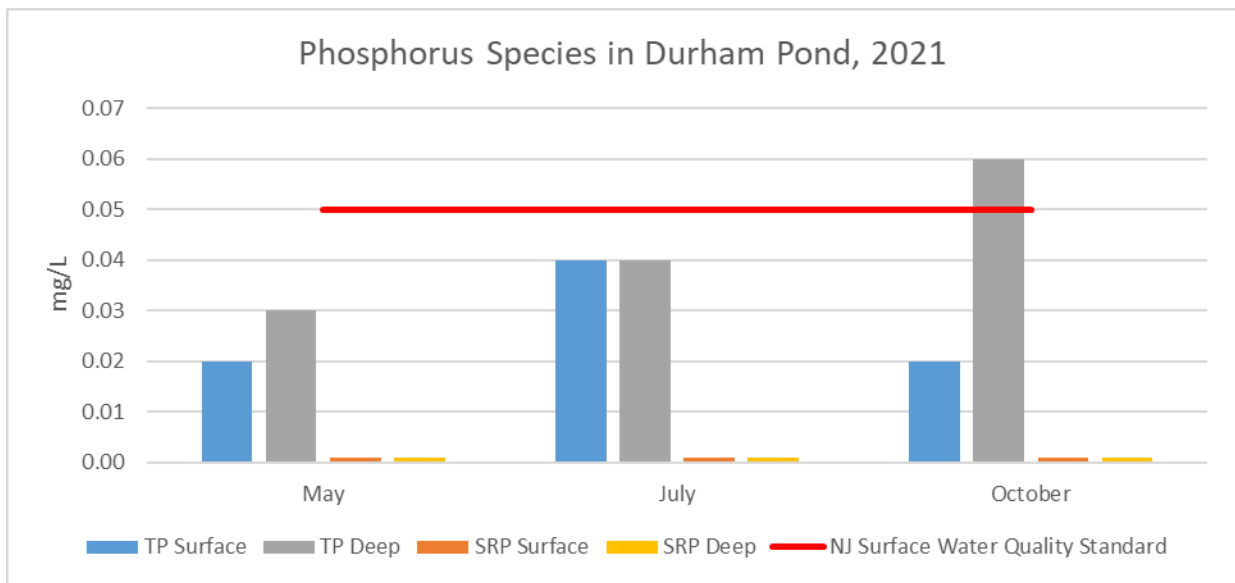


Figure 42. Concentrations of total phosphorus (TP) and soluble reactive phosphorus (SRP) measured from surface and deep samples collected in 2021 from the north station at Durham Pond.

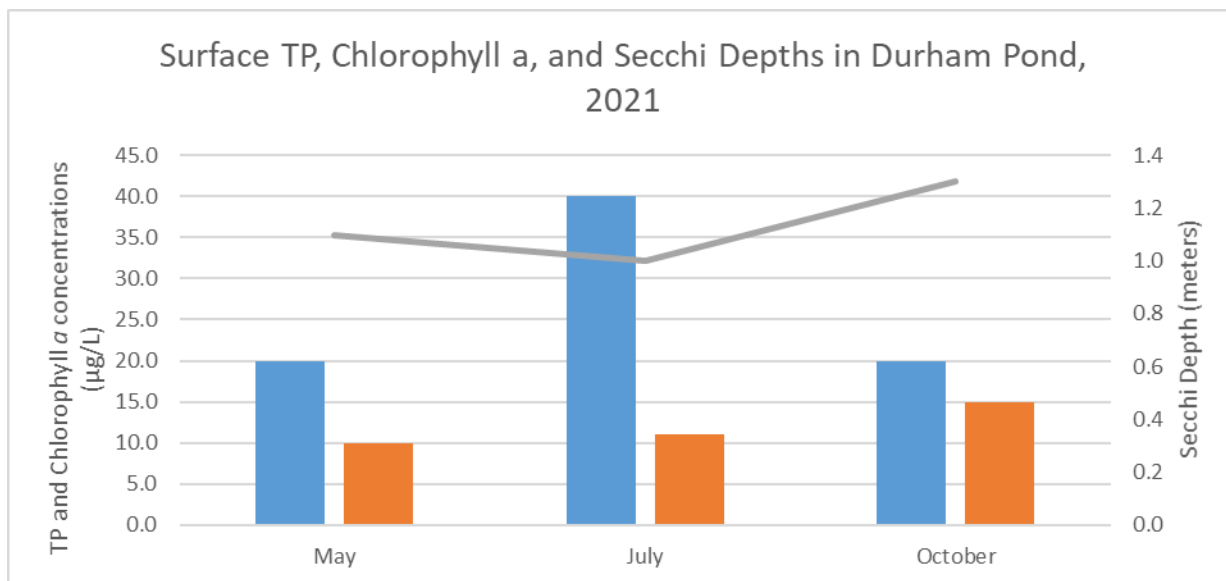


Figure 43. Concentrations of chlorophyll a (Chlorophyll a) and total phosphorus (TP), as well as Secchi depths, measured from the surface of the North station at Durham Pond in 2021.

Plankton and Macrophytes

The diatom *Melosira* was abundant in the May plankton sample, with *Dinobryon* and *Trachelomonas* also being detected at common densities. The colonial rotifer *Conochilus* was the most prevalent zooplankton genus at this time, with common densities of copepod nauplii also being detected. July saw a bloom of *Ceratium*, with the green algae genus *Sphaerocystis* also being well-represented. The copepod *Microcyclops* was the dominant zooplankter at this time, with three genera of cladocerans, including the large-bodied herbivore *Daphnia*, also being present in relatively high numbers. By October, the phytoplankton community had shifted to one largely composed of the diatom *Tabellaria* and the filamentous green algae *Mougeotia*. *Microcyclops* had remained the most prevalent zooplankter in the sample for this event.

Many of the observations of Durham Pond's macrophytes were made at the southern end of the waterbody. This area features dense populations of white water lily in areas closer to shore. Also observed to occur within the pond is the invasive species fanwort, as well as bladderwort and a native species of milfoil. The northern station was also observed to feature small amounts of bladderwort during the May event.

LAKE EMMA

In-situ Water Quality

Lake Emma's water column was relatively well-mixed and well-oxygenated in May, with only a slight temperature gradient at the Dam station. The water column became stratified at the Dam, however, in July. Furthermore, dissolved oxygen concentrations at both stations were very low during the date, with the highest concentration measuring only 3.68 mg/L. This may be due to the lake's extensive coverage with spatterdock (*Nuphar* sp.) and white water lily (*Nymphaea odorata*), which produce floating leaves at the top of the water column that reduce mixing of atmospheric oxygen into the



water column. The lake may also have a relatively high biological oxygen demand due to high amounts of organic material. By September, the lake was thermally well-mixed; however, dissolved oxygen concentrations were still low, particularly at the northern station. The water column was relatively clear in May, with a Secchi depth of 1.6 near the lake's dam. This dropped to approximately 0.8 meters in July as chlorophyll *a* increased. By September, the water column was clear to the bottom.

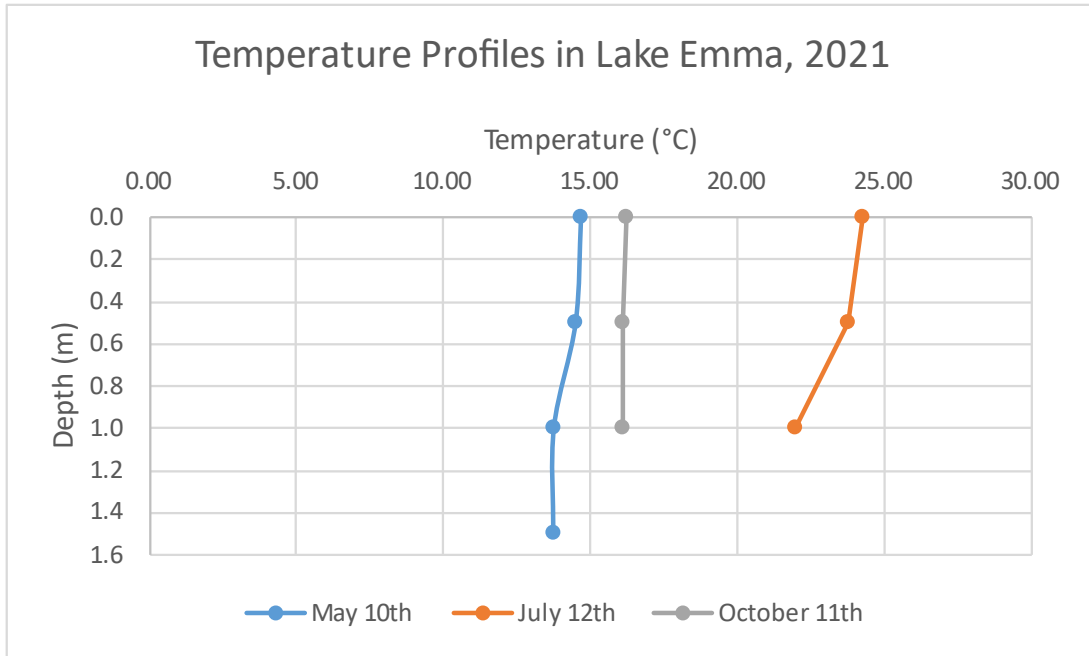


Figure 20. Temperature profiles collected during 2021 at the Dam station at Lake Emma.

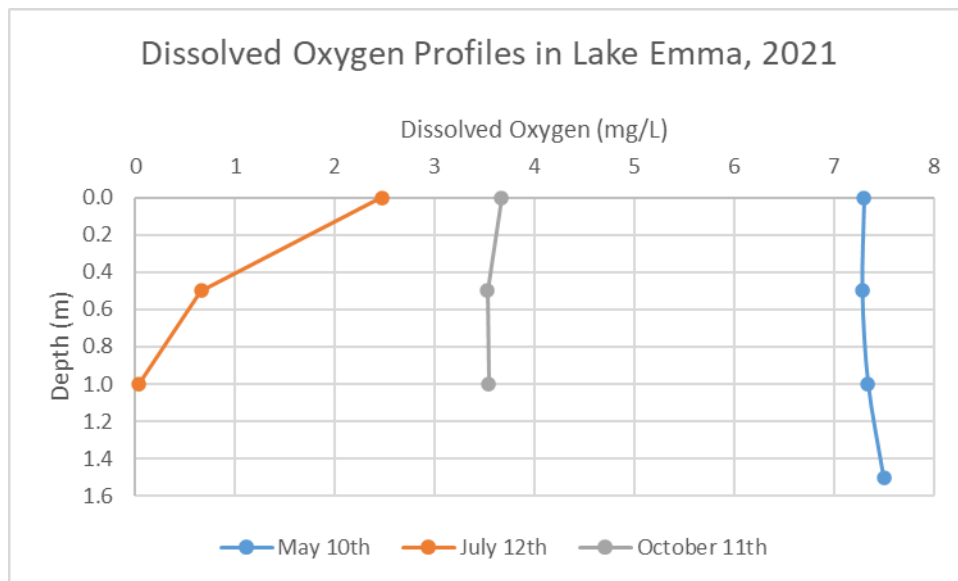


Figure 21. Dissolved oxygen profiles collected during 2021 at the Dam station in Lake Emma



Discrete Water Quality

Phosphorus concentrations in Lake Emma were relatively low during the May event, with both the surface and deep samples yielding only 0.01 mg/L. By July, surface concentrations had increased to 0.03 mg/L, and the deep sample yielded a relatively high concentration of 0.07 mg/L. This, combined with bottom anoxia measured during this time, suggests that a degree of internal phosphorus loading is occurring. Concentrations decreased by September, with surface and deep samples yielding 0.01 and 0.02 mg/L, respectively. Due to Emma's small size and shallow depth, the lake likely flushes quickly during large storm events, which may explain the drop in phosphorus by the end of the season. While this can result in a pulse of nutrients entering the waterbody from the watershed, it can also flush excess nutrients and algae from the system. SRP was not measured at detectable concentrations at any point throughout the season.

Nitrogen concentrations were generally low throughout the season, with the exception of the July event. Both surface and deep samples yielded 0.04 mg/L the May event. By July, surface concentrations had increased to 0.08 mg/L, while the deep sample yielded a concentration of 0.18 mg/L. Both the surface and deep samples yielded seasonal lows of 0.02 mg/L in September, however. Ammonia-N was low throughout the season, only being detected at 0.02 mg/L in surface and deep samples during the July event.

TSS concentrations were generally low over the course of the season, the only exception being a higher concentration of 23 mg/L in the deep sample over the course of the summer. Chlorophyll *a* similarly saw a large spike during the July event for both the surface and the deep sample. The deep sample was particularly high (120.0 µg/L), possibly due to epiphytic or benthic algae populations.

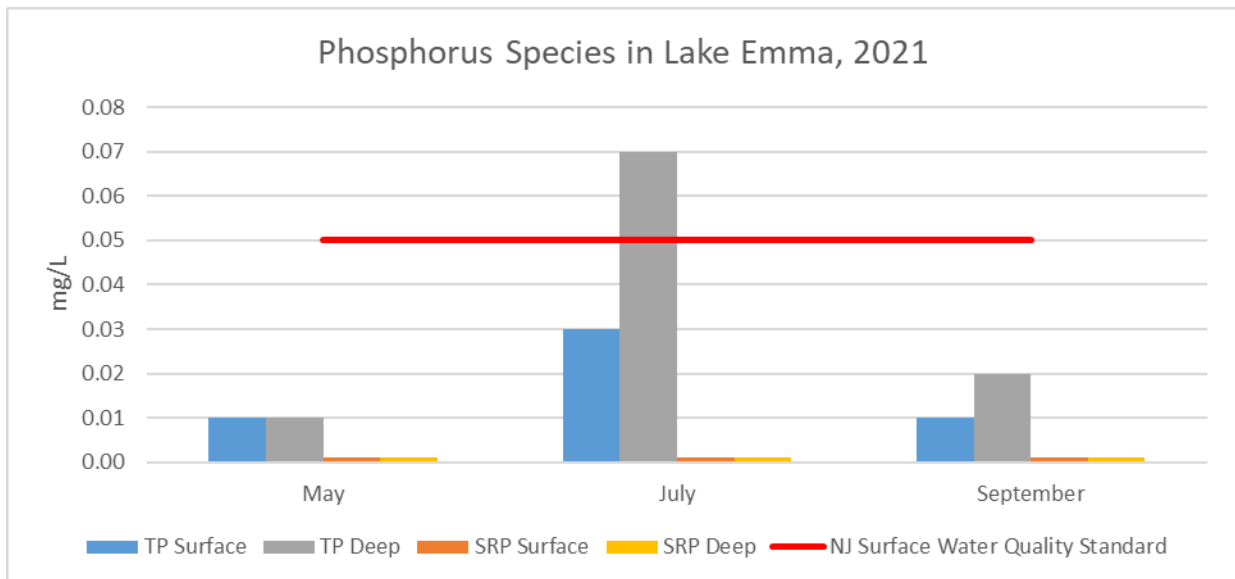


Figure 22. Concentrations of total phosphorus (TP) and soluble reactive phosphorus (SRP) measured from surface and deep samples collected in 2021 from the South station at Lake Emma.

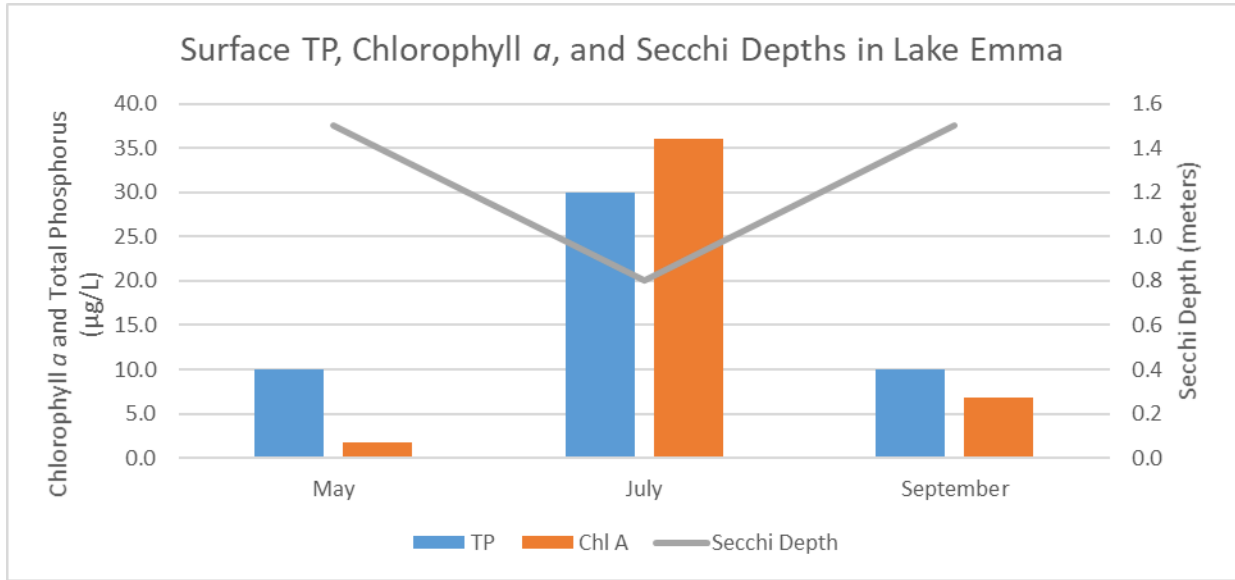


Figure 47. Concentrations of chlorophyll a (Chlorophyll a) and total phosphorus (TP), as well as Secchi depths, measured from the surface of the south station at Lake Emma on three dates in 2021.

Plankton and Macrophytes

Lake Emma's phytoplankton community was dominated by diatoms during the May event, specifically *Fragilaria* and *Synedra*. *Synedra* would continue to be the dominant phytoplankton genus through the July sample as well, although it was absent from the October sample entirely, in favor of the golden algae genus *Ochromonas*. May's zooplankton community was dominated by copepod nauplii, holding this pattern through July. By October, zooplankton densities became overall low, with no particular genus dominating.

Aquatic macrophytes are extremely prevalent throughout Lake Emma, even in the deeper areas to the south. The shallower northern half of the waterbody was observed to be almost completely covered with white water lily, spatterdock, and watershield throughout the entire growing season. During the May event, this area was also observed to contain little floating bladderwort. In addition to some of the species listed above, slightly deeper areas within the lake contain big-leaved pondweed.



LAKE AMES

In-situ Water Quality

Lake Ames featured a relatively well-mixed water column in May, particularly at the dam station. The northern station did display a temperature gradient; however, this may have been in part due to shading from the lake's dense aquatic plant populations. Both stations featured sufficient dissolved oxygen concentrations, and the water clarity as measured by Secchi disk were 1.7 meters at the dam. By mid-July, the water column had become thermally stratified, with the dam station showing a reduction in dissolved oxygen at the bottom of the water column. Secchi depths at both ends of the lake had dropped to 1.3 meters. The northern station during this event exhibited an increase in dissolved oxygen towards the bottom of the water column, possibly due to a high rate of photosynthesis by macrophytes. In October, the water column was still experiencing a degree of thermal stratification, and featured anoxia at the very bottom of the Dam station's water column. Secchi depths had increased, however, with the dam station yielding a clarity of 2 meters.

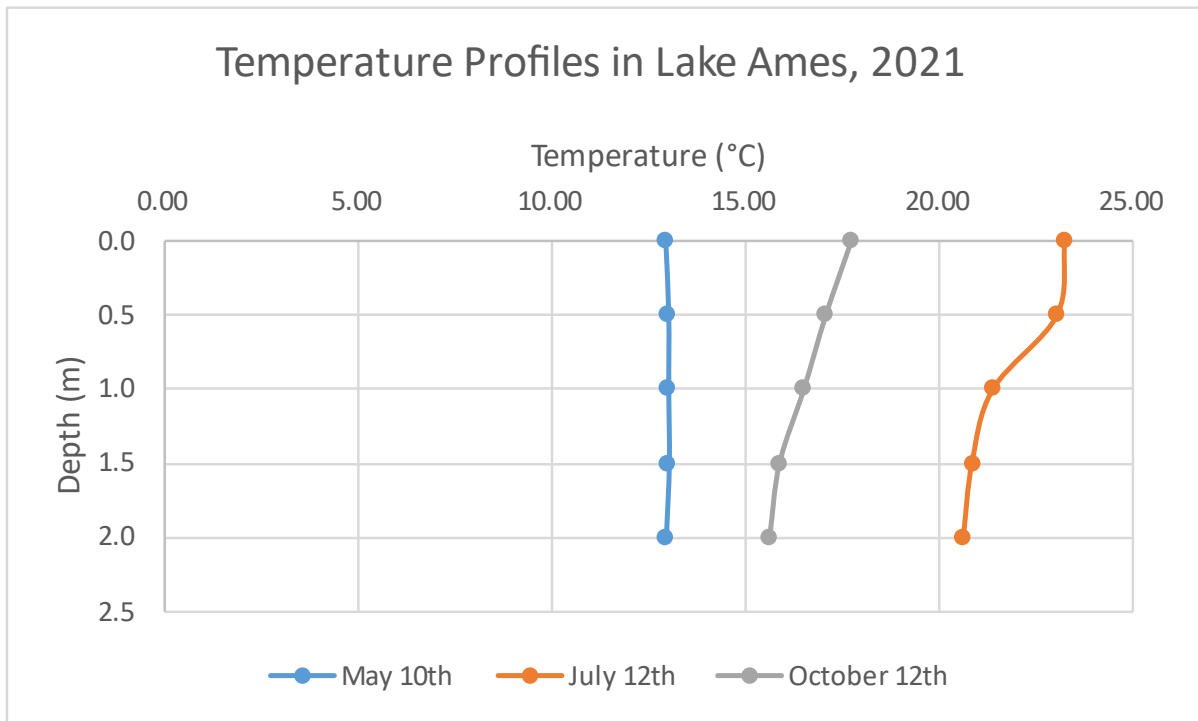


Figure 23. Temperature profiles collected during 2021 at the dam station at Lake Ames

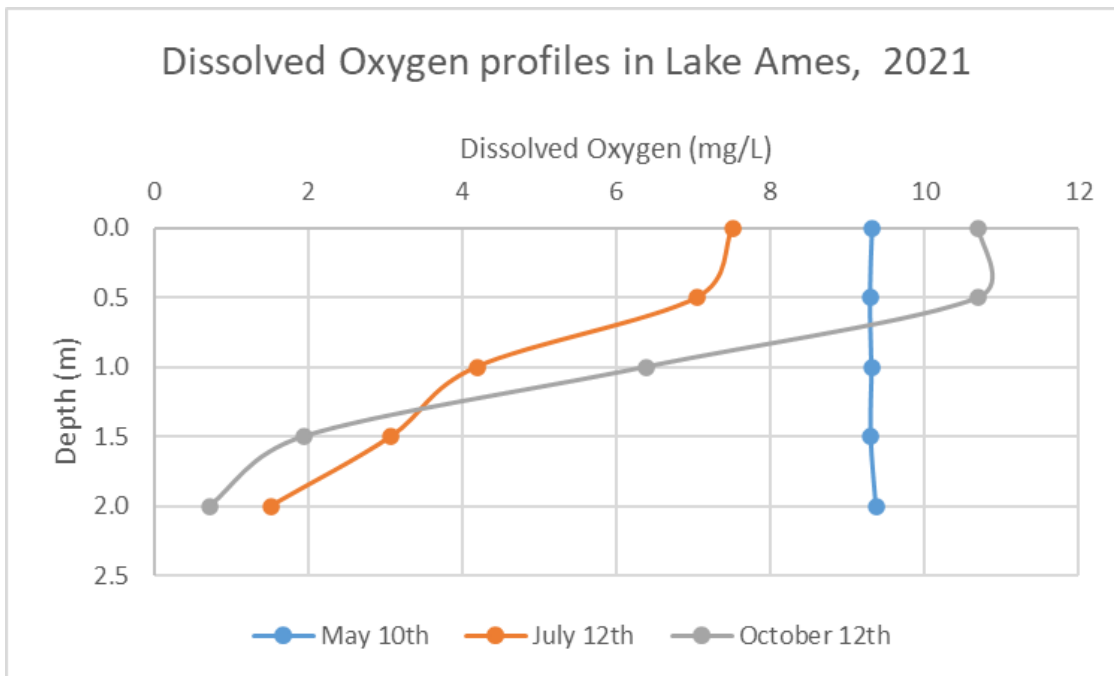


Figure 24. Dissolved oxygen profiles collected during 2021 at the dam station at Lake Ames

Discrete Water Quality

Total phosphorus concentrations in May were relatively low, with both the surface and deep samples yielding only 0.02 mg/L. These only increased to 0.03 mg/L in July. While surface phosphorus concentrations dropped to 0.01 mg/L in October, bottom concentrations increased to 0.04 mg/L. This suggests that a degree of internal phosphorus loading may be occurring. Phosphorus levels were never observed to surpass the New Jersey Surface Water Quality Standard, however. It should be noted that SRP was detected at a relatively high concentration of 0.006 mg/L in the deep sample collected during the July event.

Nitrogen concentrations were moderate throughout the season, with the surface and deep concentrations never largely varying from each other. The seasonal high nitrogen concentration was 0.10 mg/L in the deep sample during the May event. Ammonia concentrations were low throughout the season, with the only detectable concentrations occurring during the July event.

Chlorophyll *a* concentrations generally remained under 10.0 mg/L for both surface and deep samples, with the exception of a concentration of 16.0 µg/L obtained from the surface during the July event. TSS samples were overall low throughout the season, only approaching 5.0 mg/L in bottom samples during the May and October events. While Lake Ames' dense vegetation can impede boating, it also likely serves to settle incoming sediment quicker and prevent stirring of the bottom sediments.

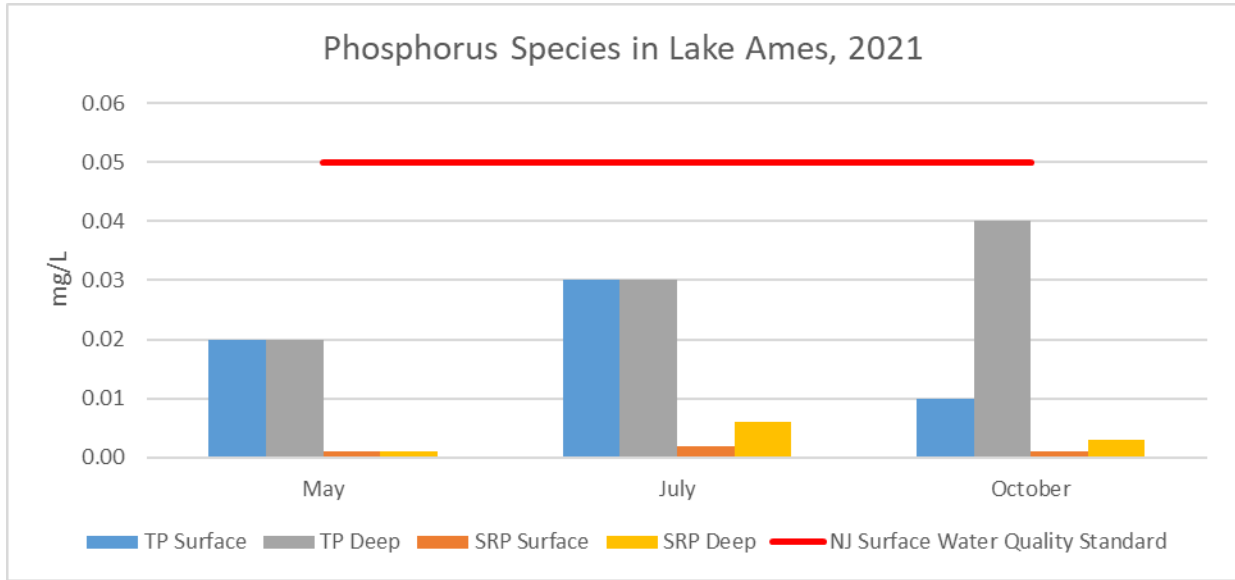


Figure 25. Concentrations of total phosphorus (TP) and soluble reactive phosphorus (SRP) measured from surface and deep samples collected in 2021 from the dam station at Lake Ames.

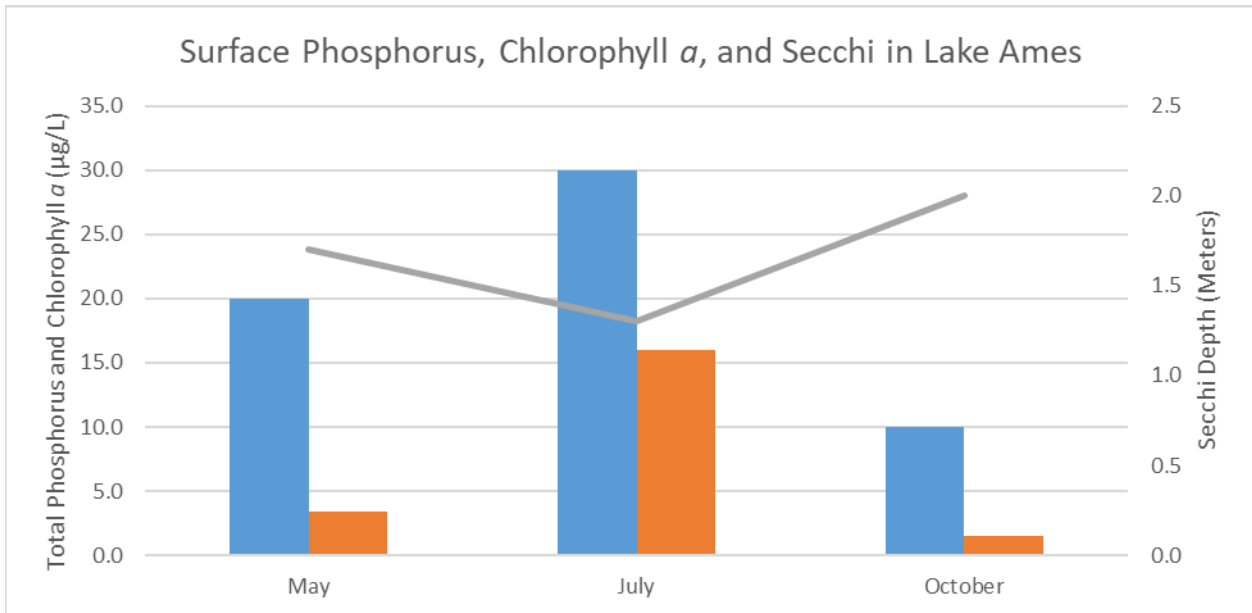


Figure 26. Concentrations of chlorophyll a (Chlorophyll a) and total phosphorus (TP), as well as Secchi depths, measured from the surface of the dam station at Lake Ames in 2021.



Plankton and Macrophytes

As with many of the other lakes in this study, Lake Ames was dominated by diatoms in May, with *Fragilaria* being abundant in the sample, while the desmid *Desmidium* was also common. Very few zooplankton were observed in this sample, with Nauplii dominating at only present densities. July saw a shift in dominance to *Ceratium* and the Cryptomonad *Chroomonas*, with another paucity of zooplankton in the sample. By October, the phytoplankton community featured abundant *Tabellaria* and *Mougeotia*. Zooplankton, while diverse and being dominated by the copepod *Microcyclops* and nauplii, were still relatively low in density during this event.

Lake Ames features extensive coverage with aquatic macrophytes, particularly the invasive plant fanwort. The edges of the waterbody were also observed to contain spatterdock, white water lily, and watershield. *Elodea*, coontail, curlyleaf pondweed, Eurasian watermilfoil, and the NJ listed rare plant Robbin’s pondweed were all observed occasionally throughout the lake over the course of the season.

LAKE TELEMAR

In-situ Water Quality

Lake Telemark’s water column was well-mixed during the May event and featured supersaturated dissolved oxygen concentrations (>100%) throughout. Water clarity during this event measured approximately 1.7 meters; this dropped to 0.9 meters in July. While dissolved oxygen concentrations dropped to a range of approximately 80 – 89.5% in July, the water column remained thermally stratified. These conditions remained fairly consistent in October, although Secchi depths had increased at this time to encapsulate the full water column.

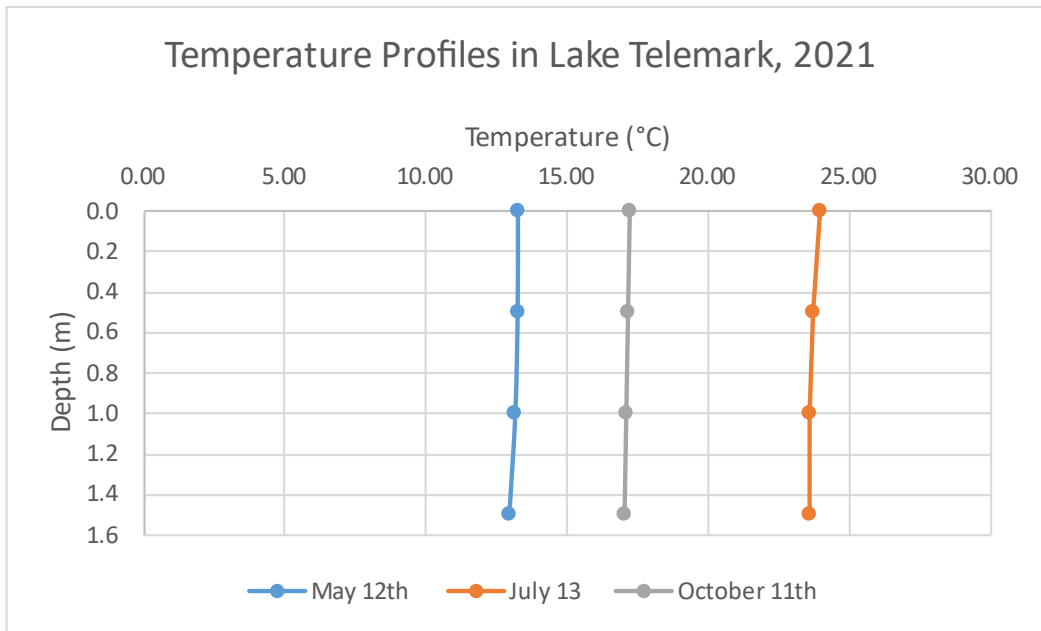


Figure 27. Temperature profiles collected during 2021 at the Dam station at Lake Telemark

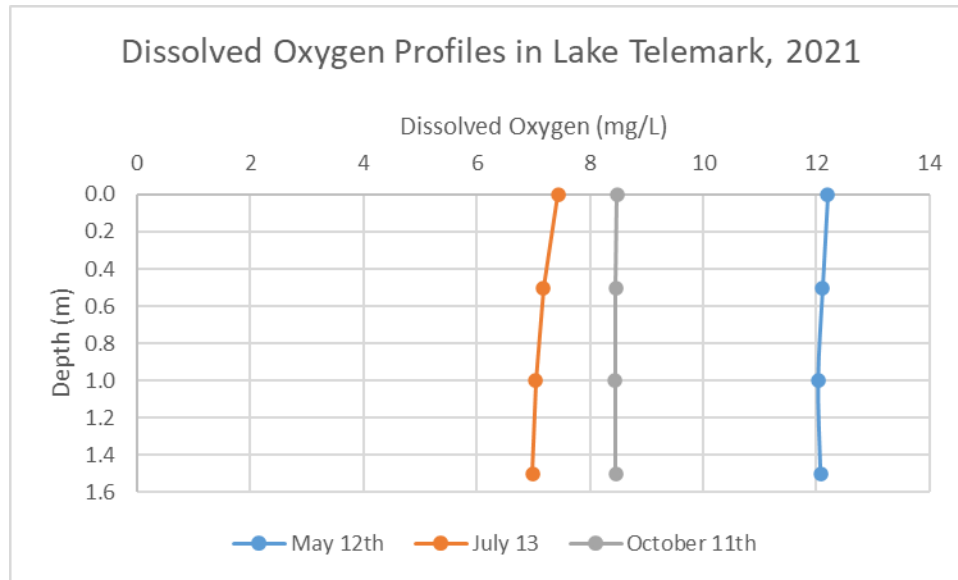


Figure 28. Dissolved oxygen profiles collected during 2021 at the Dam station at Lake Telemark

Discrete Water Quality

Lake Telemark yielded total phosphorus concentrations of 0.02 mg/L for both surface and deep samples during the May event, before increasing in the July event to 0.04 mg/L in the deep sample and 0.05 mg/L at the surface, reaching the NJ Surface Water Quality Standard threshold. This event also featured elevated SRP concentrations of 0.005 mg/L for both surface and deep samples. By September, total phosphorus concentrations dropped to 0.01 and 0.02 mg/L for surface and deep samples, respectively. SRP was also not detected during this event.

Nitrogen concentrations were measured to be somewhat elevated throughout the season, ranging from 0.11 mg/L in October to 0.15 mg/L in the Deep sample in July. Ammonia concentrations were consistently low, only reaching 0.01 mg/L during the July event.

TSS was relatively low throughout the season, ranging from 2 mg/L in the deep sample during October to 7 mg/L in the Deep sample in July. Chlorophyll *a* concentrations were very low in the beginning of the season, at 1.2 and 2.1 µg/L for the surface and deep samples, respectively. Concentrations increased significantly by the July event, however, with the surface sample yielding a value of 22.0 µg/L. By October, surface concentrations decreased to 3.7 µg/L, with the deep sample not yielding a detectable concentration.

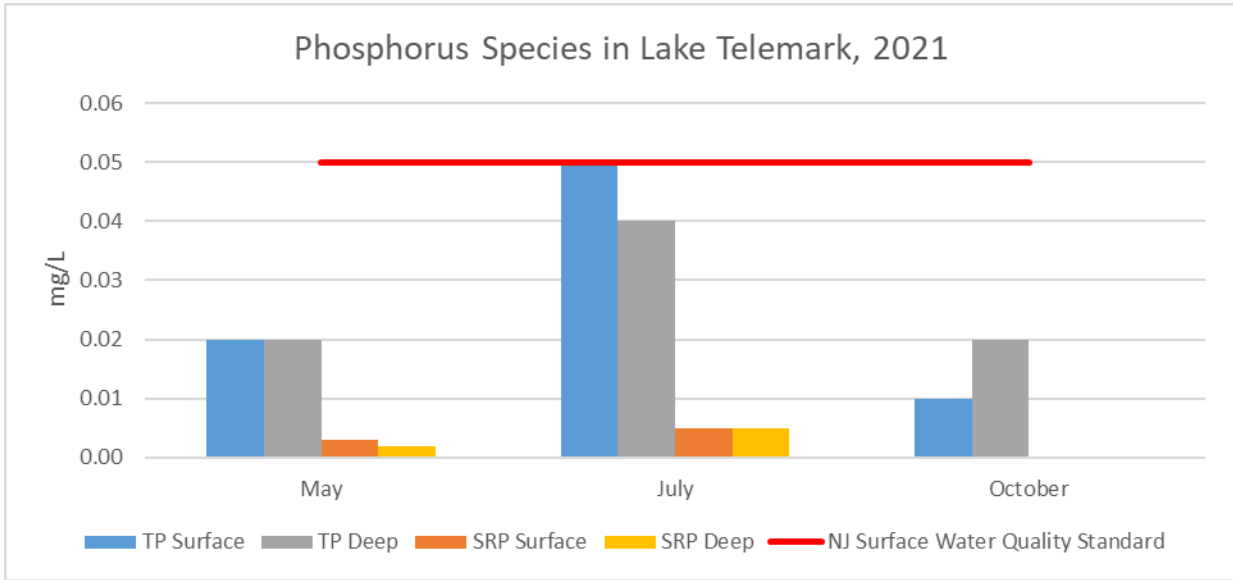


Figure 29. Concentrations of total phosphorus (TP) and soluble reactive phosphorus (SRP) measured from surface and deep samples collected in 2021 from the Dam station at Lake Telemark

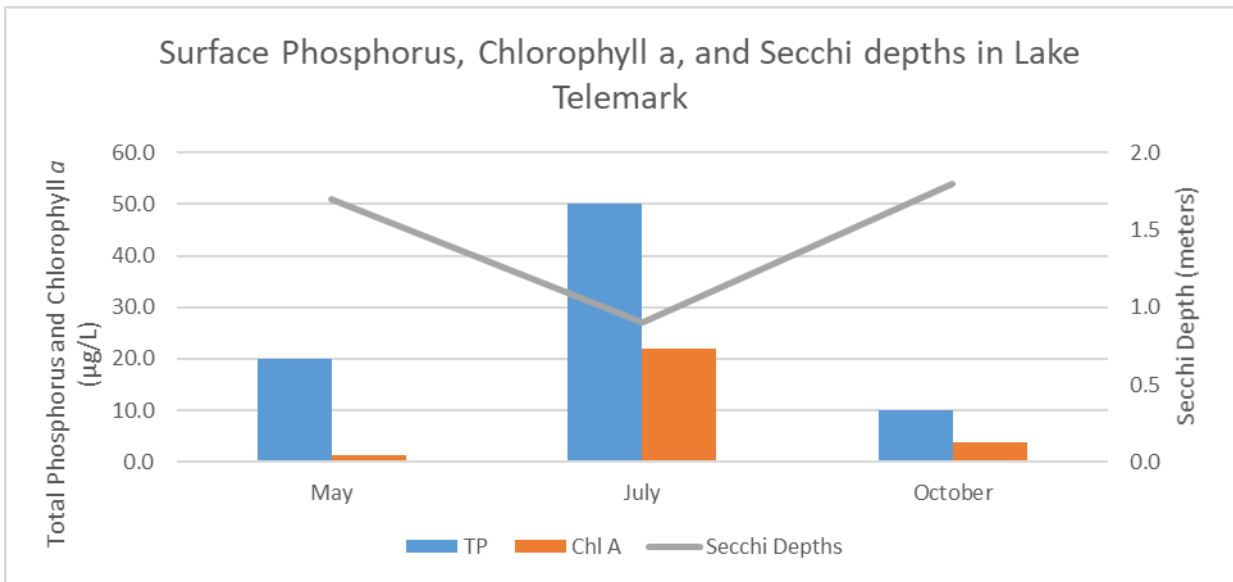


Figure 30. Concentrations of chlorophyll a (Chlorophyll a) and total phosphorus (TP), as well as Secchi depths, measured from the surface of the Dam station at Lake Telemark in 2021.

Plankton and Macrophytes

Lake Telemark's phytoplankton community was dominated by *Dinobryon* and *Trachelomonas* in May, while zooplankton populations were overall relatively low in density. *Dinobryon* continued to be a dominant taxa during July, with *Ochromonas* and *Ceratium* also being found in abundant densities. Zooplankton densities were still overall low during this event. By October, phytoplankton populations had overall dwindled, with no taxa in particular dominating the sample. The rotifer *Asplancha*, however, had become a dominant zooplankter.



Lake Telemark was observed to contain moderate densities of white water lily in the shallower northern portion of the lake, as well as in smaller amounts along the perimeter of the waterbody. Spatterdock and watershield were also occasionally observed in these areas. Eurasian watermilfoil was often observed throughout the littoral zone during each event. Fragments of *Elodea* and leafy pondweed were observed in the northern portion of the lake during the July event, and benthic algae was present throughout the season.

MT. HOPE POND

In-situ Water Quality

During the May event, Mt. Hope Pond's water column was thermally well-mixed and well-oxygenated. Water clarities for this event were very good, measuring 3.5 meters at both the north and south station. By July, the water column had become thermally stratified, with the thermocline occurring between 2 and 3 meters in depth. The pond also featured bottom anoxia in the bottom-most half-meter. Water clarities during this event were also greatly reduced, measuring 0.9 meters. This, as well as some supersaturated dissolved oxygen and high pH readings at the top of the water column, are likely due to the algae bloom that was observed to be occurring during this event. By October, the water column was well-mixed thermally and well-oxygenated and Secchi depths had improved to an average of 1.9 meters.

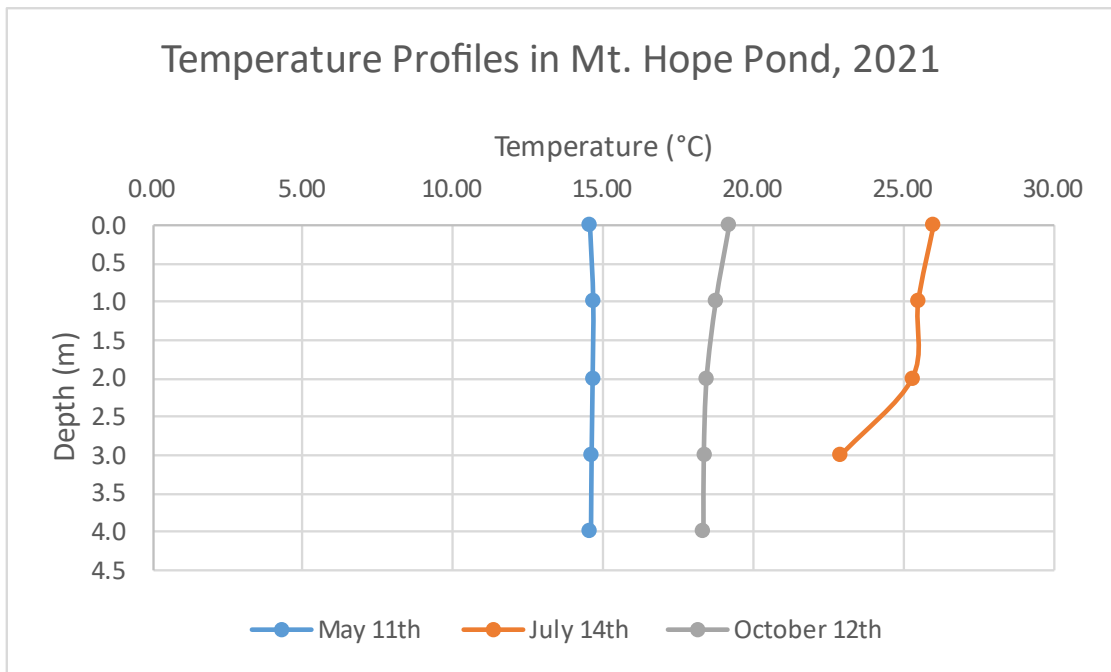


Figure 31. Temperature profiles collected during 2021 at the South station at Mt. Hope Pond

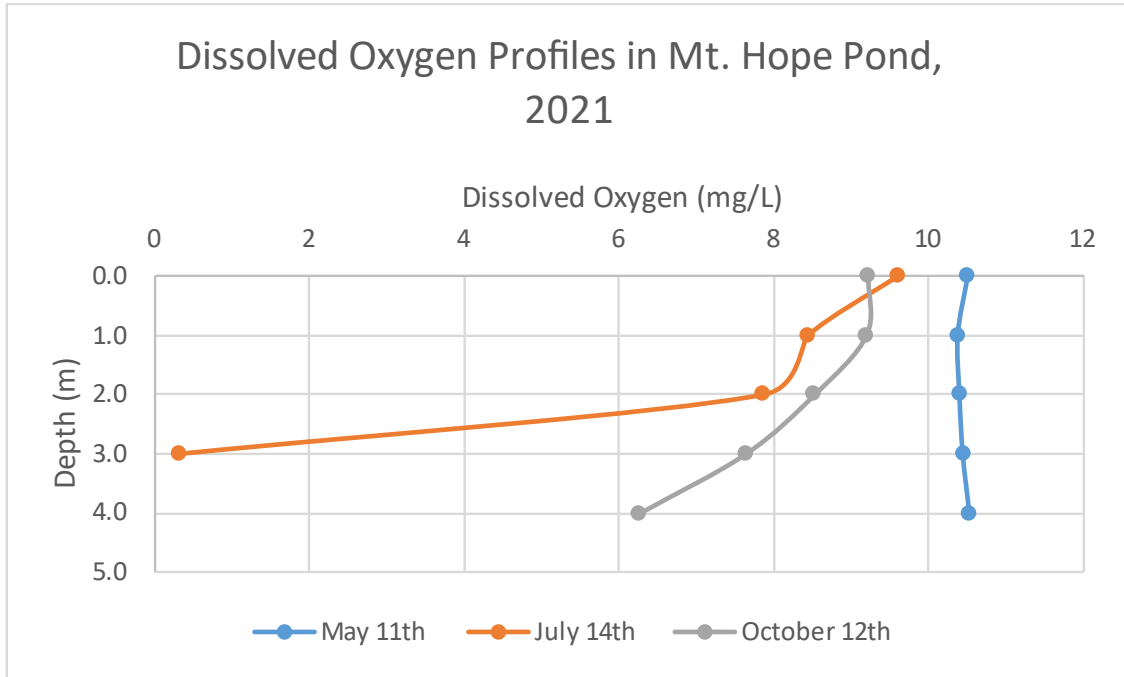


Figure 32. Dissolved oxygen profiles collected during 2021 at the South station at Mt. Hope Pond

Discrete Water Quality

Phosphorus concentrations in Mt. Hope Pond were relatively low during the May event, with both the surface and the deep sample yielding concentrations of 0.02 mg/L. The surface concentration remained consistent through July, while the deep sample had increased slightly to 0.03 mg/L. By September, surface phosphorus concentrations had increased to 0.03 mg/L, while the deep sample increased to 0.06 mg/L, above the NJ Surface Water Quality Standard. SRP was not detected in either sample from any of the sampling events.

Nitrogen concentrations were below the detectable limit during the May event for both sample depths. Concentrations reached their seasonal high in July, with samples yielding 0.08 mg/L for both the surface and deep samples. By September, nitrogen concentrations had decreased to 0.04 mg/L at the surface and 0.06 mg/L in the deep sample. These are all relatively low. Ammonia was not detected in either sample depth from any of the three events.

TSS was relatively low throughout the season, only reaching a seasonal high of 7 mg/L in July for both the surface and the deep samples. Chlorophyll *a* was below 3.0 µg/L for both the surface and the deep sample during the May event; however, in July, this increased to 18.0 and 19.0 µg/L for the surface and deep samples, respectively. October saw a further increase in the deep sample, yielding a concentration of 26.0 µg/L, while the surface sample dropped to 4.6 µg/L.

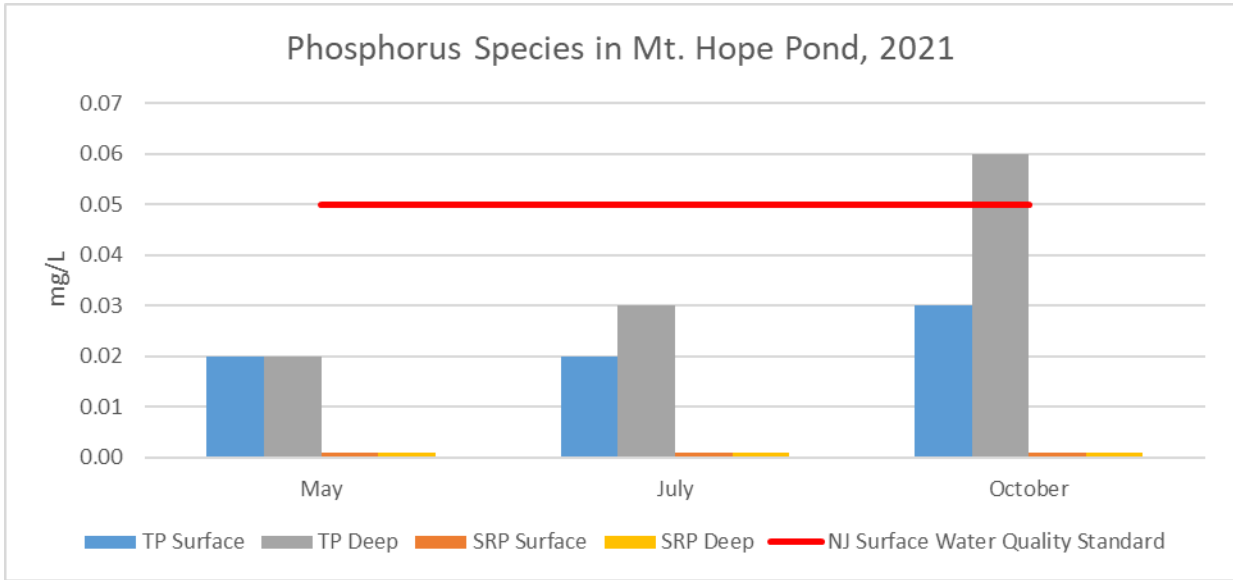


Figure 33. Concentrations of total phosphorus (TP) and soluble reactive phosphorus (SRP) measured from surface and deep samples collected in 2021 from the South station at Mt. Hope Pond

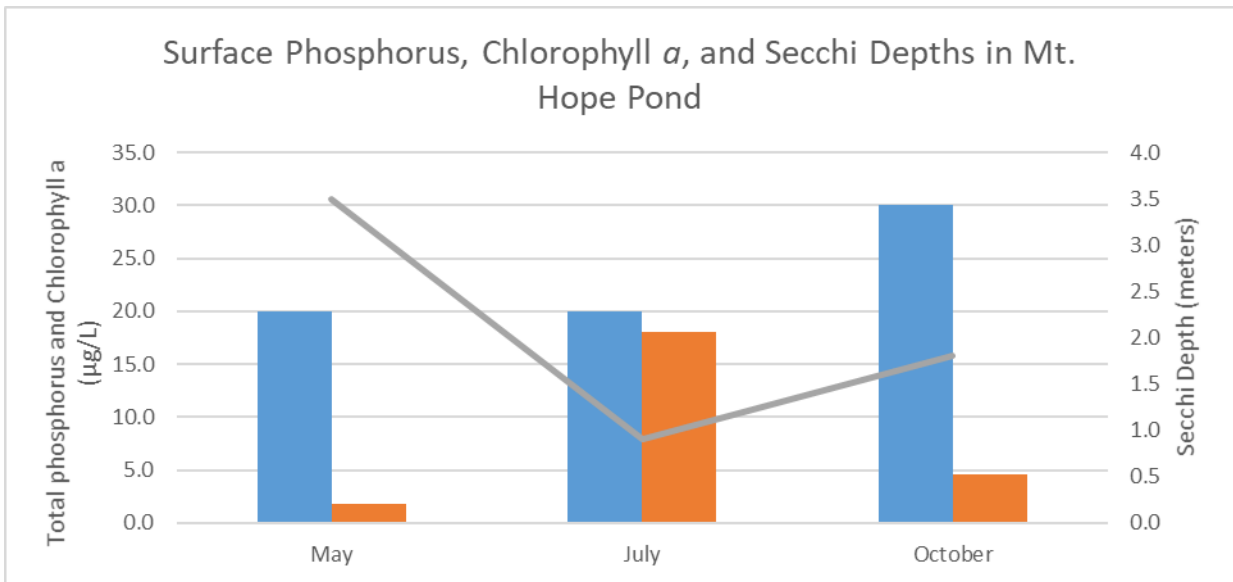


Figure 34. Concentrations of chlorophyll a (Chlorophyll a) and total phosphorus (TP), as well as Secchi depths, measured from the surface of the South station at Mt. Hope Pond in 2021.

Plankton and Macrophytes

In May, Mt. Hope Pond featured an abundance of *Melosira*, as well as common densities of *Ceratium*. The zooplankton community featured abundant copepod nauplii and relatively high amounts of *Microcyclops* and the cladoceran *Daphnia*. By July, the pond was undergoing a bloom of the cyanobacteria genus *Dolichospermum*. Zooplankton during this event consisted largely of the smaller cladoceran *Ceriodaphnia* and the rotifer *Keratella*. October saw an overall low-density phytoplankton



assemblage, with no one genus dominating the sample. *Ceriodaphnia* were still relatively common, as were *Microcyclops*, an unidentifiable Calanoid copepod, and the rotifer *Asplancha*.

Macrophytes were not observed during the May event, although small amounts of benthic algae were brought up on the anchor. During the July event, however, *Elodea* and coontail were observed to grow prevalently in the northeastern corner of the waterbody. Areas near the beach were observed to contain small amounts of *Elodea*, as well as small amounts of the benthic invasive plant mud mat, although these were not problematic at this time.

FOX'S POND

In-situ Water Quality

During 2021, Fox's Pond's water level varied between sampling events due to construction on the pond's dam. Because of this, water depths were determined to be too shallow to effectively sample for a May event. During the July event, the pond featured a relatively well-mixed and oxygenated water column, as well as water clarities averaging 1 meter. In October, when the pond was at its full water height, the water column in the northern station featured a slight temperature gradient, and dissolved oxygen reduction was measured at the bottom of both stations. Both stations featured Secchi depths of 1.5 meters during this event.

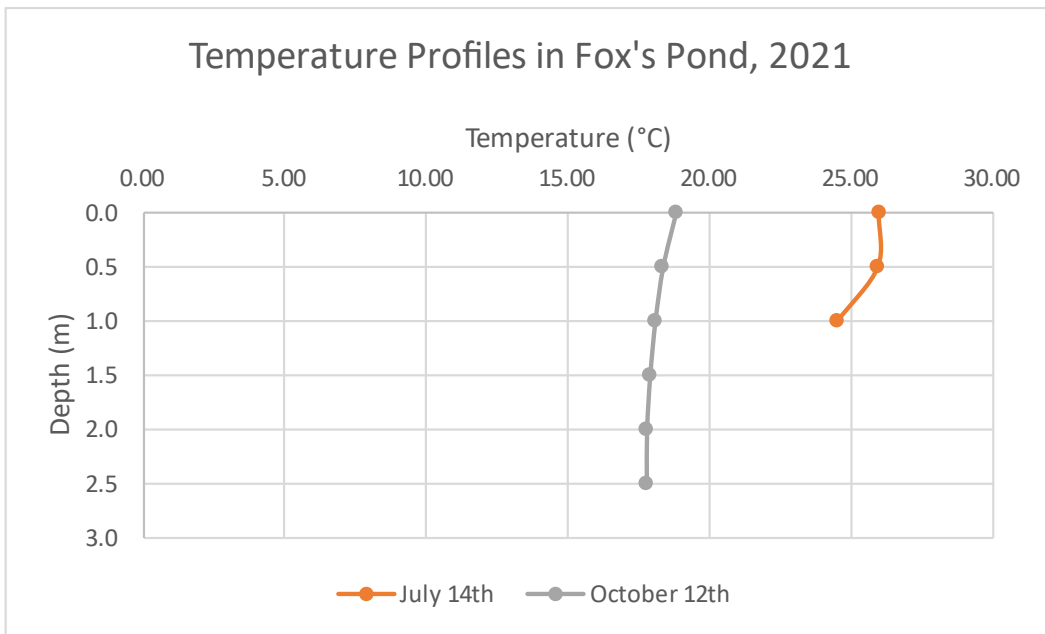


Figure 35. Temperature profiles collected during 2021 at the South station at Fox's Pond

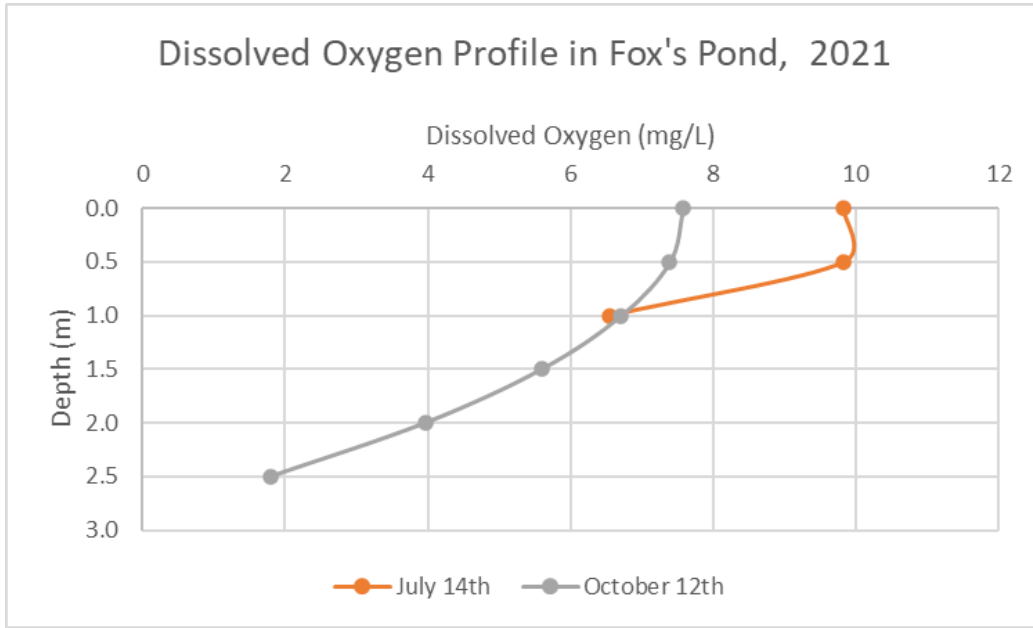


Figure 36. Dissolved oxygen profiles collected during 2021 at the South station at Fox's Pond

Discrete Water Quality

During the July event, total phosphorus at both depths measured 0.04 mg/L. By October, concentrations had increased to 0.05 mg/L and 0.06 mg/L in the surface and deep samples, respectively. The deep sample's concentration during this event exceeded the NJ Surface Water Quality Standard. SRP was not detected in either sample during either of the two events.

Nitrogen concentrations were relatively high during the July event, with the surface and deep samples yielding concentrations of 0.53 and 0.53 mg/L, respectively. These dropped in October to approximately 0.10 mg/L for both samples. Ammonia was not detected in either sample for either of the two events.

Chlorophyll *a* concentrations were largely moderate-to-high for the two events. The July event averaged 16.5 µg/L between the surface and deep samples, while the October event averaged 14.2 µg/L, although the surface sample at this event yielded the seasonal high of 22 µg/L. TSS concentrations were consistently low, with both events featuring a concentration of 4 mg/L at the surface and 5 mg/L in the deep sample.

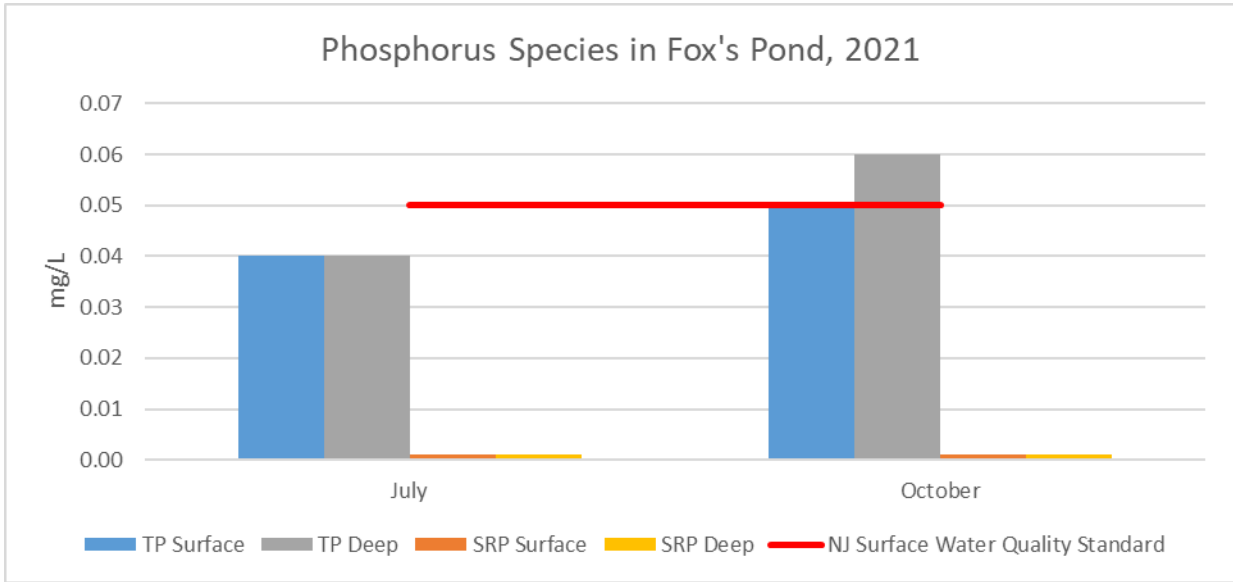


Figure 37. Concentrations of total phosphorus (TP) and soluble reactive phosphorus (SRP) measured from surface and deep samples collected in 2021 from the South station at Fox’s Pond

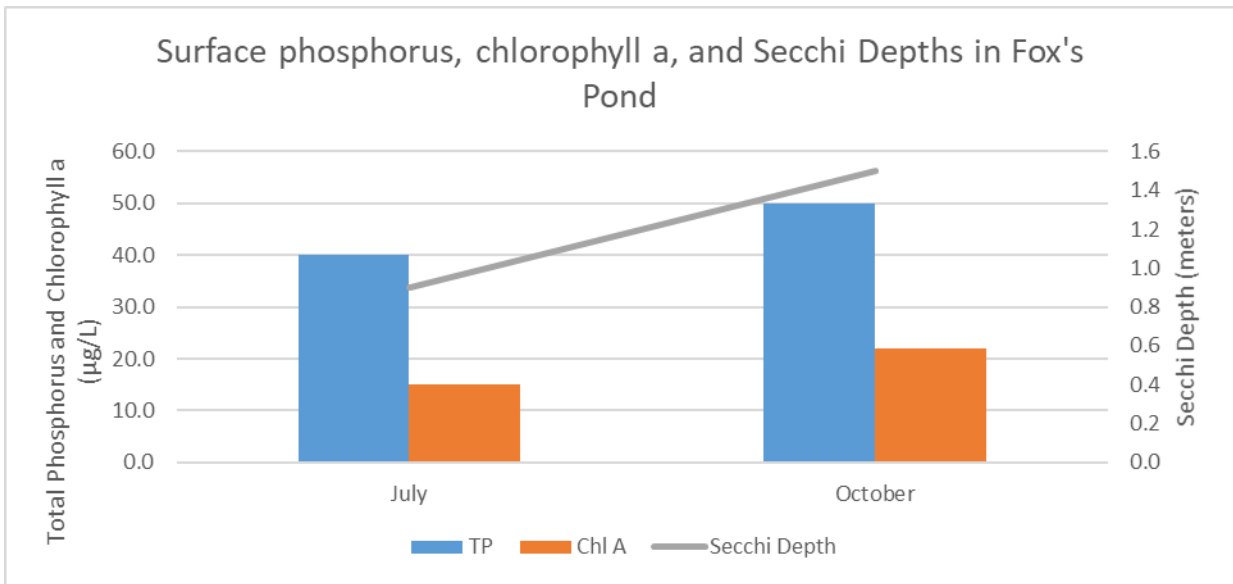


Figure 38. Concentrations of chlorophyll a (Chlorophyll a) and total phosphorus (TP), as well as Secchi depths, measured from the surface of the South station at Fox’s Pond in 2021.

Plankton and Macrophytes

In July, Fox's Pond featured a phytoplankton community dominated by *Mougeotia* and the cyanobacteria genus *Dolichospermum*. While *Mougeotia* remained the dominant taxa through October, *Dolichospermum* had dropped in density. July's zooplankton assemblage was dominated by multiple genera of rotifers, with *Keratella* and *Polyarthra* dominating. Rotifers continued to have the highest presence in October, now dominated by *Asplanchna*.



Macrophytes during the July event were mostly limited to terrestrial vegetation that had grown while the water levels were low. The invasive plant brittle naiad, however, was observed during the October event.

WHITE MEADOW LAKE.

In-situ Water Quality

White Meadow Lake's water column was measured to be well-mixed and well-oxygenated during the May event, with Secchi depths averaging 1.4 meters. Dissolved oxygen concentrations during this event were measured to be supersaturated; when considering the high pH values that were also obtained during this event, this is likely a product of increased photosynthesis from algae and/or plant growth. The water column maintained its well-mixed status through July, and although dissolved oxygen concentrations trended slightly low, these were sufficient throughout. Secchi depths averaged approximately 1.8 meters during this event. The water column remained mixed for the October event, while dissolved oxygen concentrations were measured at approximately 100% saturation. Water clarities averaged approximately 1.5 meters during this event.

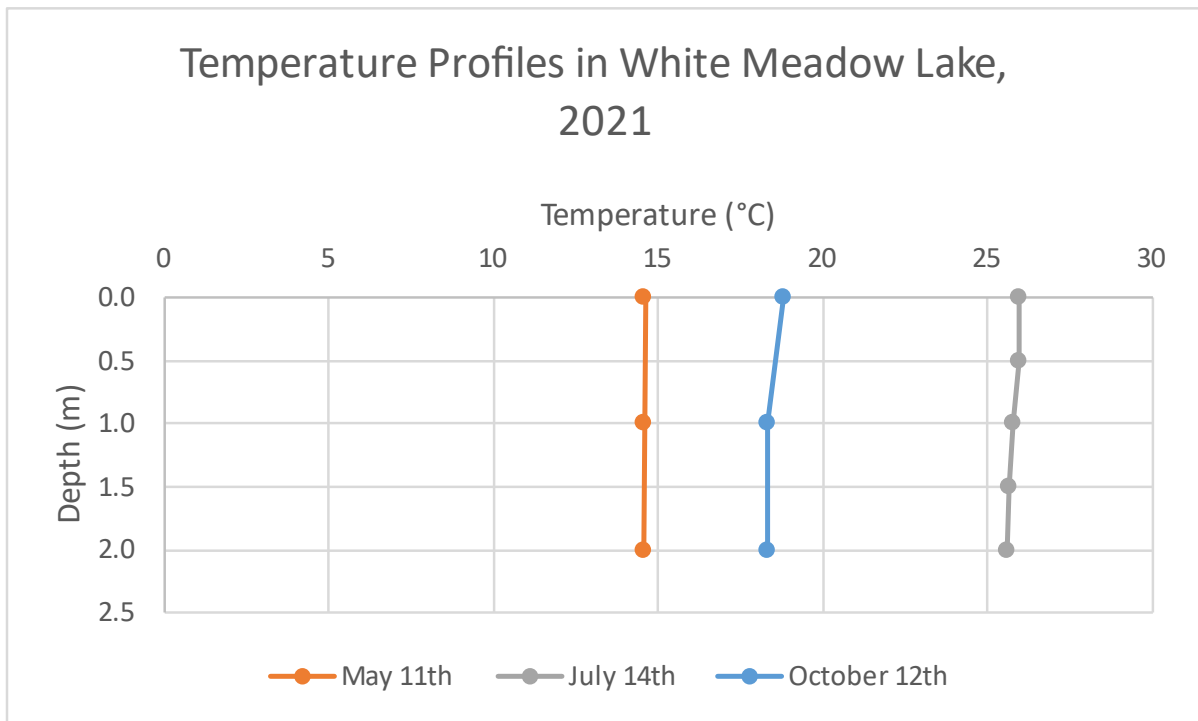


Figure 39. Temperature profiles collected during 2021 at the Dam station at White Meadow Lake

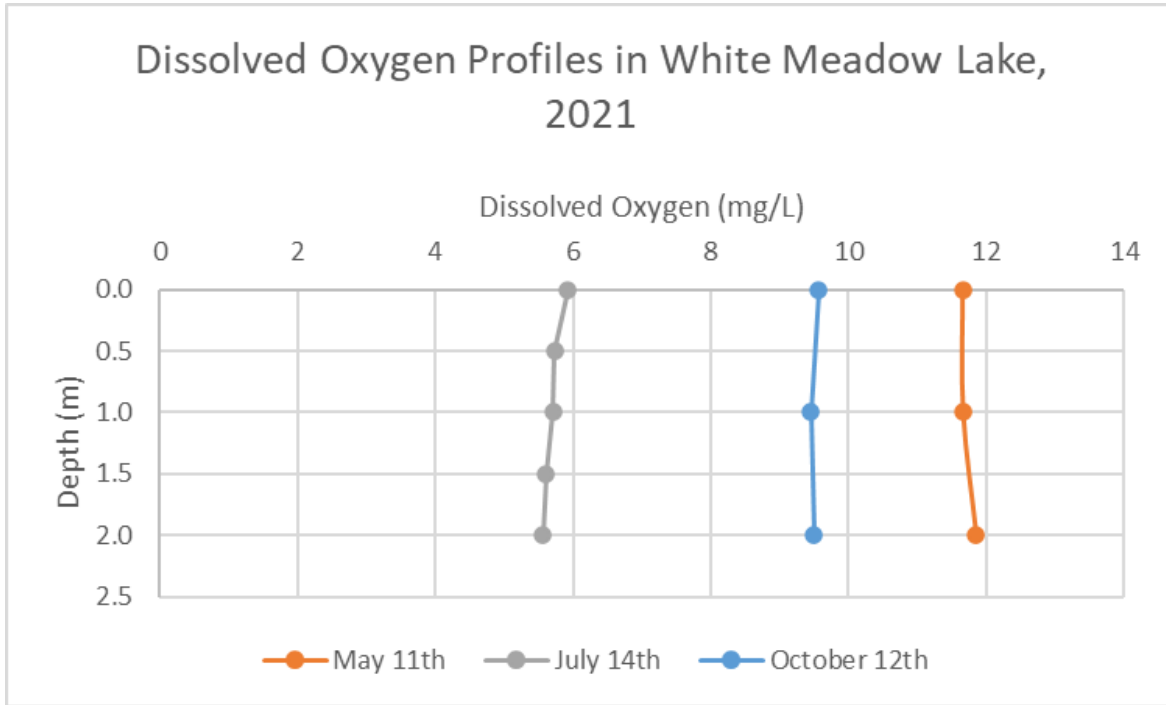


Figure 40. Dissolved oxygen profiles collected during 2021 at the Dam station at White Meadow Lake

Discrete Water Quality

The May event yielded phosphorus concentrations of 0.02 mg/L for both the surface and deep stations. These remained low through the July event, until they increased in October to 0.04 mg/L at the surface and 0.05 mg/L in the deep sample. SRP was consistently below the level of detection throughout the season. Nitrogen concentrations were relatively low throughout the season, only reaching 0.08 mg/L in October. Ammonia was not detected in any sample over the course of the season.

Total suspended solids were relatively low throughout the season, with surface concentrations averaging only 3 mg/L over the course of the year. Deep samples were slightly higher, at averaging 5 mg/L over the course of the season, but this is not problematic. Chlorophyll *a* was similarly low over the course of the year at the surface, averaging 5.9 µg/L, while deep samples were higher for the first two events, with the May event yielding a concentration of 12.0 µg/L.

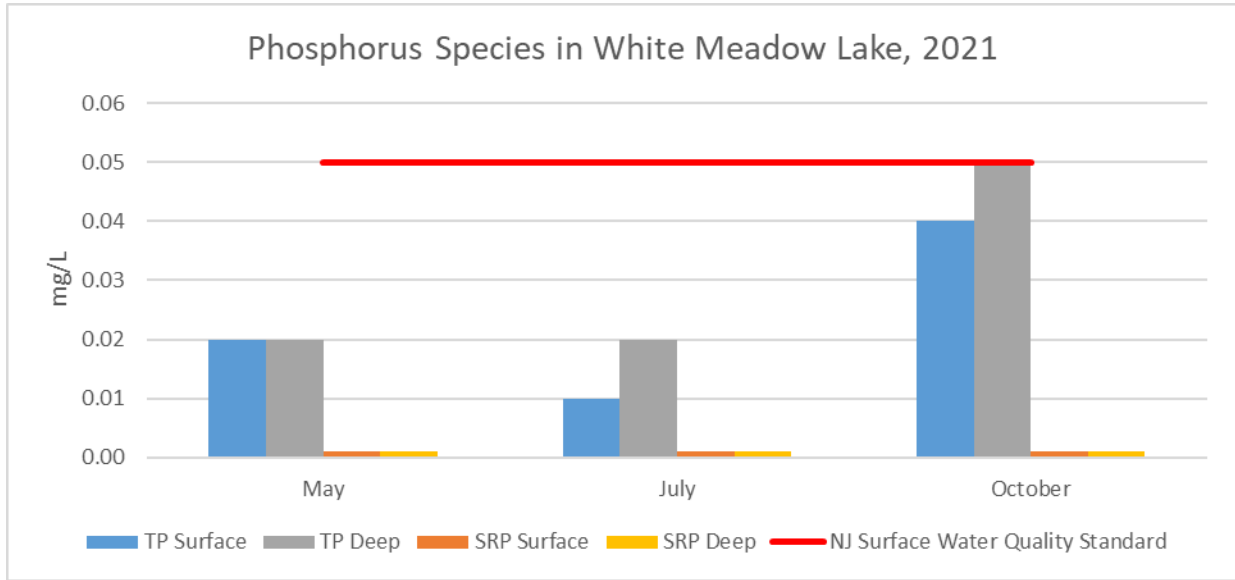


Figure 41. Concentrations of total phosphorus (TP) and soluble reactive phosphorus (SRP) measured from surface and deep samples collected in 2021 from the Dam station at White Meadow Lake.

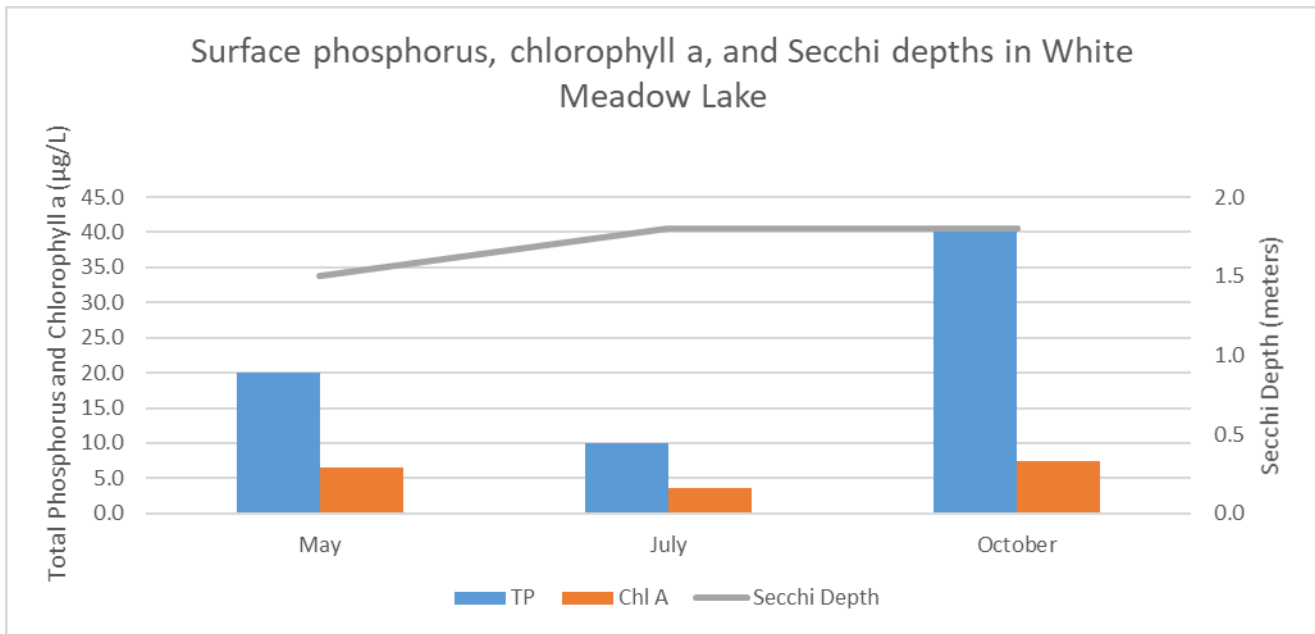


Figure 42. Concentrations of chlorophyll a (Chlorophyll a) and total phosphorus (TP), as well as Secchi depths, measured from the surface of the Dam station at White Meadow Lake in 2021.

Plankton and Macrophytes

During the May event, White Meadow Lake experienced a bloom of *Dinobryon*, with the diatom *Asterionella* also being prevalent in the sample. *Microcyclops* and *Keratella* were the most abundant zooplankters during this time. *Mougeotia* became the dominant phytoplankton genus during July, with *Ceratium* also being observed in common densities. The colonial rotifer *Conochilus* dominated the zooplankton sample during this period, with *Ceriodaphnia*, *Microcyclops*, and copepod nauplii also being common. October saw a bloom of *Dinobryon* re-emerge, as well as high densities of the



filamentous cyanobacteria genus *Lyngbya*, and an abundance of *Ceriodaphnia* and an unknown Calanoid copepod in the zooplankton sample.

During the May event, the lake was observed to contain curlyleaf pondweed, as well as benthic filamentous algae in near-shore areas. By July, the lake featured notable populations of leafy pondweed, and the filamentous algae *Spirogyra* was observed just beneath the surface near the northern boat launch. Slender naiad was pulled up with the anchor in both the mid-lake and dam sampling stations in October.



5. BASELINE WATERSHED WATER QUALITY DATA

5.1 METHODS

Water samples were collected in streams entering each Lake (when present) during base-flows in order to assess the nutrient load contributed by these streams during periods when no additional runoff is occurring. Base flows typically reflect groundwater influence as well. These sampling events occurred twice a year on days where no significant rainfall had occurred in the previous 48 hours. Each stream was sampled once per event during Spring and Late Summer/Fall of 2021. In areas where the streams were not directly accessible to sample by hand (tall bridges, difficult access, etc.), an extendable rod with a bottle attached was used to aid in sample collection. Following collection, all samples were delivered to the laboratory Environmental Compliance Monitoring in Hillsborough Township, NJ for analysis. Samples were analyzed for the following parameters:

- Total Phosphorus (TP)
- Soluble Reactive Phosphorus (SRP)
- Total Nitrogen (TN)
- Total Suspended Solids (TSS)

Streams also received a single measurement per event for *In situ* data using the same protocols as those used for lake sampling.

Additionally, Green Pond and Lake Emma did not feature any true inlets that flow during baseflow, and were not sampled for this portion of the study. Princeton Hydro was not granted permission to sample Camp Lewis Lake and Mt. Hope Lake, however one of Mt. Hope Lake's inlets was sampled at an upstream location once during the Autumn event. Maps displaying sampling locations for the baseline sampling are provided in Appendix II.

5.2 RESULTS

EGBERT LAKE

Burnt Meadow Brook featured relatively low TP concentrations during both events, with samples yielding a concentration of only 0.02 mg/L. SRP, however, was measured to be 0.004 mg/L for the May event and 0.008 for the September event. The stream did not yield any measurable concentrations of TSS during either event. Nitrogen concentrations were normal, detected at 0.38 mg/L in May and 0.25 mg/L in September. This may be expected with many streams in the region, including many of those entering the other lakes being studied. Most of these streams are likely partially fed by groundwater seepages, which naturally may contain relatively high concentrations of nitrogen.

As a non-trout stream, all of Burnt Meadow Brook's *in situ* parameters were well-within the NJ Surface Water Quality Standards. Between the two events, Burnt Meadow Brook's temperatures ranged from approximately 15.7-19.3°C. Dissolved oxygen was above 90% saturation for both events as well.



DURHAM POND

The inlet sampled in 2021 for Durham Pond, which enters the northeastern portion of the pond, itself drains from an impounded wetland, and, as such, yielded some different results from those obtained at some of the other waterbodies' inlets. TP concentrations were slightly higher than those obtained at some of the other inlets, at 0.04 mg/L, but this is still relatively low compared to the NJ Surface Water Quality Standard of 0.10 mg/L (This standard does not apply to streams in this study, as they are in the Passaic River basin). SRP was not detected in samples from either event. TSS was similarly slightly higher than in other locations, ranging from 9-10 mg/L; however, this is again largely not problematic. Lastly, nitrogen concentrations were detected to be lower than those collected at other sites, at 0.18 mg/L in May and only 0.06 mg/L in September.

While this small inlet is a non-trout stream and therefore not held to the same standards as trout maintenance or production waters, some of the measured *in situ* parameters were found to be outside the NJ Surface Water Quality Standards, particularly for dissolved oxygen and pH. During the May event, dissolved oxygen was measured at only 1.29 mg/L, while pH was measured at 6.15. Low dissolved oxygen values may be in part due to the origin of this short length of stream being a wetland, where dissolved oxygen concentrations may not be particularly high due to inaction. During the September event, all *in situ* parameters were back within the NJ standards.

LAKE TELEMAR

Hibernia Brook yielded only minimal amounts of phosphorus where the stream enters Lake Telemark, ranging from 0.01-0.02 mg/L. SRP was not detected during the May event, but was found at a concentration of 0.002 mg/L during the September event. Similarly, TSS was not detected in May, increasing only to 2 mg/L in September. Nitrogen was measured in the May sample at 0.21 mg/L, only increasing slightly to 0.25 mg/L in September.

The portion of Hibernia Brook entering Lake Telemark is classified as a trout maintenance stream. All *in situ* data collected at this inlet during the two sampling events were within standards, with sufficient dissolved oxygen, temperatures ranging from approximately 18.4-20.1°C, and pH values ranging from approximately 7.3-7.5.

LAKE AMES

Similarly to the other inlet streams sampled, Lake Ames' western inlet yielded low amounts of phosphorus, measuring at 0.01 mg/L during both events. SRP concentrations ranged from 0.003-0.006 mg/L, possibly suggesting that a relatively large amount of phosphorus passing through the tributary is not used by algae or other organisms. TSS concentrations featured a pattern similar to those obtained in Lake Telemark's inlet, with the parameter not being detected in the May sample and only being detected at 0.02 mg/L in September. Nitrogen concentrations were measured at 0.22 mg/L from the May event, dropping to 0.08 mg/L in September.

The western inlet to Lake Ames is listed as a Category 1 trout production stream, and as such is held to the strictest NJ surface water quality standards. During the 2 sampling events, however, the stream was found to be well-within these standards. Dissolved oxygen concentrations were at nearly 100% for both events, and temperatures ranged from approximately 14.9-19.0°C. pH levels were detected in a narrow range of 7.45-7.52.



MT. HOPE POND

Mt. Hope Pond's only inlet is a small groundwater seepage that enters the waterbody along its northern edge. Both the May and October samples yielded total phosphorus concentrations of 0.03 mg/L. SRP concentrations in this seepage were higher than those collected in some of the other inlets. As the groundwater seepage originates only a few feet from where it enters Mt. Hope Pond, this may be a result of most of the available phosphorus not being used by plants, algae, and other organisms in the short distance it travels before entering the waterbody. TSS concentrations in the May sample were measured at 6 mg/L, before increasing to 12 mg/L in September. Nitrogen concentrations were very low for groundwater, ranging from 0.09 mg/L during the May event to 0.16 mg/L in the September event.

While the inlet to Mt. Hope Pond largely stayed within NJ Surface Water Quality standards, pH values were lower than the acceptable range, being measured at 6.33 in May and 6.10 in September. This may in part be a product of the geology of the spring from which the small stream originates.

MT. HOPE LAKE

Mt. Hope Lake's western-most tributary was only sampled during the September event from Mt. Hope Road. Total phosphorus was somewhat high compared to many of the other inlet streams sampled, yielding a concentration of 0.04 mg/L, with an associated SRP concentration of 0.002 mg/L. The TSS concentration from the September event was measured to be 5 mg/L, and the nitrogen concentration was measured to be a relatively low 0.11 mg/L. While pH levels were slightly low during this event (6.6), this is within the acceptable range according to the NJ standards.

FOX'S POND

Sampling at the Fox's Pond inlet took place in October. Total phosphorus was relatively low during both events, ranging from 0.02-0.03 mg/L. As with several of the other inlet sites, SRP ran somewhat high, at 0.011 mg/L in May and 0.017 mg/L in October. This may be an indication that a relatively large amount of the phosphorus passing through Fox's Brook is not being used by plants or algae. The stream featured no detectable concentration of TSS during either of the two events. Nitrogen concentrations were much higher in Fox's Creek than in any of the other inlets in the study, with both events yielding a concentration of 1.30 mg/L. This is likely a product of the pond's largely urbanized watershed. Higher total phosphorus and TSS concentrations than those measured would also be expected in this scenario, however.

Fox's Brook featured cool water temperatures and sufficient oxygen during both events. pH levels were relatively high compared to most of the other sites sampled, at approximately 8-8.1 for both events, but this falls within the acceptable range determined by the NJ standards.

WHITE MEADOW LAKE

As with Fox's Pond's inlet, White Meadow Lake's inlet was sampled in October. Total phosphorus concentrations were measured to be relatively elevated in May, at 0.05 mg/L, however this dropped to 0.01 mg/L in October. SRP concentrations were also somewhat high, measuring 0.019 mg/L in May and 0.012 mg/L in October. TSS was detected at relatively low amounts during both events, only ranging from 2-5 mg/L. Nitrogen concentrations were somewhat high compared to many of the other



inlet stations in May at 0.48 mg/L. This concentration dropped, however, by the autumn sampling event to 0.23 mg/L. All *in situ* data collected during both events were within the NJ Surface Water Quality Standards.



6. TROPHIC STATE MODELING

6.1 METHODS

Utilizing data collected in the field or obtained through the lake and watershed modeling methods outlined above, multiple predictive models were used in order to estimate the status of each lake as it pertains to the amount of nutrients and the resulting biological activity that occurs within. Some of these models also may predict concentrations of phosphorus or chlorophyll *a* within the water column itself at certain times of the year.

Once estimated annual hydrologic and phosphorus loads are established for a waterbody, they can be used in conjunction with the estimated volume of the lake to determine an estimated concentration of phosphorus. The results of these models can be compared against in-lake total phosphorus values obtained in the field in order to validate the results of hydraulic and pollutant modeling. If the resulting predicted phosphorus concentrations are lower than what is typically obtained in the field, other variables may be present within the watershed and/or waterbody that were not accounted for in the model. If modeled phosphorus concentrations are similar to those collected in the field, the model(s) can be used to predict changes in overall phosphorus concentrations as a result of predicted phosphorus reductions resulting from in-lake or watershed-based management implementations.

Many of these models were run twice, for both only the watershed-based phosphorus load and for the total combined load. Details regarding each of the models are as follows:

Carlson's Trophic State Index (TSI)

Trophic state as it applies to lakes refers to the amount of nutrients in a lake and the primary productivity (growth of photosynthetic organisms) that results. This is the base of a food web in a lake from which consumers (higher organisms such as macroinvertebrates and fish) feed in order to maintain their own populations within the lake. Low levels of primary productivity in a lake result in an oligotrophic state. This usually occurs in glacial kettle ponds and lakes and is characterized by low amounts of plants and algae, very high water clarities, and a fisheries consisting of salmonids and/or other cold-water fish. Conversely, high levels of primary productivity in a lake result in a eutrophic state. Many of the small lakes and ponds in New Jersey (with some exceptions) are typically eutrophic, featuring relatively high nutrient loads, lower water clarities, and a higher propensity for algae blooms. Mesotrophic lakes refer to those with primary productivity levels between oligotrophy and eutrophy. Eutrophication describes increasing system productivity over time. This can include natural eutrophication at geological time scales and includes sediment infilling and increasing nutrient concentrations due to natural accretions of these materials, although at slow rates and with low loads. Cultural eutrophication is an accelerated eutrophication caused by excess nutrient loads entering the waterbody as a product of anthropogenic activities in the watershed. Cultural eutrophication is a much greater concern and results in greater impairment of waterbodies. This is particularly true in areas where waterbodies are artificial, that is they are created entirely or expanded via excavation or impoundment, and most of the waterbodies in this study have been significantly altered in area and volume. Eutrophication can be assessed in part through trophic state models which describe the productivity of a lake system.



The Carlson's Trophic State Index (TSI) assesses the trophic state of lakes by calculating index values based on phosphorus and chlorophyll a concentrations and Secchi depths that relate to each other on a similar scale (Carlson, 1977). The higher these numbers are, the more representative they are of eutrophic conditions.

Carlson's trophic state index (TSI) was calculated for each in-lake sampling event using surface concentrations of TP, Chlorophyll *a*, and Secchi depths collected during water quality monitoring events throughout the season. The TSI for total phosphorus is calculated as follows:

$$TSI = 14.42 \ln^{TP} + 4.15$$

Where *TSI* = Trophic State Index result for phosphorus and *TP* = total phosphorus concentration in µg/L.

The TSI for chlorophyll *a* is calculated as follows:

$$TSI = 9.81 \ln^{Chl} + 30.6$$

Where *TSI* = Trophic State Index Result for chlorophyll *a* and *Chl* = Chlorophyll *a* concentration in µg/L.

Lastly, the TSI for water clarity as Secchi depth is as follows:

$$TSI = 60 - 14.41 \ln^{SD}$$

Where *TSI* = Trophic State Index Result for Secchi depth and *SD* = Secchi depth in meters. It is important to note that this index is somewhat reversed from the others. While higher phosphorus or chlorophyll equates to higher index values and thus higher trophic state, higher clarity is indicative of reduced productivity and yields a lower value; the reverse is also true and lower clarity equates to higher index values.

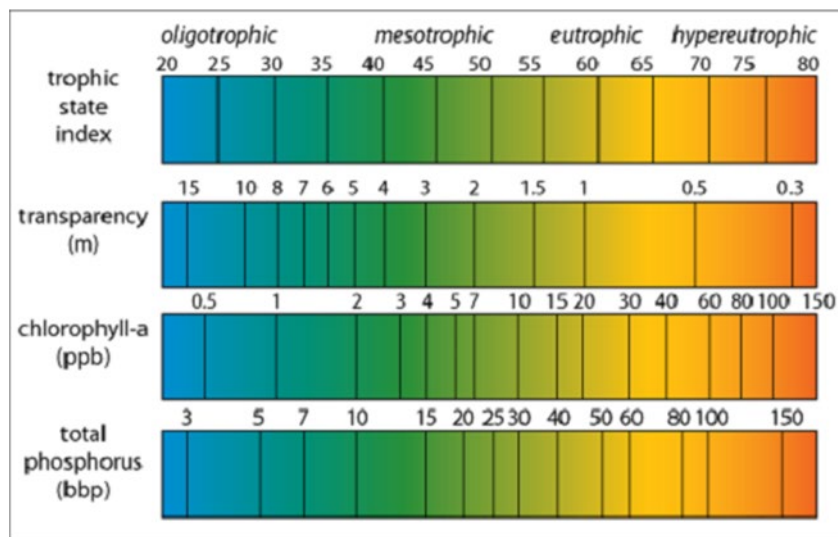


Figure 58. Ranges of trophic states for the three components of Carlson's TSI.



The resulting TSI values represent the trophic state of the waterbody along a trophic spectrum or continuum, although the three primary classifications (eutrophic, mesotrophic, or oligotrophic) are still widely used by limnologists. Each of the individual index values is supposed to yield the same value. This is built on the assumption that phosphorus is the sole control on algal density, algal density is accurately represented by chlorophyll concentrations, and that algal density is the primary determinant of Secchi clarity. In many cases, these three TSI values will differ notably from one another within a single event (e.g., chlorophyll a concentrations may be very high but relatively high Secchi depths may still be measured) indicating that some of the model assumptions are not met. An analysis of these residuals (differences) between the results of a TSI analysis can be suggestive of other conditions affecting the waterbody's trophic state and yield additional information about the ecology of the studied system. The differences between the chlorophyll-based TSI and the Secchi-based TSI and between the Chlorophyll-based TSI and the Phosphorus-based TSI can be plotted as either several dates in a year or for several years. As demonstrated in Figure 59 by Carlson and Havens (2005), the location of events in one of the "quadrants" on the graph, relative to the axes, may suggest differences in conditions during those particular events.

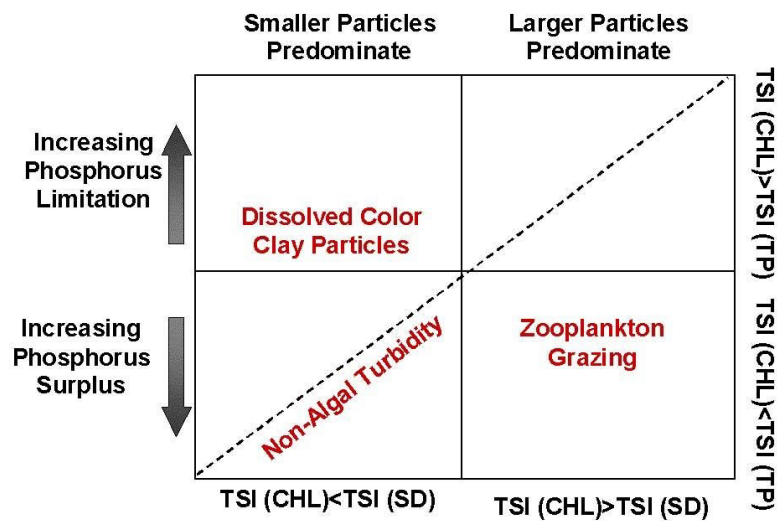


Figure 59. Carlson and Havens (2005) display possible interpretations for differences in trophic state indices when plotted on an axis.

Kirchner and Dillon’s Phosphorus Retention

This metric by Kirchner and Dillon (1975) utilizes the incoming hydraulic load from the watershed, as well as the total area of the waterbody, to estimate what percentage of incoming phosphorus will stay within the waterbody rather than be flushed from the system. The equation is as follows:

$$R = 0.426e^{(-0.271qs)} + 0.574e^{(-0.00949qs)}$$

Where R = the phosphorus retention coefficient and qs = the areal water load, calculated as the total annual hydrologic input divided by the total surface area of the waterbody.



Dillon and Rigler's Spring Phosphorus Prediction

The result of Kirchner and Dillon's phosphorus retention equation above can be directly used, as well as the estimated total annual load of phosphorus, the waterbody's hydraulic retention time, and average depth, can be used to predict total phosphorus concentrations in the water column at the beginning of the growing season (Dillon and Rigler, 1975). The equation is as follows:

$$[TP] = LT(1 - R)/Z_{mean}$$

Where [TP] = annual mean phosphorus concentration (mg/L), L = areal phosphorus loading (g/m²/yr), R = phosphorus retention, T = water retention time in years, and Z_{mean} = average depth.

Walker's Spring Phosphorus Prediction

Other models for the prediction of spring phosphorus, as well as for predicting the overall trophic state of a waterbody, are Walker's 1977 equations, which are described below:

$$P_s = \frac{LT}{Z} * \left(\frac{1}{1 + 0.8247^{0.454}} \right)$$

Where P_s = estimated spring phosphorus load, L = areal phosphorus load, T = hydraulic retention time, and Z = mean depth.

Walker's trophic state equation uses a different equation to generate spring phosphorus loads, before plotting the Log₁₀ of the estimated spring phosphorus on a graph in order to determine the trophic state probability of the lake. The equation for determining the spring phosphorus load for this purpose is as follows:

$$X = L(qs(1 + 0.824 * T^{0.454}))^{-0.815}$$

Where X = spring phosphorus, L = areal phosphorus, T = hydraulic retention time, and qs = areal water load. The log₁₀ of the result of this is plotted on the graph below in order to assess the chances of the waterbody being classifiable as one of the three main trophic states.

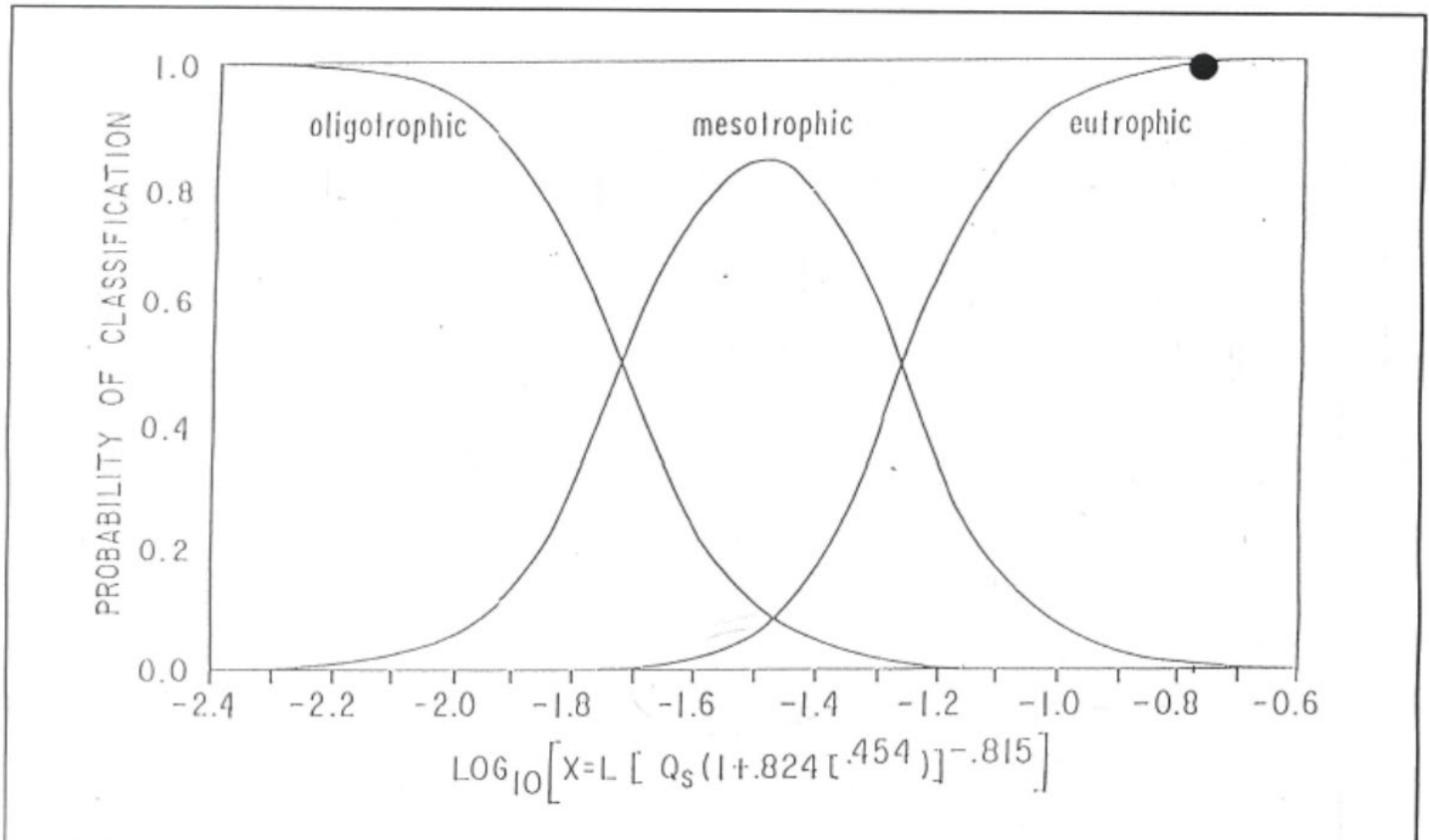


Figure 60. Walker (1977) displays how to interpret the log₁₀ of spring phosphorus concentrations in order to assess the trophic state of a waterbody.

Carlson's Predicted Average Chlorophyll

Using the predicted phosphorus loads from Walker's initial equation above, Carlson (1977) developed an equation for estimating the average midsummer chlorophyll *a*. The equation for doing so is as follows:

$$Chl. = e^{((1.449 * (LN(P_s)) - 2.442)}$$

Where *Chl.* = estimated summer average chlorophyll *a* concentrations and *P_s*.

Vollenweider's Predicted Phosphorus

Vollenweider's equation uses the incoming total phosphorus and hydraulic load, as well as the lake's mean depth and hydraulic residence time, to calculate an estimated phosphorus concentration. The equation for this metric is as follows:

$$P = \frac{L}{10 + \frac{Z_{mean}}{t}}$$

Where *P* = the predicted phosphorus concentration, *L* = the incoming phosphorus load, *Z_{mean}* = the average depth, and *t* = the hydraulic residence time.



Reckhow's Predicted Phosphorus

Lastly, this model by Reckhow () utilizes a nutrient trapping parameter to estimate phosphorus concentrations. The equation is as follows:

$$P = \frac{P_{in}}{(1 + kT_w)}$$

Where P = the predicted phosphorus load, P_{in} = the total incoming phosphorus load divided by the total hydraulic load, T_w = the retention time, and k = the nutrient trapping parameter. The equation for determining k is as follows:

$$k = 3(P_{in}^{0.53}) * T_w^{-0.75} * z_{mean}^{0.58}$$

Where k = the nutrient trapping parameter, P_{in} = the total incoming phosphorus load divided by the total hydraulic load, T_w = the retention time, and z_{mean} = the average depth.

It is important to note that many of these models are designed to consider only the external phosphorus load. They were run for the purposes of this study for both the external load and for the total phosphorus load including the external watershed load and internal phosphorus loading.



6.2 RESULTS

GREEN POND

In past years, Green Pond's trophic state has largely been oligo-mesotrophic. This was largely the case in 2021, with only occasional deviations. The May event saw the total phosphorus, chlorophyll *a*, and Secchi depth components all yield TSIs between approximately 32.4 to 37.4, indicating late-Oligotrophic status. The phosphorus TSI remained stable through July, although the chlorophyll *a* and Secchi depth TSIs increased to approximately 47.0 and 41.9, respectively, indicating mesotrophic conditions. By October, these components had both dropped back to the mid-30s, indicative of oligotrophic conditions, while the total phosphorus TSI component increased to 57.3, which is more typical of eutrophic conditions. Figure 61 below displays the fluctuations in the three TSI components over the course of the season.

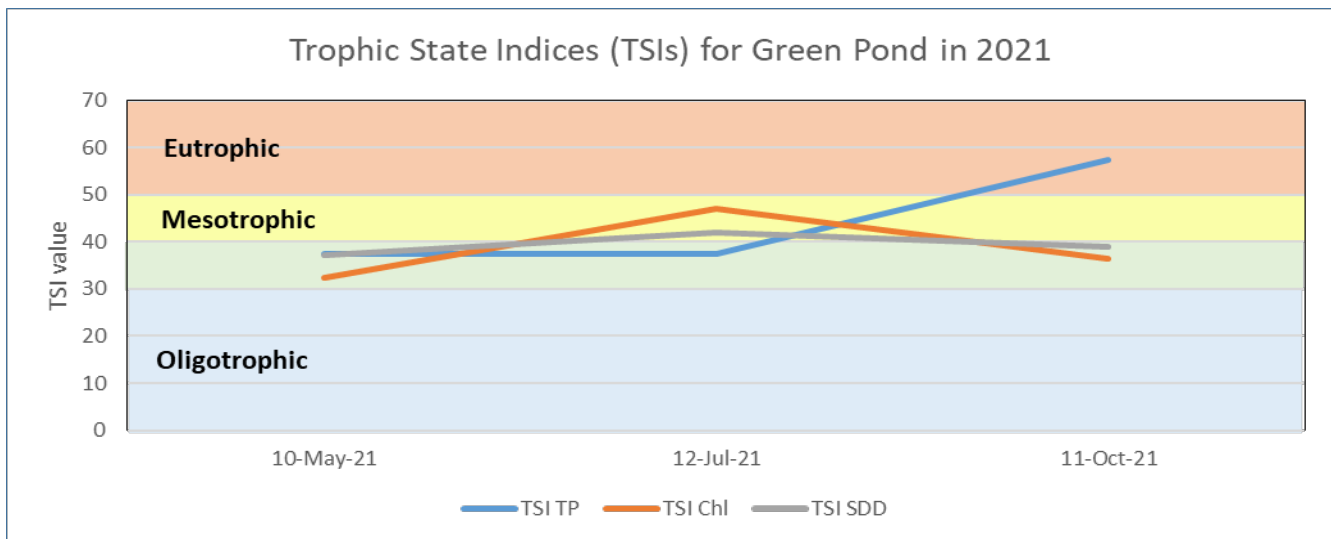


Figure 61. Changes in Trophic State Indices (TSIs) over the course of the 2021 growing season in Green Pond.

Residuals of these TSI values are plotted below in Figure 62. The points representing the May and October events are located in the bottom-left quadrant; this suggests that chlorophyll was not limited by phosphorus concentrations at these times or, in other words, that there was a phosphorus surplus. It is perhaps not a surprise this occurred at the bounds of the growing season. Full growth potential is not usually reached in May, and a surplus of phosphorus in October is likely related to the breakdown in stratification and liberation of the hypolimnetic anoxic load upon fall turnover, however as this occurred near the end of the growing season it did not result in a significant increase in algal density. During the May event in particular, Secchi depths were somewhat lower than anticipated for the measured chlorophyll concentration, suggesting some other source contributed to increased turbidity, which may be explained by suspended sediment or other matter rather than plankton densities. During the July event, transparencies were higher than would have been expected from the chlorophyll *a* values obtained; in such situations, algae populations are usually represented largely by larger particles, such as cyanobacteria colonies. Phosphorus was likely also limiting algae growth at this time.

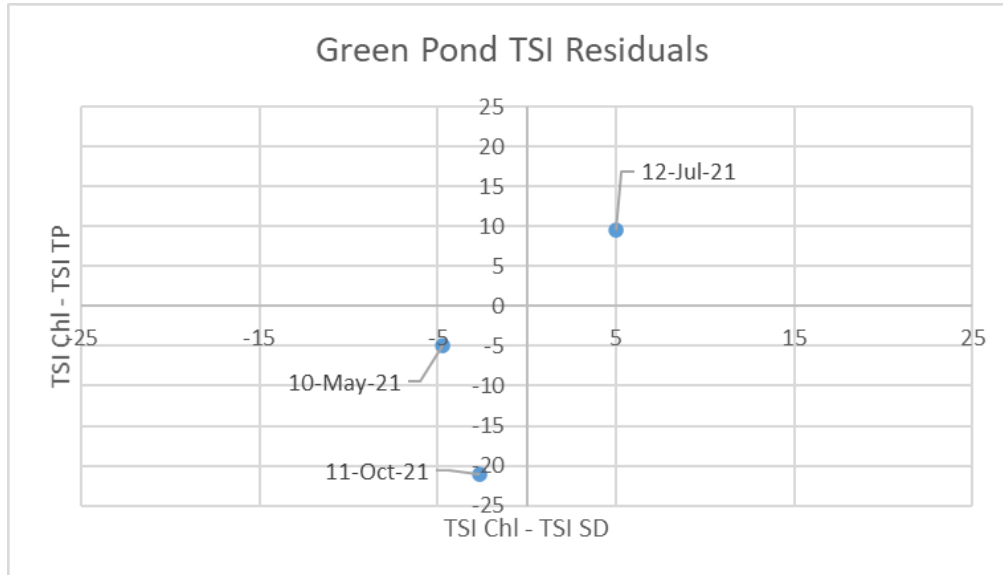


Figure 62. Residuals from TSI values obtained over the course of the 2021 growing season in Green Pond.

When assessed with Kirchner and Dillon's phosphorus retention model, Green Pond yielded an *R* value of 0.87, suggesting that a large amount of the phosphorus that enters Green Pond is retained on annual basis and not flushed from the waterbody. When this value is entered into the Dillon-Rigler predictive phosphorus model, Green Pond is estimated to have a Spring phosphorus concentration of approximately 0.006 mg/L (approximately 0.02 mg/L when also accounting for internal loading). These estimates are similar to the actual surface phosphorus concentration obtained in May of 2021 of 0.01 mg/L. The model by Walker overestimated this field value slightly, estimating a spring concentration of approximately 0.02 mg/L. According to Walker's trophic state analysis, Green Pond has approximately a 50% likelihood of being mesotrophic and an 50% likelihood of being oligotrophic, which again conforms to observed and measured conditions. Carlson's estimated summertime chlorophyll *a* model predicted a chlorophyll concentration of approximately 7.5 µg/L, a slight overestimation of the field value obtained during the July field event of 5.3 µg/L. Vollenweider's predicted phosphorus model yielded an estimated phosphorus concentration of approximately 0.005 mg/L, while Reckhow's predicted phosphorus model yielded an estimated value of approximately 0.02 mg/L. The result of Reckhow's model was utilized as the phosphorus input for Carlson's predictive chlorophyll *a*, which yielded a slightly more accurate estimation of approximately 4.9 µg/L. While the models yield variable results, they cluster near the field measured values and are generally supportive of a trophic state ranging somewhere between oligotrophy and mesotrophy. This further supports the accuracy of the pollutant loading and hydrology modeling for the lake.

EGBERT LAKE

For both the May and July events, the phosphorus TSI element for Egbert Lake was calculated to be 47.35, indicative of mesotrophic conditions. This metric increased to 57.34 in October, suggesting eutrophic conditions. The chlorophyll-based TSI was calculated to be within the late-oligotrophic range for both the May and October events, while the July event yielded a larger value of 51.36, indicative



of eutrophic conditions. Secchi depth-based TSIs remained in the eutrophic range throughout the year; however, this is related to the lake's relatively shallow depth and at times significant plant growth which limit measurable Secchi depth. Changes in all TSI values over the course of the season are displayed below in figure 63.

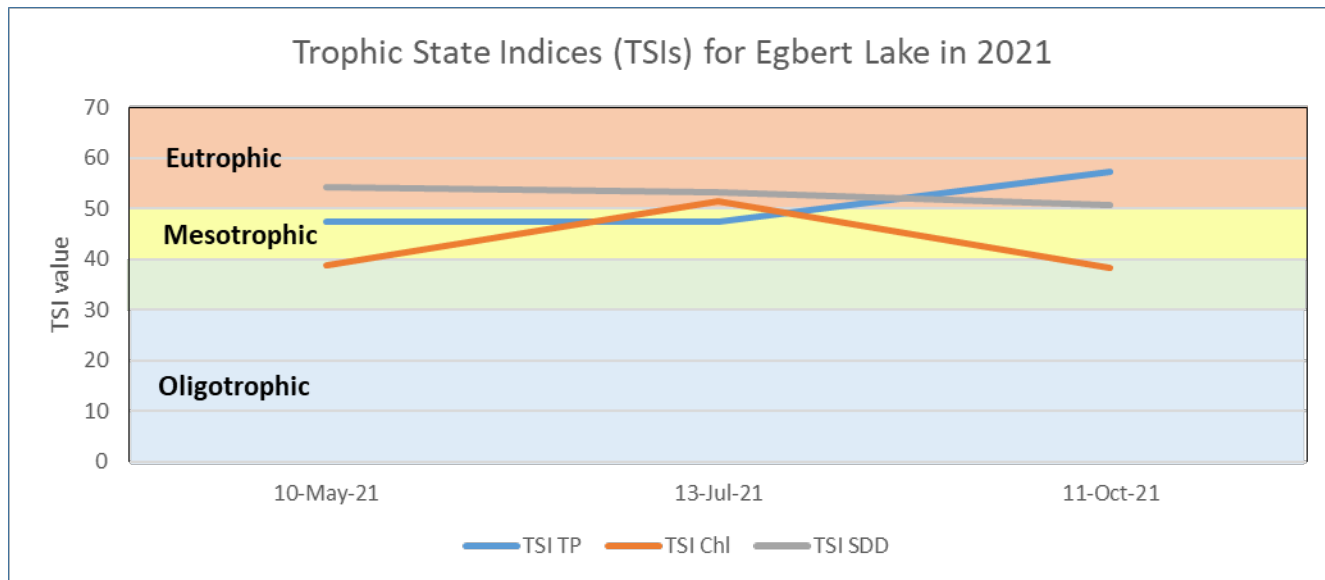


Figure 63. Changes in Trophic State Indices (TSIs) over the course of the 2021 growing season in Egbert Lake.

TSI value residuals are plotted below in Figure 64. The two points representing the May and October events are located in the lower-left quadrant, suggesting that algae growth in the lake was not limited by phosphorus concentrations at this time, and may be explained simply by lower temperatures preventing increased algae growth. Secchi-based TSIs were consistently less than those of chlorophyll a-based ones, as described above, and thus all points are located on the left of the Y-axis. As mentioned above, however, this is likely due to the limitation on Secchi depths by the lake's shallow depths and plant growth. The location of the point representing the July event in the upper half of the figure suggests that phosphorus was limiting algae growth at this time.

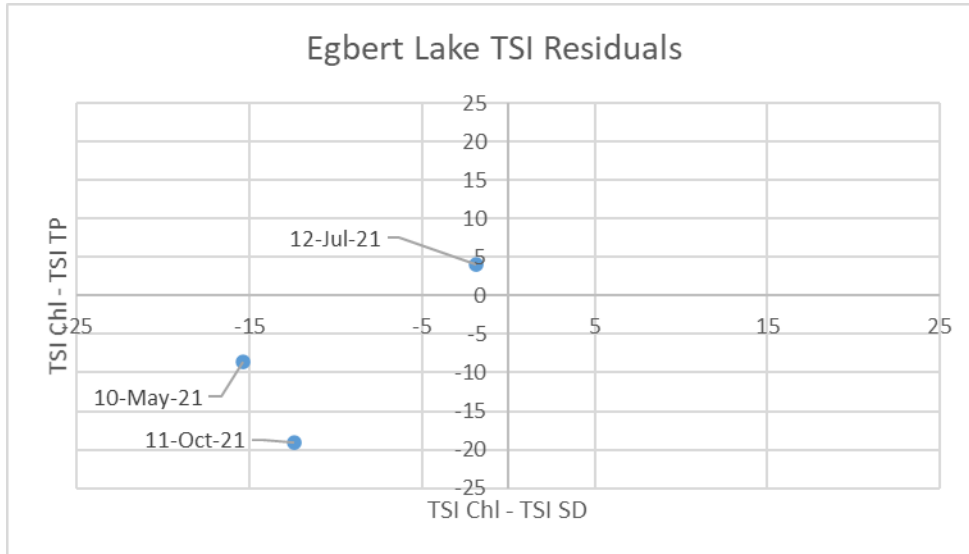


Figure 64. Residuals from TSI values obtained over the course of the 2021 growing season in Egbert Lake.

When assessed with Kirchner and Dillon's phosphorus retention model, Egbert Lake yields an *R*-value of approximately 0.50, suggesting that the lake retains approximately half of the phosphorus it receives from the watershed, with the rest flushing from the system. When this value is used in the Dillon-Rigler spring phosphorus prediction model, Egbert Lake is predicted to yield a spring-time phosphorus concentration of approximately 0.01 mg/L. This falls only slightly short of the field value obtained in May, which was assessed to be 0.02 mg/L. Walker's spring phosphorus model yielded a similar result of approximately 0.01 mg/L, and the results of Walker's trophic state analysis suggested that the lake has an approximately 80% likelihood of being mesotrophic, approximately a 10% chance of being eutrophic, and a 10% likelihood of being oligotrophic. This is slightly different from many of the results of Carlson's TSI, however, as mentioned above, this metric used limited Secchi measurements that might've yielded results more indicative of mesotrophic conditions in a deeper lake. The Walker equation also does not take into account the internal load. Using Walker's predicted phosphorus, Carlson's model predicted chlorophyll model estimated that Egbert's summertime chlorophyll *a* concentrations would be approximately 3.8 µg/L. This is an underestimation when compared to the value obtained from field samples, which was assessed to be 8.3 µg/L. Vollenweider's model predicted a phosphorus concentration of approximately 0.02 mg/L, consistent with field results, while Reckhow's model predicted a similar concentration of approximately 0.02 mg/L. The result of the Reckhow model was used in Carlson's Chlorophyll *a* model, yielding a predicted value of approximately 6.5 µg/L, closer to the value obtained in the field. Underestimation of chlorophyll indicate improved growing conditions for phytoplankton. This is common in shallow lakes which warm quickly and where there is little light limitation in the shallow water column.



DURHAM POND

Durham Pond's TSI values for chlorophyll *a* and Secchi depths were consistently within the eutrophic range (between 50 and 60) for all field events. The total phosphorus-based TSI values were also in this range during the July event; however, the May and October events yielded phosphorus TSIs in the upper-mesotrophic range (approximately 47.35). Figure 65 below displays variation in TSI values over the course of the 2021 season.

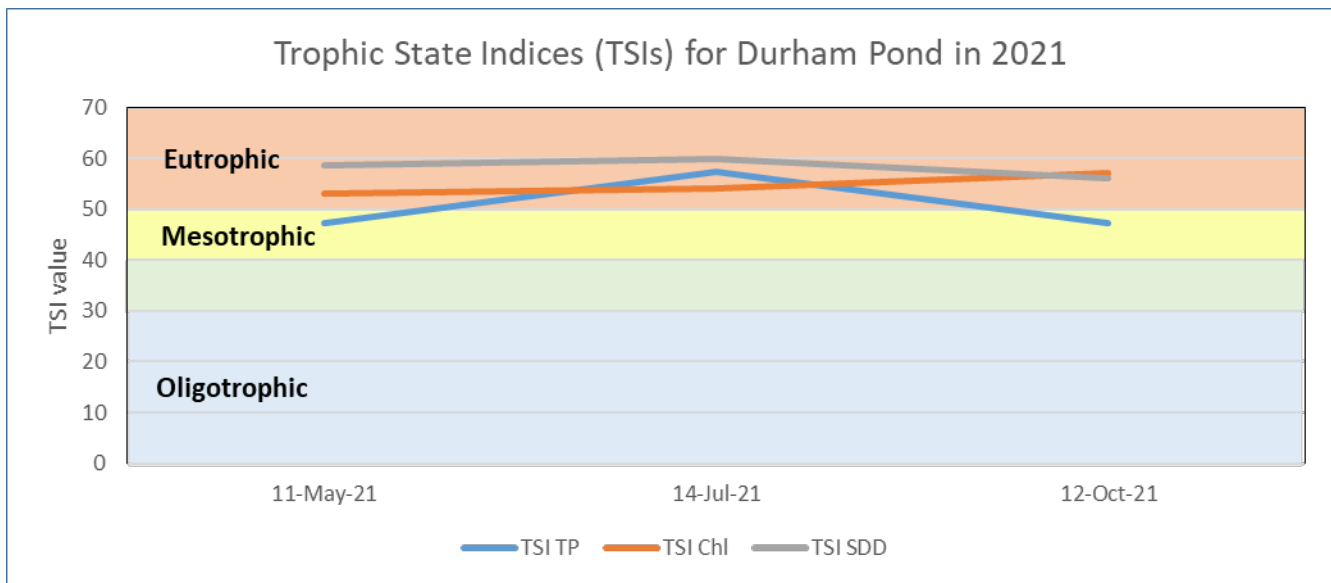


Figure 65. Changes in Trophic State Indices (TSIs) over the course of the 2021 growing season in Durham Pond.

Durham Pond's TSI residuals are plotted below in Figure 66. The point representing the May event is located in the upper-left quadrant. This suggests that phosphorus was limiting algae growth at this time and that Secchi depths may have been better explained by smaller, non-algal particulates more so than entirely due to algae growth. The point representing the July event is located in the lower-left quadrant, suggesting that algae growth was less limited by phosphorus than in other points in the year. Lastly, the point representing the October event is located in the upper-right quadrant, suggesting that phosphorus was limiting algae growth at this time, and this algae growth was likely dominated by larger particles, such as those created by cyanobacteria colonies or by other larger-celled taxa. Overall, the lake appears to be predominantly phosphorus limited.

When assessed with Kirchner and Dillon's phosphorus retention model, Durham Pond was calculated to have a retention value of approximately 0.68, suggesting the pond retains just over approximately two-thirds of all incoming phosphorus. When this value is used a part of the Dillon-Rigler predicted phosphorus model, Durham Pond is estimated to feature a springtime phosphorus concentration of approximately 0.005 mg/L. This is an underestimation from the value of 0.02 mg/L obtained from field samples, however the model yields a closer estimated value of 0.01 mg/L when the total load is used as the input. Walker's phosphorus-prediction model estimated a result of approximately 0.007 mg/L, again yielding a more accurate value of 0.02 mg/L when the total load is utilized rather than only the external load. Walker's trophic state assessment predicted that the pond has a 80% likelihood of being oligotrophic and a 20% chance of being mesotrophic. This differs from the results of Carlson's TSI and



from observations and data collected from field surveys. Carlson's predicted chlorophyll *a* model predicted a summertime chlorophyll *a* concentration of approximately 1.5 µg/L, a notable underestimation from the value obtained in the field of 11.0 µg/L. As discussed above in the residual analysis of Carlson's TSI, however, the results of the July sampling event suggest that chlorophyll *a* concentrations may not have been explained solely as a function of phosphorus concentrations at this time. Vollenweider's predicted phosphorus model predicted an underestimation of approximately 0.005 mg/L of phosphorus, while Reckhow's model yielded a prediction of approximately 0.01 mg/L. Both of these models yielded estimates closer to the field result when the total phosphorus load was used, rather than the external load only. This suggests that the internal load is in fact an important component of the phosphorus load to the lake and significantly drives the ecology of the system.

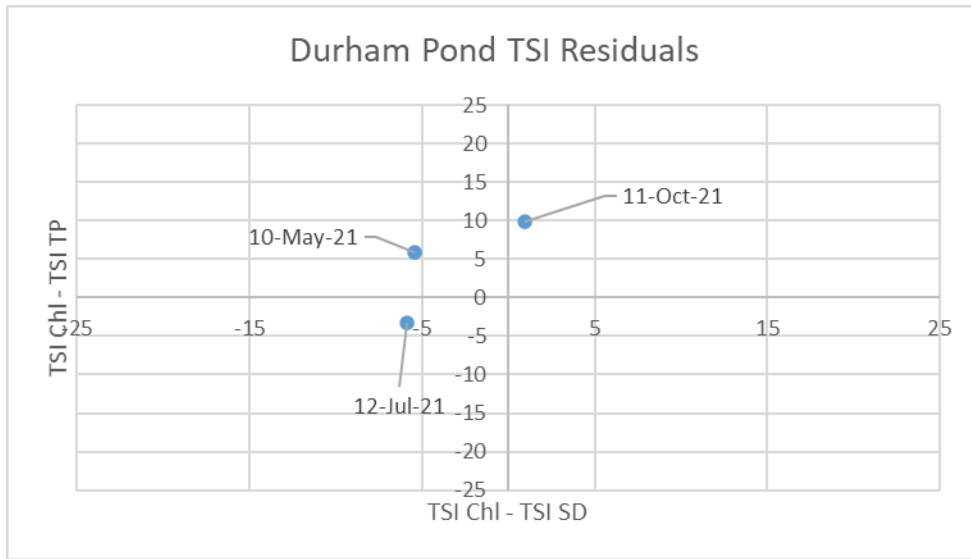


Figure 66. Residuals from TSI values obtained over the course of the 2021 growing season in Durham Pond.

LAKE EMMA

The May event yielded TSI values for the total phosphorus and chlorophyll components in the 30-40 range, suggesting a late-oligotrophic state. The Secchi depth TSI value for this date was calculated to be approximately 54.16, indicating eutrophic conditions. Similar to Egbert Lake, however, Lake Emma's relatively shallow depth and plant growth was a limiting factor for Secchi depths during some of the field events. By July, all TSI values were calculated to be approximately between 63 and 66, indicating eutrophic conditions. By October, the total phosphorus and chlorophyll TSIs had fallen to the upper-mesotrophic range, while the Secchi TSI was still indicative of eutrophic conditions. The changes in these values over the course of the 2021 growing season are displayed below in figure 67.

Residuals from Lake Emma's 2021 TSI values are plotted below in Figure 68. All three points fall very close to the x-axis, as the TSIs for phosphorus and chlorophyll *a* were very similar during these events. This indicates that phosphorus largely controlled chlorophyll and algal density in the lake. As the May and October events are plotted to the left of the y-axis, Lake Emma may have featured smaller non-algal particulates during these events that had a larger bearing on Secchi depths than algal growth did; however, as mentioned above, Secchi depths are also limited by the shallower depth of Lake Emma.



The point representing the July event is located on the right side of the y-axis, suggesting an increased presence of larger particulate algae cells or colonies.

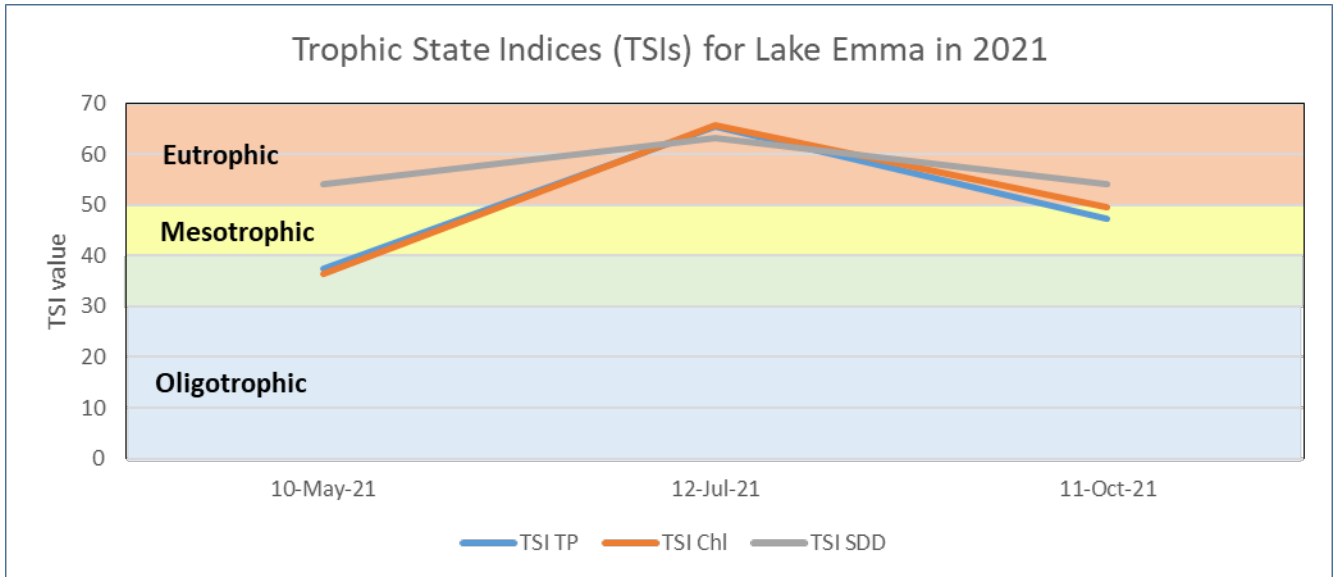


Figure 67. Changes in Trophic State Indices (TSIs) over the course of the 2021 growing season in Lake Emma.

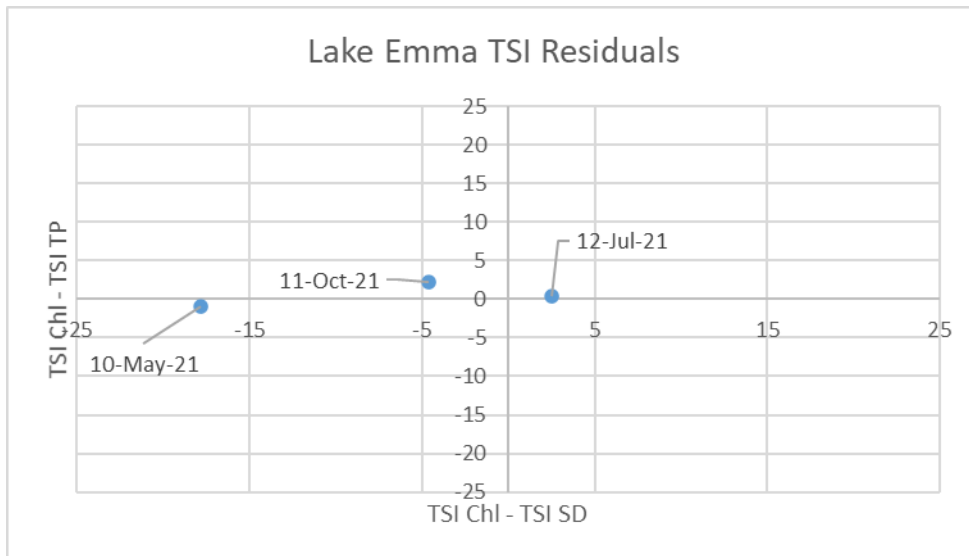


Figure 68. Residuals from TSI values obtained over the course of the 2021 growing season in Lake Emma.

Analysis with the Kirchner-Dillon phosphorus retention model yielded a retention value of 0.65, indicating that just under two-thirds of the incoming phosphorus is retained by the lake, rather than flushed from the system. When this coefficient is used in the Dillon-Rigler model, Lake Emma has an estimated springtime phosphorus concentration of approximately 0.02 mg/L. This is only a slight overestimation of the value obtained in the field, as the May event at Lake Emma yielded a concentration of 0.01 mg/L. Walker's predictive spring phosphorus model also yielded a predicted value of approximately 0.02 mg/L. The Walker trophic state model predicts the lake has an estimated



80% likelihood of mesotrophy, 15% chance of eutrophy, and an approximately 5% likelihood of being oligotrophic. Carlson's predictive chlorophyll model predicts a summertime load of chlorophyll of approximately 4.4 µg/L, a large underestimation from the July field event's concentration of 36.0 µg/L. Utilizing the total phosphorus load in this model yields a more accurate prediction of approximately 40.1 µg/L. It should also be noted that the waterbody was undergoing a bloom of *Ceratium* during this event, and chlorophyll concentrations might have been higher than the usual summer average. The Vollenweider predictive model estimated a phosphorus load of approximately 0.01 mg/L, while the Reckhow Model estimates a load of approximately 0.02 mg/L. Overall, phosphorus concentrations are relatively low, but pulses of the internal phosphorus load, particularly during periods of decreased flushing, can lead to higher than predicted phytoplankton growth.

LAKE AMES

May yielded Chlorophyll a and Total Phosphorus components of the TSI in the mesotrophic range. These increased to eutrophic levels in July before dropping to the late-oligotrophic range in October. As with some of the other smaller waterbodies in this study, Secchi depth-based TSIs were consistently in the eutrophic range. While only the October Secchi depth approached reaching the bottom of the water column, the lake's dense plant growth may have limited Secchi depths during some of the events. Figure 69 below displays the variation of TSI values over the course of the growing season.

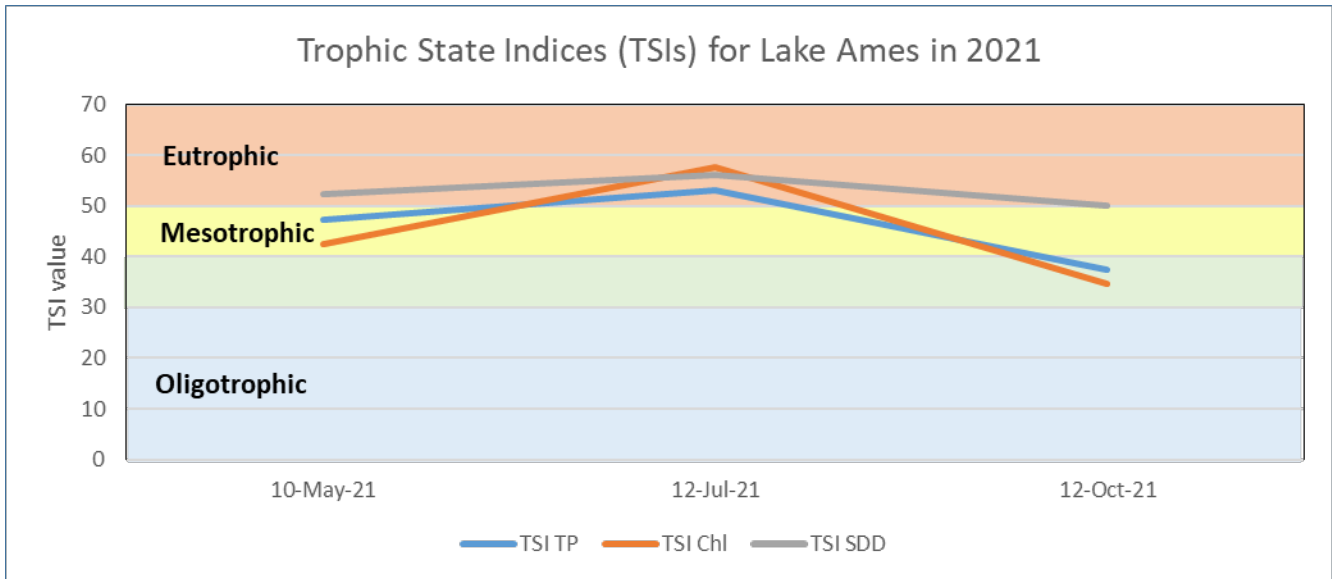


Figure 69. Changes in Trophic State Indices (TSIs) over the course of the 2021 growing season in Lake Ames.

TSI residual values for data collected from Lake Ames is plotted below in Figure 70. Points representing the May and October events are located in the lower-left corner, suggesting that phosphorus may had not been the sole limiting factor during these times of the year. It also suggests that Secchi depth may had been a product of factors other than solely algal growth, likely non-algal turbidity. The point representing the July event is located in the upper-right quadrant, suggesting that phosphorus concentrations were limiting algae growth at this time and that the algae community was dominated by larger particulates.

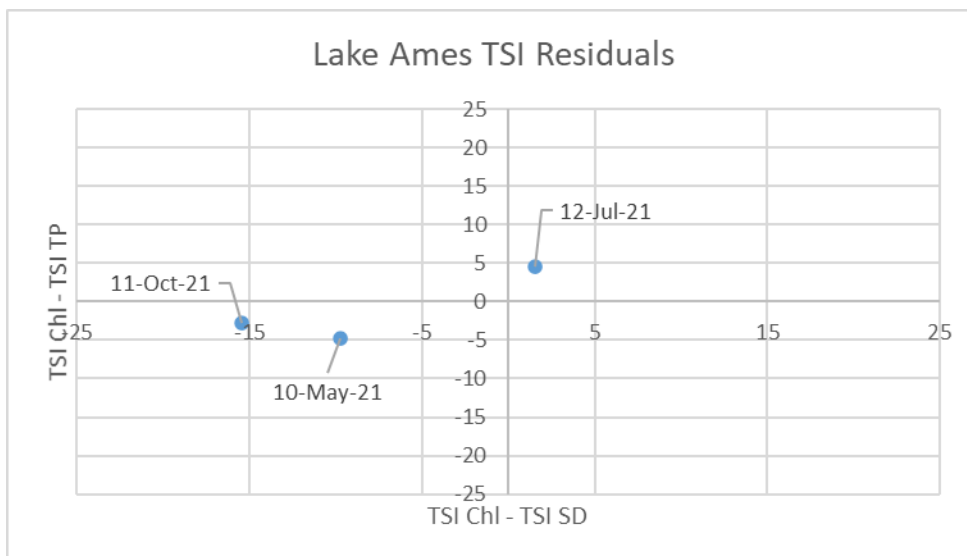


Figure 70. Residuals from TSI values obtained over the course of the 2021 growing season in Lake Ames.

When assessed with Kirchner and Dillon's model, Lake Ames features a phosphorus retention coefficient of approximately 0.21, suggesting that the lake retains less than a quarter of incoming phosphorus loads. When this coefficient is entered into the Dillon-Rigler model, Lake Ames is predicted to have a spring phosphorus load of approximately 0.02 mg/L. This matches the concentration of 0.02 mg/L obtained during the May sampling event. Walker's predictive phosphorus loading yielded a similar predicted concentration of 0.01 mg/L, and Walker's trophic state analysis indicates that the pond has an approximately 50% likelihood of being mesotrophic, an approximately 45% chance of being eutrophic, and an approximately 5% chance of being oligotrophic. Carlson's predicted chlorophyll *a* model yielded an estimated summertime chlorophyll *a* concentration of approximately 3.0 µg/L, a large underestimation of the actual concentration of 16.0 µg/L obtained during the July event, although at a minimum this represents the difference between an average estimate and a one-time measurement which may have been collected during a period of intense growth. *Ceratium* and *Chroomonas* were both abundant in the sample from this date, suggesting that these taxa might have driven chlorophyll *a* to above-average levels. Both the Vollenweider and Reckhow models predicted phosphorus concentrations of approximately 0.02 mg/L. When the result of the Reckhow model was utilized in Carlson's predicted chlorophyll model, the latter produced a result of approximately 6.0 µg/L.

LAKE TELEMAR

TSIs from the May event were variable, with the total phosphorus component yielding a value of approximately 47.3 (mesotrophic), the chlorophyll *a* component yielding a value of approximately 32.4 (late-oligotrophic) and the Secchi-based TSI yielding a value of 52.4 (eutrophic). In July, however, all values were relatively similar, ranging from approximately 60.6-61.5, suggesting eutrophic conditions, and because of the alignment of the indices indicates this is a more representative of growing season trophic state. By October, the total phosphorus-based TSI had dropped to approximately 37.4, suggesting late-oligotrophy, while the TSI for chlorophyll *a* dropped to approximately 43.4, indicative of mesotrophic conditions. The Secchi-based TSI stayed within the range indicating eutrophy, at approximately 51.2. Variations in TSI values throughout the year are displayed in Figure 71 below.

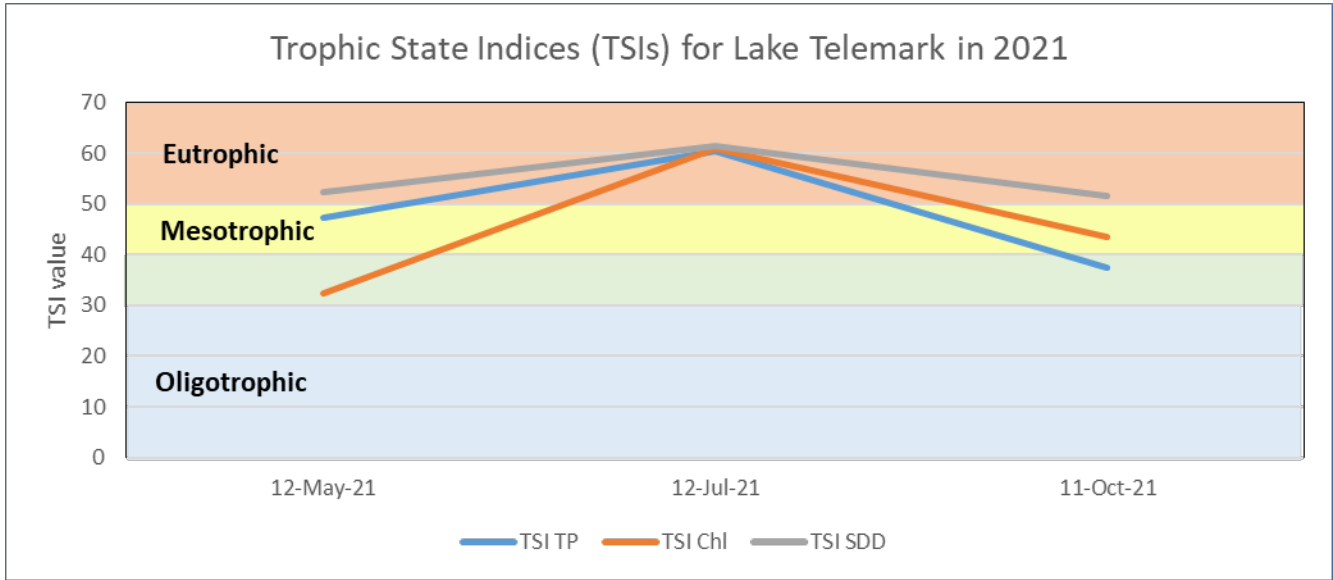


Figure 71. Changes in Trophic State Indices (TSIs) over the course of the 2021 growing season in Lake Telemark.

TSI residuals for Lake Telemark are plotted below in Figure 72. The point representing the May event is located in the bottom-left quadrant, suggesting that phosphorus was not a limiting factor for algae growth at this time. Small particles also likely dominated the system at this time, as Secchi values are lower than chlorophyll *a* concentrations would explain. The July sampling event yielded TSIs that were relatively close to each other, resulting in a point located near the intersection of the x- and y-axes. This indicates that water clarity was likely due to algae growth, and algae was likely limited by phosphorus and nitrogen relatively evenly. Lastly, the point representing the October event is located in the upper-right quadrant, suggesting that phosphorus was limiting algae growth at this time, while smaller particles likely limited water clarity more than algal particulates did.

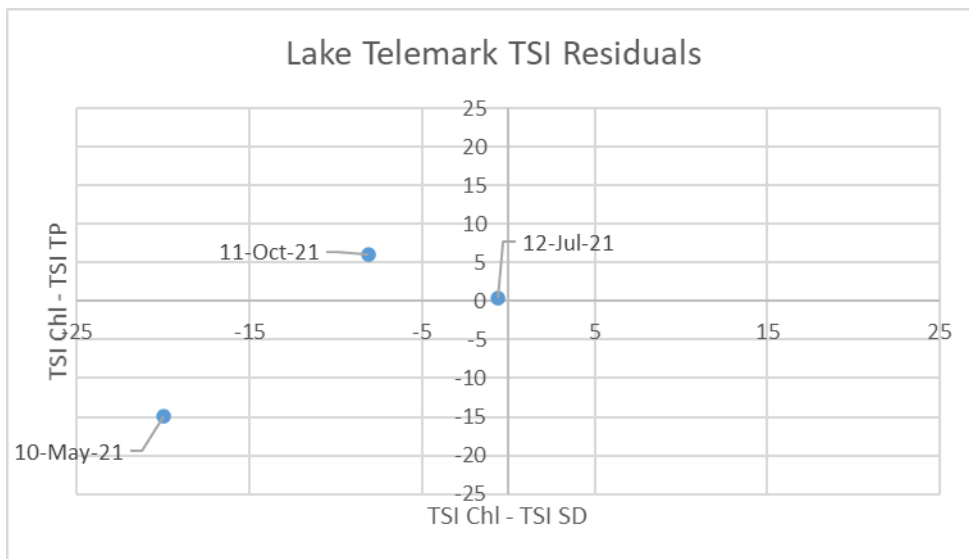


Figure 72. Residuals from TSI values obtained over the course of the 2021 growing season in Lake Telemark.



When assessed with the Kirchner-Dillon model, Lake Telemark featured a phosphorus retention coefficient of approximately 0.26, suggesting that only approximately a quarter of phosphorus entering the lake is retained rather than flushed. When entered into the Dillon-Rigler predictive phosphorus model, the lake was estimated to have a springtime phosphorus concentration of approximately 0.02 mg/L, matching the concentration obtained during the May field event. Walker's phosphorus prediction equation also yielded a similar predicted phosphorus concentration of approximately 0.02 mg/L, and the Walker trophic state model estimated that the lake has an approximately 70% chance of being eutrophic and 30% chance of being mesotrophic; this corresponds well with mid-growing season conditions. Carlson's predictive summer chlorophyll *a* model yielded an estimated concentration of approximately 4.94 $\mu\text{g/L}$, underestimating the value obtained in the field of 22.0 $\mu\text{g/L}$. The Vollenweider model and Reckhow models both predicted a slightly overestimated phosphorus concentration of approximately 0.03 mg/L. When the result of the Vollenweider model were entered into Carlson's predicted chlorophyll model, the latter produced an estimate chlorophyll concentration of approximately 10.8 $\mu\text{g/L}$.

MT. HOPE POND

For the May event, the total phosphorus and Secchi depth components of Mt. Hope Pond's TSI were calculated to be approximately 47.4 and 41.9, respectively, suggesting a mesotrophic state, while the chlorophyll component yielded a value of 36.4, suggesting a late-oligotrophic state. Given that the data these results were based on was performed earlier in the season, prior to when a large presence of algae (and associated phosphorus) would be expected to exist in the water column. The TP-based TSI remained the same for the July, however the chlorophyll and Secchi depth TSI components increased to approximately 59.0 and 61.5, respectively, suggesting the pond was in a eutrophic state and reflecting its trophic state at the peak of the summer. These decreased somewhat by October, a result of the waning growing season, with the chlorophyll component yielding a value of approximately 45.6 (indicative of mesotrophic conditions) and the Secchi-based TSI component yielding a value of approximately 51.5, suggesting eutrophic conditions. The total phosphorus-based TSI component, however, increased to approximately 53.2, also indicating eutrophy. Seasonal variations in TSI values at Mt. Hope Pond are displayed below in Figure 73.

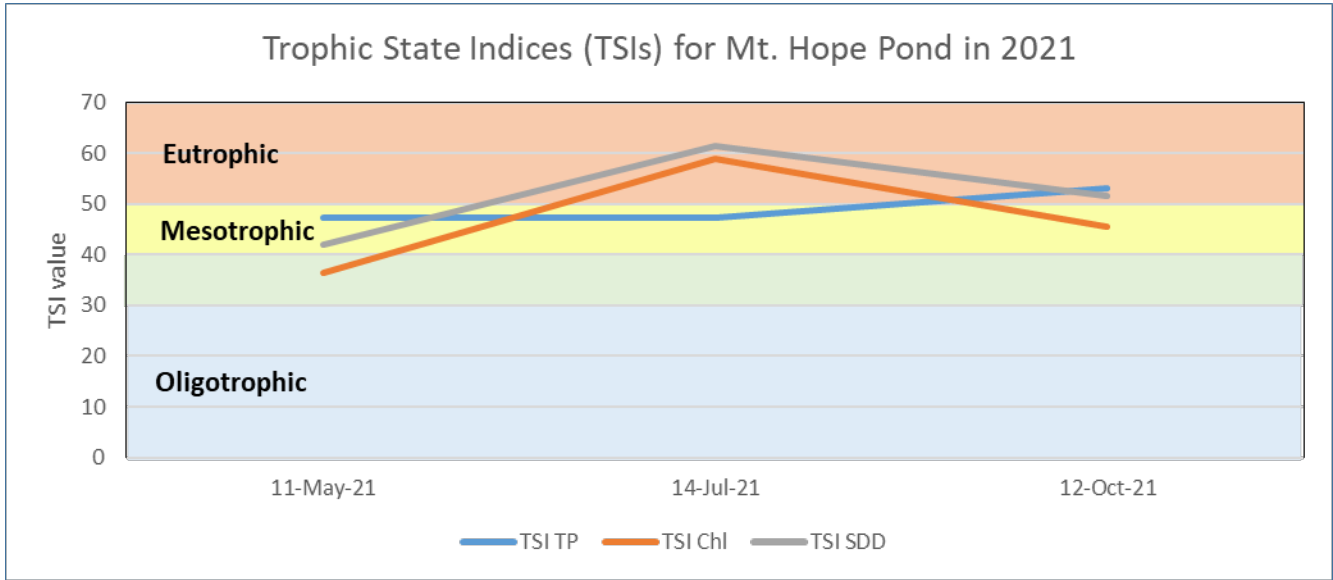


Figure 73. Changes in Trophic State Indices (TSIs) over the course of the 2021 growing season in Mt. Hope Pond.

Figure 74 below displays the plotted TSI residuals from Mt. Hope Pond. The points representing the May and October events are located in the lower-left quadrant, suggesting that clarity was largely a product of non-algal factors and that phosphorus was not limiting algae growth at these times; temperature and seasonality were likely significant limiters. The point representing the July event is located in the upper-left quadrant, relatively close to the y-axis. It's location above the x-axis suggests that algae growth was highly dependent on phosphorus during this time.

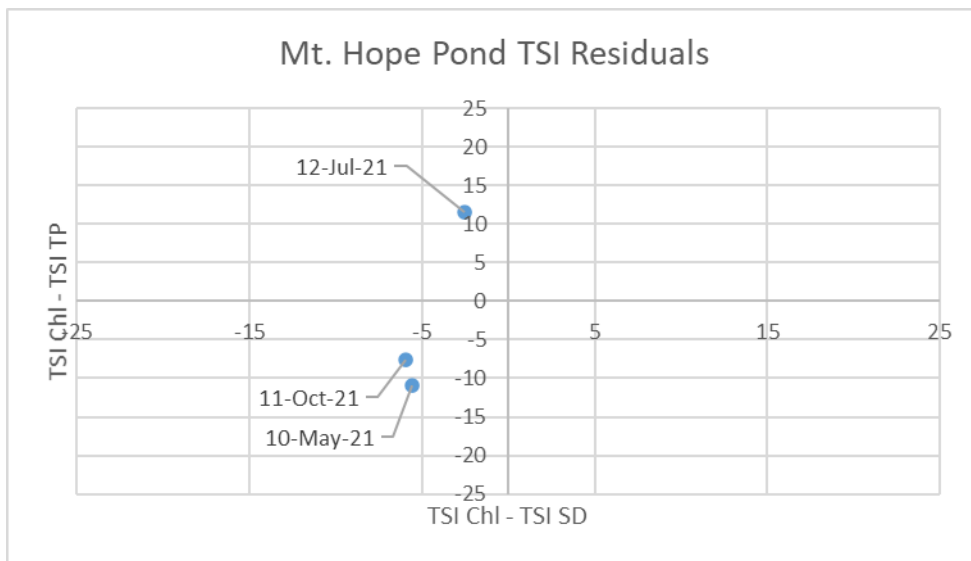


Figure 74. Residuals from TSI values obtained over the course of the 2021 growing season in Mt. Hope Pond.



When assessed with the Kirchner-Dillon model, Mt. Hope Pond yielded a phosphorus retention coefficient of approximately 0.70, suggesting that the waterbody retains a relatively large portion of incoming phosphorus and suggesting efficient nutrient utilization. When this is used for the Dillon-Rigler model for springtime phosphorus prediction, a phosphorus concentration of approximately 0.004 mg/L is estimated. This is an underestimate from the 0.02 mg/L obtained in the field during the May event; however the model yields a closer predicted concentration of approximately 0.03 mg/L when internally loaded phosphorus is also included into the model. Walker's spring phosphorus prediction model yielded a phosphorus concentration of approximately 0.006 mg/L, estimating approximately 0.05 mg/L when internal loads are also considered. Walker's trophic state model estimates that Mt. Hope Pond has a 90% likelihood of being oligotrophic, and a 10% chance of being mesotrophic when based only on the external load. When the total load is considered, the pond is estimated to have a 80% likelihood of being eutrophic and a 20% chance of being mesotrophic. Carlson's summertime chlorophyll a predictive model estimates that Mt. Hope Pond will have a summer chlorophyll a concentration of approximately 1.3 µg/L when considering only external loads, and a concentration of approximately 21.6 µg/L when considering the total load. The total load's prediction is more accurate compared to the chlorophyll a concentration obtained from the July event of 18.0 µg/L. The Vollenweider model yielded phosphorus estimates similar to those resulting from the Dillon-Rigler model, with external loads yielding an estimated concentration of approximately 0.003 mg/L and total loads yielding a prediction of approximately 0.02 mg/L. Lastly, Reckhow's predicted phosphorus model yielded a concentration of approximately 0.009 mg/L when using only external loads, while considering internal loads as well yields approximately 0.04 mg/L. Given that the modelled loads are dominated by internal processes, it is not surprising that total loads yielded much better estimates of measured phosphorus concentrations than the external loads only.

FOX'S POND

Fox's Pond was classifiable as eutrophic during each of the sampling events in 2021, with all TSI values during the July event ranging from approximately 57.17 to 61.52 and those collected during the October event ranging from 54.60 to 60.92. Figure 75 below displays the variation in TSI values between the two sampling events conducted in 2021.

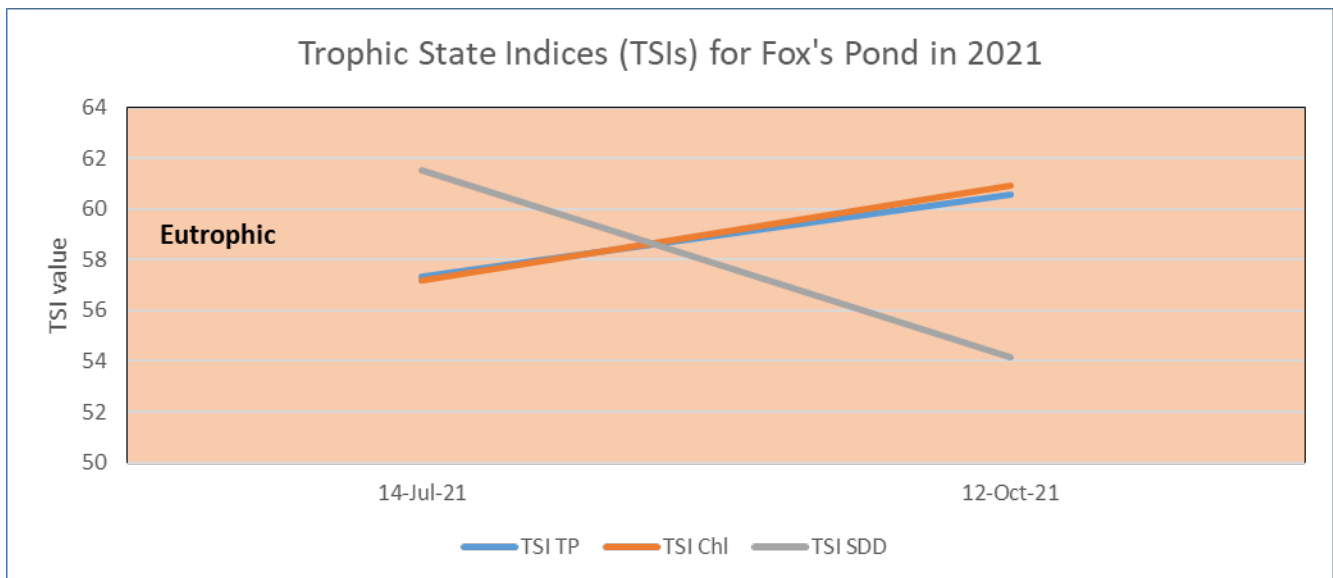




Figure 75. Changes in Trophic State Indices (TSIs) over the course of the 2021 growing season in Fox's Pond.

Figure 76 below displays the TSI residuals for both events at Fox's Pond. The points representing sampling events are located approximately on the x-axis, suggesting that algae growth was limited by phosphorus in at least the second half of the growing season. The point representing the July event was located to the left of the y-axis, suggesting that clarity may have been impacted by non-algal turbidity, while the October event is located to the right of the y-axis, suggesting the predominance of larger particles, which could include organic detritus, large-celled algae, or even zooplankton grazing.

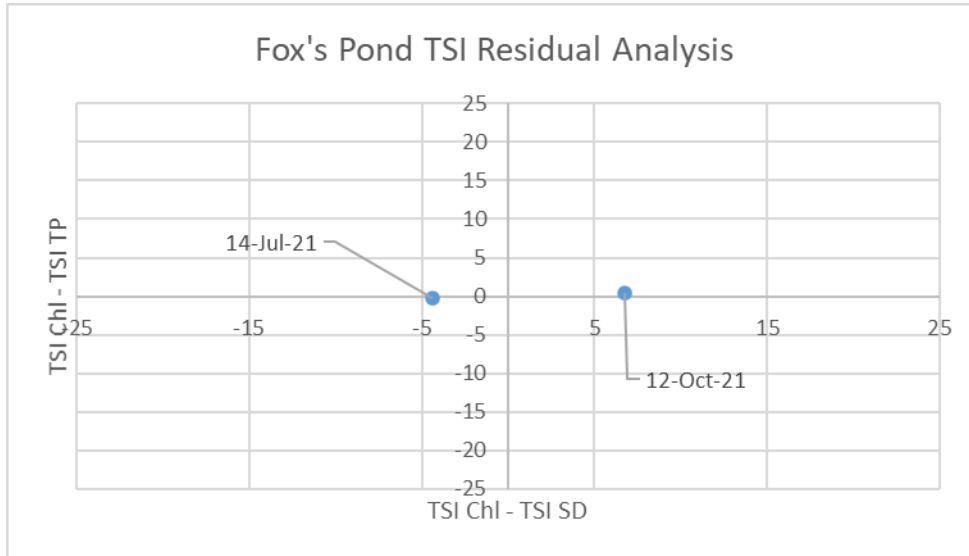


Figure 76. Residuals from TSI values obtained over the course of the 2021 growing season in Fox's Pond.

When assessed with the Kirchner-Dillon phosphorus retention model, Fox's Pond has a calculated R value of approximately 0.43, suggesting that the pond retains less than half of all incoming phosphorous. When using this value in the Dillon-Rigler model, Fox's Pond is estimated to yield a spring phosphorus concentration of approximately 0.01 mg/L. As a Spring sampling event was not conducted in 2021 for Fox's Pond, this will need to be assessed against the springtime results of future sampling efforts. Walker's predicted springtime phosphorus model predicts a similar concentration of approximately 0.01 mg/L, while Walker's trophic state model estimates that the pond has an approximately 80% chance of being mesotrophic and a 10% likelihood of being eutrophic, and the same likelihood of being oligotrophic. Carlson's predicted summer chlorophyll yielded an estimation of approximately 2.29 µg/L of chlorophyll *a*, a large underestimation from the 15.0 µg/L obtained in July. The Vollenweider model estimated a phosphorus concentration of approximately 0.01 mg/L, while the Reckhow Model yielded an estimated concentration of approximately 0.02 mg/L.

WHITE MEADOW LAKE

The May event yielded total phosphorus- and chlorophyll-based TSI values indicative of mesotrophic conditions, at approximately 47.4 and 49.1, respectively. The Secchi-based TSI value was calculated to be 54.2, indicating eutrophic conditions. Similar Secchi-based TSI values were obtained during all events. The total phosphorus component yielded a lower value for July, at approximately 37.4,



indicative of late-oligotrophic conditions, while the chlorophyll a-based TSI value remained within the mesotrophic range at approximately 43.2. Both of these TSI components increased to be consistent with eutrophic conditions in October, with total phosphorus yielding a value of approximately 57.3 and Chlorophyll a yielding a value of approximately 50.2. Figure 77 below displays the variation in TSI values over the course of the 2021 growing season. The increase in late season phosphorus likely represents seasonal senescence and decomposition. Management efforts seem to be effective at limiting phosphorus concentrations until fall turnover.

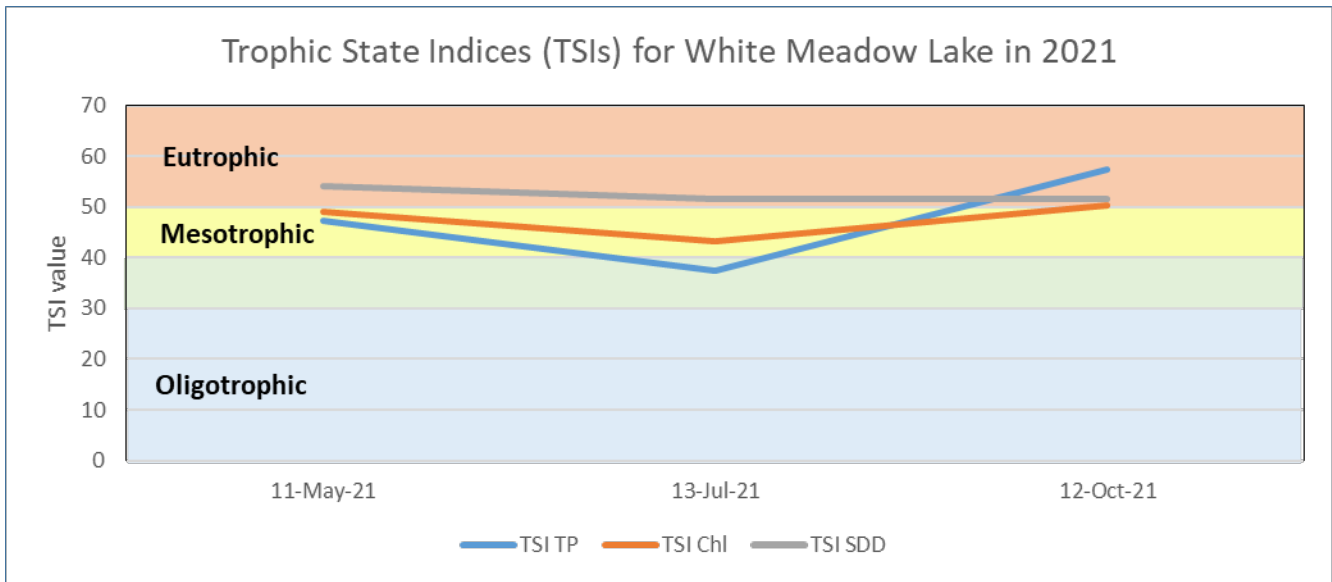


Figure 77. Changes in Trophic State Indices (TSIs) over the course of the 2021 growing season in White Meadow Lake.

TSI residuals are plotted below in Figure 78. All three events are represented by points to the left of the y-axis, suggesting that water clarity over the course of the season was generally somewhat influenced by non-algal turbidity than dense phytoplankton populations. The May and July events are located above the x-axis, suggesting that algae populations were limited by phosphorus concentrations during these events, whereas the location of the point representing the October event below the x-axis suggests that algae growth was not limited solely by phosphorus concentrations on this date.

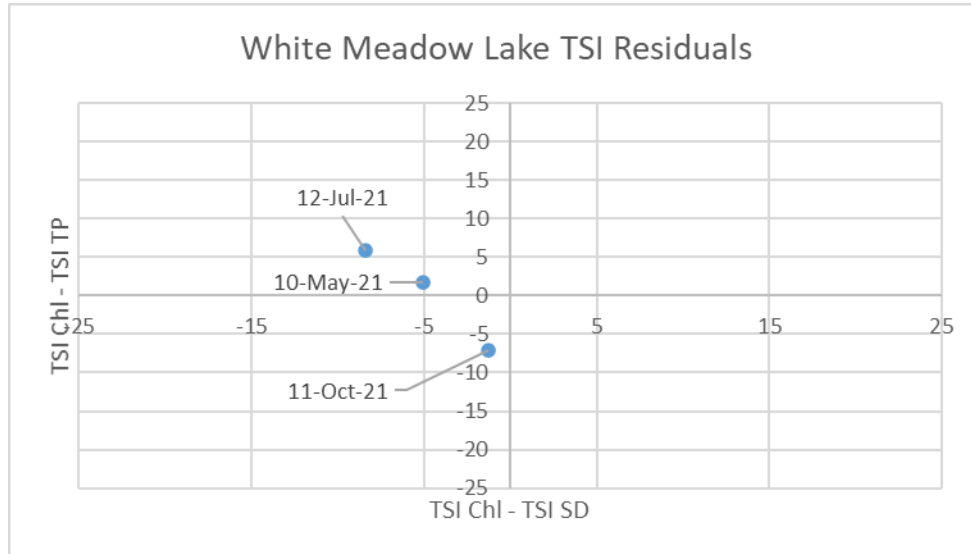


Figure 78. Residuals from TSI values obtained over the course of the 2021 growing season in White Meadow Lake.

When assessed with the Kirchner-Dillon model, White Meadow Lake was assessed to have a phosphorus retention coefficient of approximately 0.59, suggesting that the lake retains over half of its incoming phosphorus load. The Dillon-Rigler model estimated a very low springtime phosphorus concentration of less than 0.0001 mg/L. When the internal load was also considered, the model yielded a predicted concentration of approximately 0.05 mg/L, an overestimation of the May concentration obtained in the field of 0.02 mg/L. Lower than estimated concentrations likely show the efficacy of water column destratification and the use of nutrient inactivants, as well as much of the productivity of the system being represented in plant biomass which is not well captured by the chlorophyll parameter. Walker's predictive model yielded similar results, with the total load yielding a slightly higher estimate of approximately 0.06 mg/L. Using only the external load, the Walker trophic state model estimates that the lake has a 100% chance of being oligotrophic, whereas using the total load estimated that it instead has a 95% likelihood of being eutrophic and only an approximately 5% chance of being mesotrophic. Because of the very low predicted phosphorus values obtained by the other models, Carlson's predicted summer chlorophyll model predicted a concentration of less than 0.0001 µg/L. When considering the internal load, this model estimates a summertime chlorophyll a concentration of approximately 31.3 µg/L, a large overestimation compared to the field result obtained in July of 3.6 µg/L. Similar to the other models, the Vollenweider and Reckhow models yielded a predicted phosphorus concentration of well below 0.0001 mg/L, whereas, when the total phosphorus load is considered, they yield predicted concentrations of approximately 0.05 mg/L and 0.06 mg/L, respectively. Lake management efforts have yielded positive results, both in decreasing measurable concentrations of phosphorus relative to the models, and in reducing the chlorophyll concentrations relative to their potential based on calculated phosphorus loads.



7. IN-LAKE CONCLUSIONS AND RECOMMENDATIONS

Given the variety of waterbodies in Rockaway Township (in regards to size, volume, watersheds, and other factors), it is not surprising that the issues that affect each waterbody vary. Many of the waterbodies with larger watersheds (such as Lakes Telemark and Ames) featured more modeled incoming nutrients through this avenue than from internal loading, whereas waterbodies with lower inflow (such as Green Pond, Lake Emma, and Mt. Hope Pond) feature a higher phosphorus load through internal loading. Princeton Hydro therefore will provide recommendations in the balance of this report for management measures that can be taken in each lake and its watershed. A more detailed and comprehensive description of some of the watershed-based recommendations are provided in Section 8.

Because the Township of Ringwood is focused on watershed-based solutions, recommendations will be broken into watershed-based and In-lake solutions. In-lake recommendations are provided for the benefit of each waterbody's community; however, should a community wish to move forward with any of the in-lake recommendations, the community must do so without contribution from the township. Additionally, general recommendations that can apply to all of the lakes studied are provided at the end of the section.

7.1 GREEN POND

Green Pond features a small watershed (relative to the size of the waterbody) that is largely forested, although notable portions are urbanized and produce a significant amount of added nutrients, largely through septic systems. While these should not be ignored, the majority of the pond's total phosphorus load is estimated to originate from internal loading. While the pond has generally featured excellent water clarity and minimal amounts of cyanobacteria, both the internal and external loads should be addressed in order to maintain the high quality of this waterbody.

Based on these findings, Princeton Hydro recommends the following:

WATERSHED-BASED RECOMMENDATIONS

As will be described in great detail in the following section, Princeton Hydro recommends three measures which will involve treating runoff and/or preventing erosion in the urbanized area north of the pond. One of these recommendations include a restored shoreline along Dawson Drive that features vegetation that would intercept some nutrients entering the pond via stormwater. Additionally, recommendations are provided for two gravel parking lots which may benefit from the creation of raingardens or bioswales to treat runoff. These areas also could potentially be converted to a porous surface in order to further reduce runoff.

IN-LAKE RECOMMENDATIONS

Zooplankton and Fisheries Assessments – Green Pond was observed in 2021 to have a paucity of larger-bodied herbivorous zooplankton taxa, such as the cladoceran *Daphnia*. These larger herbivores can be instrumental in the control of green algae and some other taxa. Additionally, zooplankton are a critical piece of the food-web in a lake and serve as a food based for younger life stages of many fish. Low numbers of larger zooplankton can be caused by an over-abundance of limnetic (open-water-living) fish, such as alewife or golden shiners. This can be assessed by conducting more quantitative



counts of zooplankton populations, as well as by conducting a fisheries survey. The fisheries survey can also be used to assess the condition of other fish species in the lake and guide stocking efforts.

7.2 EGBERT LAKE

Egbert Lake is a smaller waterbody with a relatively high flushing rate, receiving a majority of its nutrients from the watershed rather than from internal loading. The lake also features an abundance of aquatic plants, including the invasives Eurasian water milfoil and curlyleaf pondweed, that may impede boating. Currently, the Township allows fishing and boating on Egbert Lake, but not swimming.

Based on these findings, Princeton Hydro recommends the following:

WATERSHED-BASED RECOMMENDATIONS

Egbert Lake's watershed was not found to contain any specifically problematic areas in need of restoration. One potential option, however, is the removal of the lake's dam and the conversion of the old lakebed into a vegetated floodplain. This would provide benefits to Burnt Meadow Brook and prevent further costs associated with inspections and maintenance of the lake's dam. A similar project was performed recently in Rockaway township with the removal of the dam at Camp Hudsonia in order to restore Hibernia brook. One of the obvious downsides to this strategy is the loss of the recreational value that the lake may provide, although the stream as it passes through the old lake bed could potentially be managed for trout fishing.

IN-LAKE RECOMMENDATIONS

Floating Wetland Islands – Egbert Lake may benefit from the installation of floating wetland islands (FWIs). FWIs uptake nutrients that would be otherwise used by undesirable plants and algae. Additionally, these structures have the added benefit of providing fish habitat and shading out some aquatic vegetation. They are planted with wetland species including aesthetically pleasing flowering plants. In particular, the area immediately adjacent to the lake's inlet may be a preferred location for a wetland island installation so that incoming nutrients can be intercepted before moving to the rest of the lake.

Aeration System – While internal loading is not as big of a phosphorus source for Egberts Lake as watershed-based inputs are, algae and cyanobacteria growth may nonetheless be decreased by addressing this nutrient source. One method of addressing this problem is by the installation of a destratification system. This usually consists of one or more compressors on the lake's shoreline connected to an array of diffusers at the bottom of the lake. These provide a constant mixing action that allows the lake to remain thermally mixed, decreasing the opportunity for benthic anoxia to occur. As with Green Pond, a feasibility study should be conducted prior to the installation of any aeration systems. Additionally, a bathymetry of the waterbody would assist in identifying candidate locations for installing diffusers. Further years of water quality sampling should also be conducted before a system is implemented.

Bathymetric Survey – As mentioned previously, modeling of the internal load and trophic state for Egbert's Lake were in part conducted using rough estimates of depth and volume. A bathymetric survey, or mapping of the lake bottom, could provide more detailed information used for refining these models. This information is also useful in the installation of an aeration system. Such a survey can also



be used to measure the volume of sediment in the bottom of the lake. This will be necessary if dredging is eventually planned for this waterbody.

Biochar – A newer technology that Princeton Hydro has conducted work with recently is biochar, a plant-based charcoal product that can be loaded into porous bags and other structures for the use of filtering phosphorus and other pollutants out of the water. In Egbert Lake, biochar can be installed in Burnt Meadow Brook immediately prior to where the stream enters the lake or can be installed in the lake itself under buoys.

Zooplankton and Fisheries Assessment – As with Green Pond, Egberts Lake was observed in 2021 to feature very few large herbivorous zooplankton. These organisms graze on green algae and can exert a degree of control on populations of green algae and other taxa. These organisms should also be examined regarding the lake's fishery. Currently, fishing is one of the main recreational activities available to the public at Egbert Lake Park. A lack of large-bodied zooplankton may suggest that the fishery is dominated by smaller fish, a common occurrence in lakes with large amounts of vegetative cover. A zooplankton study involving more quantitative assessments of zooplankton populations may shed further light on the status of these organisms in Egberts Lake. Additionally, the township may benefit from a fish survey in order to make informed decisions on future fish stockings and other fisheries management efforts.

7.3 DURHAM POND

Durham Pond is a large pond relative to many of the other waterbodies assessed, featuring a largely forested watershed, and a moderate flushing rate. Phosphorus loads are contributed to the pond relatively similarly by both external and internal loading, although internal loading yields a slightly greater load each year. The pond features moderate-to-dense vegetation growth, particularly on the southern end. The waterbody is used by the Camp Winnebago Boy Scout Camp primarily for boating, fishing, and swimming.

Based on these findings, Princeton Hydro recommends the following:

WATERSHED-BASED RECOMMENDATIONS

As will be described in greater detail below, Princeton Hydro recommends improving drainage of the parking lot across from the camp office. This could involve installation of vegetated pavers or porous pavement, which would allow for better drainage of rainwater prior to runoff. Additionally, it is recommended that raingardens or bioretention features be installed along the perimeter of the lot or within the lot itself, if possible, in order to retain sediment and nutrients and to disrupt the flow of runoff. A small tributary to the pond located along Timberbrook Road was also identified as a possible restoration location and could benefit from the installation of vegetated buffers along the sides of the road.

IN-LAKE RECOMMENDATIONS

Bathymetric Survey – As with Egbert Lake and many other waterbodies in this study, Durham Pond could benefit from a bathymetric study, or a mapping of the water and bottom sediment depth. Such a study could provide several benefits, including the refinement of water quality models and the identification of other deep areas that may feature anoxia during the summer months. This would also be necessary if the pond were to be dredged.



Nutrient Inactivation and/or Sequestration – As described above, the application of products such as Alum or Phoslock® can be used to remove phosphorus from the water column, making it unavailable to algae. Durham Pond may benefit from applying alum during instances of increased algae growth during the summer, or from applying Phoslock® during the spring to reduce the rate of internal loading altogether. Due to the tendency of alum to lower the pH of water, prior to application, an alum bench test must be performed. The purpose of this test is to assess the approximate amount of alum that can be applied to the waterbody before the pond's pH drops to a level dangerous to fish and other aquatic life.

Biochar – Durham Pond may benefit from the installation of biochar bags; in particular, bags of biochar can be installed in one or more of the pond's three inlets. This allows for phosphorus and other nutrients and pollutants to be removed from the water immediately prior to its entering the waterbody. Biochar bags should be changed periodically to maintain their effectivity.

Vegetation Management – As mentioned above, Durham Pond features moderate-to-dense vegetation growth, particularly in the southern portion of the waterbody, which can pose a nuisance to swimmers and boaters. While some vegetation should be maintained for fish habitat, nutrient uptake, and other ecosystem services, Camp Winnebago may wish to manage this vegetation in the areas most frequently used by campers. Aquatic macrophytes can be treated with herbicides; however in a lot of cases this will need to be done each year. Another potential option is the mechanical removal of plants, although the location of the boat launching site at the southern end of the waterbody, accessible only by unpaved camproad, may make this a logistically challenging option. For some species, this would also have to be performed yearly, particularly if those species can reproduce via fragmentation. A more in-depth survey of the lake's vegetation community may also be desirable in order to develop better management strategies.

7.4 CAMP LEWIS LAKE

Camp Lewis Lake features a large watershed relative to the waterbody size; this watershed is largely forested, but contains some urbanized areas to the west. Most of the nutrients entering the waterbody are estimated to originate from groundwater and from camp latrines, while incoming sediment is most often a product of runoff from forested areas.

In-lake data for Camp Lewis Lake was not collected during 2021; as such, recommendations are restricted to those that can be performed in the watershed. As will be discussed below, the Marcella Fire Department's parking lot and adjacent woodlot is a candidate area for a vegetated bioswale, which could serve to reduce runoff and uptake nutrients from water drained from the parking lot, road, and nearby properties.

7.5 LAKE EMMA

Lake Emma is a small, shallow lake with a relatively high flushing rate. A large majority of the lake's estimated annual phosphorus load originates from internal loading. The lake's watershed largely consists of wetlands and forested lands, with a small portion, including areas immediately west of the lake, consisting of urbanized land. The northern end of the lake features extensive coverage with floating aquatic vegetation, and the lake undergoes periods of overall low dissolved oxygen.



Based on these results, Princeton Hydro recommends the following:

WATERSHED-BASED RECOMMENDATIONS

There is some uncertainty as to the direction of flow between Lake Emma and the small pond located immediately to the north of Green Pond Road. It is recommended that this connection be explored to greater detail. Should this pond be found to regularly drain into Lake Emma, it is recommended that it be converted into a constructed wetland or bioretention forebay to treat water draining into it and passing into Lake Emma. Another option for Lake Emma is to manage the waterbody as a Treatment forebay/retention wetland for waterbodies downstream. This would largely involve many of the in-lake management solutions described below. Alternatively, the waterbody's dam may be removed in order to restore the lake to a natural stream corridor.

Another recommendation involves improvements made to the Marcella Community Club's parking lot north of the lake. These would involve a combination of porous pavement and vegetated filters or parking lot "islands".

IN-LAKE RECOMMENDATIONS

Biochar – As with some of the other lakes in this study, Lake Emma may benefit from the addition of biochar. As Lake Emma does not have any permanent inlets, this would likely be most effective in the form of buoys with biochar bags suspended underneath. These could be placed in multiple areas of the pond to absorb some of the nutrients introduced to the water column through internal loading or from the watershed. These bags would likely be installed in Spring at the start of the growing season and replaced approximately halfway through the growing season.

Aeration – As mentioned above for Egberts Lake, Lake Emma may benefit from the installation of an aeration system in order to keep the water column relatively well-mixed during the summer months. This would be particularly effective if diffusers can be located adjacent to the dam, where the lake is deepest and features bottom anoxia.

Floating Wetland Islands – Another option for the removal of nutrients from the water column in Lake Emma is the installation of floating wetland islands. These will serve to remove nutrients from the water column through uptake by planted vegetation and the beneficial biofilm that grows over time on the planting matrix. These can be placed in multiple locations throughout the lake, including the shallower northern area.

Bathymetric Survey – A mapping of Lake Emma's water and sediment depths may assist in refining the models located in the sections above and in assisting with installations of aeration systems and other management equipment, if desired. The element of a bathymetry pertaining to sediment depth and volume would also be particularly useful in assessing the apparent sedimentation of the shallower northern portion of the lake and would be required prior to a dredging operation.

Dredging - Dredging is the removal of sediments that have accumulated on the bottom of a waterbody. In Lake Emma, this would be particularly effective if utilized on the shallow, northern portion of the waterbody. Dredging a waterbody can have a variety of positive effects, including the physical removal of a large amount of nutrients and a potentially large reduction in aquatic vegetation. Both yellow and White water lilies in particular are usually best controls by removal of the entire root structure, and dredging may aid with this. However, prior to dredging operations various local and



state-level permits will need to be obtained. Additionally, Lake Emma's community will need to conduct a dredging feasibility study, in which any additional topographic information is collected in order to generate the signed and sealed engineering drawings required for the permit. This also includes detailed chemical tests of sediment samples in order to assess for containments and physical qualities, as these will in part determine where and how dredge spoils can be disposed of. Dredging can be a very expensive operation, but the positive impacts to the lake would likely be immediately noticeable in years following operations.

7.6 LAKE AMES

Lake Ames features a very large watershed with two major streams and, as such, has a very high flushing rate. A large majority of incoming nutrients are estimated to originate from septic tanks and groundwater within the watershed. A small degree of internal loading is estimated to occur; however this is relatively minor compared to the large external load. The lake also features extensive aquatic vegetation growth, particularly by the invasive plant fanwort.

Based these observations, Princeton Hydro recommends the following:

WATERSHED-BASED RECOMMENDATIONS

As with Lake Emma and Egbert Lake, one possible management action is to remove the Lake's Dam and allow the area to return to a stream corridor. While this would remove the current recreational value of the lake, it would serve to improve sediment stability, allow for a floodplain/wetland to uptake incoming nutrients from the watershed, and reconnect trout habitat. Another recommendation involves restoration of the western tributary by stabilizing the banks adjacent to the Snake Hill Road Bridge, which would reduce sedimentation and associated nutrients entering Lake Ames. Lastly, it is recommended that stormwater BMPs be utilized in some of the parking areas on Picatinny Arsenal property.

IN-LAKE RECOMMENDATIONS

Biochar – Ames Lake may benefit from the installation of biochar bags in the two main inlet streams shortly before confluence with the lake. As likely the main conveyors of nutrients to the lake, removal of nutrients from these streams prior to entry may significantly reduce the annual external nutrient load.

Vegetation Management – Lake Ames features very dense populations of the invasive aquatic plant fanwort, which forms mats on the water's surface over significant areas of the lake. While aquatic vegetation is beneficial when growing in smaller populations for fish habitat, sediment settling, and nutrient uptake, large populations can lead to imbalances in the fishery, water flow issues, and dissolved oxygen crashes at the end of the season when the vegetation decomposes. The township may wish to treat this population with an herbicide such as fluoridone. Another option is physical/mechanical removal, which has an additional benefit of removing nutrients from the waterbody directly. A downside to this is an increase in fragmentation, which can lead to regrowth in some species.

Zooplankton and Fisheries Assessment – In 2021, Lake Ames was observed to feature relatively low abundances of zooplankton. As explained above, this can have deleterious effects on the lake's fishery and lead to a lack of natural control over green algae and other phytoplankton taxa. In the case of Lake Ames, the large density of aquatic plants may be reducing predation on smaller fish



species and age groups, leading to an overpopulation of these species. Fish populations may then become stunted as the base of the food supply dwindles. This can be assessed by a quantitative zooplankton study and a fish survey. A fish survey will also provide information to Rockaway Township to assist in making management decisions regarding fisheries management.

Bathymetric Survey – As with many other lakes in the study, a recent bathymetric survey was not found to be available for Lake Ames. An updated bathymetric survey can provide important information allowing for a more accurate calculation of water volume and average depth. Additionally, this survey can be used to obtain accurate estimates of sediment volume, which will be necessary if Rockaway Township wishes to eventually dredge part of the lake.

7.7 LAKE TELEMAR

Lake Telemark is a relatively small lake with a sizeable watershed and, accordingly, a high flushing rate. The presence of an aeration system kept the lake well-mixed thermally and well-oxygenated over the course of the season, preventing anoxia and associated advanced internal loading. A majority of the lake's estimated annual nutrient load instead originates in the lake's watershed. The lake is immediately surrounded with urbanized area, with a mix of forested areas and urbanized areas further north and east in the watershed. The lake features nuisance plant growth in its northern half, represented largely by waterlilies and the invasive Eurasian watermilfoil.

Based on these observations, Princeton Hydro Recommends the following:

WATERSHED-BASED RECOMMENDATIONS

Several watershed based recommendations are provided in the following section for reducing sediment and nutrient loads into Lake Telemark. The areas adjacent to the DPW and bus garage were identified as being a potential location for a vegetated bioretention system, the installation of permeable pavement, and the installation of manufactured treatment devices in the existing stormwater drainage system. Similar recommendations are also recommended below for the Katharine D. Malone Elementary School. The parking lot of the Holy Trinity Lutheran Church was identified as a potential site for conversion of existing pavement to a porous paving method in order to reduce runoff. The nearby athletic fields were identified as a candidate for an adjacent vegetative buffer, as well as the fields' parking lot, which can be treated with buffer strips, redirection of flow, and vegetated pavers. Similar projects were recommended for the Norway Field parking lot. Lastly, the removal of the Hudsonia Pond dam was recommended in order to restore the stream corridor in this portion of Hibernia Brook. A large portion of this project has already been completed.

IN-LAKE RECOMMENDATIONS

Further Sampling and Assessment of the Western Tributary – While the inlet assessment for Lake Telemark focused on Hibernia Brook, the western inlet should also be examined in future years due to the size of its drainage area, as well as the possibility of contaminated groundwater influence from a large area of groundwater contamination on adjacent Picatinny Arsenal land.

Biochar – The installation of biochar in the three inlets entering Lake Telemark may benefit the lake greatly by removing nutrients from incoming streamflow. This may be especially useful as a majority of the lake's nutrient load is coming from external sources. Biochar can be installed at each inlet immediately upstream of the confluence with the lake at the beginning of each growing season in the



spring. Biochar bags will need to be changed out approximately halfway through the season to maintain maximum nutrient uptake.

Floating Wetland Islands – Floating wetland islands may also assist in reducing the nutrient load in Lake Telemark. These structures provide an additional benefit of shading out submerged vegetation in areas directly beneath them. Because of this, the shallower areas in the north and southeastern areas of the waterbodies are good candidate locations, particularly immediately adjacent to the inlet streams that enter the lake in these locations.

Vegetation Management – The shallower areas of Lake Telemark feature moderate densities of the invasive aquatic plant Eurasian watermilfoil. These populations likely pose a nuisance to boaters and swimmers. Should Lake Telemark's community wish to have these populations treated with herbicide, the newer herbicide ProcellaCOR® targets milfoil at low-doses and is made to prevent regrowth for up to three years. Physical/mechanical removal of these plants is also a viable option for control; however, care must be taken to minimize fragmentation of collected plants, as Eurasian watermilfoil spreads readily through fragmentation.

Zooplankton and Fisheries Assessments – Zooplankton populations were typically observed at relatively low populations in Lake Telemark during the 2021 season. As mentioned above for Lake Ames, this can sometimes be a symptom of an overabundance of smaller fish life stages and can cause stunting, as well as a lack of natural control on green algae and other plankton taxa. This can be further assessed with a fisheries survey and quantitative studies of zooplankton populations.

7.8 MT. HOPE POND

Mt. Hope Pond features a largely forested watershed with only a relatively small amount of urbanization to the east. Due to its depth, the lake thermally stratifies and features bottom anoxia during the later summer months, leading to a higher internal source of phosphorus than that generated by the watershed. The pond was observed to be experiencing a cyanobacteria bloom during the July event.

Based on these observations, Princeton Hydro recommends the following:

WATERSHED-BASED RECOMMENDATIONS

As will be described in greater detail in the following section, Princeton Hydro identified the northeast parking area and access area as a candidate for restoration. It is recommended that the current gravel surface be replaced with vegetated pavers in order to reduce runoff, associated erosion, and sediment and nutrient inputs into the pond. This project would also include the installation of a subsurface stormwater storage system, further reducing runoff into the pond.

IN-LAKE RECOMMENDATIONS

Nutrient Inactivation/sequestration – The internal loading of phosphorus observed in Mt. Hope Pond may be alleviated in part with the use of a nutrient inactivation treatment such as alum. This product can be applied in the middle of the summer in order to drop phosphorus concentrations to the bottom, where they will be less available to algae. Alternatively, the pond may benefit from a treatment with Phoslock®, which is applied early in the growing season and prevents phosphorus from leaving bottom sediments during periods of anoxia. Should alum be considered, Mt. Hope Pond will need to receive



an alum bench test, a study of how much product the lake can receive before the pH drops to levels harmful to aquatic life.

Aeration – Another method for reducing internal loading in Mt. Hope Pond is to use an aeration system to prevent bottom anoxia from occurring. As with Green Pond, Mt. Hope Pond may benefit from the preservation of its thermocline rather than full destratification. This requires a hypolimnetic aeration system or a system that produces “nanobubbles” in order to oxygenate the bottom without mixing the water column.

Bathymetric Survey – Mt. Hope Pond would likely benefit from an updated bathymetric survey. In addition to the generate of a depth map, this survey would collect data that can be used to better refine limnological models. It is also advisable to conduct a bathymetry prior to the installation of an aeration system in order to better assess potential locations for diffusers.

Floating Wetland Islands – Mt. Hope Pond may also benefit from the installation of floating wetland islands. These structures serve to absorb some nutrients from the water column before they can be used by algae and would be best placed in the shallower northern end of the waterbody. They also can provide habitat for fish and other aquatic animals.

7.9 MT. HOPE LAKE

Mt. Hope Lake features a sizeable watershed that contains Mt. Hope Pond and its full watershed, as well as forested areas to the northeast, urbanized areas to the west, and quarry operations to the immediate north. In-lake data was not collected during the 2021 growing season; as such, recommendations will largely focus on watershed-related loads.

WATERSHED-BASED RECOMMENDATIONS

The Catherine A. Dwyer Elementary School features two parking lots that were identified as areas where management solutions could potentially be implemented. One of these is the installation of porous pavement in downhill areas of the lot (such near entrances) that would allow for reduced runoff and retain a portion of incoming stormwater. Another recommendation for this area is the installation of raingardens in the grassy areas adjacent to each parking lot. This would also serve to increase infiltration and reduce runoff.

7.10 WHITE MEADOW LAKE

White Meadow Lake features a largely urbanized watershed, particularly in the areas immediately surrounding the lake. The watershed also includes Mt. Hope Pond and Mt. Hope Lake and their full respective watersheds. The lake has also been confirmed recently to harbor a population of common carp, which are estimated to cause a disproportionately high amount of internal loading. The density of this population, however, is not currently known. The lake has received a number of projects over the last several years to reduce the entry of nutrients into the lake, including an aeration system and an alum injection system.

Based on these observations, Princeton Hydro recommends the following:



WATERSHED-BASED RECOMMENDATIONS

As will be described in greater detail in the following section, a Parking lot along Mount Hope Road was identified as a location that may be a candidate for two projects. These include the installation of porous pavement and/or the removal of some pavement to be converted into a vegetated bioretention strip. The Beach 2 and nearby boat launch parking lots were also identified as potential project sites. In this area, nearby swales can be converted into rain gardens, while parts of the parking lot can be converted to porous pavement. Also recommended were a shoreline restoration project near the White Meadow Lake Country Club, a porous paving system at the Beach 3 parking lot, and revegetation and improvements to the streambank of a drainage stream, also near Beach 3. Further details regarding these projects are provided in the following section.

IN-LAKE RECOMMENDATIONS

Biochar – Biochar bags can be installed in the lake's main inlet and in some of the major stormwater flowpaths immediately upstream of where they enter the lake. The lake's main inlet, the outlet from Mt. Hope Lake, is a particularly advantageous area to target, as this stream drains the lake's largest subwatershed; biochar bags installed here could potentially intercept a large amount of nutrients before they enter the lake. Biochar bags would likely be installed at the beginning of the growing season and changed out halfway through the summer in order to maintain their effectiveness.

Fisheries/Carp Survey – The population of common carp in White Meadow Lake are estimated to yield a disproportionately high amount of phosphorus via their feeding behavior. The current population size, however, is not presently known, and can influence the amount of phosphorus they are estimated to add. While efforts to remove common carp should also be undertaken, a survey of the lakes' fishery is also recommended to obtain an estimate of the approximate density of carp in the lake and the level of effort that will be needed to remove a significant amount of them. A survey of the lake's overall fishery will also assist in making decisions regarding future stocking efforts and other fisheries management efforts.

Floating Wetland Islands – White Meadow Lake may also benefit from the installation of floating wetland islands. These structures serve to absorb some nutrients from the water column before they can be used by algae and would be best placed in the shallower northern end of the waterbody. They also can provide habitat for fish and other aquatic animals.

7.11 FOX'S POND

Fox's pond features a watershed that is largely urbanized and is estimated to yield a majority of its annual phosphorus load. While phosphorus measured from discrete samples were slightly elevated, SRP concentrations remained below detectable concentrations for both events. The pond also featured relatively high concentrations of chlorophyll *a* during each event.

Based on these observations, Princeton Hydro recommends the following:

WATERSHED-BASED RECOMMENDATIONS

One of the locations identified for potential work within Fox's Pond's watershed was the Rockaway Township Municipal Building. Some of the jobs proposed for this site include the installation of a subsurface retention system, an improvement to an existing swale to include vegetation,



improvements to the outlet stream and receiving small pond, and conversion of some of the parking lot area to a porous pavement system.

IN-LAKE RECOMMENDATIONS

Biochar – As a majority of Fox's Pond's estimated yearly phosphorus load is estimated to originate from its watershed, the installation of biochar bags in the pond's main inlet may allow for notable reductions in nutrients entering the pond itself. As described for other waterbodies above, biochar bags would likely be installed in the beginning of the growing season (approximately April) and changed out once at the middle of the summer in order to maximize nutrient uptake.

Floating Wetland Islands – As with many of the waterbodies above, Fox's Pond may benefit from the installation of floating wetland islands, which serve to uptake some of the nutrients entering the waterbody before they can be utilized by algae. These may be a particularly favorable option for a park pond such as Fox's Pond, as these islands can be planted with aesthetically pleasing flowering plants and can be accompanied by on-shore signage for educating the public as to their purpose. The islands also can provide habitat for fish and other wildlife. If installed in Fox's Pond, these may best be utilized in the northern area near the pond's inlet.

7.12 GENERAL RECOMMENDATIONS

Princeton Hydro recommends the following actions that apply to all waterbodies in this study. As above, these are split into watershed-based and in-lake recommendations.

WATERSHED-BASED RECOMMENDATIONS

As will be further explained in the next section of this report, Princeton Hydro recommends the stabilization of lake shorelines, the enhancement of the riparian zone (the area where the shoreline meets the water's edge), and creating clearly defined and stabilized watercraft access points. While certain areas are recommended for some of the waterbodies in their respective recommendations, this applies to all areas of lakes in the study where shoreline erosion may be a problem.

IN-LAKE RECOMMENDATIONS

Annual Water Quality Monitoring – Princeton Hydro strongly recommends the establishment of an annual water quality monitoring program. This not only allows for the establishment of long-term trends, but allows lake managers to assess the progress and effectivity of established management implementations, detect problems as they arise, and set management goals. Ideally, a monitoring program should follow the timing and methodology utilized by Princeton Hydro in 2021, with at least three events occurring over the course of a year, and each event featuring the sampling of *In-situ* and discrete water quality data. Particulars and attention to other components can be tailored to suit an individual lake's needs, and indeed may change over the course of several years as a lake community's needs change.

Septic System Influence Assessments – As mentioned in the watershed modeling section, homeowner septic systems can contribute to a large percentage of a lake's annual phosphorus and nitrogen loads. This can particularly be a significant factor on lakes surrounded by homes, such as some of those assessed in this study. Individual homeowners can reduce their impact on a lake by keeping their septic system regularly maintained and by upgrading them as needed. Any issues found to occur with a



particular septic system should be addressed as soon as possible so as to keep advanced nutrient loading to a minimum.

A “septic-snooper” assessment can be performed to identify areas of a lake where septic effluent is leaching into the water column. In such a survey, *In-situ* data would be collected at several points around the entirety of the developed portion of a lake’s shoreline. Sharp increases in specific conductivity can be indicative of septic system influence, which can then be further tested for by the collection of discrete water samples for the analysis of bacterial counts and nutrients such as nitrates. Samples collected at the surface of the mid-lake or dam station should also be collected for comparison.

Successful septic management involves the integration of public education, product modification, septic system inspection and maintenance, and water conservation practices. Routine inspections and pump outs (once every three years) are the two best, but often the most controversial, elements of septic management programs.

There is an innate resistance by homeowners to periodic inspections or to follow a pump out schedule. Basically, the prevailing thought among most homeowners is “if it flushes, it’s OK”. However, as has been demonstrated through multiple nationwide septic management studies, routine inspections help decrease the occurrence of large-scale failures through the early identification of the more easily corrected, less costly problems. Routine pump outs also decrease the buildup of sludge and grease in the septic tank itself, both of which can be transported into the leach field and create clogging problems. In general, the inspections and pump outs should be viewed as an insurance policy for the long-term proper operation of the septic system. Interestingly, most septic failures can be linked to the clogging and failure of the septic field.

Additionally, homeowners should be educated regarding the use of septic tank chemical additives or the disposal of paint, solvents or left-over household chemicals and cleaning products in septic systems. Public education fliers and brochures on septic management are readily available through the NJDEP, NALMS and regional watershed and environmental groups. A variety of public information septic management fact sheets are available through the USEPA’s Small Flows Clearing House (www.nesc.wvu.edu), which specializes in the dissemination of information pertaining to septic systems and other types of on-site waste water treatment systems. This includes information pertaining to septic tank additives, enzymes, and bacteria inoculants, none of which have any positive benefits. Such products often give a false sense of maintenance to the property owner and may actually dissuade them from regularly pumping or inspecting their system.



8. WATERSHED-BASED CONCLUSIONS AND RECOMMENDATIONS

A primary reason for conducting this study was to identify what can be done in the watersheds of the Township to minimize the annual pollutant load of each. With this data from Section 3, the watershed-based management options can be determined, with the ultimate goal being minimization of surface water quality issues, if any. This should allow for identification of those sub-watersheds having the greatest impact as well as those sub-watersheds having the most manageable (correctable) loads. Using this data, a list of best management practices (BMPs) is being provided to the Township that could effectively manage the pollutant loads generated by each major sub-watershed's specific pollutant loads. Emphasis has been given to bioretention type systems that can be implemented on a lot-specific or regional scale. Such BMPs have a high propensity for the removal of nutrients. An examination and discussion of the water quality benefits of restoring and/or creating wetland buffers, riparian buffers, and lakefront aquascape shorelines should also be performed. Where possible, based on inspections of the watershed or information contained in reports made available, identifying examples of site-specific locations where wetland buffers, riparian buffers, and lakefront aqua scaping could potentially be implemented as part of future watershed management efforts is stressed. If applicable, preliminary base cost estimates have been developed for the design and construction of each recommended stormwater management BMP. All of these BMPS should be eligible for funding through the NJDEP 319(h) program. Applications are accepted annually by the NJDEP.

Given the private nature of most of the lakes, initiating these projects would require the Township to serve as the "steward" for the lakes and their watershed. In terms of financial assistance for the design and implementation of any recommended projects, a number of potential avenues of funding should be considered and possibly pursued such as:

- Federal and/or state grants, loans or technical assistance. Example programs include the state's Non-Point Source 319(h) program, federal and state environmental education grants and other sources such as US EPA, US Army Corp of Engineers and possibly United States Department of Agriculture;
- small-scale county or municipal grants or projects that fund the planting of native vegetation;
- establishment of unique agreements such as the creation of wetlands as part of a mitigation bank to compensate for the loss of wetlands associated with development within the watershed;
- cooperative agreements between private property owners (i.e. residential developments, golf courses) and local / county agencies to implement stabilization and/or vegetation-based projects; and,
- other modes of funding such as private, non-profit sources, land or tax credit incentives and municipal agreements for future development or establishment of open space lands.



Specifically, the following list of potential funding sources is provided. Additional funding sources may be or become available in beyond those listed below. Potential State Sources of Funding for Watershed Restoration Projects More details on the potential sources of funding through the programs listed below can be found at www.nj.gov/dep/grantandloanprograms.

- Non-Point Source Pollutant Control Grants (funds provided to NJDEP through Section 319 (h) of the federal Clean Water Act) to address watershed-based, non-point source pollution.
- Water Quality Management Planning Pass-Through Grants (funds provided to NJDEP through Section 604 (b) of the federal Clean Water Act), primarily to conduct wastewater management planning activities and develop management plans for on-site wastewater treatment systems.
- Dam Restoration & Inland Water Projects Loan Program (1992 Dam Restoration and Clean Water Trust Fund) can provide low-interest loans to assist in the funding of dam restoration, flood control projects, water pollution control projects, and water-related recreation and conservation projects.
- Green Acres Grants & Loans (funds provided through previous Green Acres bond issues and the 1998 Garden State Preservation Trust) can be used by municipalities or counties to acquire and/or develop municipal or county land for public recreation and conservation purposes.
- Green Acres Nonprofit Acquisition Grants (funds provided through previous Green Acres bond issues and the 1998 Garden State Preservation Trust) can be used by tax-exempted, non-profit organizations to acquire open space for recreation and conservation purposes statewide, and to develop outdoor recreational facilities in certain urban or densely populated municipalities and counties. All land funded under this program must be open to the public.
- Environmental Infrastructure Financing Program (funds provided by NJDEP and the New Jersey Environmental Infrastructure Trust) can provide low-interest loans for the construction of a variety of water quality protection measures and for open space acquisition.



8.1 WATERSHED MANAGEMENT MEASURES

This section corresponds to the third of the EPA elements and consists of a description of the management measures necessary in the Rockaway Township community to achieve load reductions as well as a description of the areas where those measures will be implemented. This is one of the most important components of this document and consists of a list of projects that could be designed and implemented to reduce Total Suspended Solids (TSS), Total Phosphorus (TP), and other pollutant loads entering the lakes. In addition to the nutrient removal, the project recommendations also include projects to improve flooding and climate change resiliency.

Princeton Hydro reviewed desktop information including parcel boundaries, soils, topography, and land use/landcover as well as aerials to identify potential sites. These sites were then field evaluated to determine recommendable best management practice(s), site constraints, and confirm feasibility to accommodate green infrastructure and provide efficient pollutant removal. Green infrastructure refers to natural and engineered ecological systems that treat stormwater in a way that mimics natural process; ex: bioretention systems or rain gardens that receive stormwater and sequester nutrients. In addition to green infrastructure, general recommendations for stormwater management and riparian zone improvements are also included in the report.

Princeton Hydro evaluated and identified sites within the watersheds of the eleven (11) areas of interest within the Township. These areas of interest are primarily lakes and ponds and their associated watershed or drainage area, and include Green Pond, Egbert Lake, Durham Lake, Camp Lewis, Lake Emma, Telemark Lake, Lake Ames, Mount Hope Pond, Mount Hope Lake, White Meadow Lake, and Fox's Pond. Figure 79 below depicts these water bodies, and the site locations described in more detail in the subsequent sections. Table 118 presents a list of the proposed Best Management Practice (BMP), the amount of TSS removed, and an estimated project costs.

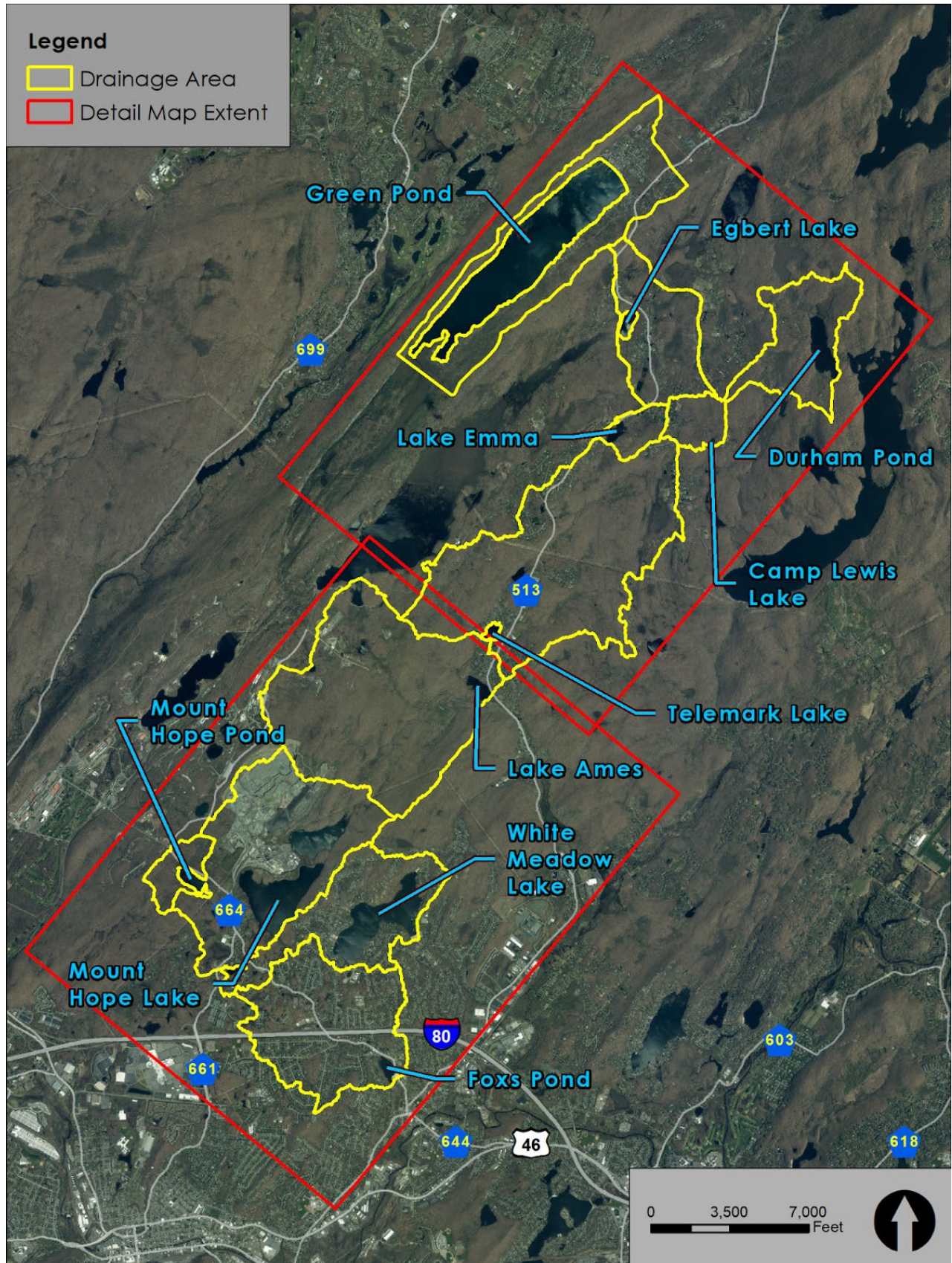


Figure 79: Site Location Overview. Refer to Figures 80 and 81 below for insets.

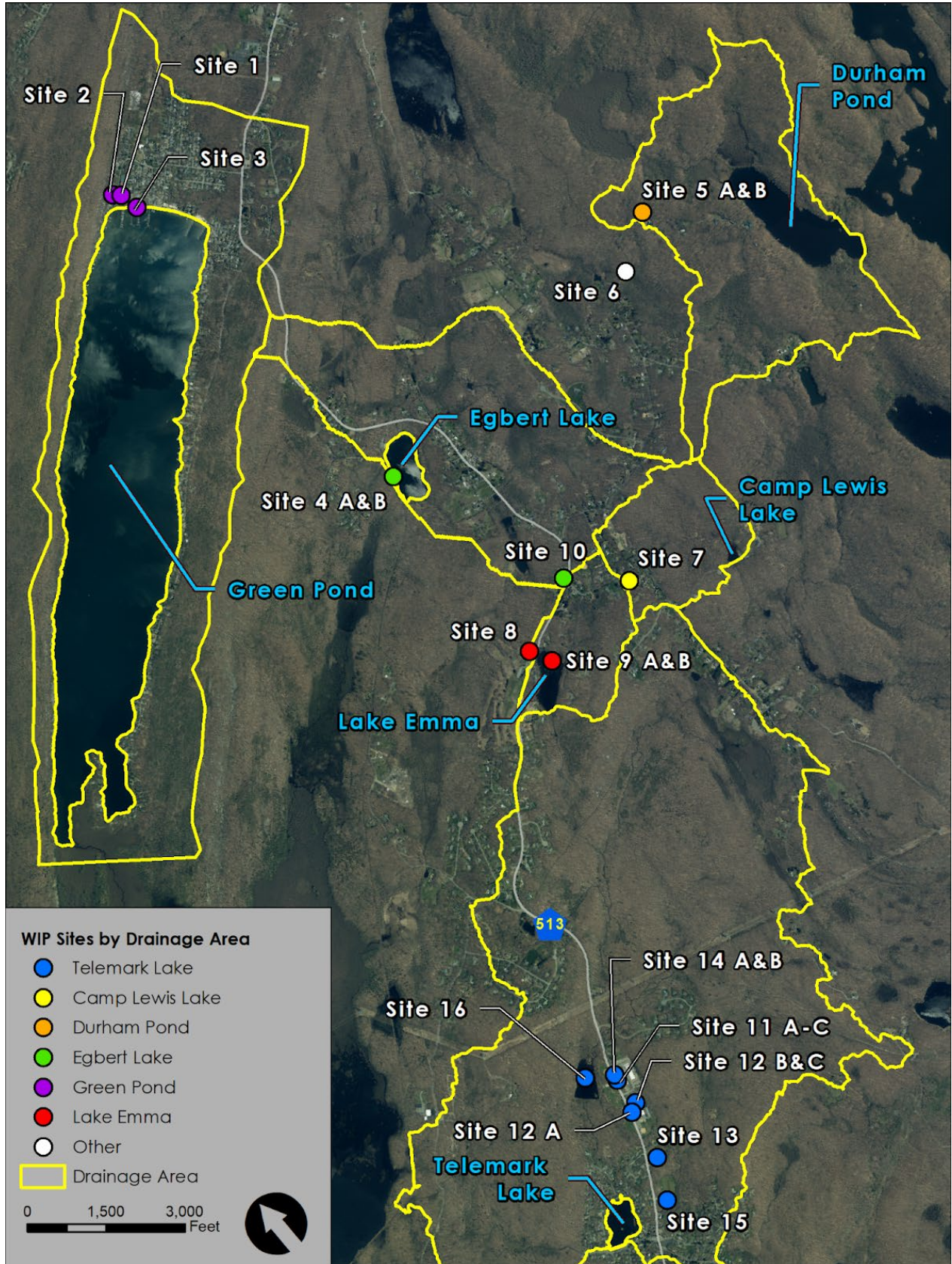


Figure 80: Rockaway Township Watershed Implementation Plan Site Locations - North - for Telemark Lake, Camp Lewis Lake, Durham Pond, Egbert Lake, Green Pond, and Lake Emma.

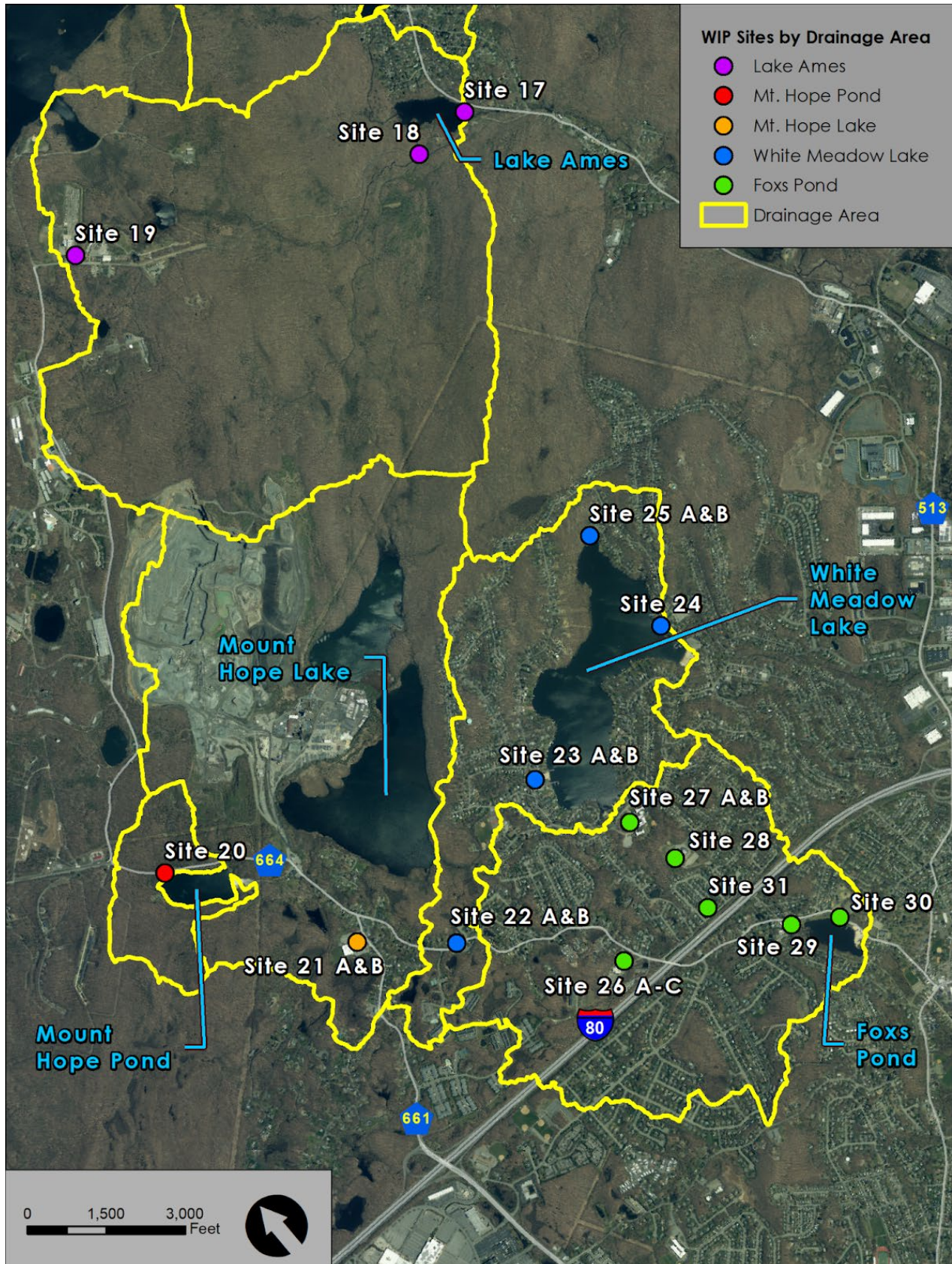


Figure 81: Rockaway Township Watershed Implementation Plan Site Locations - South for Lake Ames, Mount Hope Pond, Mount Hope Lake, White Meadow Lake, and Foxx Pond.



Table 118: Watershed Best Management Practice Site Summary

<u>Site</u>	<u>Proposed BMP</u>	<u>TSS REMOVAL Rate (%)</u>	<u>Potential Project Cost (\$)</u>
Green Pond			
Site 1	Dawson Drive Shoreline Stabilization Riparian Plantings and Increased Vegetation	60-80	\$50,000 - \$200,000
Site 2	Cliffside Road Gravel Parking Lot Bioswale/Rain Garden	60-80	\$150,000 - \$450,000
Site 3	Tennis Courts and Adjacent Gravel Parking Lot Rain Garden	60-80	\$150,000 - \$350,000
Egbert Lake			
Site 4A	Impoundment Removal and Floodplain Restoration	-	\$1,500,000 - \$3,000,000
Site 4B	In-Lake Floating Wetland Islands, Biochar and Aeration Installation	-	\$75,000 - \$150,000
Durham Pond			
Site 5A	Camp Winnebago Gravel Parking Lot Porous Pavement	80	\$200,000 - \$300,000
Site 5B	Camp Winnebago Gravel Parking Lot Rain Garden Installation	60-80	\$100,000 - \$200,000
Site 6	Timberbrook Road Vegetation Conveyance Buffer	60-80	\$100,000 - \$300,000
Camp Lewis			
Site 7	Introducing a Bioswale in Marcella Fire Department Woodlot	60-80	\$100,000 - \$200,000
Lake Emma			
Site 8	Conversion of Adjacent Inlet Pond into Constructed Wetland or Bioretention Forebay	90	\$125,000 - \$250,000
Site 9A	In-Lake Floating Wetland Islands, Biochar, Phoslock and Aeration Installation	-	\$50,000 - \$150,000
Site 9B	Impoundment Removal, Stream Corridor and Floodplain Restoration	-	\$300,000 - \$750,000
Site 10	Installation of Porous Pavement, Vegetated Parking Lot Islands, Vegetated Filter Boxes at Marcella Community Club	80	\$100,000 - \$500,000
Telemark Lake			
Site 11A	DPW and Bus Garage Bioretention System Construction	90	\$250,000 - \$750,000



Site 11B	Reducing Impervious Surfaces Near Untreated Stormwater Grates in DPW Parking Lot	80	\$150,000 - \$500,000
Site 11C	Installation of a Manufactured Treatment Device in Existing DPW Stormwater Line	See N.J.A.C. 7:8-5.7(d)2	\$250,000 - \$750,000
Site 12A	Creation of Bioretention System Along Parking Lot of Katharine D. Malone School	90	\$250,000 - \$750,000
Site 12B	Reducing Impervious Surfaces Near Untreated Stormwater Grates in Katharine D. Malone Parking Lot	80	\$150,000 - \$500,000
Site 12C	Installation of a Manufactured Treatment Device in Existing Katharine D. Malone School Stormwater Line	See N.J.A.C. 7:8-5.7(d)2	\$250,000 - \$750,000
Site 13	Reduction of Impervious Surfaces and Increased Porosity along Holy Trinity Lutheran Church Parking Lot	80	\$100,000 - \$200,000
Site 14A	Increased Vegetative Buffer Between Hudsonia Field and Green Pond Road	60-80	\$50,000 - \$150,000
Site 14B	Addition of Vegetated Pavers and Buffer Strips in Hudsonia Field Gravel Lot	60-80	\$100,000 - \$300,000
Site 15	Addition of Vegetated Pavers and Buffer Strips in Norway Field Parking Lot	60-80	\$100,000 - \$300,000
Site 16	Hudsonia Pond	-	.
Lake Ames			
Site 17	Removal of Lake Ames Impoundment and Restoration of Floodplain	-	\$750,000 - \$1,500,000
Site 18	Snake Hill Road Channel Crossing Bank Stabilization	80	\$250,000 - \$1,500,000
Site 19	Disconnection of Impervious Surface on Army Properties	80	\$125,000 - \$200,000
Mount Hope Pond			
Site 20	Mount Hope Road Parking Area Vegetated Pavers with Underdrains and Subsurface Storage	60-80	\$500,000 - \$750,000
Mount Hope Lake			
Site 21A	Increased Porous Pavement at Catherine A Dwyer Elementary Parking Lot	80	\$200,000 - \$400,000
Site 21B	Planting Rain Gardens Along Grassed Areas at Catherine A Dwyer Elementary School	60-80	\$150,000 - \$250,000
White Meadow Lake			
Site 22A	Increasing Porous Paving Within Mount Hope Road Parking Lot	80	\$150,000 - \$200,000
Site 22B	Removal of Asphalt Bordering Mount Hope Road, Replaced with a Vegetated Bioretention Strip	60-80	\$150,000 - \$300,000



Site 23A	Conversion of the Grassed Swale into a Rain Garden Along West Lake Shore Drive Parking Lot	60-80	\$75,000 - \$200,000
Site 23B	Addition of Porous Pavement Strips Within West Lake Shore Drive Parking Lot	80	\$150,000 - \$300,000
Site 24	Restoration of White Meadow Lake Country Club Shoreline Vegetation	60-80	\$30,000 - \$75,000
Site 25A	Construction of a Porous Paving System Within North Lake Shore Drive Beach Area	80	\$150,000 - \$500,000
Site 25B	Enhancing the Riparian Buffer Along Drainage Stream at Beach 3	60-80	\$250,000 - \$500,000
Fox's Pond			
Site 26A	Porous Paving/Subsurface Detention System at Rockaway Township Municipal Building	80	\$150,000 - \$200,000
Site 26B	Altering Rock-Lined Swale to Vegetated Swale at Rockaway Township Municipal Building	60-80	\$50,000 - \$200,000
Site 26C	Retrofitting Retention Pond at Rockaway Township Municipal Building	50-90	\$500,000 - \$1,000,000
Site 27A	Installation of Floating Wetland Island and Biochar at Copeland Middle School Pond	-	\$30,000 - \$100,000
Site 27B	Retrofitting Retention Basin at Copeland Middle School	50-90	\$200,000 - \$400,000
Site 28	Planting Rain Gardens at Stony Brook Elementary School	60-80	\$150,000 - \$300,000
Site 29	Impervious Asphalt and Underground Storage at Rockaway Township Municipal Parking Lot	90	\$150,000 - \$500,000
Site 30	Conversions of the Existing Lawn Areas into Bioretention Systems at Academy Street Parking Lot	90	\$150,000 - \$300,000
Site 31	Creating Right-Of-Way (ROW) Bioswales/Vegetated Filter Boxes Connecting to Route 80 Residential Drainage Area	60-80	\$50,000 - \$100,000

Notes:
 1. Site locations are shown on the above figures.
 2. Total suspended solids (TSS) removal efficiencies are based on the New Jersey Stormwater BMP Manual.
 3. The costs presented are approximate and subject to variability over time and the sizing of the BMP.



The cost estimates provided below are estimates for the entire project phase, including design, engineering, possible regulatory permitting, and implementation/installation (construction). While the cost estimates are predicted based on the entire project phase, final costs will vary based on many components that are involved in project design and implementation. Some of these components include, but are not limited to:

- **Site Investigations** – Part of the design process includes several different onsite investigation efforts including topographic survey, wetland delineation, and soils investigations. These investigations and the information gathered during them provide an understanding of the site conditions, any potential design challenges, and permitting pathways for the site.
 - **Depth to Bedrock** – The presence of shallow bedrock can result in implementation complications and a substantial increase in implementation costs.
 - **Depth to Water Table** – The presence of a shallow water table may indicate the presence of a wetland and/or recharge area for groundwater. Thus, this can result in complications as well as an increase in permitting and implementation costs.
 - **Utility Conflicts** – Location of sewer lines, gas lines, power lines, fiber optic lines all need to be located and mapped before any earth-moving or infrastructure work can be initiated. Without such information results could be extremely costly and even disastrous.
 - **Permit Requirements** – Depending on the site features and its location relative to the lake and associated waterways, regulatory permitting can vary from none to minimal to substantial. Thus, the potential required permitting must be determined to quantify the total costs associated with the design phase. While general permitting costs were estimated in the proposed cost for each project, the fees can vary based on access, size of the overall project and project type which have not been determined at this phase. The costs do not include permits specific to the Highlands Region. Due to the location of lakes and their watersheds being in the protected Highlands Region, additional permitting may be required.
- **Access and Ownership** – Issues such as rights-of-way and easements need to be identified and agreements in place prior to the progression of the design. Additionally, the source of the funding for implementation may limit where a project can be implemented. For example, typically if a project is being funded through an NPS 319 grant, the project site typically must be located on public / community lands. Private land can be not used for a project site for such grant funding; however, private easements or access approval can be allowed.
- **Maintenance Requirements** – The key to the long-term effectiveness of any watershed / stormwater project is for it to be well maintained. This will include routine activities such as clean-outs and media replacements as well as non-routine activities such as repairs or additional work after particularly large storms. The party responsible for the maintenance of the project needs to be well established and that party needs to be well informed on the maintenance requirements and costs. Any shared services agreements need to be well established prior to the initiation of a project.

It should also be noted that due to the location of the sites in the Highlands Region, Highlands Act exemptions may be required for certain projects depending on the type of property. These potential Highlands Act exemptions were not considered during the creation of this document, and thus will need to be considered during the next phase of project development.

PROPOSED SITE RECOMMENDATIONS

GREEN POND

The drainage area to Green Pond is generally forested with clusters of bedrock outcrops. The majority of the residential and community facilities buildings are located on the northern end of the lake and eastern edge. Minimal stormwater infrastructure or conveyance features were observed within the watershed. In addition, it appears that most of the runoff enters the lake as sheet flow. Three (3) raised on-site septic systems were observed during the visit inspections. Two of these are in the park north of Johnson Road and the other was located between Sunny Side Lane and Bonnie Brae Road.

SITE 1: SHORELINE STABILIZATION



Photos 1-2: Dawson Drive, grass patches and residential docks along the Northern shoreline of Green Pond (left) and stone wall erosion (right).

The northern shore features a row of houses and businesses approximately 25 yards from the water. The lake edge is lined with a boulder toe, with a maintained lawn along between the water edge and Dawson Drive. There are multiple dock connections along this bank of the lake. This combination of impervious road coverage, loose gravel and sand, as well as mowed grass patches directly along the lake shoreline offers minimal resistance or filtration of surface flow and sediment transportation during rain events. Certain areas along the waterfront, primarily pathways created to allow residents access points to launch smaller watercraft, showed signs of erosion and visible deposition of stones and gravel within the immediate areas (Photos 1, 2). Implementing runoff reducing measures along the shoreline will require education and compromise on the benefits of the practices of the adjacent property owners and users as these improvements may include changes to access, aesthetic view, and landscaping maintenance.

Recommendation Site 1: The recommendation for this site is to convert the grassed area between the water's edge and the edge of pavement to native meadow with designated locations for access to the docks and to launch smaller watercraft like kayaks. Some of these areas could include stable connections for runoff to enter the lake to reduce erosion along the shoreline. The introduction of plants within the grass buffer will help to mitigate sediment and pollutant transport by slowing the speed of water and allowing for increased uptake of nutrients. The root structures serve to strengthen the shoreline and reduce erosion and the need to repeatedly

add stone and gravel that has been washed away. Minor regrading of the vegetated buffer could also be implemented in this area to retain, filter, and convey water.

Cost Site 1: Depending on the area and actual recommended components implemented at the site, the approximate cost for design, permitting, and implementation of this BMP recommendation is anticipated to be between \$50,000 and \$200,000.

SITE 2: CLIFFSIDE ROAD GRAVEL PARKING LOT

Near the intersection of Cliffside Road and West Shore Road, there is a large gravel parking lot located at the base of the elevated ridge and treeline that runs along the western shore of the lake. This site receives runoff from the ridgeline, flowing towards the lake to the southwest, and from the adjacent grass areas. The Green Pond maintenance and groundskeeping buildings are just to the north of this lot and any materials such as mulch, soil or other organics held there may contribute to nutrient input flowing towards the lake during rain events.



Photo 3: Gravel parking lot facing the North and the entrance Green Pond Maintenance Building

Recommendation Site 2: The recommendation for this site is the creation of a bioswale or rain garden along the parking lot to provide water retention, filtration, and nutrient uptake from the stormwater runoff. This would involve creating a depression in the landscape with gently sloped sides, and filled with plants, stones, and engineered planting media. The retention of flow would allow for sediments to settle out as well as mitigate erosion caused by faster flowing runoff over gravel surfaces. Some potential locations for a bioswale could be along the treeline edge of the parking lot, within the lawn area, or within the ornamental plant buffer between the tennis courts and Cliffside Road. An additional recommendation could be the conversion of the impervious gravel road and parking lot to an underdrained porous surface. This would provide for filtration and removal of a potential sediment and nutrient source.

Cost Site 2: Depending on the quantity, size, and location of a BMP, the approximate cost for design, permitting, and implementation of this BMP recommendation is anticipated to be between \$150,000 and \$450,000.

SITE 3: TENNIS COURTS AND ADJACENT GRAVEL PARKING LOT

Immediately south of the community tennis courts, located between Cliffside Road and Bonnie Brae Road, is a gravel parking lot that is roughly 100 feet by x 50 feet in size.



Photo 4: Small gravel parking lot to the south of Tennis courts along Cliffside Road

Recommendation Site 3: Similar to the recommendations for the adjoining parking lot mentioned above (Site 2), this small gravel lot could be included in the drainage area of a bioswale or be a good location for a rain garden. Vegetation has started to grow through and reclaiming part of the lot along the northern side and the implementation of a rain garden there could help mitigate runoff from the nearby roads and the tennis courts. Creating a depression in the lot to direct water to a low point, paired with planting shrubs, perennials and other native plants would help mitigate the impacts of the nearby impervious surface and minimal stormwater drainage at present. An additional recommendation could be the conversion of the impervious gravel road and parking lot to an underdrained porous surface. This would provide for filtration and removal of a potential sediment and nutrient source.

Cost Site 3: The approximate cost for design, permitting, and implementation of this BMP recommendation is anticipated to be between \$150,000 and \$300,000.

EGBERT LAKE

The drainage area to Egbert Lake is forested with residential homes mostly accessed from State Route 513. There are seven smaller ponds within the watershed which are located on private property and were not visited as part of the inspection. A natural buffer of trees, shrubs, and meadow grasses border the entire perimeter of the shoreline. A gravel walking/biking path runs atop the western portion of the embankment. The inflow comes from the northeast through the wooded area between the lake and Route 513. The lake outflows into the woods to the west and forms Burnt Meadow Brook. Egbert Lake can become filled with dense submerged aquatic vegetative growth during the summer growing season and this is driven by the generally shallow and uniform depth of the lake.



Photo 5: Egbert Lake from the parking lot, facing SE

SITE 4: POTENTIAL IMPOUNDMENT REMOVAL AND FLOODPLAIN RESTORATION

Recommendation Site 4: The watershed and surrounding area around Egbert Lake is well vegetated with minimal spots that identify as problematic. Within the lake there are two recommendations to help improve the health of the lake ecosystem. One recommendation (Site 4a) would be to potentially remove the embankment along the western shore and restore the natural floodplain and wetland characteristics that would have existed pre-impoundment. The removal of the impoundment would not only restore the ecosystem to a more native condition, but also would reduce the need for continued monitoring and maintenance on the embankment.

The second recommendation (Site 4b) would be the installation of in-lake management practices including floating wetland islands, aeration, and biochar. During the summer months Egbert Lake can become filled with submerged aquatic vegetation (SAV). The density of this SAV fills the water column and can be harmful to biological organisms and the lake ecosystem. Introducing in-lake management practices could serve not only to remove nutrients from the water that can be used by nuisance plant growth, but also would create shaded areas to block submerged plants' access to sunlight.

Cost Site 4a: The approximate cost for design, permitting, and implementation of this BMP recommendation is anticipated to be between \$1,500,000 and \$3,000,000.

Cost Site 4b: The approximate cost for design, permitting, and implementation of this BMP recommendation is anticipated to be between \$75,000 and \$150,000.

DURHAM POND

Access to the pond itself was not obtained for the site inspections. The drainage area to the Durham Pond is forest and possibly wetlands or former ponds. Boy Scouts of America Camp Winnebago is located within the drainage area most proximate to the lake. There appears to be some cabins and buildings associated with the camp along the road toward the lake. There are a few residential homes scattered throughout the drainage area.

SITE 5: BOY SCOUT GRAVEL PARKING LOT



Photo 6: Camp Winnebago gravel Parking lot, facing N.

A clearing of trees and a large gravel parking lot are located near the main cabins at the entrance of Boy Scouts of America Camp Winnebago. The lot is approximately 48,000 square feet in area and connects to Winnebago Road. The lot shows signs of washed-out ruts and pothole depressions due to surface flow. Improving drainage in this parking lot would not only improve the condition of the parking surface, but also minimize loose gravel and sediment transportation during storm events.

Recommendation Site 5: The first potential recommendation (Site 5A) for this site would be to install a porous or vegetative paving system throughout the parking area. Introducing an option such as permeable grass pavers would not only reduce potholes and standing water but would help in absorbing and slowing water before it flows towards Durham Lake. The vegetation and filtration allow for sediment settling and pollutant removal. This option would not reduce the amount of parking spaces within the lot.

The second potential recommendation (Site 5B) is the installation of rain gardens or bioretention features along the perimeter of the lot and/or throughout the lot to break up connected impervious surfaces. Rain gardens and similar BMPs are resilient to climate change and require minimal maintenance, as well as provide enhanced visual aesthetics in a parking area. Both BMP practices will be able to prevent excess sediment and nutrients from entering the pond from this location, allowing for cleaner stormwater runoff to enter the pond, improving its water quality.

Either of these recommendations could be completed in sections, or both can be implemented and connected to each other.

Cost Site 5A: The approximate cost for design, permitting, and implementation of this BMP recommendation is anticipated to be between \$200,000 and \$300,000.

Cost Site 5B: The approximate cost for design, permitting, and implementation of this BMP recommendation is anticipated to be between \$100,000 and \$200,000.

SITE 6: CHANNEL, PIPE DISCHARGE AND GRAVEL ROADWAY STABILIZATION



Photos 7-8: Timberbrook Road and sediment and gravel deposition in nearby creek

Timberbrook Road, between its intersection with Jacobs Road and the entrance of Camp Winnebago, has loose gravel and shows signs of erosion. At this location the road transitions from paved to gravel and there is a culvert crossing for a small stream, tributary to Durham Pond. Along the shoulder of the road, the stream channel exhibits visible gravel deposits from the road. In its current state the accumulation does not appear to impede stream flow but after continued erosion and gravel loss from the road there may be issues with water movement and stream ecosystem health in the future.

Recommendation Site 6: The recommendation for this site is creating a vegetation buffer along the sides of the road near the culvert. This barrier and conveyance would act as a simple fix to reduce gravel and debris from washing directly into the creek and continuing to fill in the channel. Increased vegetation would also allow water to be taken up through root structures, which could assist in slowing and filtering the flow.

Cost Site 6: The approximate cost for design, permitting, and implementation of this BMP recommendation is anticipated to be between \$100,000 and \$300,000.

CAMP LEWIS

Access was not gained to inspect Camp Lewis, however within the drainage area for the lake located in the camp there were several locations with large impervious surfaces or clear signs of water erosion. Any improvements made to these targeted areas would still be beneficial in combating further stormwater damages and impaired water quality in the watershed.

SITE 7: FIRE DEPARTMENT

Marcella Fire Department, located along Upper Hibernia Road, has a parking lot, grass lawn and adjoining wood lot identified as areas of potential improvement. The parking lot and grass areas could provide space for BMPs that reduce sheet flow coming off the asphalt and mowed lawn. The wood lot has a slight depression compared to the surrounding area and was saturated with water during the field visit. In its current state the vegetation is a dense understory thicket with woody debris.



Photos 9-10: Marcella Fire Department woodlot and southern parking lot.

Recommendation Site 7: The recommendation for this site is to take advantage of the natural low point in the woodlot and create a bioswale or other bioretention area. This location already has a gradually sloping vegetative buffer between the impervious area and the recommended best management practice. Removing some of the downed woody debris, creating a bioswale and populating it with more water tolerant perennial plants could be an effective usage of this currently unused woodlot. This option would also minimize reducing parking space in the fire department's parking lot. Any runoff from the residential houses that back up to this woodlot to the east would also be slowed and filtered in addition to flow from the road and fire department.

Cost Site 7: The approximate cost for design, permitting, and implementation of this BMP recommendation is anticipated to be between \$100,000 and \$200,000.

LAKE EMMA

Lake Emma's drainage area is mostly forested with scattered residential properties and an athletic facility in the headwaters where the drainage area abuts the drainage areas for Lake Egbert and Camp Lewis.

SITE 8: RESTORATION OF THE ADJACENT INLET POND

On the northern side of Green Pond Road directly across from Lake Emma, there is a small inlet pond approximately 0.15 acres in size. The pond is entirely covered in aquatic vegetation, predominantly white-water lily (*Nymphaea odorata*). There is a vegetated buffer between this pond and the road, which is beneficial for reducing pollutants and runoff. There is a connection between this water feature to Lake Emma, however when one flows into the other is unknown. This pond could be a source of nutrient input to potentially the lake as well as waterbodies within the Township. Prior to implementing any recommendation and estimating nutrient removal efficiencies the interaction between this pond and Lake Emma needs to be investigated and understood.



Photo 11: Small Inlet Pond across from Lake Emma

Recommendation Site 8: The conversion of this pond to a constructed wetland or bioretention forebay to treat water entering Lake Emma as well as stabilizing any accumulated sediment which may have already accumulated. The installation of filter media such as Biochar could be incorporated to adsorb additional nutrients from the system.

Cost Site 8: The approximate cost for design, permitting, and implementation of this BMP recommendation is anticipated to be between \$125,000 and \$250,000.

SITE 9: LAKE EMMA

Lake Emma can be a best management practice itself as a treatment forebay for Lake Telemark and Lake Ames.

Recommendation Site 9A: The implementation of in-lake management practices to reduce the vegetation growth throughout the lake by reducing the nutrient accumulation, aeration of the water column, and filtering of the water. A combination of BMPs could be installed with Lake Emma including BioChar, floating wetland islands, phoslock, and/or aeration system.



Cost Site 9A: The approximate cost for design, permitting, and implementation of this BMP recommendation is anticipated to be between \$50,000 and \$150,000.

Recommendation Site 9B: The removal of the impoundment, Lake Emma, including the restoration of a natural stream corridor with floodplain access and sediment stabilization will reduce the nutrient load within the system and downstream lakes. The installation of native vegetation within the impoundment will use and transform the nutrients.

Cost Site 9B: The approximate cost for design, permitting, and implementation of this BMP recommendation is anticipated to be between \$300,000 and \$750,000.

SITE 10: CHURCH COMMUNITY PARKING LOT

The Marcella Community Club, located at the intersection of Green Pond Road and Upper Hibernia Road, has an asphalt parking lot measuring approximately 75 feet by 135 feet. There were no stormwater drains noted during the site visit and a large, and relatively flat, impervious surface could present challenges with drainage during rain events.



Photos 12-13: Marcella Community Club parking lot along Green Pond Road

Recommendation Site 10: The recommendation for this site is to discount the impervious surface. This could be completed in a variety of ways depending on the use and subsurface soil conditions. The installation of porous pavement vegetated depressed parking lot islands, and/or manufactured vegetated filter boxes such as the Filterra could be possible best management practices implemented at this site. These could also be installed in combination with each other to maximize the removal efficiency.

Cost Site 10: The approximate cost for design, permitting, and implementation of this BMP recommendation is anticipated to be between \$100,000 and \$500,000.

TELEMARK LAKE

Telemark Lake's drainage area includes the drainage area to Lake Emma and is primarily forested with the expectation of a few residential communities off Green Pond Road and public facilities including a church, elementary school, recreation fields, and bus garage.

SITE 11: DPW AND BUS GARAGE

The Department of Public Works (DPW) and Bus Garage have several large grass areas around the perimeter of the parking lots and along Green Pond Road. The entrance of the DPW parking lot has a series of stormwater drains along both sides that take surface flow from the adjoining lots and grass surfaces. The high concentration of impervious surfaces paired with maintained lawn areas provide a potential for a variety of treatment to reduce runoff and pollutants from entering the stormwater system and ultimately Hibernia Brook and Telemark Lake.



Photos 14-15: Grass field separating Green Pond Road and Bus Garage parking lot & entrance to DPW parking lot

Recommendation Site 11: The first recommendation (Site 11A) for this site is the implementation of a bioretention system in the grassed area between the parking lot and Green Pond Road. Providing a sheet flow connection from the road and parking lot, retaining the water and filtering it through native vegetation and soil media to use and remove nutrients from the stormwater. Another recommendation (Site 11B) would be the conversion of the existing impervious surfaces to a porous material or reducing the surface area of impervious surfaces directly connected to the stormwater pipe without treatment. Additionally (Site 11C), the installation of a manufactured treatment device or multiple devices along or in line with the existing stormwater system would provide treatment of additional runoff.

Cost Site 11A: The approximate cost for design, permitting, and implementation of this BMP recommendation is anticipated to be between \$250,000 and \$750,000.

Cost Site 11B: The approximate cost for design, permitting, and implementation of this BMP recommendation is anticipated to be between \$150,000 and \$500,000.

Cost Site 11C: The approximate cost for design, permitting, and implementation of this BMP recommendation is anticipated to be between \$250,000 and \$750,000.

SITE 12: KATHARINE D. MALONE ELEMENTARY SCHOOL

Katharine D. Malone Elementary school is located along Green Pond Road (Route 513) just south of the DPW and bus parking lot. Similarly, the school has large parking lot areas with impervious surfaces and maintained lawn areas for recreation.

Recommendation Site 12: The first recommendation (Site 12A) for this site is the implementation of a bioretention system in the grassed area between the parking lot and Green Pond Road. Providing a sheet flow connection from the road and parking lot, retaining the water and filtering it through native vegetation and soil media to use



and remove nutrients from the stormwater. Another recommendation (Site 12B) would be the conversion of the existing impervious surfaces to a porous material or reducing the surface area of impervious surfaces directly connected to the stormwater pipe without treatment. Additionally (Site 12C), the installation of a manufactured treatment device or multiple devices along or in line with the existing stormwater system would provide treatment of additional runoff. These BMPs would offer minimal interference with school activities and could provide an excellent outdoor classroom environment to engage and educate students.

Cost Site 12A: The approximate cost for design, permitting, and implementation of this BMP recommendation is anticipated to be between \$250,000 and \$750,000.

Cost Site 12B: The approximate cost for design, permitting, and implementation of this BMP recommendation is anticipated to be between \$150,000 and \$500,000.

Cost Site 12C: The approximate cost for design, permitting, and implementation of this BMP recommendation is anticipated to be between \$250,000 and \$750,000.

SITE 13: CHURCH

Holy Trinity Lutheran Church is located near the intersections of Colonial Road and Green Pond Road. It has a front and rear parking lot connected along the southern side of the building. Along the perimeter of the rear lot is a grass corridor and wooded area. The southern entrance to the parking lot has a stormwater drain that directs water into a drainage feature within the treeline. Several small clearings in vegetation exist as access paths into the woods.



Photos 16-17: Holy Trinity Lutheran Church rear parking lot and buffering woodlot

Recommendation Site 13: The recommendation for this site would be the conversion of the existing impervious surfaces to porous surfaces and/or reducing the area of impervious surfaces.

Cost Site 13: The approximate cost for design, permitting, and implementation of this BMP recommendation is anticipated to be between \$100,000 and \$200,000.

SITE 14: ATHLETIC FIELDS

Across the street from the DPW building and bus garage, there is a sports field complex called Hudsonia Field. The complex includes gravel parking lots and access roads, soccer fields, and a baseball field. The complex drains directly to Hudsonia Pond or Hibernia Brook which is the primary inlet into Telemark Lake. During the site visit, ruts and washout depressions were observed in the grass section bordering Green Pond Road.



Photo 18: Grass section between Hudsonia baseball field and Green Pond Road, facing north

Recommendation Site 14: The recommendation (Site 14A) for this site includes increased vegetative cover and reduced mowing to create a vegetative buffer and filter strip within a stretch of meadow grass. This BMP would not impede access to the sporting fields, would minimize groundskeeping and would add structure to the eroding land with increased root density. Planting native perennial plants would also create suitable habitat for native fauna as well as contribute to the aesthetic value of the park. The installation of management practices (Site 14B) within the gravel parking and access areas such as vegetated pavers, redirecting of flow, and buffer strips to reduce the formation of gullies and transport of sediment downstream.

Cost Site 14A: The approximate cost for design, permitting, and implementation of this BMP recommendation is anticipated to be between \$50,000 and \$150,000.

Cost Site 14B: The approximate cost for design, permitting, and implementation of this BMP recommendation is anticipated to be between \$100,000 and \$300,000.

SITE 15: NORWAY FIELDS

Norway Field consists of a gravel parking lot and grass athletic field with a small creek along the western portion of the park. There is a gradual slope from Green Pond Road down to the parking lot and water from the road flows towards the lot and creek. During the site visit large potholes of water were evident throughout the lot. The woodlot buffering the stream has a walking path that is cleared of vegetation. The creek appears to be stable with boulders throughout and vegetation along the banks.



Photos 19-20: Norway Field parking lot & small creek along the western side of the park

Recommendation Site 15: The recommendation at this site is the installation of best management practices within the gravel parking and access areas such as vegetated pavers, redirecting of flow, and buffer strips to reduce the formation of gullies and transport of sediment downstream. This BMP would help add stability to the parking lot and eliminate stagnant water collection in potholes, increase vegetation cover and reduce stone and sediment from washing into the nearby creek.

Cost Site 15: The approximate cost for design, permitting, and implementation of this BMP recommendation is anticipated to be between \$100,000 and \$300,000.

SITE 16: HUDSONIA POND

Hudsonia Pond is located immediately upstream of Lake Telemark and within the athletic complex. This impoundment was amid removal and stabilization during the site visit. The removal of the impoundment provides water quality benefits due to stabilizing sediments, access to the floodplains and wetlands for nutrient uptake and filtration, and reduced surface area of open water to regulate temperatures. Flowing water also helps to oxygenate the water column and reduce the potential growth for algae.

Cost Site 16: There is no additional cost for this site at this time as it has already been designed and permitted. It is also currently under construction.

LAKE AMES

Lake Ames is located in between Route 513 and Snake Hill Road. It has two primary inflows and discharges into Hibernia Brook to the southeast. An impoundment on the southeast side of the lake leads to a slope down into the floodplain of Hibernia Brook. Near the dam there is a mowed beach area to allow access to the lake, and a gravel pull off parking lot approximately 40 yards from the shoreline. The drainage area to Lake Ames includes Lake Telemark and Lake Emma. The area draining directly into Lake Ames is primarily forest with tributaries originating from Lake Denmark, and Picatinny Homeland Defense properties. The area in the immediate vicinity of Lake Ames and along Green Pond Road is residential.

SITE 17: RESTORATION OF THE LAKE AMES IMPOUNDMENT

Lake Ames is an approximately 16-acre lake with two main tributaries, Hiberina Brook from the north and an unnamed tributary from the southwest. The lake is impounded by an earthen embankment with a rock spillway near Snake Hill Road and an emergency overflow channel along Green Pond Road.



Photos 21-22: Hiberina brook outflow along Lake Ames impoundment (left) & vegetation along backside of the impoundment

Recommendation Site 17: The recommendation for this site is the removal of the embankment, restoration of the impoundment into floodplains with native vegetation, and stabilization of the channel(s) through the impoundment. The removal of the impoundment provides water quality benefits due to stabilizing sediments, access to the floodplains and wetlands for nutrient uptake and filtration, and reduced surface area of open water to regulate temperatures. Flowing water also helps to oxygenate the water column and reduce the potential growth for algae.

Cost Site 17: The approximate cost for design, permitting, and implementation of this BMP recommendation is anticipated to be between \$750,000 and \$1,500,000.

SITE 18: CHANNEL CROSSING AND BANK STABILIZATION ALONG SNAKE HILL ROAD

This stream is one of two primary inflows for Lake Ames. It forms in the higher elevation portions between Snake Hill and Anomaly Roads and connects with the lake along its southwestern shore. The stream's channel crosses underneath Snake Hill Road at a point roughly 200 yards away from its discharge into Lake Ames. A stone bridge and concrete culvert allow passage beneath Snake Hill Road, and several culvert pipes are seen in the channel on both sides of the road. A dry braided channel was observed, which is likely only saturated during times of high flow. This stream reach has vegetated banks with varying channel substrate. There are some banks which have signs of erosion.



Photos 23-24: Unnamed tributary with remnants of piping (left) & culvert channel crossing under Snake Hill Road (right)

Recommendation Site 18: The recommendation at this site is the removal of the remnant pipe sections and the stabilization of eroded or eroding banks. The stabilization measures will vary depending on the height of the bank, the cause of the erosion, and the flow rates through the reach. Further investigation is necessary to determine the extent of the stabilization required.

Cost Site 18: The approximate cost for design, permitting, and implementation of this BMP recommendation is anticipated to be between \$250,000 to \$1,500,000 due to the undetermined extent and potential stabilization methods.

SITE 19: DISCONNECTION OF IMPERVIOUS SURFACE ON ARMY PROPERTIES

Based on aerial imagery there are large areas of asphalt and other impervious surfaces within the Picatinny Military Complex. This runoff likely washes from the base into nearby streams and eventually ends up in Lake Ames.

Recommendation Site 19: Specific site recommendations are not possible without access to the property, however a variety of BMPs could be effective at improving drainage and mitigating large areas of continuous impervious surfaces. Some of these BMPs may be porous pavement, depressed parking lot islands, manufactured treatment devices, vegetated buffers, and rain gardens. There may also be the opportunity for bank stabilization along the mountain streams which discharge into Lake Ames.

Cost Site 19: The approximate cost for design, permitting, and implementation of this BMP recommendation is anticipated to be between \$125,000 and \$200,000 per project depending on type and size of the management project.

MOUNT HOPE POND

Mount Hope Pond is a small pond directly south of Mount Hope Road. This pond receives stormwater runoff from the surrounding forested area, a residential property, a parking area, as well as the impervious surface of Mount Hope Road. This pond then discharges into Mount Hope Lake to its east via a small stream. Mount Hope Road and the surrounding area contains impervious surfaces contribute stormwater runoff containing sediment and pollutants to enter Mount Hope Pond untreated. These areas will be the focus for the implementation of stormwater BMPs, as the management of these areas will have the greatest impact on the health and water quality of the pond. Additionally, any management measures installed at this location will help reduce the sediment and nutrient loading to Mount Hope Lake.

SITE 20: MOUNT HOPE ROAD PARKING AREA

In the northeast corner of the pond, a gravel access turnoff/parking area is located off Mount Hope Road. This area includes a steep sloped boat ramp from the flatter parking area. The turnoff is located at the bottom of a steep portion of Mount Hope Road. The combination of steep slopes, gravel surfaces, and large drainage areas contribute to the erosion issues observed on the site. The below Photos 25 and 26 depict the gullies created by this combination of features resulting in pollutants and sediment entering the pond untreated.



Photos 25-26: Signs of Erosion on boat launch area (left), and Mount Hope Road drainage leading to area (right)

Recommendation Site 20: The BMP recommendation for this location will be vegetated pavers with underdrains and subsurface storage. This system would replace the gravel and soil parking area/ramp area currently shown on site. The vegetated pavers would stabilize this location, preventing sediment from entering the pond via stormwater runoff here. The vegetation within the pavers would sequester unwanted nutrients before they enter the pond. Additionally, this proposed BMP would include a subsurface stormwater storage system. This would give the pond more stormwater resiliency during larger storm events by reducing the total runoff volume contributed to the pond from this location. As storms increase in intensity due to climate change, this feature of this BMP will become more useful.

Estimated Costs Site 20: The approximate cost for design, permitting, and implementation of this BMP recommendation is anticipated to be between \$500,000 and \$750,000.



MOUNT HOPE LAKE

The Mount Hope Lake watershed is largely a forested area but contains a sizable quarry in the north end. This lake receives water from Mount Hope Pond from the west, as well as runoff from the surrounding residential areas, forested areas, quarry, and streets. Mount Hope Lake is in the southeast portion of the watershed. It discharges to the southeast into White Meadow Lake via a stream flowing next to the White Meadow Lake softball fields. Thus, any stormwater management measures introduced in this watershed will reduce the pollutant load to White Meadow Lake.

SITE 21: CATHERINE A DWYER ELEMENTARY

Catherine A Dwyer Elementary School is located off of Mount Hope Avenue. The school contains two asphalt parking lots which contribute to the stormwater system running under Mount Hope Avenue via an existing stormwater piping and inlet system located within the parking lots. This stormwater system conveys the stormwater runoff from these parking lots, adjacent residential lots, and street drainage to its discharge into Mount Hope Lake.



Photos 27-28: Two Potential BMP locations at Dwyer Elementary parking lot entrances

Recommendation Site 21A: One recommended BMP for this site would be to intercept the surface stormwater runoff from the parking lots with a porous pavement system at the parking lot entrance, down-gradient of the parking lot areas. Portions of the entrance driveways of the asphalt parking lots would be removed and replaced with a porous pavement system containing subsurface storage options such as pipes or subsurface chambers. Representative areas for the BMPs can be shown in Photos 27-28 above. These BMPs would intercept the surface and piped runoff from the parking lots, store it within the BMPs piping or chambered systems, and discharge back into the existing street drainage system. These practices could also intercept some of the street drainage to infiltrate and store it within the subsurface systems, for additional stormwater volume management. Stormwater runoff reduction into the lake via BMP filtration and storage are beneficial as they allow for the site and lake to become more resilient to larger storm events caused by climate change. Additionally, these porous paving systems could be applied in a modular way to various parking spaces around the parking lot, allowing for a greater volume of runoff to be treated at this location from those areas as well.

Recommendation Site 21B: Another recommendation would be to replace the grassed areas located in and bordering the parking lots with rain gardens. Grassed areas such as the ones shown in Photo 26 would have curb cuts installed on them, with portions of the grassed area converted into a rain garden. This would accomplish the



same goal and have the same stormwater management capabilities as the porous paving systems, with an additional vegetative component on the surface of the practice. Another benefit to this BMP system is that rain gardens would also be able to serve as an educational tool by having informational signs posted next to them, informing school students and the public of how they are constructed and how they manage stormwater.

Estimated Costs Site 21A: The approximate cost for design, permitting, and implementation of this BMP recommendation is anticipated to be between \$200,000 and \$400,000.

Estimated Costs Site 21B: The approximate cost for design, permitting, and implementation of this BMP recommendation is anticipated to be between \$150,000 and \$250,000.

WHITE MEADOW LAKE

White Meadow Lake receives most of its inflow from an inlet stream located on the southwest shoreline of the lake, which drains from Mount Hope Lake. White Meadow Lake discharges into White Meadow Brook to its east, which is a tributary to the Rockaway River. Most of the drainage area for this lake consists of residential properties and streets, with a few beach areas and parking lots around the shoreline.

SITE 22: MOUNT HOPE ROAD PARKING LOT

Along Mount Hope Road and to the west of White Meadow Lake is a vacant parking lot. This parking lot's drainage system includes two catch basins and associated piping to collect and convey the runoff from the parking lot and parts of Mount Hope Road before discharging directly into the lake, as shown in Photo 27 below. Multiple stormwater management measures would be implemented at this location.



Photo 29: Mount Hope Road roadside inlet and part of surrounding parking lot area

Recommendation Site 22A: This porous pavement system will intercept the two-inlet drainage system before it discharges into the storm pipe on the north side of Mount Hope Road. This BMP will be equipped with an underground piping or chamber apparatus and gravel storage to properly contain and convey the runoff draining to this system. Additionally, the porous pavement system will intercept surface runoff from parts of Mount Hope Road, lessening stormwater impact on surrounding areas. The reduction of impervious area draining into the lake from this location will improve the water quality of the lake by reducing contaminant contribution stemming from Site 22, since the site will have an area to infiltrate the stormwater directly into the ground. This BMP improvement also allows for more local stormwater storage for this watershed, reducing stormwater loading further downstream. This is an added measure to protect against increasing storm intensity due to climate change and provides an added area of storage within this watershed's drainage system.

Recommendation Site 22B: In addition to the porous paving system installed at this location, part of the asphalt bordering Mount Hope Road could be removed, with a vegetated bioretention strip installed in place instead. A location such as Photo 29 shown above would be able to have part of the impervious area of the parking lot and the impervious area of Mount Hope Road split by a bioretention stormwater storage system. This system would be able to accomplish the same runoff filtration and storage goal as the porous paving system, with an added vegetated component to increase filtration. These systems would also be hydraulically connected and

discharged using the existing piping system. This BMP could receive runoff from both the parking lot and the street, which provides more overall runoff storage by giving stormwater runoff another location to drain to on Site 22.

Estimated Costs Site 22A: The approximate cost for design, permitting, and implementation of this BMP recommendation is anticipated to be between \$150,000 and \$200,000.

Estimated Costs Site 22B: The approximate cost for design, permitting, and implementation of this BMP recommendation is anticipated to be between \$150,000 and \$300,000.

SITE 23: WEST LAKE SHORE DRIVE PARKING LOT

Site 23 are the two parking lots located at the Beach 2 boat launch of White Meadow Lake, between West Lakeshore Drive and the shoreline of the lake. The discharge channel from Mount Hope Lake splits the two parking lots. These parking lot areas are sloped towards the lake and contain grassed swale conveyance systems which empty into the stream system and thus the lake. The parking lot areas are primarily used in the summer months, when the beach area is more active, and contain no other drainage system other than the grassed swales. Refer to Photos 30 and 31 below for the location of the swales pertaining to the parking lot.



Photos 30-31: Parking lots and grassed swale conveyance systems

Recommendation Site 23A: The conversion of the grassed swale into a rain garden would provide greater nutrient uptake and sediment removal. Refer to Figure 82 below for a schematic of the rain garden locations pertaining to the river and lakefront area.

Recommendation Site 23B: In addition to the rain garden conversion, porous paving strips could be installed in the middle of the parking lot. This would add an additional stormwater filtration and storage element to the site. This measure also extends the life of the rain garden and prevents rain garden erosion/clogging, as the stormwater runoff velocity and volume traveling to the rain garden is reduced when passing over the porous paving strip. Refer to Figure 82 below for a schematic of the porous paving strip locations pertaining to the river and lakefront area.

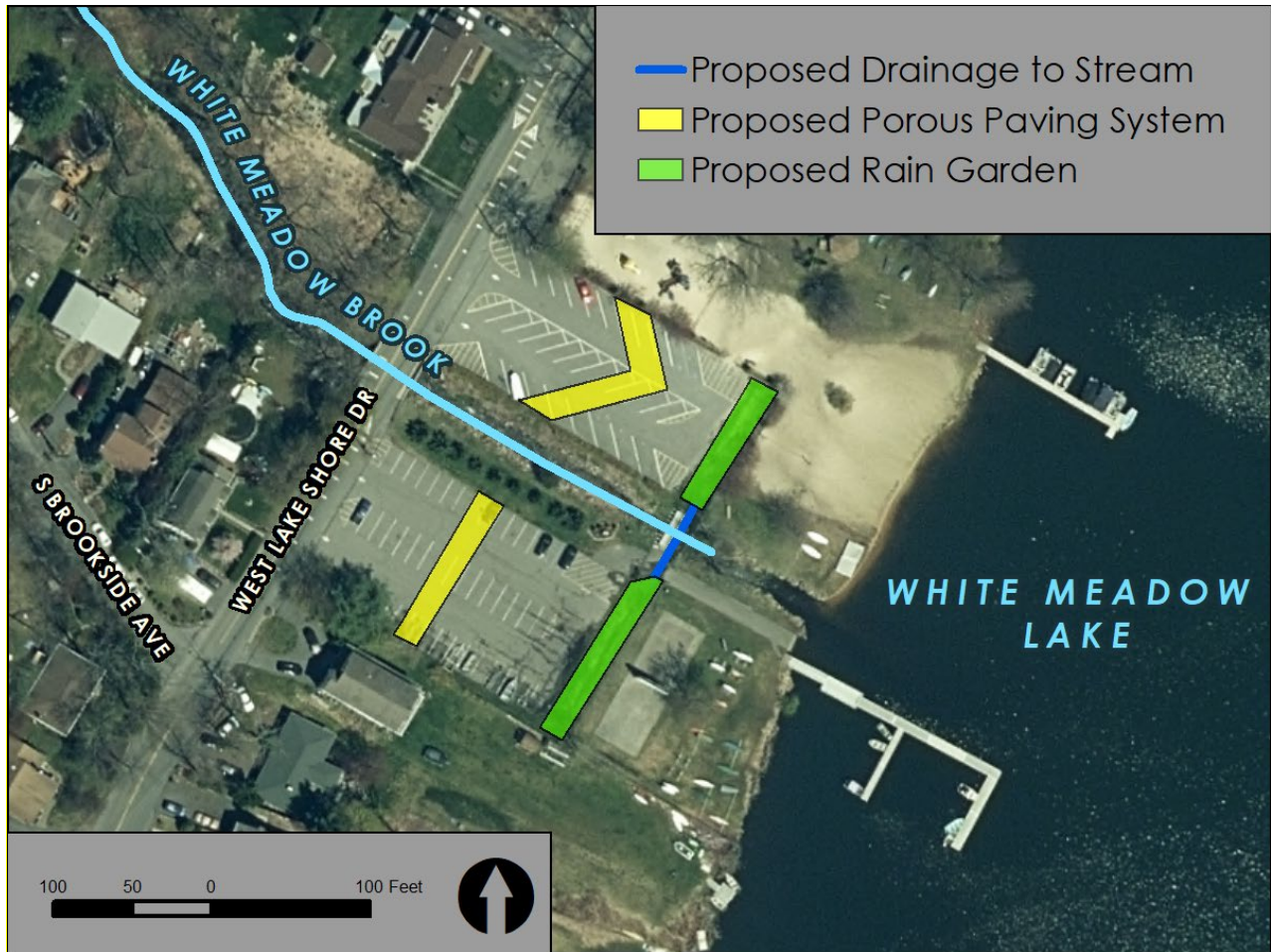


Figure 82: Overall Site

Estimated Costs Site 23A: The approximate cost for design, permitting, and implementation of this BMP recommendation is anticipated to be between \$75,000 and \$200,000.

Estimated Costs Site 23B: The approximate cost for design, permitting, and implementation of this BMP recommendation is anticipated to be between \$150,000 and \$300,000.

SITE 24: WHITE MEADOW LAKE COUNTRY CLUB

Site 24 is the White Meadow Lake Country Club and grounds surrounding the building. This building is located on the southeast end of White Meadow Lake, adjacent to the dam. This area contains a parking lot, boat launch, boat docks, and a grassed area that borders the lake. The manicured lawn runs directly up to the shoreline of the lake with minimal shoreline vegetation separating the lawn from the lake, as shown in Photo 32. Because of this, pollutants and sediment drain directly to the lake from the lawn with minimal interception or nutrient filtration from shoreline vegetation. This area presents an opportunity for shoreline improvements to prevent sediment and pollution addition into the lake.



Photo 32: Area for potential shoreline restoration along Site 24

Recommendation Site 24: Improvements to the shoreline vegetation would reduce nutrient loading to the lake from this location, as an improved vegetated shoreline will provide a buffer to filter and/or use these nutrients. Additionally, shoreline herbaceous vegetation will stabilize the soil and provide a deterrent to geese and other animals from accessing the lake at these locations. Shoreline health can also be improved by maintenance measures, such as leaving a 10-15 feet unmowed border along the shoreline area.

Estimated Costs Site 24: The approximate cost for design, permitting, and implementation of this BMP recommendation is anticipated to be between \$30,000 and \$75,000.

SITE 25: NORTH LAKE SHORE DRIVE BEACH AREA / BEACH 3

Site 25 is located along the shoreline in the northeast corner of White Meadow Lake at Beach 3. Site 25 includes a parking area along North Lake Shore Drive, as well as a lakeside beach recreation area. This area is used for general recreation by the public, especially during the summer months. This location also contains a small drainage stream that receives runoff from the parking lot, North Lake Shore Drive, and the surrounding residential community stormwater system. The stream channel along the perimeter of the beach lot has exposed soil along the streambanks and lack of vegetated buffer. Refer to Photos 33 and 34 below for an example of the parking lot and stream bank areas respectively.



Photos 33-34: Parking Lot- Potential Porous Paving Location and Stream Channel on site



Recommendations Site 25A: The first recommendation will be to construct a porous paving system within the sites parking area to manage the stormwater runoff from the parking lot and street area of North Lake Shore Drive. This will provide an initial pollutant and volume reduction of the impervious stormwater runoff entering the stream at this location, since the stormwater will filter through the porous paving system instead of draining direction into the stream. A representative example of a porous paving location can be shown in Photo 33 above.

Recommendations Site 25B: In addition to the porous paving system, riparian enhancements to the drainage stream will also reduce the pollutant load to White Meadow Lake. At a minimum, the riparian buffer on both sides of the drainage stream should be enhanced with native vegetation. The riparian plantings along the streambank that borders Beach 3 should be prioritized, as the landscaped grass at Beach 3 is a source of unwanted sediment and nutrients. The streambanks were exhibiting minor signs of erosion during the site visit, and riparian plantings will help to stabilize the soil. In addition to the riparian plantings, select streambank stabilization along the drainage stream will further address the bare soil that is currently eroding into the lake. Bank stabilization measures will stabilize this soil and further reduce the pollutant load to the lake.

Estimated Costs Site 25A: The approximate cost for design, permitting, and implementation of this BMP recommendation is anticipated to be between \$150,000 and \$500,000.

Estimated Costs Site 25B: The approximate cost for design, permitting, and implementation of this BMP recommendation is anticipated to be between \$250,000 and \$500,000.

FOX'S POND

Fox's Pond is in the southern end of the Township between Mount Hope Road and Lakeside Drive. Most of the inflow to Fox's pond enters via Fox's Brook at the northern end of the pond, receiving runoff from various residential and commercial properties on both sides of Interstate-80(I-80), I-80, and the municipal complex. Fox's pond discharges into a continuation of Fox's Brook at the southern end of the pond which then flows to Rockaway River.

SITE 26: ROCKAWAY TOWNSHIP MUNICIPAL BUILDING

The municipal complex comprises Rockaway Township Municipal Offices, Police Department, and Public Library as well as associated parking lots and travel ways. The Department of Public Works and Recycle Center is located to the south of the main complex. These two Municipal components are divided by a brook that eventually drains to Fox's pond. This brook receives drainage from the various impervious parking areas around the site, as well as runoff from the roadways and surrounding residential areas through underground stormwater piping systems passing through Site 26. The outlet for all of the drainage in this area is a water body to the southeast of the site. The small water body shows signs of poor water quality, with lots of algae present, and has an outlet control structure plugged or not working properly. The brook and subsequent water body receive a large amount of impervious runoff and sediment from the bordering parking areas of the municipal building, street areas, residential lots surrounding the area, and potentially Route 80 runoff as well.

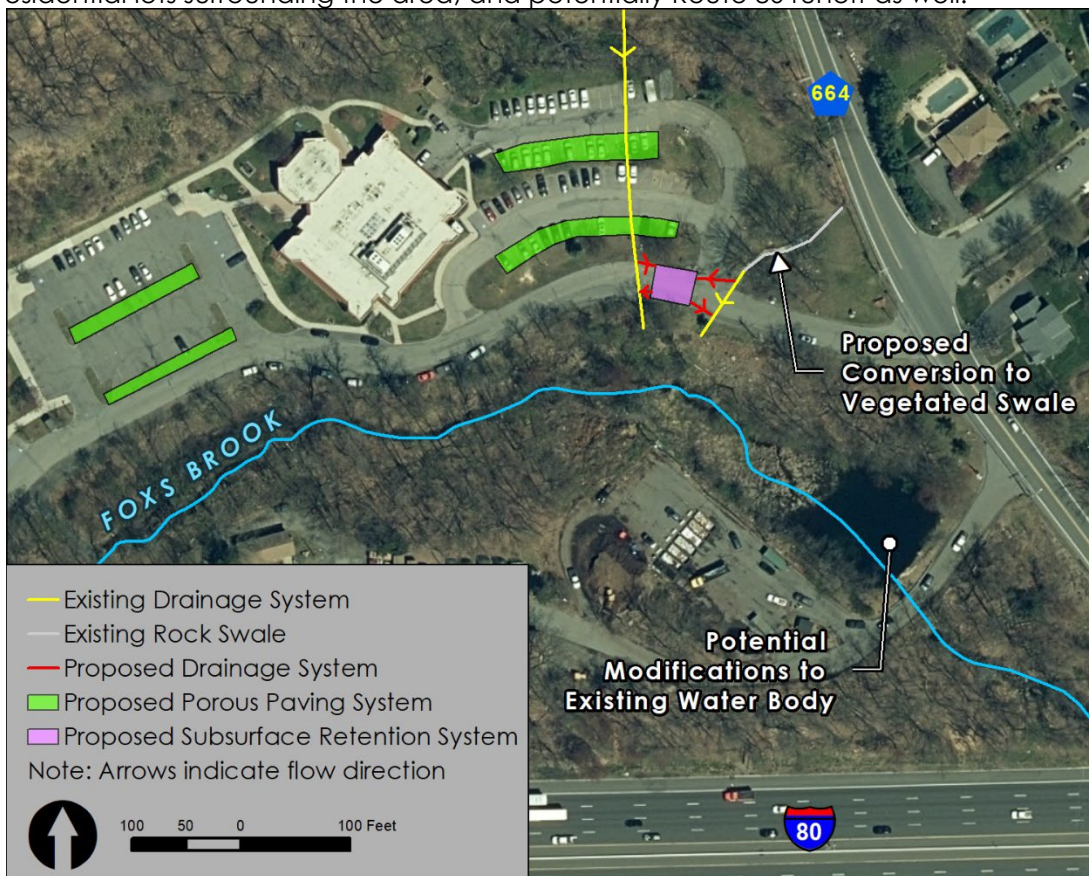


Figure 83: Site BMP Makeup

The recommended BMP practices at this location can be shown in the figure above.

Recommendation Site 26A- Subsurface Retention System: The existing drainage system running under the center parking lot area would be intercepted by a subsurface retention BMP before it outlets to the brook area. This system would use inlet and outlet control structures to store and filter some runoff stemming from the existing residential system and overflow from the vegetated swale system, before said runoff enters the brook at this location. This would reduce pollutant and runoff volume loading from this location.

Recommendation Site 26B- Vegetated Swale: Additionally, Figure 83 above shows the location of a proposed grassed swale. The location is currently a rock-lined swale, as shown in Photo 35. This swale receives impervious drainage from the west side of Mount Hope Road and conveys it to a piping system at the edge of the asphalt entranceway, where it outlets at the brook. This swale could be replaced with a vegetated swale containing check dams. The vegetated portions of this BMP would better filter pollutants in the runoff, while the check dams control runoff velocity and erosion, before it enters the piped conveyance system under the roadway. This alternative BMP would control runoff and filter pollutants better than the current one at this location.



Photos 35-36: Current conditions of side rock-lined swale and Outlet structure of retention pond, showing outlet area blocked

Recommendation Site 26C- Brook and Water Body Modifications: The brook and water body are the outlet for the residential drainage system, neighboring streets, and municipal parking lot stormwater runoff. The water body outlet structure, shown in Photo 36 above, currently seems to have an overflow pipe blocked, with a degrading structure surrounding it. A modified water body and outlet structure area would allow for the proper drainage of the water body, increasing the flushing rate and decreasing the amount of time for plankton nutrient assimilation and reproduction. Modifications such as channel reconstruction, a sediment forebay, dredging, and removal of the outlet structure are all possible improvements to this location, depending on township use and needs. The brook draining from Route 80 to this location would also be listed for various potential improvements to the site. Some ecological improvements can be made by adding native emergent vegetation to provide additional nutrient assimilation before the water is discharged downstream. The combination of ecological activity improvement along with the stormwater drainage improvements described above will not only increase the water quality of the lake further downstream, but also improves the climate change resiliency of this location.

Recommendation Site 26D- Various Porous Paving Systems: The surrounding impervious parking lot areas of the site provide many locations for stormwater improvements. The site has no curb separating the impervious areas

from the brook, allowing stormwater runoff to drain directly to the brook area unabated. The installation of various porous paving systems as shown in Figure 83 above would allow for stormwater runoff to be filtered and stored at said locations. This would reduce the total volume of runoff and total amount of pollutants entering the brook from this site.

Estimated Costs Site 26A: The approximate cost for design, permitting, and implementation of this BMP recommendation is anticipated to be between \$150,000 and \$200,000.

Estimated Costs Site 26B: The approximate cost for design, permitting, and implementation of this BMP recommendation is anticipated to be between \$50,000 and \$200,000.

Estimated Costs Site 26C: The approximate cost for design, permitting, and implementation of this BMP recommendation is anticipated to be between \$500,000 and \$1,000,000.

Estimated Costs Site 26D: The approximate cost for design, permitting, and implementation of this BMP recommendation is anticipated to be between \$150,000 and \$300,000.

SITE 27: COPELAND MIDDLE SCHOOL

Copeland Middle School is located along Lake Shore Drive. This site contains an asphalt parking lot and pond at the front of the school property. The pond collects the stormwater runoff from the surrounding school property and streets, which are piped into the pond at various locations. The inlet and outlet pipes were obscured by vegetation during the site visit as well as vegetation growing in the open water.



Photo 37: Pond at the front of the Copeland Middle School property

Recommendation Site 27a - In-Lake Restoration: The first recommendation for this site is the implementation of “in-lake” management measures in the pond. This recommendation provides an opportunity to “treat” and/or “filter” the nutrient load that originates on the impervious property around the school and within the accumulated material within the pond. These recommendations can include the installation of biochar bags and floating wetland islands (FWIs). Both management techniques utilize natural processes to remove nutrients from the water column.

Recommendation Site 27b - Basin Retrofit: An alternative measure for this site involves retrofitting or modifying this existing basin to a length retention time, maximize flow length, and nutrient uptake. While more complex and expensive, this approach would provide a greater reduction in the pollutant load originating from this site. Such a conversion would likely include modifications to or replacement of the basin outlet structure, potential regrading of the basin slopes and bottom, and vegetating the basin with native plant species.

Estimated Costs Site 27a: The approximate cost for design, permitting, and implementation of this BMP recommendation is anticipated to be between \$30,000 and \$100,000.

Estimated Costs Site 27b: The approximate cost for design, permitting, and implementation of this BMP recommendation is anticipated to be between \$200,000 and \$400,000.

SITE 28: STONY BROOK ELEMENTARY SCHOOL

Stony Brook Elementary School is located off Stony Brook Road. The school complex includes an asphalt parking lot area, and an asphalt driveway connecting to Stony Brook Road. There were no observed stormwater management practices to retain or treat the runoff from these impervious surfaces. Thus, the stormwater runoff does not have any area to allow pollutants or nutrients to be filtered naturally or sequestered before entering Fox's pond, which degrades the water quality of the pond. The southern entrance driveway extending to Stony Brook Road contains stormwater piping responsible for draining the driveway area, as well as the impervious asphalt parking lot of the school all conveying it offsite.



Photos 38-39: Facing downstream and upstream at a potential stormwater BMP location at Stony Brook Elementary

Recommendation Site 28: As shown in Photos 38-39 above, the grassed area along the asphalt drive leading to Stony Brook Road would be an ideal location for a rain garden or other similar retention BMP. The inlet shown in the photographs above is connected to the outlet of stormwater drainage from the impervious parking lot area and driveway. A subsurface storage component would also be added to the rain garden to allow for stormwater storage and filtration within the practice itself. This rain garden would intercept stormwater from the impervious surfaces and filter pollutants from the impervious parking lot and driveway areas that drain to it. While this reduces pollution of Fox's Pond further downstream of the drainage line, it will also reduce stormwater runoff volume during major storm events, by storing some of the runoff volume within the soil of BMP. This BMP can also reduce flooding risk of the surrounding area caused by climate change.

Estimated Costs Site 28: The approximate cost for design, permitting, and implementation of this BMP recommendation is anticipated to be between \$150,000 and \$300,000.

SITE 29: MUNICIPAL BUILDING AT 19 MT. HOPE ROAD

The parking lot area of a Rockaway Township Municipal Building at 19 Mt. Hope Road directly borders the northeastern side of Fox's Pond. This area is used by municipal workers and used for parking for access to the ponds walking paths. As shown in Photo 40 below, this site includes multiple impervious parking lots and streets within its drainage area that feed into its stormwater system. This stormwater system then directly discharges into Fox's Pond from the northeast.



Photo 40: Parking lot area of American Legion and Municipal area bordering Fox's Pond

Recommendation Site 29: As shown, the parking lot area entrance and various parking spots would be an ideal location for a porous paving system. Since the parking lot area contains a large amount of impervious asphalt, the porous paving system would be able to have a storage area underneath of the system, allowing for the storage of water and filtration of sediment from the water before it's discharged into the pond. This site provides the ability for parts of this system to be modular, installed in certain parking spaces as well. Additionally, the porous paving system would be able to intercept the existing stormwater pipe leaving the site under the entranceway, providing more treatment volume. This improves water quality by removing pollutants from the pond and allows for greater management of stormwater stemming from this location. This BMP system would initially delay excess runoff from entering the pond all at once during a storm event, which provides a way for this area to reduce flooding and manage stormwater runoff more effectively.

Estimated Costs Site 29: The approximate cost for design, permitting, and implementation of this BMP recommendation is anticipated to be between \$150,000 and \$500,000.

SITE 30: ACADEMY STREET PARKING LOT

This site is a church parking lot that borders Fox's Pond to the East, off of Academy Street. This parking lot is used by the public to attend the church nearby, and to recreate at Fox's Pond across the street. This parking lot contains 33,000 square feet of impervious area that drains into Fox's Pond. Currently, the parking lot has no type of stormwater management system, with runoff from the parking lot draining along the surface to Academy Streets drainage system, which is piped directly into the pond. Because of this, there are no existing stormwater management features on this site.



Photos 41-42: South side of parking lot and entrance area, showing potential locations of BMPs.

Recommendation Site 30: The first recommendation would be the conversions of the existing lawn areas into bioretention systems. Due to the size of the parking lot, it is anticipated that multiple features may be necessary to treat the runoff. The main bioretention swale system would be bordering the southern part of the parking lot, extending the length of the grass strip and ending near the parking lot entrance; this area can be seen in Photos 41-50 above. The swale would drain to an outlet structure before connecting to the piped conveyance system on Academy Street and discharging into Fox's Pond. In addition to this bioretention practice, several parking spaces could be converted into smaller bioretention infiltration systems, spaced out through the parking lot. Since the parking lot is not full most of the time for church, converting some spaces to a bioretention practice would be an easy way to increase stormwater volume management and nutrient uptake at this location.

Estimated Costs Site 30: The approximate cost for design, permitting, and implementation of this BMP recommendation is anticipated to be between \$150,000 and \$300,000.

SITE 31: ROUTE 80 RESIDENTIAL DRAINAGE AREA

The residential area on the north side of Route 80, which drains to an outlet at the intersection of Barry Drive and Willow Road is the confluence of drainage for the surrounding residential area including Henry Street, Barry Drive, and Willow Road. The outlet of this drainage can be shown in Photo 43 below, which discharges into a concrete and rock lined channel area, before continuing to a piping system which travels under Route 80 and ends at Fox's pond. Many of the streets in this drainage area contain a grassed section next to them.



Photo 43: Outlet of street drainage system that drains to piping system under Route 80

Recommendation Site 31: Many of the streets in this drainage area contain a grassed section next to them, which would present opportunities for modular stormwater filtration in the form of right-of-way (ROW) bioswales or vegetated filter boxes with connections to the existing stormwater system. One such area can be shown in Photo 44 below. As shown, there is a two-inlet system directly next to a grass strip bordering the roadway, leading to the corner. A BMP could be installed here, and in various locations like this, in this residential area. These BMPs would intercept the residential and street stormwater drainage prior to the runoff entering inlets flowing to the main stormwater piping system that outlets at Photo 43's location. These BMPs would be modular in format and installed at various locations around this area or in various residential locations in any of the watersheds described in this report, as available.



Photo 44: Example Location of ROW Bioswale on Barry Drive

Estimated Costs Site 31: The approximate cost for design, permitting, and implementation of this BMP recommendation is anticipated to be between \$50,000- \$100,000 per BMP.



GENERAL RECOMMENDATIONS

Along with the specific practices listed for the Best Management Practices (BMPs) within watersheds of the 11 lakes within the Township that were identified to be evaluated. Princeton Hydro also provides the following general recommendations for implementation throughout the watershed including bank stabilization, riparian zone enhancement, and defined stabilized access points as well as in-lake measures for all applicable locations in the project area.

WATERSHED

BANK STABILIZATION

Bank stabilization measures which reduce bank slopes, and stabilizing areas of exposed soil near bodies of water will aid in the reduction of the nutrient load entering the various ponds. While some areas are specifically defined within the following sites, this recommendation should be broadly applied to any area within these lake systems that would need it.

RIPARIAN ZONE ENHANCEMENT

The riparian zone is characterized as the buffer surrounding the border of a stream, river, and other surface bodies of water, many times where hydrophilic vegetation resides. Sometimes, these locations can have vegetation enhancements to introduce more of this type of aquatic plantings into a specific area. During Princeton Hydro's site visit it was noted that some banks of the ponds, streams, swales, or other conveyances systems contain exposed soil containing little vegetation and/or invasive species. In aquatic settings, vegetation acts as a buffer between the pollutant-rich stormwater and the body of water it surrounds. Eroded and unvegetated banks can be a source of nutrients and sediment into the lake. Additionally, the vegetation on the banks will filter pollutants contained in the stormwater before it enters the water body. Vegetation within a riparian zone should consist of native species and include herbaceous groundcover and trees and shrubs for soil stability. This vegetation can manage sediment and nutrient loads discharging into the lake. Some areas where this can be implemented are listed specifically below however this can be implemented along any segment of bank.

DEFINED AND STABILIZED ACCESS POINTS

Around the lakes there are multiple locations for storing and launching boats including kayaks. Many of these lakes do not have defined launch points and the banks are eroded and vertical which makes continued access difficult and can cause further sediment load to enter the lake. Some of these locations are specifically identified as a part of the sites listed below, however there are other locations that are not specifically identified. Defining a location for boaters to access the water and buffering storage and foot traffic near the bank in all other areas will provide vegetate buffer and start to stabilize the banks. Vegetation can be planted in the non-access area to provide stabilization and to deter the use for access. Pending on the access location, stabilization methodology, and size permits may be required from regulatory agencies.

SEPTIC SYSTEM MANAGEMENT

Generally speaking, it can be assumed that homes within 300' of a lakes shoreline have groundwater-based influence on the lake or tributary. The homes within some of the Townships watersheds are most likely serviced by septic systems (on-lot wastewater treatment systems). Septic management should therefore be implemented to help minimize nutrient loading and protect against septic failures that could result in bacterial inputs. Successful septic management involves the integration of public education, product modification, septic system inspection and maintenance, and water conservation



practices. In addition, it may rely on the use of advanced on-site wastewater renovation/treatment designs to correct failing systems or to dictate the construction of new systems in environmentally sensitive sections of the watersheds.

Product modification usually refers to the use of non-phosphorus or low phosphorus products that minimize septic-related phosphorus loading to the environment. However, it also applies to the use of septic tank chemical additives or the disposal of paint, solvents or left-over household chemicals and cleaning products in septic systems. Public education fliers and brochures advising against such practices are readily available through the NJDEP and regional watershed groups (e.g., Lake Hopatcong Commission). Additional related public information fact sheets of this nature can be obtained through the EPA's Small Flows Clearing House, which specializes in the dissemination of information pertaining to septic systems and other types of on-site waste water treatment systems. Such educational material would prove beneficial in this respect. All residents should be educated about the serious impacts to their septic systems of improperly disposed household chemicals and degreasing agents. These products can cause serious upsets to the biological treatment processes that occur in the septic tank itself and in the soils of the disposal field. Equally important, these products can result in serious groundwater pollution and the contamination of drinking water wells.

Also, the public should be educated concerning the lack of any benefit associated with enzymes, bacteria inoculants, or other products advertised as septic tank supplements. Such information should be made available through the Township to residents. As demonstrated by the EPA (USEPA, 1997), these products do very little to enhance septic system operation. They also give a false sense of maintenance to the property owner and may actually dissuade them from regularly pumping or inspecting their system. Also, residents should be cautioned about the use of garbage disposal units/grinders. Excessive or improper use of these devices can increase organic loading and further stresses the system's operation by adding to both the sludge and grease layers. Furthermore, once ground up, the disposed solids can be converted into fine particulate material that resists settling. This can decrease the operational efficiency of a septic system and accelerate the clogging of the leach field.

Inspections and routine maintenance are usually the two controversial elements of most septic management programs. There is an innate resistance by homeowners to allow periodic inspections or to comply with a mandatory pump out schedules. Basically, the prevailing thought among most homeowners is "if it flushes, it's OK". However, as has been demonstrated in studies conducted as part of nationwide septic management studies, routine inspections help decrease the occurrence of large scale failures by identifying the more easily corrected, less costly problems early on (NYSDEC, 1994). Similarly, routine pump outs decrease the buildup of sludge and grease in the septic tank itself, both of which can be transported into the leach field and create clogging problems. In general, the inspections and pump outs should be viewed as an insurance policy for the long-term proper operation of the septic system and not an imposition of the property rights of a homeowner. It should be noted that for older tanks, there may be some liability associated with their pump out. For example old metal tanks that have become corroded or hand built cesspools can collapse once the liquid and sludge has been removed.

Water conservation measures are intended to reduce hydrologic loading to the leach field. Included in this category are the use of low flush toilets, flow reduction fixtures and other similar devices designed



to reduce water usage. It can also encompass lifestyle habits such as spreading out laundry wash loads over a number of days, shorter showers, and other similar cooperative techniques.

PET WASTE MANAGEMENT

Another localized source of nutrients that can be easily controlled is that of pet waste. In addition to providing an ample source of phosphorus, these wastes are unsightly and may cause health concerns due to high fecal coliform bacteria concentrations in storm water runoff coming into contact with waste sources. Reduction of pet waste as a nutrient source can be obtained through the implementation of and the enforcement of an ordinance requiring the retrieval of pet wastes and through the pet owner's compliance. As stated previously, these ordinances can be difficult to police and enforce. However, this type of ordinance should be easily accomplished and enforced in the County and Township owned parks located in the headwater areas of each watershed.

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.

As part of the ongoing strategy to reduce the influx of lawn related pollutants into Chesapeake Bay, the National Park Service has started to use native ground covers to reduce the need for fertilization and irrigation (NPS News-Notes, 1996). Similar types of low maintenance vegetative cover have been promoted by NJDEP (NJDEP, 2004) and the Metropolitan Council of Governments (Schueler, 1987) as part of an overall strategy of reducing NPS loading.

Minimizing disturbance and utilizing natural landscaping are preventative pollutant load management techniques. When properly implemented these techniques can eliminate the need for the repeated fertilization of lawns, decrease the rate or frequency of pesticide applications and decrease irrigation requirements.

The pathway to implementation is through a successful public education program that demonstrates the advantages of implementing natural landscaping into the residential developments in the watershed. In the existing developments lawn areas can be easily retrofitted with natural landscaping features. Areas of the watershed located in the Township's watershed consist of residential development which contains little to no storm water management measures. Such measures should especially be promoted at transition points and along riparian zone corridors, especially along the main tributaries.

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. The Hudson-Essex-Passaic County Soil Conservation District, possibly in



conjunction with the local Township's environmental commissions or other interested parties could also develop a backyard habitat program and provide hands on demonstration and other information on monthly basis during the growing season. Often the impediment for homeowner buy in is a lack of understanding of what natural landscaping techniques look like and how they function. The most effective mechanisms to overcome this obstacle are demonstration projects. The Township should implement similar techniques on public property to demonstrate that these features are aesthetically pleasing, economically feasible, and have low maintenance requirements as compared with typical turf lawn cover. Funding for these types of projects may be available from the Natural Resource Conservation Service (NRCS) or the US Fish and Wildlife Service (USFWS). They also usually require a voluntary agreement or contract between the funding agency and the partner for long-term maintenance. Most of these projects also are cost-share and have a funding ratio of 75% grant and 25% match. For qualifying projects the NRCS and/or USFWS will provide expert technical assistance directly to both private and public landowners.

FERTILIZER MANAGEMENT

It should be noted that the New Jersey legislature has passed new rules regulating fertilizer composition and usage. More information of this law, which went into effect in January 2010, can be obtained by downloading copies of the bill (S-2554/A-2290). The most significant feature of the law is that it bans phosphorus from over the counter fertilizers (the types of products sold at most big box retail stores). The legislation also limits the amount of nitrogen (0.7 lbs/1,000 ft²) in the fertilizer and specifies that at least 20% of the nitrogen must be in a time release formula. The legislation also restricts the timing of fertilizer application (no fertilizer applications between November 15 and March 1). Although the passage of this legislation may have significantly reduced fertilizer related loading to lakes, the Township should continue promote the voluntary measures discussed below.

The primary developed land use in most watersheds of New Jersey 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 Township 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 Township 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.



IN-LAKE

AERATION

Aeration is an in-lake management technique used to convert an anoxic (anaerobic) environment into an oxic (aerobic) environment. The main purpose of an aeration systems is to preclude the internal release of phosphorus from the anoxic bottom sediment of a lake that often occurs during periods of thermal stratification. There are various aeration techniques that can be used to positively affect dissolved oxygen concentrations. Some techniques manage oxygen levels throughout the entire water column while others focus on the management of oxygen within a limited, defined portion of the water column. The two commonly used aeration techniques include destratification systems and hypolimnetic aeration systems. Due to the relatively shallow nature of the study lakes throughout Rockaway Township and the fact that they do not support cold-water fisheries, a destratification system would likely be the best aeration technique.

With a destratification system, compressed air is used to vertically circulate the entire water column in a manner that prevents thermal stratification from becoming established or from persisting. This essentially results in relatively uniform, surface to bottom, water column temperatures. Because water temperatures are essentially uniform, there are minimal density differences throughout the water column. Without the presence of any thermal gradients preventing mixing, the entire vertical water column can be easily circulated. It is the exposure of the water to the atmosphere that results in full water-column reoxygenation rather than directly from the compressed air.

When properly designed and operated, destratification can be accomplished by the placement of a limited number of compressed air diffusers in the deeper portion of the subject lake. Aeration systems are generally operated from April through September when they should run 24/7. The cost for the purchase and installation of an aeration system is dependent on the number of diffusers and the location of the onshore compressors, as the rubber tubing is typically the most expensive component. Once installed, maintenance is relatively simple and involves changing the air filter a couple of times per year and compressor maintenance every few years. After installation, annual costs include the utility bill to run the compressors during the growing season.

BIOCHAR

Biochar is a processed wood material that has a high affinity to adsorb a variety of pollutants. There is currently a strong interest in using biochar to remove phosphorus from water since it tends to be the primary limiting nutrient for freshwater algae. Specifically, elevated phosphorus concentrations not only increase algae biomass, but also favor cyanobacteria, the algal group that has the potential to produce cyanotoxins and other compounds that may impact the health of humans, pets, and livestock.

This material can be placed into flotation balls, sausages, or cages and tethered along a beach area swimming line, where an inlet enters the lake, or within streams themselves. Biochar set out in lakes and ponds, including stormwater ponds. It has been shown to remove dissolved phosphorus directly out of the nearshore waters, contributing toward limiting algal growth. Biochar set in streams will intercept these nutrients as the water passes through. Additionally, the relatively low cost of the Biochar and its re-use as a form of mulch make it a particularly attractive means of contributing toward the removal of in-lake phosphorus. Biochar strategically placed in lakes offers the opportunity to remove internally released phosphorus from the system, further complimenting the watershed management measures that reduces nutrient loads closer to the source. As such, biochar can remove legacy phosphorus and other nutrients that have built up in the sediments over time from the system completely, especially if the biochar is removed and replaced throughout the season.

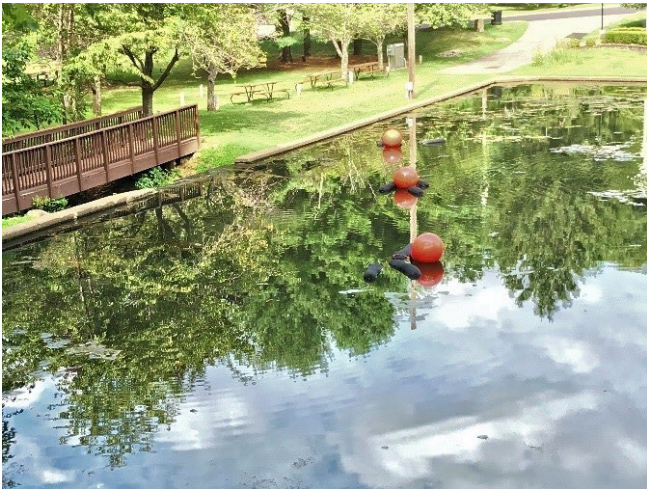


Photo 45-46: Examples of biochar being used in ponds (left) and streams (right).

DREDGING

Dredging is an effective, but expensive, lake management technique. Dredging involves the removal of accumulated unconsolidated sediments from the bottom of a lake. A dredging feasibility study is required to determine what contaminants, if any, are present in the sediment as well as to determine the cost-effectiveness of such an operation. Dredging feasibility studies include, at a minimum, an updated bathymetric assessment and sediment sampling.

Dredging has multiple benefits, including deepening, nutrient control (removal), toxic substance removal, and rooted macrophyte control. All these benefits, except for toxic substance removal, would improve the quality of most of these study lakes. Sediment removal directly results in the deepening of a lake and provides nutrient control through the removal of phosphorus-rich sediment, which can otherwise cause internal phosphorus loading in lakes that stratify and become anoxic in the deeper water during the summer months. Sediment removal also results in the direct removal of plant matter as well as viable substrate for plant growth. Dredging costs vary greatly based on several factors, including the amount of proposed dredged material, what contaminants are present, and which type of dredging (mechanical, hydraulic, etc.) is applicable.

FLOATING WETLAND ISLANDS

Floating wetland islands (FWIs) are constructed of recycled plastic material, are typically planted with native, water loving vegetation and then anchored to the lake bottom. Functionally, these units have been utilized to slow inflow and precipitate sediments. Furthermore, the high surface area of the constructed wetland material and root mass of planted vegetation serve as habitat for bacteria which assimilate and process phosphorus and nitrogen. Nitrogen uptake also occurs via direct assimilation from the plants.

The manufacturer of the FWIs typically collects information prior to manufacturing in order to design an area and material density which is optimized for the intention of the installer. These islands can be installed alone, or for more effectiveness, be utilized in conjunction with emergent vegetation or other shoreline restoration methods described in this report.

INVASIVE SPECIES MANAGEMENT

Invasive Species management is a broad term but in this report is generally referred to as invasive plant management. Common aquatic invasive plants, such as curlyleaf pondweed (*Potamogeton crispus*), Eurasian



watermilfoil (*Myriophyllum spicatum*), brittle naiad (*Najas minor*), and *Phragmites* sp., among others, outcompete native species. Due to a lack of native predators, these invasive species often grow to nuisance densities which can impede recreation and completely displace native species from the local ecosystem. At excessive densities, invasive submerged aquatic vegetation (SAV) can act as a source of nutrients to the lake when the plants senesce.

The two most common forms of invasive plant management include herbicide applications and mechanical harvesting. The best invasive plant management programs are adaptive and involve early inspection, rapid action and a collaborative approach. A good control program is designed to control excessive nuisance plant growth but not eliminate native plant populations. Aquatic plants are part of a healthy, balanced lake ecosystem that provide nutrient uptake, as well as food and habitat for insects and fish. Additionally, native shoreline and riparian vegetation stabilizes the soil and reduces the rate of shoreline and streambank erosion.



9. REFERENCES

- Carlson, R.E. 1977. A trophic state index for lakes. *Limnol. Oceanogr.* 22:361-369.
- Carlson, R.E., and K.E. Havens. 2005. Simple Graphical Methods for the Interpretation of Relationships Between Trophic State Variables. *Lake and Reservoir Management*, 21:1, 107-118.
- Center for Watershed Protection. 2003, Pollution Source Control Practices, Version 1.0, Center for Watershed Protection Manual 8.
- Center for Watershed Protection, Anne Kitchell and Tom Schueler, February 2005, Unified Stream Assessment: A User's Manual 10, Version 2, Ellicott City, MD
- Center for Watershed Protection. 2008, Municipal Pollution Prevention/Good Housekeeping Practices, Version 1.0, Center for Watershed Protection Manual 9.
- Cooke, G.D., E.B. Welch, S.A. Peterson and P.R. Newroth. 1993. Restoration and Management of Lakes and Reservoirs. 2nd Edition. CRC Press LLC. Boca Raton, Florida.
- Clayton, Jr. 1995. Storm water Retrofits - A tool for Watershed Enhancement. *Watershed Protection Techniques*. 1(4): 188-191.
- Daniel, W.W. 1990. Applied Non-Parametric Statistics, 2nd Edition. PWS-KENT Publishing Company. Boston, Mass.
- Dennis, J., J. Noel, D. Miller, and C. Eliot. 1989. Phosphorus Control in Lake Watersheds. A Technical Guide to Evaluating New Development. Maine Dept. of Environmental Protection.
- Dillon, P.J., and F.H. Rigler. 1975. A simple method for predicting the capacity of a lake for development based on lake trophic status. *Journal of the Fisheries Research Board of Canada*, 32: 1519-1531.
- Emerson, C.H., Welty, C., Traver, R.G., "A Watershed-Scale Evaluation of a System of Storm water Detention Basins" *ASCE Journal of Hydrologic Engineering*, Vol. 10, No. 3, pgs. 237-242 May/June 2005.
- ESRI. *ArcMap – ArcGIS Desktop v10.8.1*.
- Evans, B.M., S.A. Sheeder, D.W. Lehning, (2003) A spatial technique for estimating streambank erosion based on watershed characteristics. *J. Spatial Hydrology* 3(2).
- Evans, B.M., D.W. Lehning, K.J. Corradini, G.W. Petersen, E. Nizeyimana, J.M. Hamlett, P.D. Robillard, R.L. Day, (2002) A comprehensive GIS-based modelling approach for predicting nutrient loads in watersheds. *J. Spatial Hydrology* 2(2).
- Evans, B.M., Corradini, K.J. (2006) *AVGWLF Version 7.2 A Guide to Creating Software-Compatible Data Sets (Revised August 2008)*, Penn State Institutes of Energy and the Environment, The Pennsylvania State University
- Evans, B.M., D.W. Lehning, K.J. Corradini (2008) *AVGWLF Version 7.1 Users Guide*, Penn State Institutes of Energy and the Environment, The Pennsylvania State University.
- Goan, P., and R. Runyon. Lake Water Quality Assessment Report – Lake Ames, Rockaway Township, Morris County. New Jersey Department of Environmental Protection, Division of Water Resources.



Goan, P., and R. Runyon. Lake Water Quality Assessment Report – Mount Hope Pond, Rockaway Township, Morris County. New Jersey Department of Environmental Protection, Division of Water Resources.

James, W. F. and J. W. Barko. 2000. Sediment resuspension dynamics in canopy-forming and meadow-forming submerged macrophyte communities. US Army Corps of Engineers, Aquatic Plant Research Program.

Kirchner, W.B., and P.J. Dillon. 1975. An empirical method of estimating the retention of phosphorus in lake. *Water Resources Research*, 11(1), 182-183.

Lamarra, V.A. Jr. 1975. Digestive activities of carp as a major contributor to the nutrient loading of lakes. *Internationale Vereinigung für theoretische und angewandte Limnologie: Verhandlungen*, 19:3, 2461-2468.

Lubnow, F.S. and S.J. Souza. 1999. The General Ecology and Management of a Shallow, Polymictic Lake in Northern New Jersey. 19th International Symposium of the North American Lake Management Society. November, 1999, Reno, Nevada.

Lubnow, F., S.J. Souza and G.C Holdren. 1994. The use of biological interactions in developing a lake management program. *Lake and Reservoir Management* Vol. 9, No. 2, 93 p.

Madden, J.D., et. al. 2001. The interaction between water movement, sediment dynamics and submersed macrophytes. *Hydrobiologia* 444: 71-84.

Maidment, D.R. 1993. *Handbook of Hydrology*. McGraw-Hill, Inc. New York, NY.

NALMS. 2010. *Lake and Reservoir Manual*. Terrene Institute.

New Jersey Department of Environmental Protection, Division of Watershed Management. April, 2008. Amendment to the Northeast, Upper Raritan, Sussex County and Upper Delaware Water Quality Management Plans – Total Maximum Daily Load Report for the Non-Tidal Passaic River Basin Addressing Phosphorus Impairments. Trenton, New Jersey.

New Jersey Department of Environmental Protection, Division of Watershed Management. October 2009. Amendment to the Northeast Water Quality Management Plan and Sussex County Water Quality Management Plan – Total Maximum Daily Loads for Pathogens to Address 25 Lakes in the Northeast Water Region. Trenton, New Jersey.

New Jersey Department of Environmental Protection, Division of Water Monitoring and Standards. Surface Water Quality Standards. N.J.A.C. 7:9B

New Jersey Department of Environmental Protection, Division of Water Monitoring and Standards. Water Quality Data Exchange System.

New Jersey Department of Environmental Protection (NJDEP) (2006) New Jersey Integrated Water Quality Monitoring and Assessment Report. Water Monitoring and Standards. Trenton, New Jersey.

New Jersey Department of Environmental Protection (NJDEP) (2008) NJDEP Digital Data Downloads, Bureau of Geographic Information Systems. <http://www.state.nj.us/dep/gis/>, accessed June 2008.



New Jersey Department of Environmental Protection (NJDEP) (2006) New Jersey Integrated Water Quality Monitoring and Assessment Report. Water Monitoring and Standards. Trenton, New Jersey.

New Jersey Department of Environmental Protection (NJDEP) (2007) Flood Hazard Area Control Regulations (N.J.A.C.7:13)

New Jersey Department of Environmental Protection (NJDEP) (2008) Wildlife Species of Special Concern in New Jersey. <http://www.state.nj.us/dep/fgw//spclsp.htm>.

New Jersey Department of Environmental Protection (NJDEP). March 2022. Classification Exemption Areas-Well Restriction Areas for New Jersey, Edition 20220301 (Envr_mon_gw_CEA)(Web Mercator ArcGIS Online Service)(Spatial Data) <https://njdep.maps.arcgis.com/home/item.html?id=bfd549e193a947e9923492da13c24e4b>.

New Jersey Division of Fish and Wildlife. Rockaway Park Lake (Bathymetric Survey Map).

New Jersey Geological Survey (NJGS) (1993) Geological Survey Report GSR-32, A Method for Evaluating Ground Water Recharge Areas in New Jersey.

Natural Resource Conservation Service (NRCS) (1998) Soil Quality Information Sheet, Available Water Capacity, January 1998.

Natural Resource Conservation Service (NRCS) (2008) Web Soil Survey, <http://websoilsurvey.nrcs.usda.gov/>, accessed June 2008.

Natural Resource Conservation Service (NRCS) (2010) Soil Survey Geographic (SSURGO) Database, <http://soils.usda.gov/survey/geography/ssurgo/>.

Natural Resource Conservation Service (NRCS) (2010) Key to Glaucconitic Soils in Coastal Plains of New Jersey, <http://websoilsurvey.nrcs.usda.gov/>.

NYSDEC. 2005. A Primer on Aquatic Plant Management in New York State.

Nurnberg, G.K. 1996. Trophic state of clear and colored, soft- and hardwater lakes with special consideration of nutrients, anoxia, phytoplankton and fish. *Lake and Reservoir Management* 12: 432-447

Nurnberg, G.K. 1985. Availability of phosphorus upwelling from iron-rich anoxic hypolimnion. *Arch Hydrobiologia* 104:459-476.

Princeton Hydro, LLC. Green Pond 2008 Lake Management and Total Maximum Daily Load (TMDL) Report. July 2008.

Princeton Hydro, LLC. Green Pond 2021 Water Quality Monitoring Report. December 2021.

Princeton Hydro, LLC. White Meadow Lake 2021 Lake Management Report. December 2021.

QGIS v3.22.2-Białowieża.

Reckhow, K. H., M. N. Beaulac, and J. T. Simpson. 1980. Modeling phosphorus loading and lake response under uncertainty: A manual and compilation of export coefficients. Report No. EPA-440/5-80-011. U. S. EPA, Washington, D.C.



Reckhow, K.H. 1988. Empirical Models for trophic state in Southeastern US Lakes and Reservoirs. JAWRA Journal of the American Water Resources Association, 24(4):723-734.

Rockaway Township, New Jersey. Egberts Lake Park. <https://www.rockawaytownship.org/Facilities/Facility/Details/Egberts-Lake-Park-6>

Schueler, T. 1996. Urban Watershed BMPs: A workshop on innovative watershed restoration and protection techniques. The Center for Watershed Protection and The Engineering Society of Baltimore, Inc. Baltimore, Maryland.

Souza, S.J., F.S. Lubnow and C. Borek. 2000. Integration of SAV control and nutrient limitation techniques for the successful management of blue green algae blooms at White Meadow Lake, Rockaway, NJ. 20th International Symposium of the North American Lake Management Society. November, Miami, Fla.

Souza, S.J., F. S. Lubnow, and J.P. Bell. 1998. Use of GIS to identify and prioritize Phase II watershed management restoration projects for the Lake Hopatcong and Lake Musconetcong watershed, New Jersey. 18th International Symposium of the North American Lake Management Society. November, 1998, Banff, Alberta, Canada.

Souza, S.J. 1998. Pond Ecology. Course Session, Pond Dredging, Maintenance and the Natural Landscape. Office of Continuing Education, Cook College, Rutgers University. May, 1998

Souza, S.J., F.S. Lubnow, and R.L. Conner. 1994. An innovative use of alum to control blue-green algae blooms in Lake Mohawk New Jersey. Proceedings Abstracts: North American Lake Management Society, Vol. 9(2).

Souza, S.J., J.D. Koppen, and R. Conner. 1987. Aquatic SAV harvesting: A cost effective means of improving the recreational, aesthetic and water quality conditions of Lake Hopatcong. Seventh Annual International Symposium, North American Lake Management Society. Orlando, Florida.

Souza, S. J. and P. A. Perry. 1977. Land and Recreational Development at New Jersey Green Ponds. Water Resources Research Institute. Technical Publication A-043-NJ. Rutgers University, New Brunswick, NJ.

USEPA. 2002. Onsite Wastewater Treatment Systems Manual. Office of Water, Office of Research and Development. Washington, D.C. EPA/625/R-00/008.

U.S. EPA. 1990. Lake and Reservoir Restoration Guidance Manual. 2nd Edition. Report No. EPA 440/4-90-006. U.S.EPA, Washington, D.C.

USEPA. 1997. Compendium of Tools for Watershed Assessment and TMDL Development. EPA841-B-97-006. Washington D.C.

United States Environmental Protection Agency (USEPA) (2005) "Handbook for Developing Watershed Plans to Restore and Protect Our Water" EPA 841-B-08-002

United States Geological Survey. *StreamsStats* v4.7.0. <https://streamstats.usgs.gov/ss/>

Uttormark, P.E., J.D. Chapin, and K.M. Green. 1974. Estimating nutrient loading of lakes from nonpoint sources. Report No. EPA-660/3-74-020, U.S. EPA., Corvallis, OR.



Vollenweider, R.A. 1975. Input-Output Models, with Special Reference to the Phosphorus Loading Concept in Limnology. *Schweiz. Z. Hydrologie*, 37:53-84.

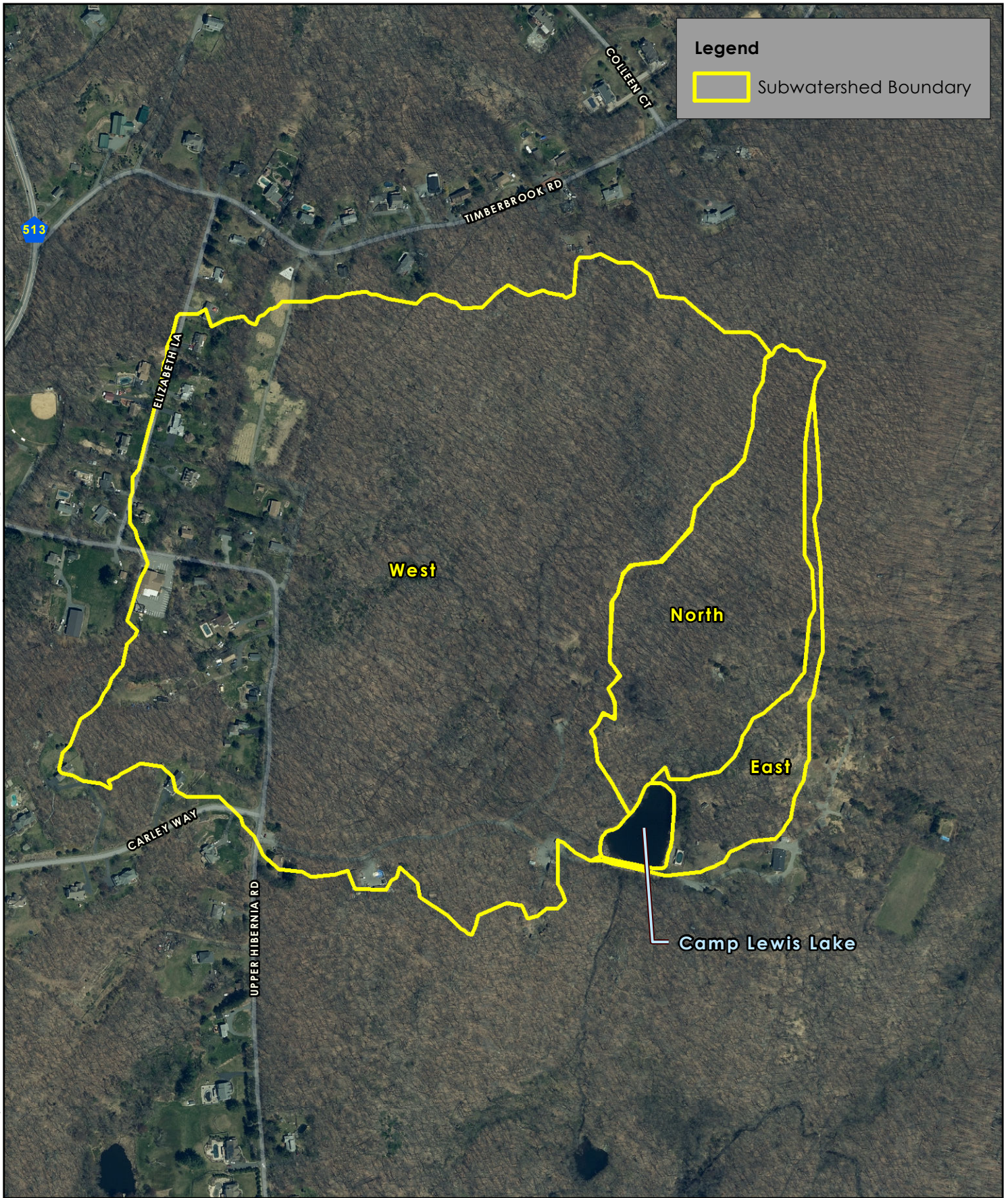
Walker, W.W. 1977. Some Analytical Methods Applied to Lake Water Quality Problems. Ph.D. dissertation, Harvard University.

Wanielista, M.P., Y.A. Youseff, and J.S. Taylor. 1982. Storm water Management to Improve Lake Water Quality. Report No. EPA-600/52-82-048, U.S. EPA, Municipal Env. Res. Lab., Cincinnati, OH.

Wetzel, R.G. 1983. *Limnology* 2nd Edition. W.B. Saunders Co., Philadelphia, PA.

APPENDIX I:
WATERSHED MAPS

File: P:\0883\Projects\0883007\GIS\MXD\Subwatershed_Maps\Camp_Lewis_Subwatershed.mxd, 2/22/2022, Drawn by bsmith, Copyright Princeton Hydro, LLC.



NOTES:
 1. Subwatersheds were delineated by Princeton Hydro using Model My Watershed: modelmywatershed.org
 2. 2020 orthoimagery obtained from NJ Office of Information Technology (NJ OIT), Office of Geographic Information Systems (OGIS).

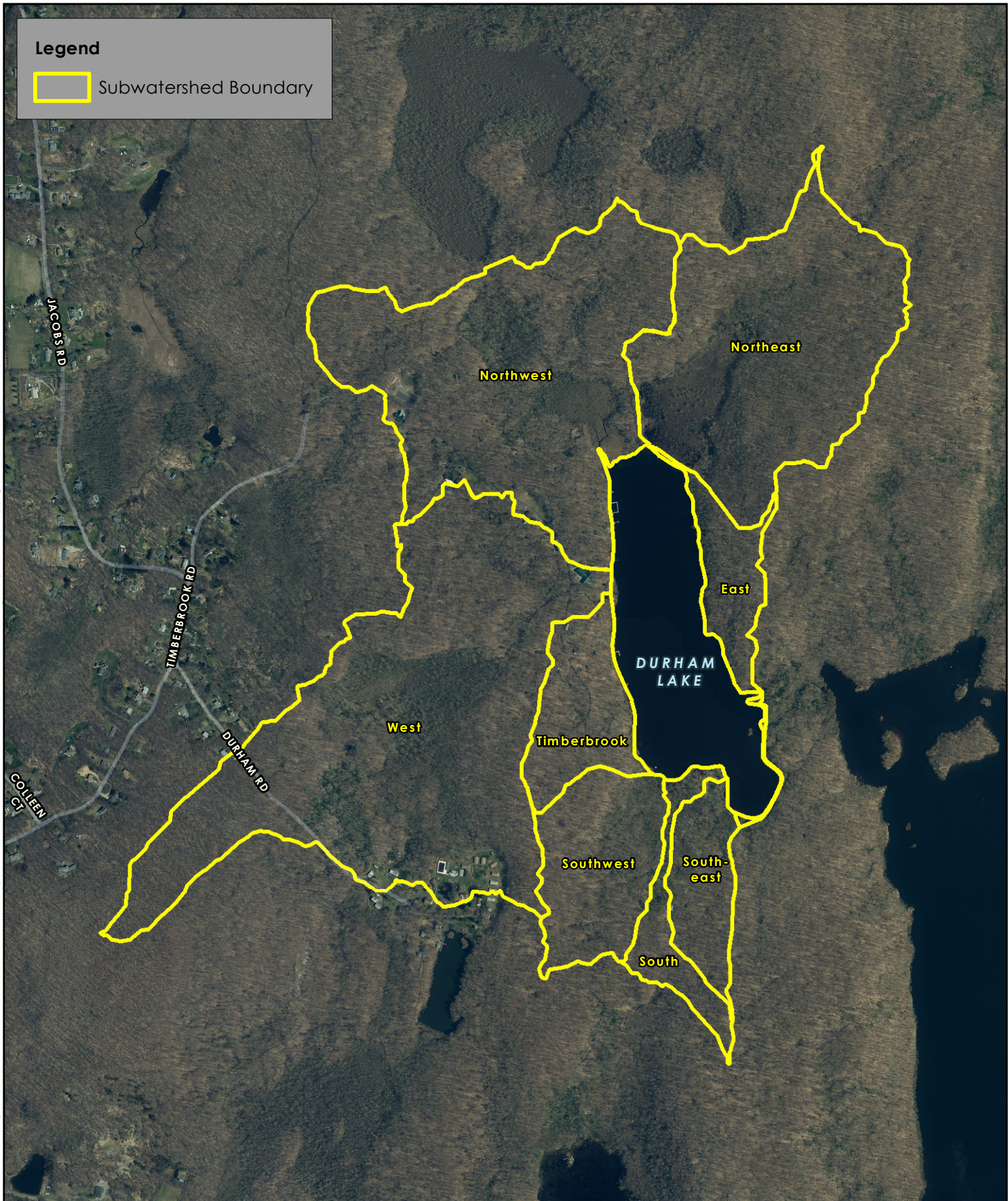
CAMP LEWIS LAKE SUBWATERSHEDS

WATERSHED IMPLEMENTATION PLAN
 ROCKAWAY TOWNSHIP
 MORRIS COUNTY, NEW JERSEY



Map Projection: NAD 1983 StatePlane New Jersey FIPS 2900 Feet

File: P:\08883\Projects\08883007\GIS\MXD\Subwatershed_Maps\Durham_Lake_Subwatershed.mxd, 2/22/2022, Drawn by bsmifh, Copyright Princeton Hydro, LLC.



NOTES:
 1. Subwatersheds were delineated by Princeton Hydro using Model My Watershed: modelmywatershed.org
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Map Projection: NAD 1983 StatePlane New Jersey FIPS 2900 Feet

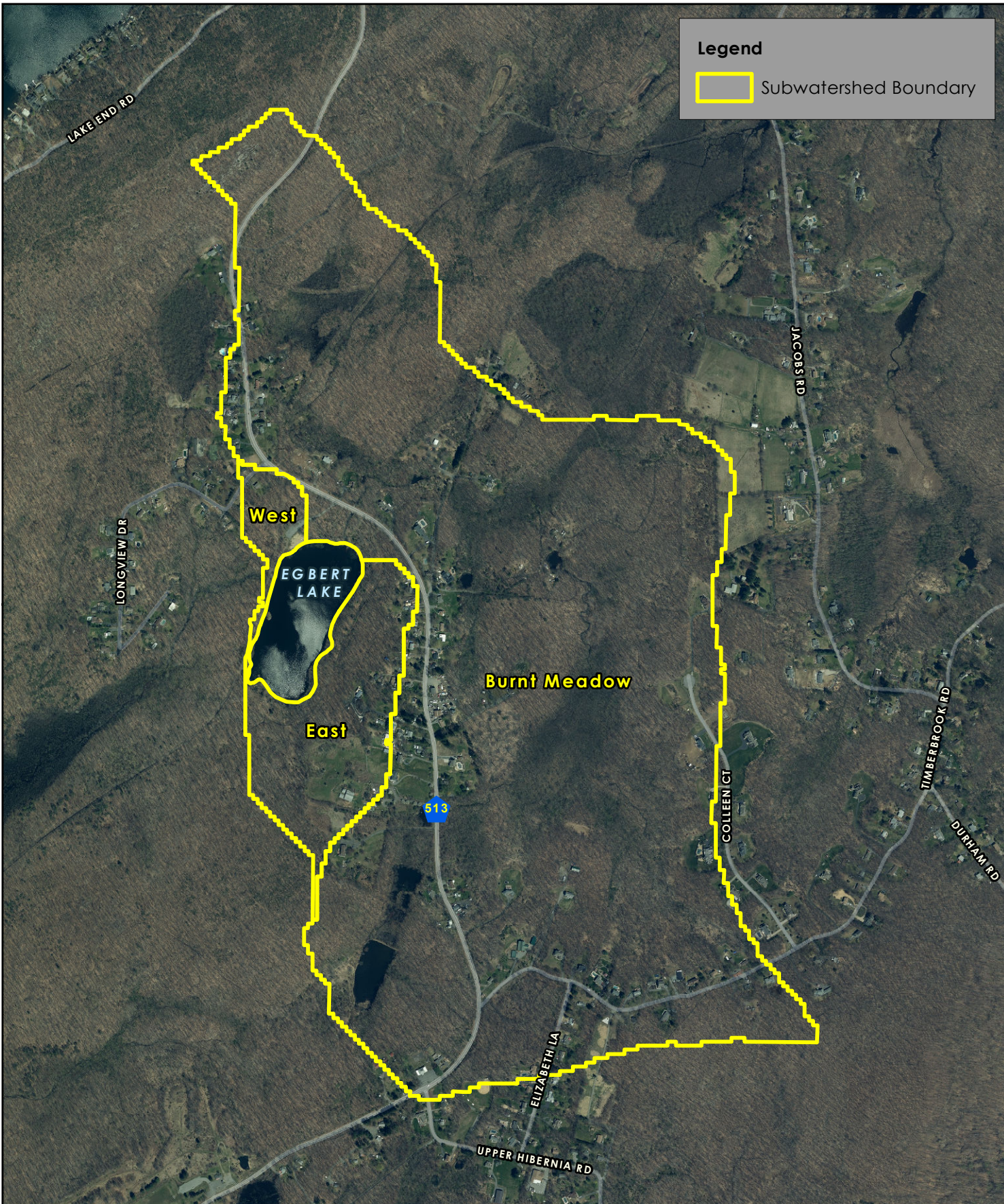
DURHAM LAKE SUBWATERSHEDS

WATERSHED IMPLEMENTATION PLAN
 ROCKAWAY TOWNSHIP
 MORRIS COUNTY, NEW JERSEY



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File: P:\08883\Projects\08883007\GIS\MXD\Subwatershed_Maps\Egbert_Lake_Subwatershed.mxd, 2/22/2022, Drawn by bsmith, Copyright Princeton Hydro, LLC.



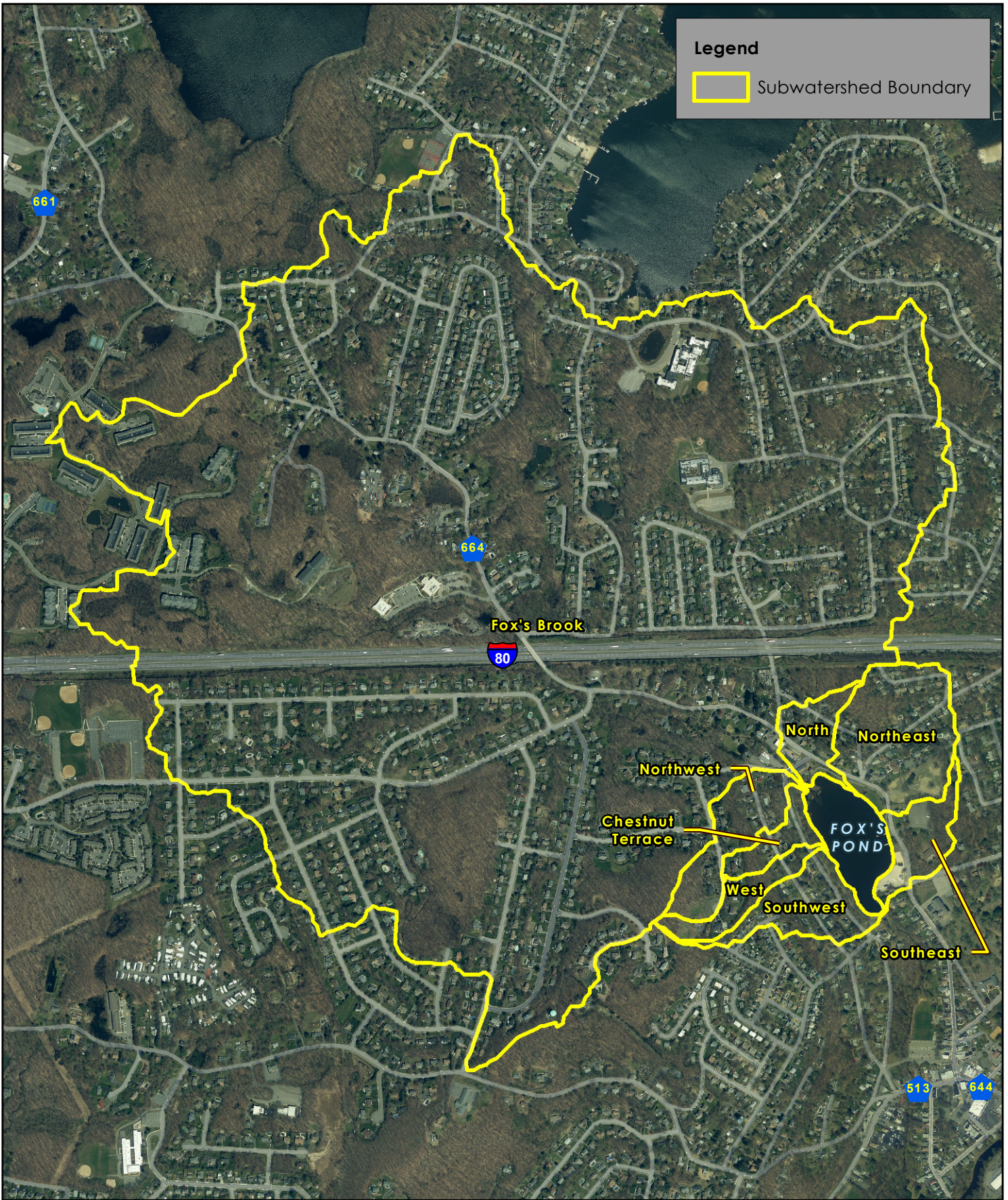
NOTES:
 1. Subwatersheds were delineated by Princeton Hydro using Model My Watershed: modelmywatershed.org
 2. 2020 orthoimagery obtained from NJ Office of Information Technology (NJ OIT), Office of Geographic Information Systems (OGIS).



EGBERT LAKE
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File: P:\08833\Projects\08833007\GIS\MXD\Subwatershed_Maps\Foxs_Pond_Subwatershed.mxd, 2/24/2022, Drawn by bsmith, Copyright Princeton Hydro, LLC.



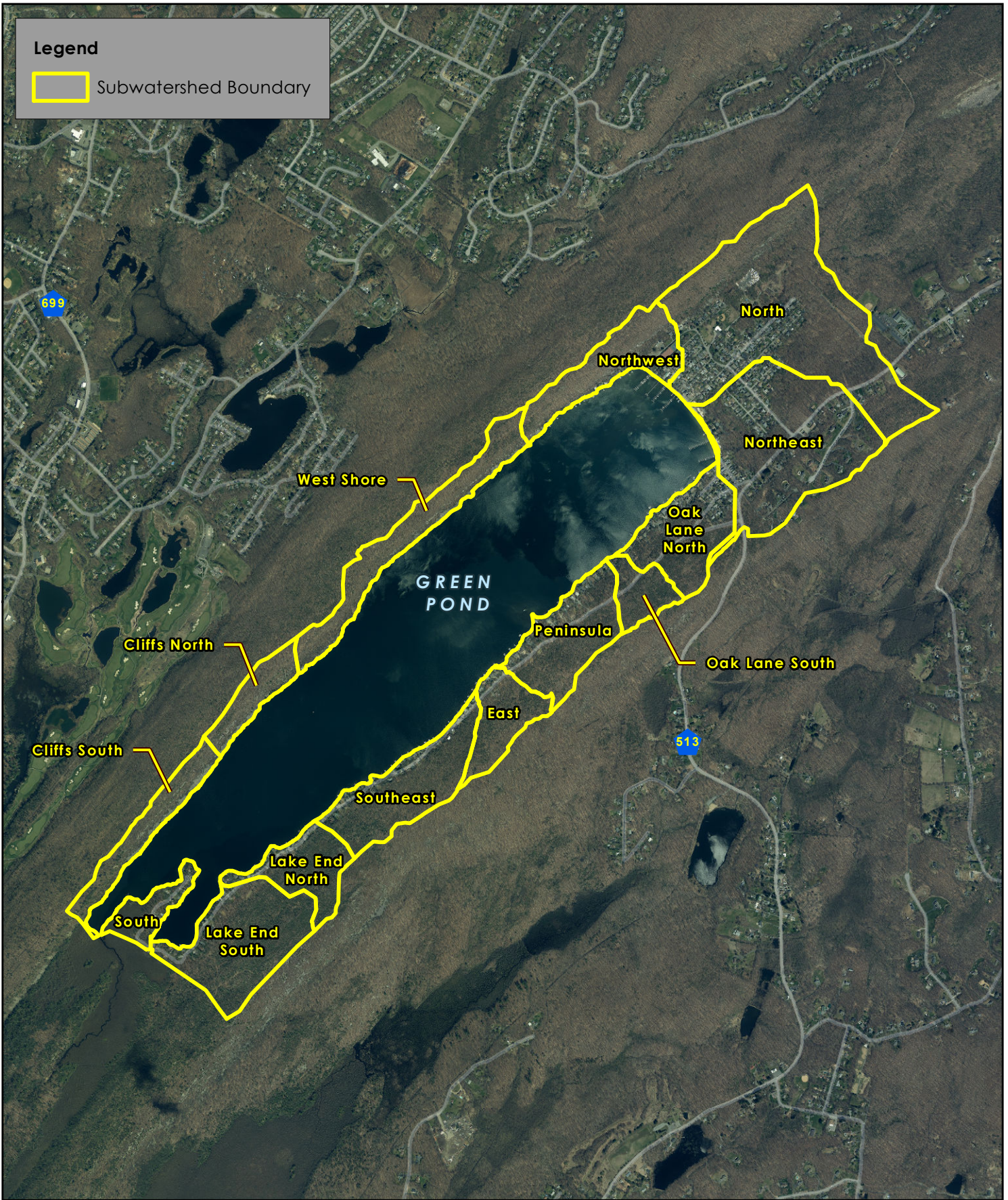
NOTES:
 1. Subwatersheds were delineated by Princeton Hydro using Model My Watershed: modelmywatershed.org
 2. 2020 orthoimagery obtained from NJ Office of Information Technology (NJ OIT), Office of Geographic Information Systems (OGIS).

0 550 1,100 Feet
 Map Projection: NAD 1983 StatePlane New Jersey FIPS 2900 Feet

FOX'S POND
SUBWATERSHEDS
 WATERSHED IMPLEMENTATION PLAN
 ROCKAWAY TOWNSHIP
 MORRIS COUNTY, NEW JERSEY

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File: P:\08883\Projects\0883007\GIS\MXD\Subwatershed_Maps\Green_Pond_Subwatershed.mxd, 2/16/2022, Drawn by bsmith, Copyright Princeton Hydro, LLC.



Legend

Subwatershed Boundary

NOTES:
 1. Subwatersheds were delineated by Princeton Hydro using Model My Watershed: modelmywatershed.org
 2. 2020 orthoimagery obtained from NJ Office of Information Technology (NJGIT), Office of Geographic Information Systems (OGIS).

 0 1,000 2,000 Feet

Map Projection: NAD 1983 StatePlane New Jersey FIPS 2900 Feet

GREEN POND SUBWATERSHEDS

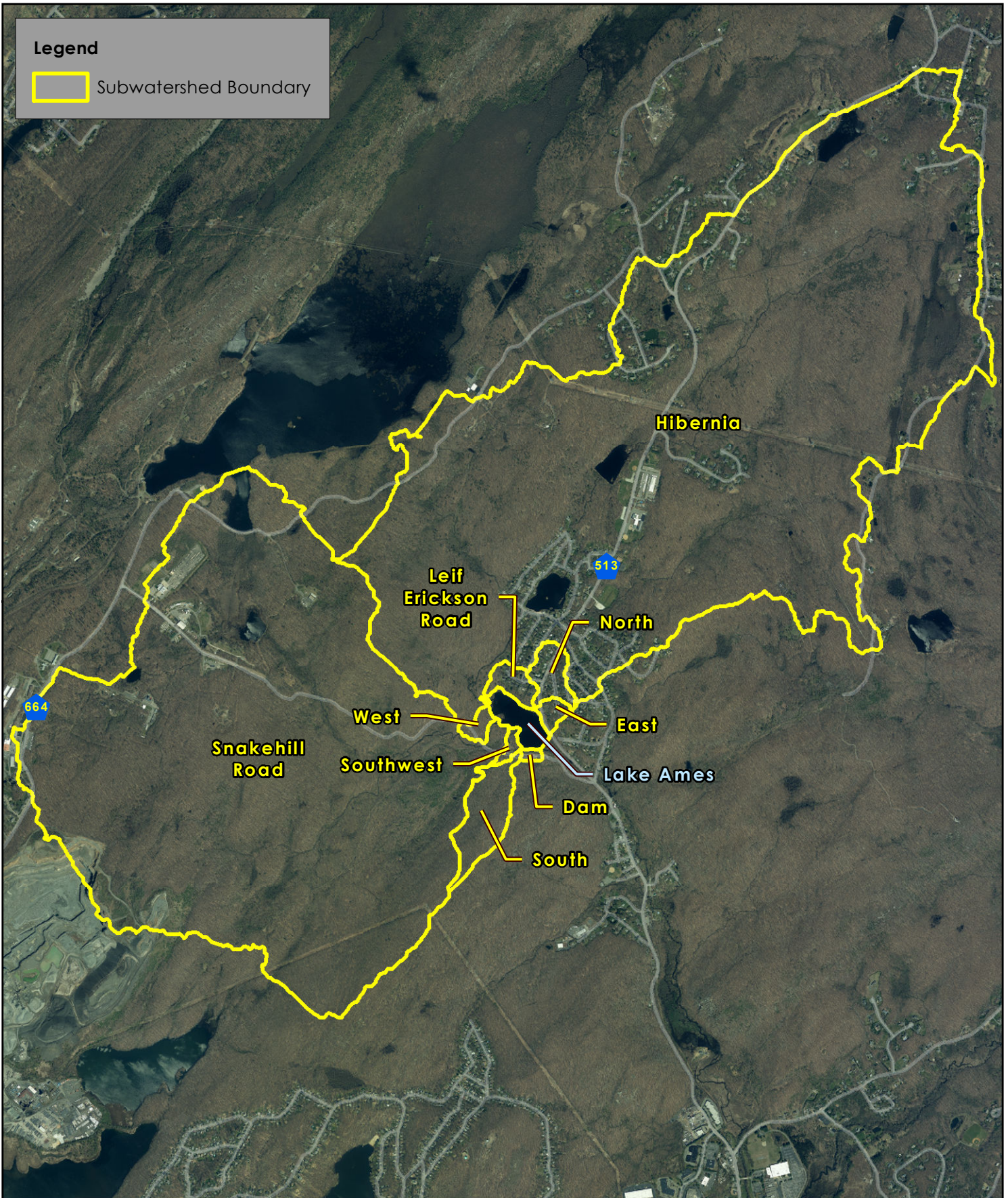
WATERSHED IMPLEMENTATION PLAN
ROCKAWAY TOWNSHIP
MORRIS COUNTY, NEW JERSEY




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File: P:\08883\Projects\08883007\GIS\MXD\Subwatershed_Maps\Lake_Ames_Subwatershed.mxd, 2/22/2022, Drawn by bsmith, Copyright Princeton Hydro, LLC.



Legend

 Subwatershed Boundary

- NOTES:
1. Subwatersheds were delineated by Princeton Hydro using Model My Watershed: modelmywatershed.org
 2. 2020 orthoimagery obtained from NJ Office of Information Technology (NJ OIT), Office of Geographic Information Systems (OGIS).

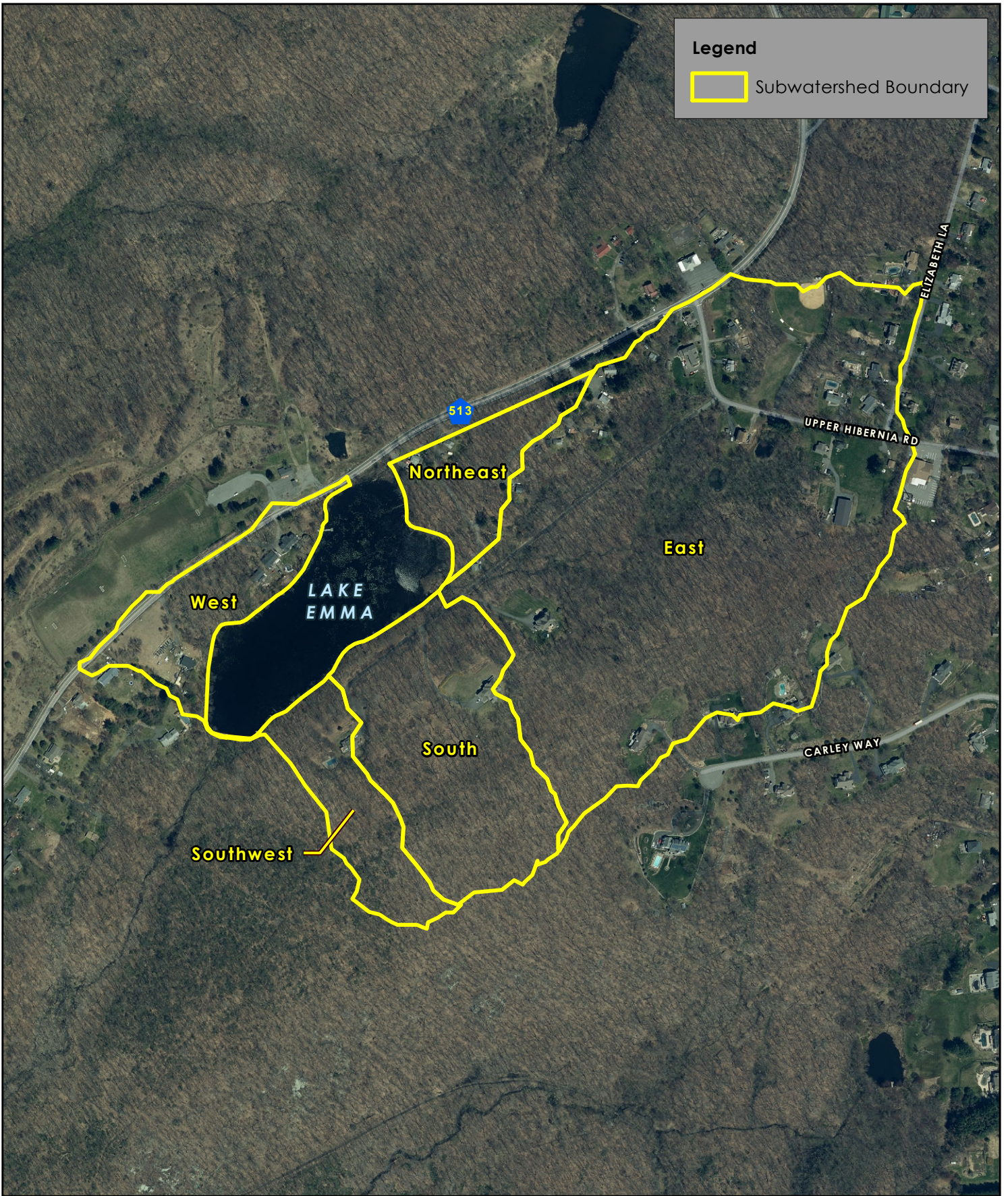
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Map Projection: NAD 1983 StatePlane New Jersey FIPS 2900 Feet

LAKE AMES
SUBWATERSHEDS
 WATERSHED IMPLEMENTATION PLAN
 ROCKAWAY TOWNSHIP
 MORRIS COUNTY, NEW JERSEY

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File: P:\08883\Projects\0883007\GIS\MXD\Subwatershed_Maps\Lake_Emma_Subwatershed.mxd, 2/22/2022, Drawn by bsmifh, Copyright Princeton Hydro, LLC.



Legend

Subwatershed Boundary

NOTES:
 1. Subwatersheds were delineated by Princeton Hydro using Model My Watershed: modelmywatershed.org
 2. 2020 orthoimagery obtained from NJ Office of Information Technology (NJ OIT), Office of Geographic Information Systems (OGIS).




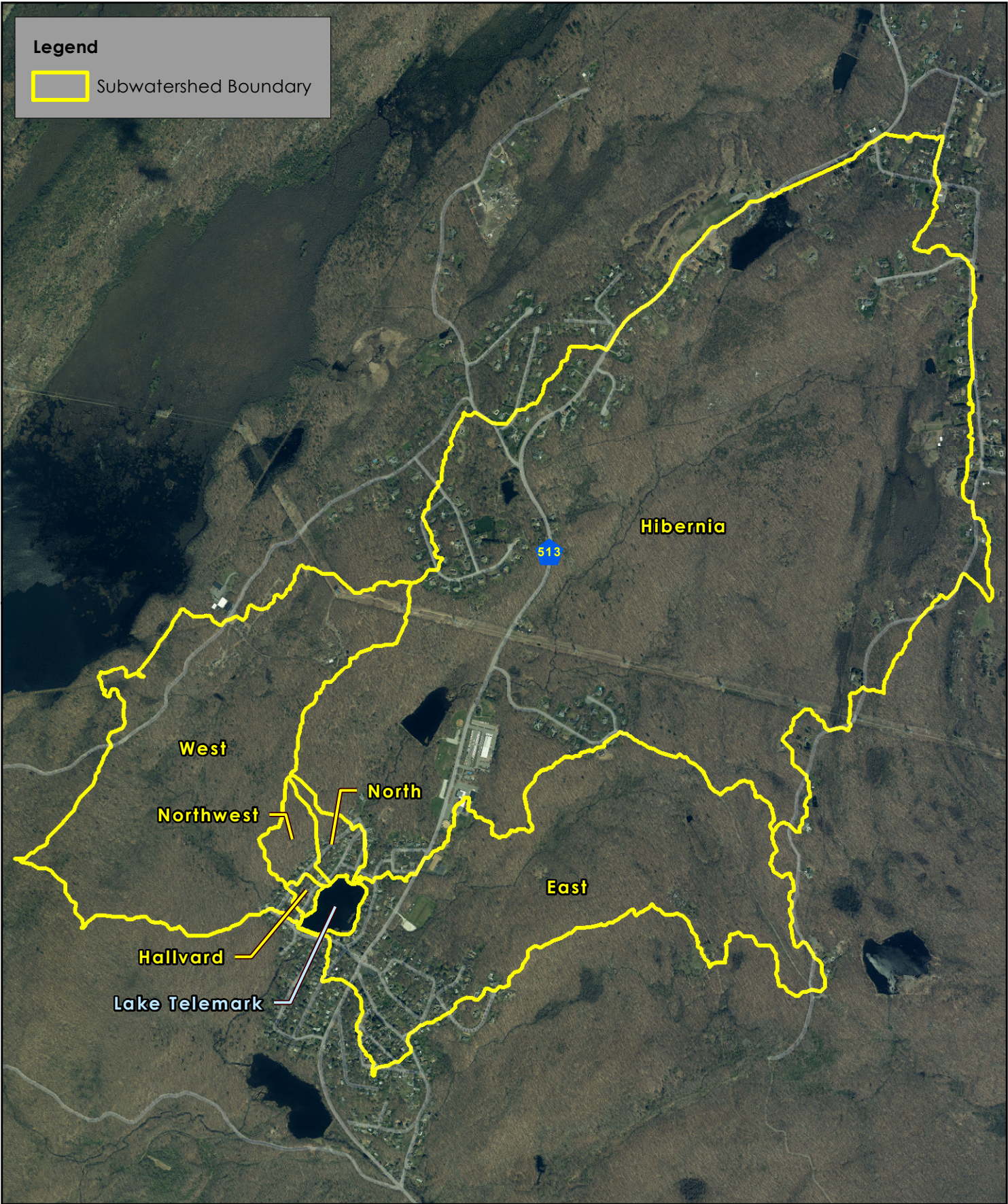
LAKE EMMA
SUBWATERSHEDS
 WATERSHED IMPLEMENTATION PLAN
 ROCKAWAY TOWNSHIP
 MORRIS COUNTY, NEW JERSEY

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File: P:\0883\Projects\0883007\GIS\MXD\Subwatershed_Maps\Lake_Telemark_Subwatershed.mxd, 2/22/2022, Drawn by bsmith, Copyright Princeton Hydro, LLC.

Legend

 Subwatershed Boundary



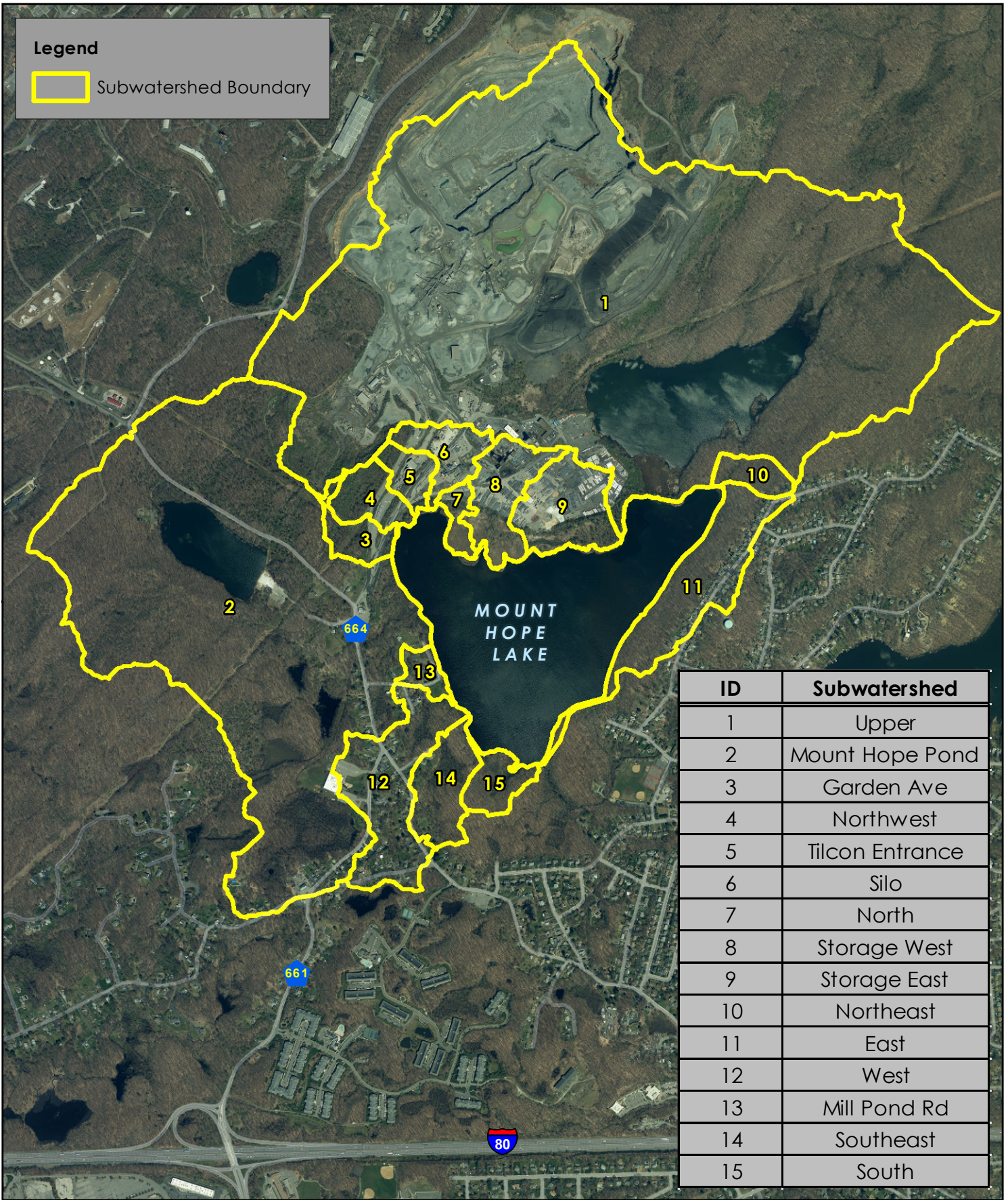
NOTES:
 1. Subwatersheds were delineated by Princeton Hydro using Model My Watershed: modelmywatershed.org
 2. 2020 orthoimagery obtained from NJ Office of Information Technology (NJ OIT), Office of Geographic Information Systems (OGIS).

 0 850 1,700 Feet
 Map Projection: NAD 1983 StatePlane New Jersey FIPS 2900 Feet

**LAKE TELEMAR
 SUBWATERSHEDS**
 WATERSHED IMPLEMENTATION PLAN
 ROCKAWAY TOWNSHIP
 MORRIS COUNTY, NEW JERSEY

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File: P:\0883\Projects\0883007\GIS\MXD\Subwatershed_Maps\Mt_Hope_Lake_Subwatershed.mxd, 2/22/2022, Drawn by bsmith, Copyright Princeton Hydro, LLC.



Legend

Subwatershed Boundary

ID	Subwatershed
1	Upper
2	Mount Hope Pond
3	Garden Ave
4	Northwest
5	Tilcon Entrance
6	Silo
7	North
8	Storage West
9	Storage East
10	Northeast
11	East
12	West
13	Mill Pond Rd
14	Southeast
15	South

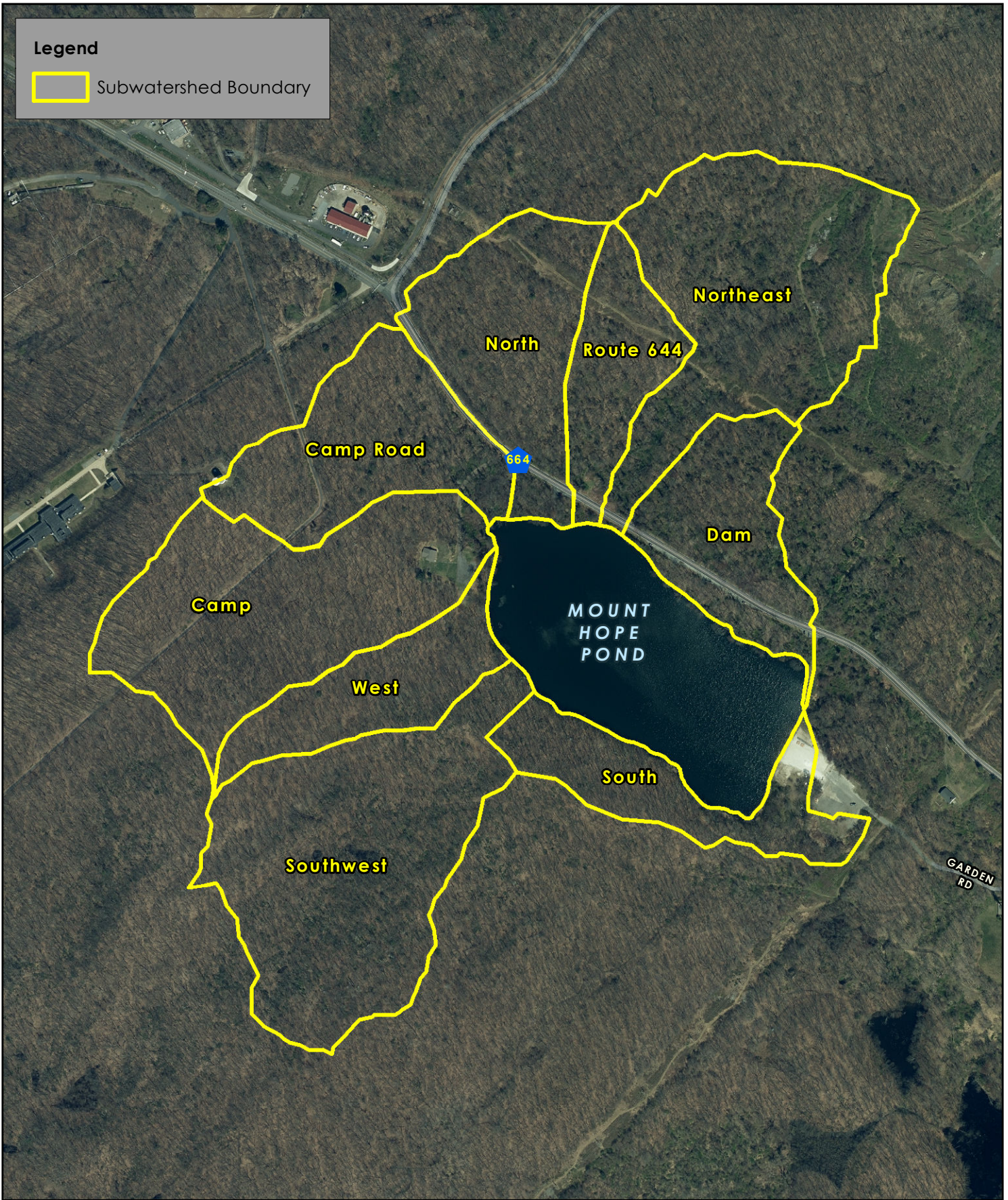
NOTES:
 1. Subwatersheds were delineated by Princeton Hydro using Model My Watershed: modelmywatershed.org
 2. 2020 orthoimagery obtained from NJ Office of Information Technology (NJGIT), Office of Geographic Information Systems (OGIS).

0 750 1,500 Feet
 Map Projection: NAD 1983 StatePlane New Jersey FIPS 2900 Feet

MOUNT HOPE LAKE
SUBWATERSHEDS
 WATERSHED IMPLEMENTATION PLAN
 ROCKAWAY TOWNSHIP
 MORRIS COUNTY, NEW JERSEY

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File: P:\08833\Projects\08833007\GIS\MXD\Subwatershed_Maps\Mt_Hope_Pond_Subwatershed.mxd, 2/22/2022, Drawn by bsmith, Copyright Princeton Hydro, LLC.



Legend

Subwatershed Boundary

NOTES:
 1. Subwatersheds were delineated by Princeton Hydro using Model My Watershed: modelmywatershed.org
 2. 2020 orthoimagery obtained from NJ Office of Information Technology (NJ OIT), Office of Geographic Information Systems (OGIS).

 0 250 500 Feet

Map Projection: NAD 1983 StatePlane New Jersey FIPS 2900 Feet

MOUNT HOPE POND SUBWATERSHEDS

WATERSHED IMPLEMENTATION PLAN
ROCKAWAY TOWNSHIP
MORRIS COUNTY, NEW JERSEY


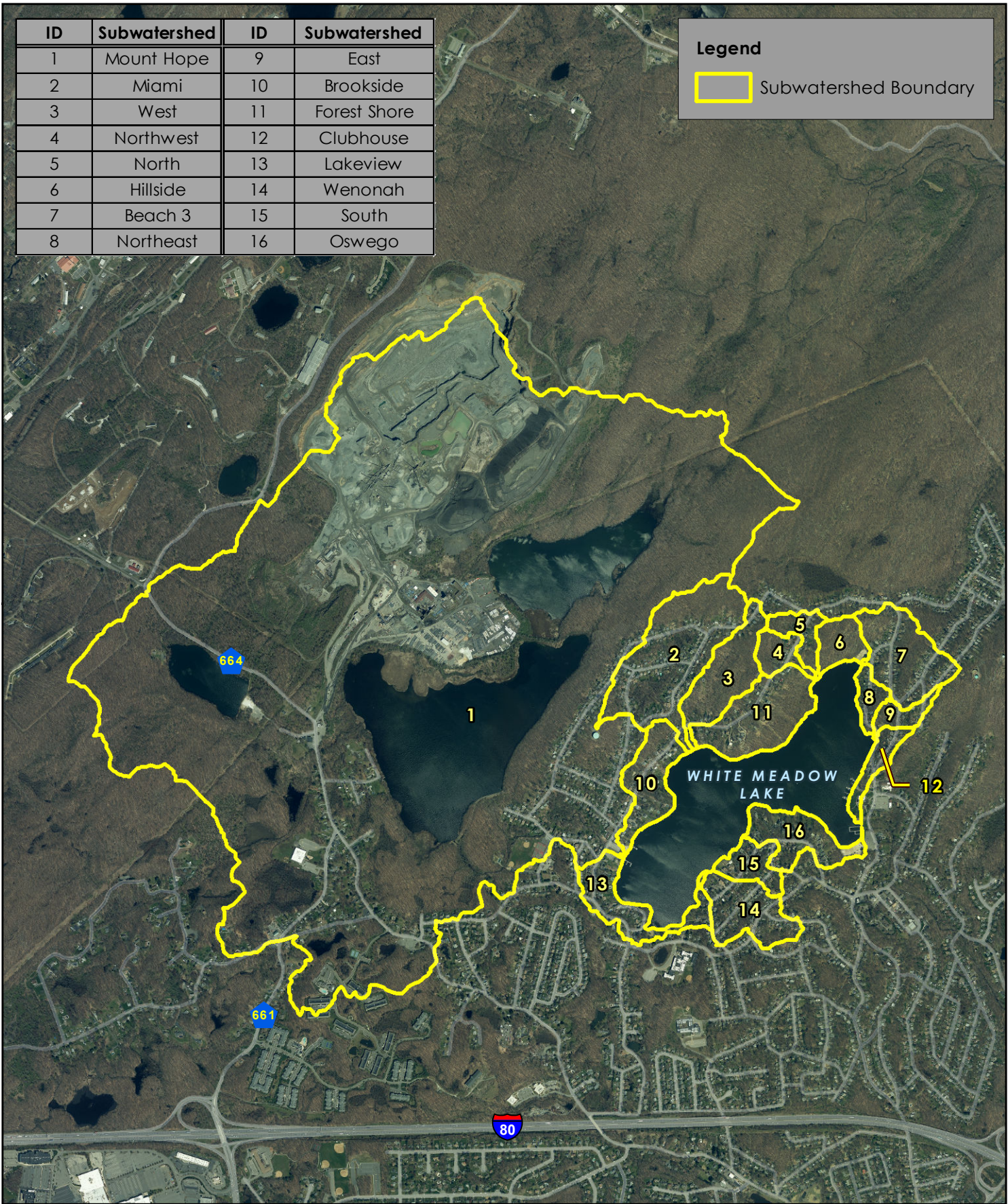


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ID	Subwatershed	ID	Subwatershed
1	Mount Hope	9	East
2	Miami	10	Brookside
3	West	11	Forest Shore
4	Northwest	12	Clubhouse
5	North	13	Lakeview
6	Hillside	14	Wenonah
7	Beach 3	15	South
8	Northeast	16	Oswego

Legend

 Subwatershed Boundary


File: P:\0883\Projects\0883007\GIS\MXD\Subwatershed_Maps\White_Meadow_Lake_Subwatershed.mxd, 2/23/2022, Drawn by bsmith, Copyright Princeton Hydro, LLC.

NOTES:
 1. Subwatersheds were delineated by Princeton Hydro using Model My Watershed: modelmywatershed.org
 2. 2020 orthoimagery obtained from NJ Office of Information Technology (NJ OIT), Office of Geographic Information Systems (OGIS).

 0 1,000 2,000 Feet
 Map Projection: NAD 1983 StatePlane New Jersey FIPS 2900 Feet

WHITE MEADOW LAKE SUBWATERSHEDS

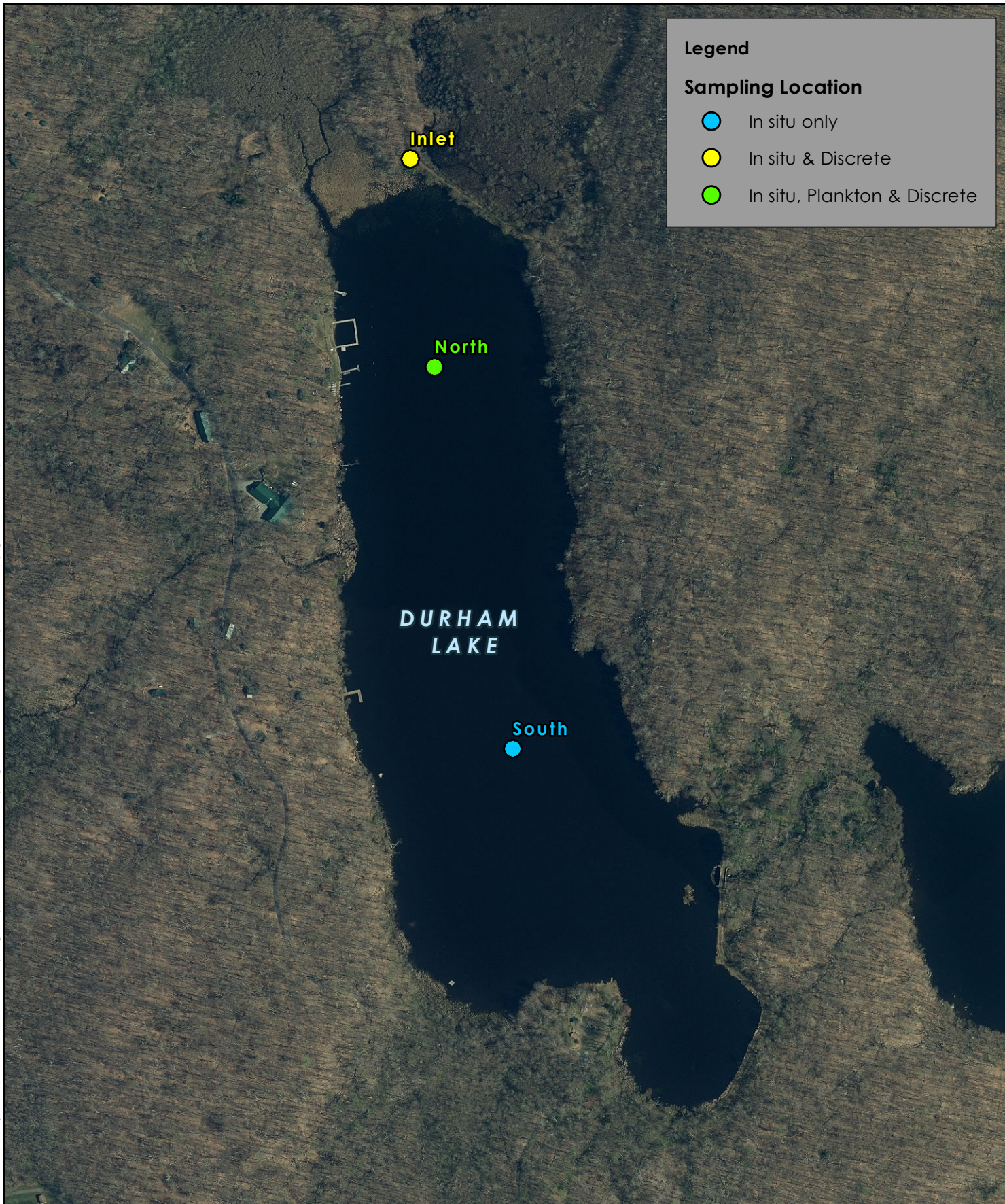
WATERSHED IMPLEMENTATION PLAN
 ROCKAWAY TOWNSHIP
 MORRIS COUNTY, NEW JERSEY



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APPENDIX II:
WATER QUALITY SAMPLING LOCATIONS

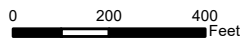
File: P:\08883\Projects\0883007\GIS\MXD\Sampling_Maps\Durham_Lake_Sampling.mxd, 2/24/2022, Drawn by bsmith, Copyright Princeton Hydro, LLC.



NOTES:
1. Sampling locations are approximate.
2. 2020 orthoimagery obtained from NJ Office of Information Technology (NJGIT), Office of Geographic Information Systems (OGIS).

DURHAM LAKE SAMPLING LOCATION MAP

WATERSHED IMPLEMENTATION PLAN
ROCKAWAY TOWNSHIP
MORRIS COUNTY, NEW JERSEY



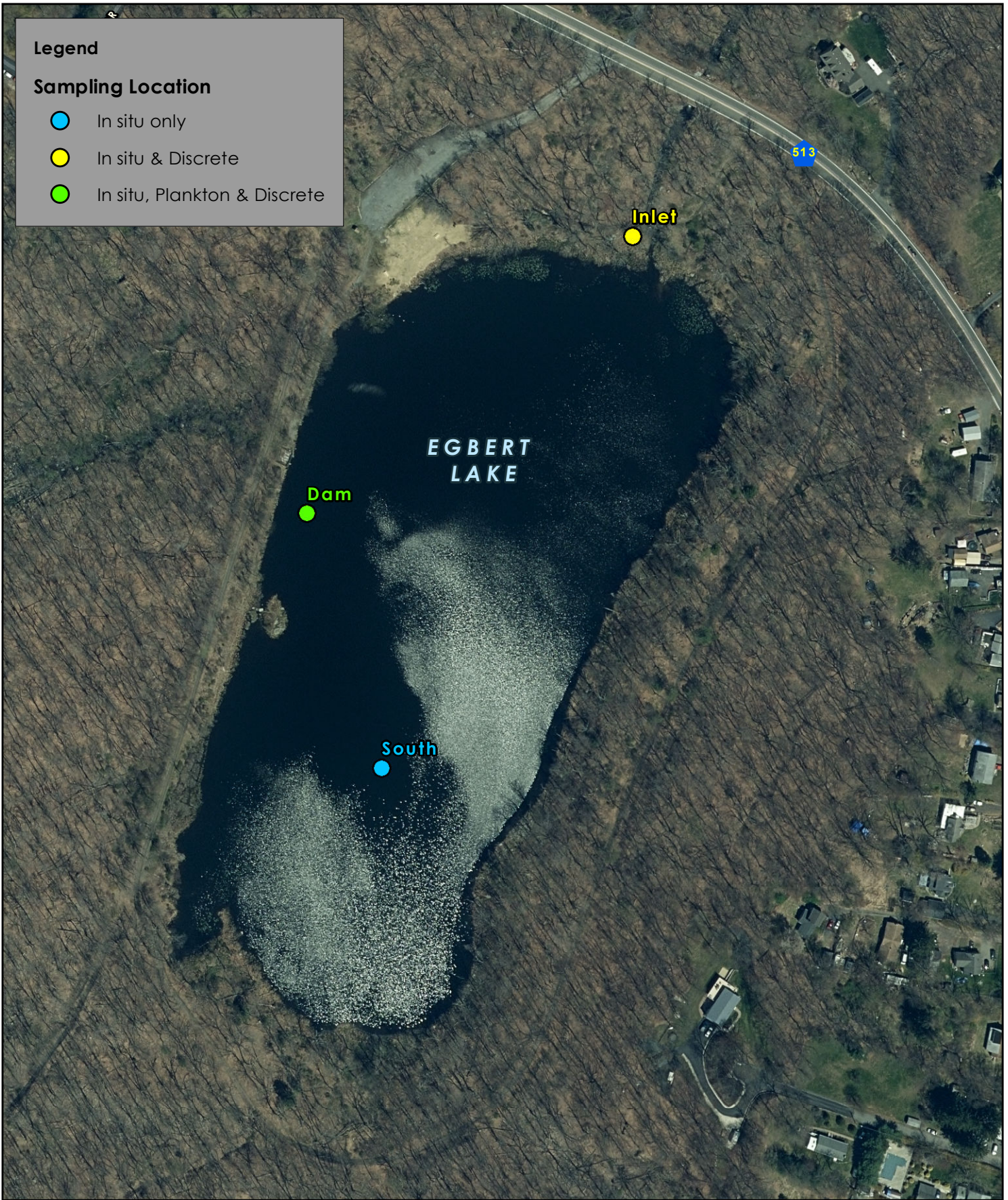
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File: P:\08883\Projects\0883007\GIS\MXD\Sampling_Maps\Egbert_Lake_Sampling.mxd, 2/24/2022, Drawn by bsmith, Copyright Princeton Hydro, LLC.



Legend

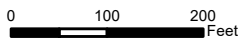
Sampling Location

- In situ only
- In situ & Discrete
- In situ, Plankton & Discrete

NOTES:
 1. Sampling locations are approximate.
 2. 2020 orthoimagery obtained from NJ Office of Information Technology (NJ OIT), Office of Geographic Information Systems (OGIS).

EGBERT LAKE SAMPLING LOCATION MAP

WATERSHED IMPLEMENTATION PLAN
 ROCKAWAY TOWNSHIP
 MORRIS COUNTY, NEW JERSEY



Map Projection: NAD 1983 StatePlane New Jersey FIPS 2900 Feet



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Legend

Sampling Location

- In situ only
- In situ & Discrete
- In situ, Plankton & Discrete

File: P:\08883\Projects\0883007\GIS\MXD\Sampling_Maps\Foxs_Pond_Sampling.mxd, 2/24/2022, Drawn by bsmith, Copyright Princeton Hydro, LLC.

NOTES:
 1. Sampling locations are approximate.
 2. 2020 orthoimagery obtained from NJ Office of Information Technology (NJ OIT), Office of Geographic Information Systems (OGIS).

FOX'S POND SAMPLING LOCATION MAP

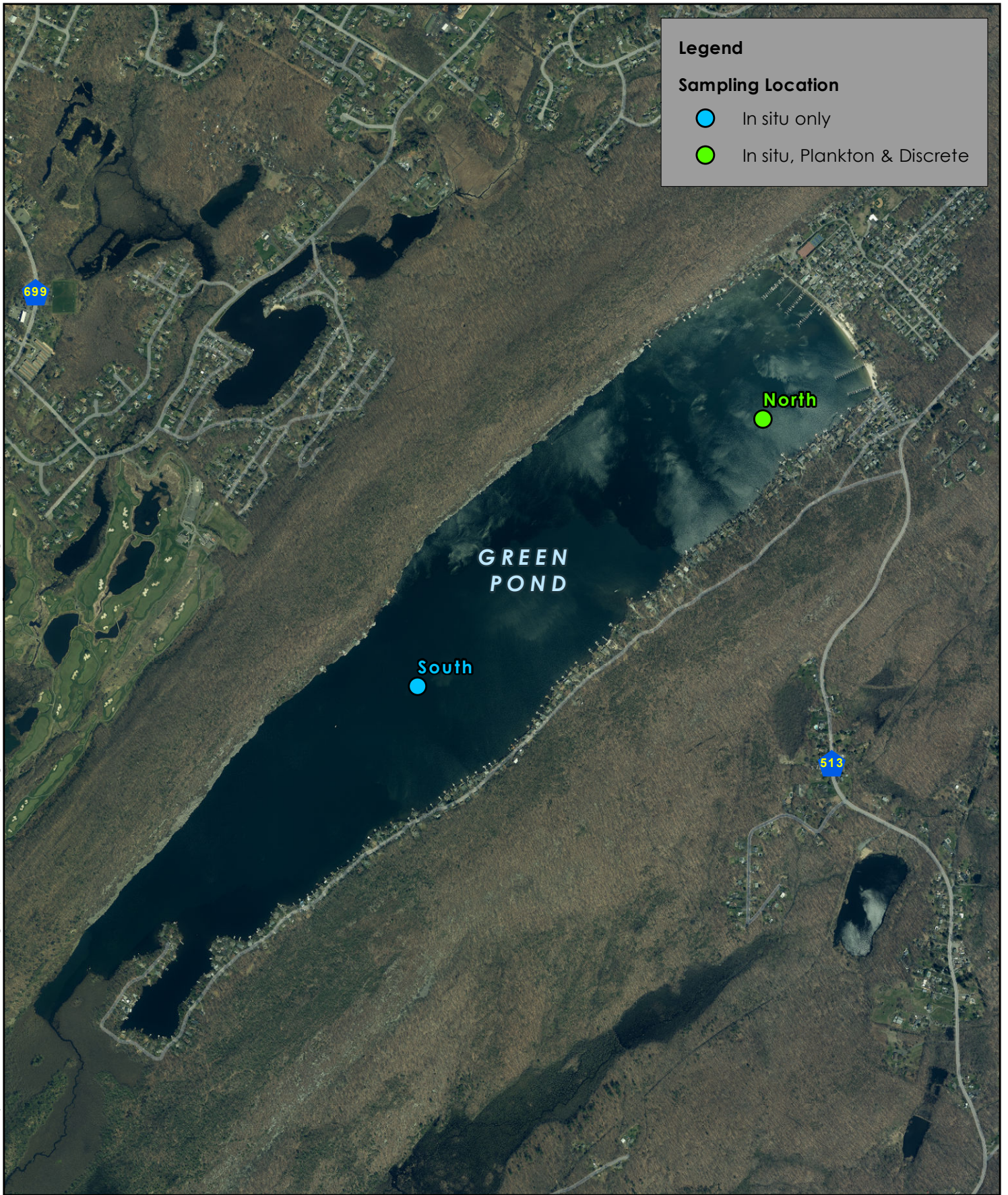
WATERSHED IMPLEMENTATION PLAN
 ROCKAWAY TOWNSHIP
 MORRIS COUNTY, NEW JERSEY



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File: P:\08883\Projects\0883007\GIS\MXD\Sampling_Maps\Green_Pond_Sampling.mxd, 2/24/2022, Drawn by bsmith, Copyright Princeton Hydro, LLC.



NOTES:
1. Sampling locations are approximate.
2. 2020 orthoimagery obtained from NJ Office of Information Technology (NJ OIT), Office of Geographic Information Systems (OGIS).

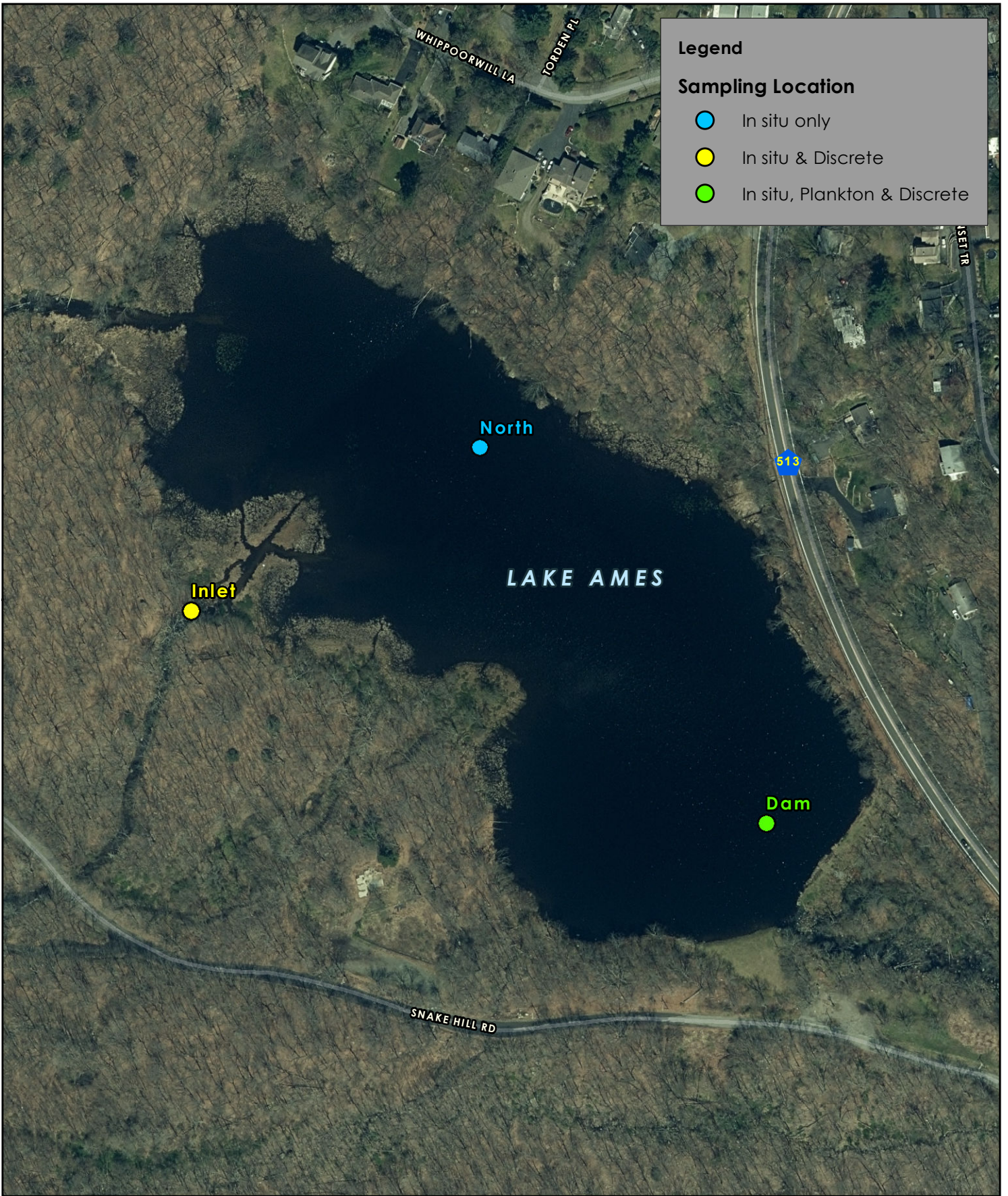
GREEN POND SAMPLING LOCATION MAP

WATERSHED IMPLEMENTATION PLAN
ROCKAWAY TOWNSHIP
MORRIS COUNTY, NEW JERSEY



Map Projection: NAD 1983 StatePlane New Jersey FIPS 2900 Feet

File: P:\08883\Projects\0883007\GIS\MXD\Sampling_Maps\Lake_Ames_Sampling.mxd, 2/24/2022, Drawn by bamifh, Copyright Princeton Hydro, LLC.



Legend

Sampling Location

- In situ only
- In situ & Discrete
- In situ, Plankton & Discrete

NOTES:
 1. Sampling locations are approximate.
 2. 2020 orthoimagery obtained from NJ Office of Information Technology (NJ OIT), Office of Geographic Information Systems (OGIS).

LAKE AMES SAMPLING LOCATION MAP

WATERSHED IMPLEMENTATION PLAN
 ROCKAWAY TOWNSHIP
 MORRIS COUNTY, NEW JERSEY



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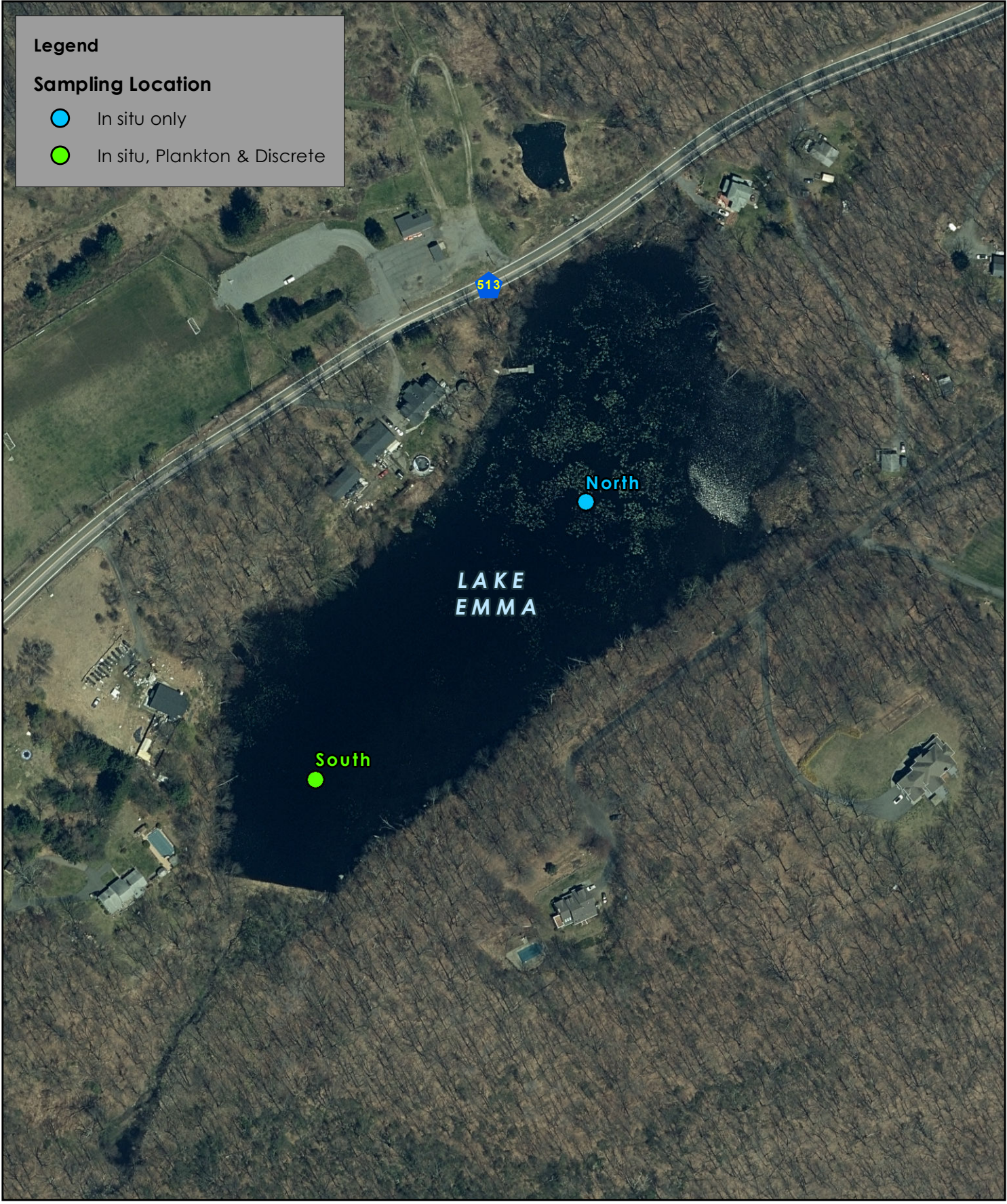
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File: P:\08883\Projects\0883007\GIS\MXD\Sampling_Maps\Lake_Emma_Sampling.mxd, 2/24/2022, Drawn by bsmith, Copyright Princeton Hydro, LLC.

Legend

Sampling Location

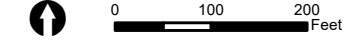
- In situ only
- In situ, Plankton & Discrete



NOTES:
 1. Sampling location map
 2. 2020 orthoimagery obtained from NJ Office of Information Technology (NJ OIT), Office of Geographic Information Systems (OGIS).

LAKE EMMA SAMPLING LOCATION MAP

WATERSHED IMPLEMENTATION PLAN
 ROCKAWAY TOWNSHIP
 MORRIS COUNTY, NEW JERSEY



Map Projection: NAD 1983 StatePlane New Jersey FIPS 2900 Feet



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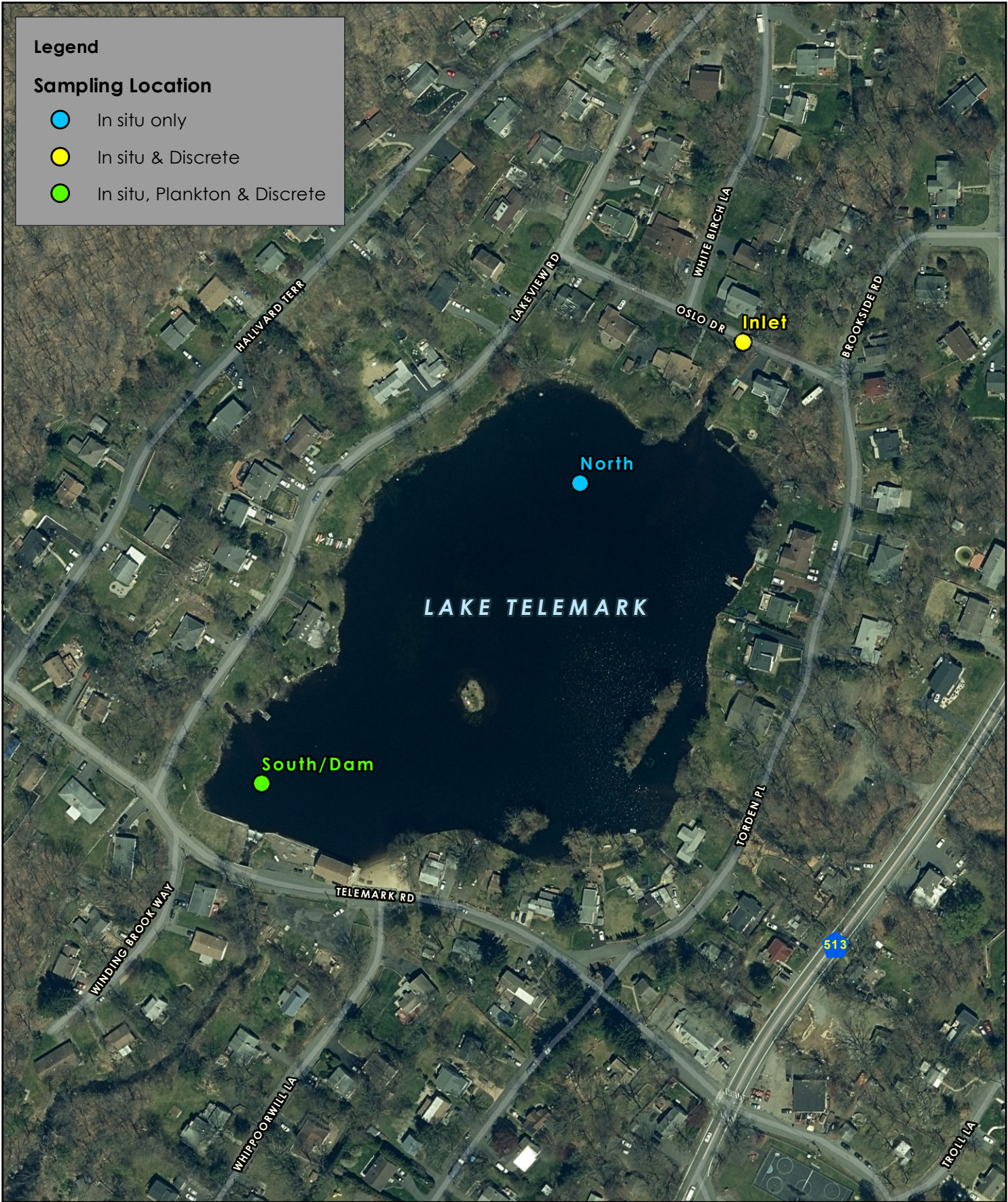
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File: P:\08833\Projects\0883007\GIS\MXD\Sampling_Maps\Lake_Telemark_Sampling.mxd, 2/24/2022, Drawn by bsmith, Copyright Princeton Hydro, LLC.

Legend

Sampling Location

- In situ only
- In situ & Discrete
- In situ, Plankton & Discrete



NOTES:
 1. Sampling locations are approximate.
 2. 2020 orthoimagery obtained from NJ Office of Information Technology (NJ OIT), Office of Geographic Information Systems (OGIS).

LAKE TELEMAR SAMPLING LOCATION MAP

WATERSHED IMPLEMENTATION PLAN
 ROCKAWAY TOWNSHIP
 MORRIS COUNTY, NEW JERSEY



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Map Projection: NAD 1983 StatePlane New Jersey FIPS 2900 Feet



File: P:\0883\Projects\0883007\GIS\MXD\Sampling_Maps\Mt_Hope_Lake_Sampling.mxd, 2/24/2022, Drawn by bsmith, Copyright Princeton Hydro, LLC.

Legend

Sampling Location

 In situ & Discrete



NOTES:
 1. Sampling locations are approximate.
 2. 2020 orthoimagery obtained from NJ Office of Information Technology (NJOTI), Office of Geographic Information Systems (OGIS).

MOUNT HOPE LAKE SAMPLING LOCATION MAP

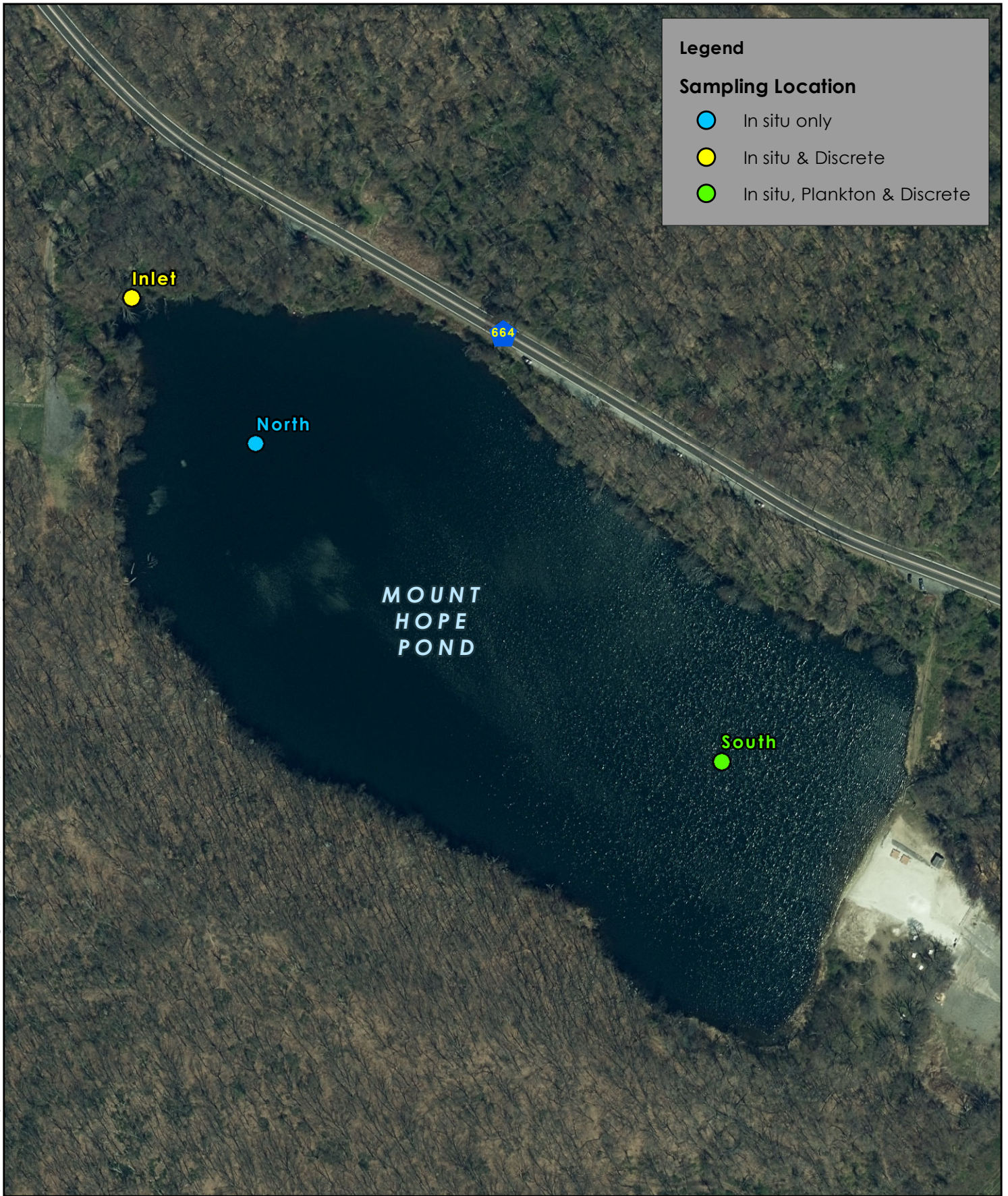
WATERSHED IMPLEMENTATION PLAN
 ROCKAWAY TOWNSHIP
 MORRIS COUNTY, NEW JERSEY




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File: P:\08883\Projects\0883007\GIS\MXD\Sampling_Maps\Mt_Hope_Pond_Sampling.mxd, 2/24/2022, Drawn by bsmifh, Copyright Princeton Hydro, LLC.



NOTES:
1. Sampling locations are approximate.
2. 2020 orthoimagery obtained from NJ Office of Information Technology (NJ OIT), Office of Geographic Information Systems (OGIS).

MOUNT HOPE POND SAMPLING LOCATION MAP

WATERSHED IMPLEMENTATION PLAN
ROCKAWAY TOWNSHIP
MORRIS COUNTY, NEW JERSEY



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0 100 200 Feet

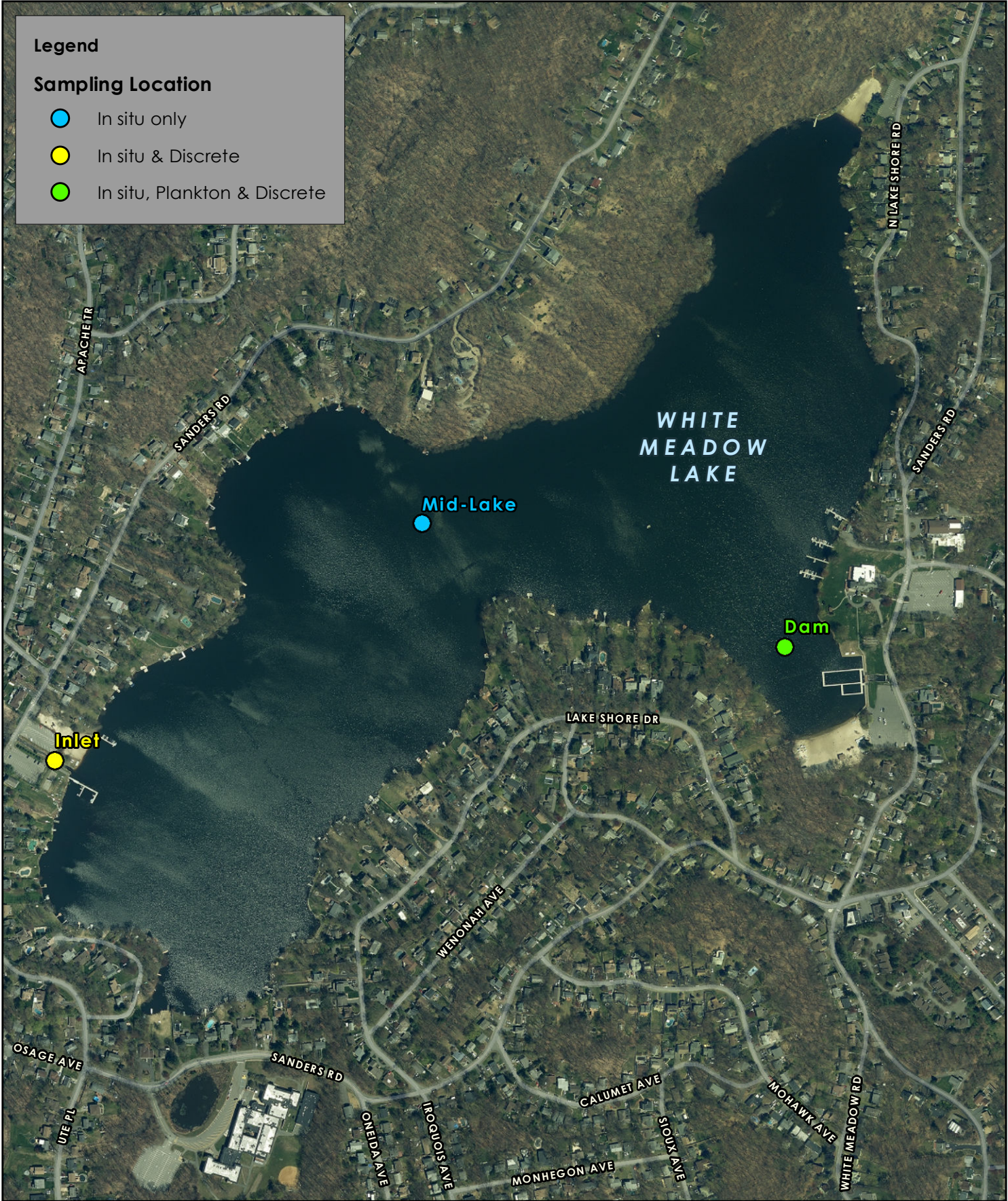
Map Projection: NAD 1983 StatePlane New Jersey FIPS 2900 Feet

File: P:\08883\Projects\0883007\GIS\MXD\Sampling_Maps\White_Meadow_Lake_Sampling.mxd, 2/24/2022, Drawn by bamifh, Copyright Princeton Hydro, LLC.

Legend

Sampling Location

- In situ only
- In situ & Discrete
- In situ, Plankton & Discrete



NOTES:
 1. Sampling locations are approximate.
 2. 2020 orthoimagery obtained from NJ Office of Information Technology (NJGIT), Office of Geographic Information Systems (OGIS).

WHITE MEADOW LAKE SAMPLING LOCATION MAP

WATERSHED IMPLEMENTATION PLAN
 ROCKAWAY TOWNSHIP
 MORRIS COUNTY, NEW JERSEY



APPENDIX III:
IN SITU WATER QUALITY DATA

In-Situ Monitoring for Rockaway Lakes 5/10/2021								
Station	Depth (m)			Temperature	Specific Conductance	Dissolved Oxygen		pH
	Total	Secchi	Sample	°C	µS/cm	mg/L	% Sat.	S.U.
Green Pond South	5.4	4.9	0.0	14.04	91.88	10.09	101.59	7.66
			1.0	14.09	91.44	10.07	101.58	7.56
			2.0	14.08	91.56	10.07	101.73	7.62
			3.0	14.08	91.19	10.07	101.79	7.61
			4.0	14.08	91.16	10.07	101.44	7.64
			5.0	14.08	91.14	10.03	101.27	7.60
Green Pond North	12	4.9	0.0	13.68	91.90	10.18	101.9	7.60
			1.0	13.92	91.45	10.05	101.07	7.65
			2.0	14.02	91.35	10.03	101.00	7.62
			3.0	14.01	91.38	10.02	101.00	7.60
			4.0	14.00	91.36	10.02	100.77	7.60
			5.0	14.00	91.35	10.01	100.97	7.56
			6.0	13.98	91.42	9.98	101	7.54
			7.0	13.85	91.44	9.86	99.1	7.50
			8.0	13.72	91.49	9.68	97.04	7.44
			9.0	13.48	91.67	9.48	94.2	7.35
			10.0	12.43	91.38	8.36	85.37	7.05
			11.0	11.61	91.73	6.71	64.85	6.78
			12.0	11.49	91.75	6.54	62.54	6.71
Egbert Lake Dam	2.3	1.5+	0.0	14.51	335.19	9.63	97.6	7.28
			0.5	14.25	335.13	9.68	97.5	7.43
			1.0	14.15	335.45	9.7	97.2	7.35
			1.5	13.86	332.34	9.04	88.2	7.24
			2.0	13.39	329.62	8.38	82.2	7.21
Egbert Lake South	1.9	1.6	0.0	14.52	331.54	9.17	92.86	7.47
			0.5	14.42	328.11	9.16	93.13	7.43
			1.0	14.08	327.66	9.15	91.78	7.46
			1.5	14.03	325.9	9.1	91.31	7.47
Lake Emma Dam	1.5	1.5+	0.0	14.68	179.5	7.3	74.5	7.05
			0.5	14.50	179.94	7.28	74.1	7.05
			1.0	13.77	179.55	7.34	73.4	7.03
			1.5	13.75	179.63	7.5	75.3	7.03
Lake Emma North	1.1	1.1+	0.0	14.60	176.35	7.49	76.4	7.04
			0.5	14.08	171.53	7.56	75.9	7.00
Lake Ames North	1.4	1.4+	0.0	13.17	192.66	9.71	94.5	7.22
			0.5	12.89	190.60	9.62	93.2	7.25
			1.0	11.86	136.12	9.85	92.7	7.35
Lake Ames Dam	2.3	1.7	0.0	12.96	184.00	9.32	90.3	7.25
			0.5	13.01	184.69	9.29	90.2	7.25
			1.0	13.01	183.79	9.31	90.3	7.23
			1.5	13.02	185.46	9.3	90.1	7.25
			2.0	12.97	178.93	9.37	90.7	7.25

In-Situ Monitoring for Rockaway Lakes 5/11/2021								
Station	Depth (m)			Temperature	Specific Conductance	Dissolved Oxygen		pH
	Total	Secchi	Sample	°C	µS/cm	mg/L	% Sat.	S.U.
White Meadow Lake Mid	2.2	1.25	0.0	14.50	436.67	11.75	118.25	9.08
			0.5	14.51	436.14	11.79	118.56	9.10
			1.0	14.40	435.85	11.99	120.74	9.12
			1.5	14.30	435.42	12.23	121.90	9.17
			2.0	14.19	435.21	12.34	123.08	9.19
White Meadow Lake Dam	2	1.5	0.0	14.59	521.35	11.66	117.20	9.11
			1.0	14.57	479.88	11.67	117.13	9.11
			2.0	14.55	429.80	11.85	120.28	9.21
Mt. Hope Pond North	3.7	3.5	0.0	14.78	162.75	10.81	109.23	7.78
			1.0	14.68	162.61	10.72	108.28	7.72
			2.0	14.50	162.02	10.64	106.77	7.67
			3.0	14.42	163.14	10.99	110.50	7.77
			3.5	14.39	163.34	11.53	116.01	8.32
Mt. Hope Pond South	4.3	3.5	0.0	14.52	149.36	10.51	105.63	7.71
			1.0	14.68	169.48	10.39	105.18	7.62
			2.0	14.65	162.50	10.41	105.00	7.58
			3.0	14.60	162.42	10.45	105.87	7.54
			4.0	14.57	162.37	10.53	106.32	7.60
Durham Pond North	3.3	1.1	0.0	14.69	48.41	9.42	95.48	7.00
			1.0	13.97	48.38	9.37	93.28	6.87
			2.0	13.63	48.20	9.10	90.11	6.75
			3.0	12.84	46.77	6.71	65.14	6.32
Durham Pond South	2.6	1.1	0.0	14.94	46.57	9.55	97.32	6.81
			1.0	14.94	46.68	9.55	97.28	6.83
			2.0	14.88	48.04	9.62	97.75	6.87
			2.5	14.87	47.99	9.62	97.98	6.90

In-Situ Monitoring for Rockaway Lakes 5/12/2021								
Station	Depth (m)			Temperature	Specific Conductance	Dissolved Oxygen		pH
	Total	Secchi	Sample	°C	µS/cm	mg/L	% Sat.	S.U.
Lake Telemark North	1.4	1.4+	0.0	13.33	223.46	12.54	122.0	8.73
			0.5	13.38	224.15	13.23	123.7	8.28
			1.0	12.64	226.13	12.64	117.0	8.31
Lake Telemark South	2.0	1.7	0.0	13.24	215.11	12.2	118.2	8.07
			0.5	13.23	216.63	12.11	117.5	8.01
			1.0	13.15	217.29	12.03	116.3	7.99
			1.5	12.94	216.10	12.07	116.4	7.97

In-Situ Monitoring for Ringwood Lakes 7/12/2021								
Station	Depth (m)			Temperature	Specific Conductance	Dissolved Oxygen		pH
	Total	Secchi	Sample	°C	µS/cm	mg/L	% Sat.	S.U.
Ames - North	1.4	1.3	0.0	23.63	192.06	5.08	60.74	7.21
			0.5	22.75	189.91	5.96	69.99	7.16
			1	20.17	127.55	8.21	93.70	7.39
Ames - Dam	2.1	1.3	0.0	23.23	169.48	7.51	89.43	7.29
			0.5	23.03	149.30	7.05	81.54	7.21
			1.0	21.39	137.100	4.19	48.98	7.04
			1.5	20.86	145.850	3.08	35.02	6.9
			2.0	20.64	157.96	1.52	11.76	6.77
Emma - Dam	1.4	0.8	0.0	24.24	161	2.47	30.09	6.57
			0.5	23.74	194.18	0.66	7.09	6.40
			1.0	21.96	196.39	0.04	0.41	6.33
Emma - North	1.1	0.5	0.0	24.47	155.02	3.68	42.20	6.71
			0.5	22.52	165.18	0.06	0.71	6.41
			1.0	22.53	172.84	0.05	0.61	6.34
Green Pond - South	2.9	5.3	0.0	25.82	96.77	7.96	100.85	7.41
			1.0	25.80	96.78	7.96	100.57	7.45
			2.0	25.75	96.73	7.94	100.37	7.47
			3.0	25.69	96.8	7.86	99.23	7.47
			4.0	25.65	96.75	7.46	96.73	7.46
			5.0	25.27	99.05	4.47	56.73	7.06
Green Pond North	3.5	12.2	0.0	26.03	96.58	7.97	101.26	7.45
			1.0	25.97	96.77	7.97	101.21	7.47
			2.0	25.93	96.78	7.98	101.13	7.53
			3.0	25.88	96.76	7.92	100.05	7.51
			4.0	25.78	96.82	7.75	97.94	7.46
			5.0	25.39	96.71	7.53	93.23	7.42
			6.0	21.40	96.54	7.55	89.79	7.01
			7.0	18.28	94.9	7.13	76.51	7.02
			8.0	16.19	94.96	5.22	54.34	6.59
			9.0	13.92	98.97	1.01	10.46	6.19
			10.0	13.38	101.27	0.22	1.64	6.02
			11.0	13.00	104.81	0.00	0.00	5.97
12.0	12.93	105.6	0.00	0.00	5.96			

In-Situ Monitoring for Ringwood Lakes 7/13/2021								
Station	Depth (m)			Temperature	Specific Conductance	Dissolved Oxygen		pH
	Total	Secchi	Sample	°C	µS/cm	mg/L	% Sat.	S.U.
Durham - North	3.1	1.0	0.0	27.75	49.94	7.36	91.96	7.41
			1.0	25.76	50.09	6.59	82.18	7.28
			2.0	24.79	53.27	2.18	26.42	6.88
			2.5	22.9	59.52	1.49	15.99	6.60
Durham - South	1.4	1.1	0.0	25.55	49.65	7.04	87.76	7.07
			0.5	25.55	49.67	7.00	87.08	7.07
			1.0	25.47	50.39	6.84	82.31	7.01
Egbert's - Dam	2.3	1.6	0.0	25.19	326.22	8.36	103.58	7.63
			0.5	25.23	325.77	8.37	103.51	7.73
			1.0	24.34	353.33	5.67	73.44	7.40
			1.5	24.36	331.02	2.46	19.54	6.95
			2.0	22.64	284.54	4.89	57.76	7.02
Egbert's - South	1.9	1.4	0.0	25.32	317.31	7.49	92.97	7.38
			0.5	25.47	317.04	7.29	90.76	7.43
			1.0	24.58	282.68	2.09	22.91	6.95
			1.5	23.74	294.86	0.32	2.73	6.83
Telemark - North	1.0	0.9	0.0	23.83	216.7	6.78	81.36	7.19
			5.0	23.66	216.43	6.71	79.91	7.10
Telemark - South	1.9	0.9	0.0	23.93	205.1	7.44	89.47	7.15
			0.5	23.69	201.94	7.18	85.39	7.13
			1.0	23.56	201.17	7.04	83.82	7.09
			1.5	23.54	201.16	6.98	83.27	7.06

In-Situ Monitoring for Ringwood Lakes 7/14/2021								
Station	Depth (m)			Temperature	Specific Conductance	Dissolved Oxygen		pH
	Total	Secchi	Sample	°C	µS/cm	mg/L	% Sat.	S.U.
White Meadow - Mid	2.1	1.75	0.00	25.68	363.00	7.38	91.95	8.01
			0.50	25.67	365.69	7.06	86.36	7.84
			1.00	25.59	365.11	6.93	86.70	7.80
			1.50	25.54	364.85	7.00	87.17	7.82
			2.00	25.49	365.30	6.80	84.41	7.75
White Meadow - Dam	2.3	1.8	0.00	25.99	372.95	5.93	74.39	7.54
			0.50	25.97	372.23	5.73	72.13	7.48
			1.00	25.80	370.36	5.71	71.44	7.45
			1.50	25.64	372.20	5.61	70.01	7.42
			2.00	25.61	372.51	5.56	69.24	7.41
Mt. Hope Pond - South	3.2	0.9	0.00	26.00	147.04	9.60	121.02	9.48
			1.00	25.48	146.49	8.44	118.26	9.42
			2.00	25.27	143.95	7.87	97.00	8.97
			3.00	22.86	154.25	0.32	3.58	7.09
Mt. Hope Pond - North	3.5	0.9	0.00	26.03	148.25	10.13	127.52	9.61
			1.00	25.56	147.41	9.96	124.13	9.58
			2.00	25.16	145.32	5.74	68.57	7.91
			3.00	22.54	156.20	0.29	2.55	6.84
Fox's Pond - Mid	1.1+	1.1	0.00	25.33	224.52	9.68	117.94	8.13
			0.50	24.79	222.08	9.17	111.58	7.82
Fox's Pond - South	1.3	0.9	0.00	25.96	219.50	9.83	122.47	8.36
			0.50	25.93	219.47	9.83	122.70	8.35
			1.00	24.47	329.60	6.55	77.21	7.59

In-Situ Monitoring for Ringwood Lakes 10/11/21								
Station	Depth (m)			Temperature	Specific Conductance	Dissolved Oxygen		pH
	Total	Secchi	Sample	°C	µS/cm	mg/L	% Sat.	S.U.
Green Pond - South	5.5	4.5	0.00	18.02	98.08	8.74	95.05	7.52
			1.00	18.05	97.92	8.72	94.97	7.49
			2.00	18.07	97.93	8.72	94.86	7.49
			3.00	18.08	97.93	8.70	94.70	7.44
			4.00	18.07	97.93	8.69	94.66	7.43
			5.00	18.05	97.94	8.67	94.42	7.41
Green Pond - North	11.5	4.3	0.00	17.93	98.44	8.45	91.73	7.32
			1.00	18.03	98.27	8.43	91.61	7.34
			2.00	18.02	98.29	8.43	91.58	7.35
			3.00	18.03	98.27	8.41	91.40	7.30
			4.00	18.03	91.45	8.40	91.46	7.32
			5.00	18.01	98.29	8.39	91.23	7.30
			6.00	18.01	98.25	8.38	91.37	7.26
			7.00	18.00	98.24	8.36	90.91	7.26
			8.00	17.99	98.26	8.34	90.79	7.23
			9.00	17.98	98.31	8.33	90.38	7.24
			10.00	17.84	99.99	7.45	77.80	7.14
11.00	17.49	104.53	5.87	58.11	6.97			
Egbert - South	2	2.0+	0.00	17.26	286.42	6.90	73.97	7.10
			0.50	17.24	285.19	6.88	73.19	7.10
			1.00	17.25	284.66	6.86	73.03	7.11
			1.50	17.20	283.37	6.81	72.39	7.12
Egbert - Dam	2.1	1.9	0.00	17.22	289.80	7.24	77.03	7.10
			0.50	17.24	291.04	7.21	76.88	7.10
			1.00	17.22	290.96	7.22	76.87	7.11
			1.50	17.18	290.73	7.19	76.70	7.12
Emma - Dam	1.5	1.5+	0.00	16.23	136.05	3.67	38.24	6.67
			0.50	16.10	136.32	3.53	36.72	6.61
			1.00	16.07	136.20	3.54	36.61	6.60
Emma - North	1	1.0+	0.00	16.21	147.80	0.69	7.02	6.51
			0.50	16.02	147.08	0.33	3.30	6.40
			1.00	15.95	147.61	0.29	2.94	6.35
Telemark - North	1.4	1.4+	0.00	16.80	285.83	7.58	79.17	7.00
			0.50	16.67	287.46	7.34	76.50	7.02
			1.00	16.22	295.18	6.91	71.58	7.00
Telemark - South	1.8	1.8+	0.00	17.18	267.44	8.48	89.58	7.23
			0.50	17.12	267.70	8.45	89.31	7.23
			1.00	17.10	265.81	8.44	88.62	7.23
			1.50	16.99	265.51	8.46	89.03	7.23

In-Situ Monitoring for Ringwood Lakes 10/12/20								
Station	Depth (m)			Temperature	Specific Conductance	Dissolved Oxygen		pH
	Total	Secchi	Sample	°C	µg/L	mg/L	% Sat.	S.U.
Durham - North	3.5	1.3	0.00	17.60	51.93	7.39	79.26	7.05
			1.00	17.33	51.56	7.07	75.19	6.94
			2.00	17.25	51.81	6.85	72.22	6.63
			3.00	17.16	53.88	4.33	43.74	6.65
Durham - South	3	1.5	0.00	18.02	51.23	8.16	88.12	6.91
			0.50	17.74	51.89	8.03	86.40	6.92
			1.00	17.65	51.77	7.98	85.67	6.95
			1.50	17.47	51.98	7.06	75.66	6.88
			2.00	17.37	52.18	5.77	59.67	6.73
Ames - North	1.8	1.5	0.00	17.56	251.89	10.21	108.27	7.46
			0.50	17.09	248.03	9.86	103.65	7.36
			1.00	16.60	231.57	7.86	80.71	7.19
			1.50	15.92	191.44	5.12	52.60	6.96
Ames - Dam	2.2	2.0	0.00	17.71	228.69	10.70	113.96	7.54
			0.50	17.06	220.44	10.70	107.77	7.55
			1.00	16.50	215.47	6.38	60.18	7.21
			1.50	15.88	223.65	1.94	19.23	6.86
			2.00	15.63	229.61	0.72	5.97	6.69
White Meadow - Mid	2.2	1.2	0.00	18.42	381.23	9.27	100.75	7.80
			0.50	18.36	380.75	9.29	100.81	7.84
			1.00	18.33	380.71	9.31	100.95	7.88
			1.50	18.20	378.01	9.67	104.66	8.03
			2.00	18.15	378.80	9.09	96.51	7.94
White Meadow - Dam	2.2	1.8	0.00	18.80	355.04	9.57	104.81	8.08
			1.00	18.34	374.55	9.46	102.65	8.04
			2.00	18.34	374.06	9.50	103.07	8.02
Mt. Hope Pond - South	4.3	1.8	0.00	19.16	163.32	9.22	102.07	7.60
			1.00	18.73	162.67	9.20	100.75	7.54
			2.00	18.44	162.85	8.53	92.77	7.38
			3.00	18.35	162.90	7.64	82.69	7.22
			4.00	18.34	164.00	6.27	67.53	7.05
Mt. Hope Pond - North	3.5	2	0.00	19.20	163.29	9.24	102.34	7.29
			1.00	19.11	163.14	9.24	102.20	7.33
			2.00	18.97	163.08	9.29	102.44	7.34
			3.00	18.54	162.73	8.11	88.14	7.23
Fox's Pond - North	2.5	1.5	0.00	19.52	544.58	7.50	82.89	7.68
			0.50	19.45	541.38	7.29	80.24	7.60
			1.00	18.31	544.04	3.96	42.07	7.33
			1.50	18.08	542.54	4.03	42.62	7.27
			2.00	17.85	548.92	3.87	41.59	7.24
Fox's Pond - South	2.7	1.5	0.00	18.79	543.07	7.58	82.12	7.51
			0.50	18.34	544.29	7.39	79.89	7.50
			1.00	18.07	540.45	6.71	72.10	7.44
			1.50	17.89	529.51	5.59	58.15	7.35
			2.00	17.78	551.56	3.96	42.01	7.23
			2.50	17.77	595.21	1.80	18.52	7.07

<i>In situ</i> water quality data collected in inlet streams in Rockaway Township						
Date	Location	Temp	DO	DO%	SpC (μS/cm)	pH
5/24/2021	Durham	20.49	1.29	14.59	37.51	6.15
	Egbert	15.67	8.93	91.47	457.45	6.99
	Telemark	18.37	9.00	96.96	296.18	7.48
	Ames	14.80	9.87	98.41	140.83	7.52
	White Meadow	17.82	8.91	95.08	432.22	7.53
	Mt. Hope Pond	16.37	9.69	100.23	0.07	6.33
	Fox's Pond	16.04	9.42	96.42	937.45	8.02
9/23/2021	Durham	20.04	5.04	56.77	40.20	6.99
	Egbert Lake	19.26	8.36	93.49	440.65	7.11
	Telemark	20.13	8.72	98.55	278.75	7.26
	Ames	19.04	8.89	97.82	151.40	7.45
	Mt. Hope Pond	15.33	9.49	97.72	217.78	6.10
	Mill Pond	21.47	8.27	96.32	166.53	6.60
10/12/2021	White Meadow	18.17	8.73	94.43	397.20	7.72
	Fox's Pond	17.27	9.74	103.20	876.10	8.09

APPENDIX IV:
DISCRETE WATER QUALITY SAMPLE DATA

Discrete Monitoring Data for Rockaway Lakes - 2021													
Date	Station	TP		SRP		Chl A		NO3-N		NH3-N		TSS	
		S (mg/L)	D (mg/L)	S (mg/L)	D (mg/L)	S (ug/L)	D (ug/L)	S (mg/L)	D (mg/L)	S (mg/L)	D (mg/L)	S (mg/L)	D (mg/L)
May-21	Lake Telemark	0.02	0.02	0.003	0.002	1.2	2.1	0.12	0.12	ND <0.01	ND <0.01	5	6
	Green Pond	0.01	0.01	ND	ND	1.2	3.0	0.01	ND	0.02	0.01	ND	ND
	Egbert Lake	0.02	0.02	ND	ND	2.3	5.1	0.05	0.05	0.01	0.01	ND	6
	Lake Emma	0.01	0.01	ND	ND	1.8	2.0	0.04	0.04	ND <0.01	ND <0.01	ND	ND
	Lake Ames	0.02	0.02	ND	ND	3.4	4.9	0.09	0.10	ND <0.01	ND <0.01	4	5
	White Meadow Lake	0.02	0.02	ND	ND	6.6	12.0	0.02	0.02	ND <0.01	ND <0.01	3	3
	Mt Hope Pond	0.02	0.02	ND	ND	1.8	2.8	ND	ND	ND <0.01	ND <0.01	3	2
	Durham Pond	0.02	0.03	ND	ND	10.0	6.9	0.05	0.10	ND <0.01	ND <0.01	2	3
	Camp Lewis Lake	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Mt Hope Lake/Mill Pond	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Fox's Pond	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
July-21	Lake Telemark	0.05	0.04	0.005	0.005	22.0	17.0	0.14	0.15	0.01	0.01	6	7
	Green Pond	0.01	0.01	ND <0.002	ND <0.002	5.3	3.5	0.03	0.06	0.01	0.02	ND <2	11
	Egbert Lake	0.02	0.06	ND <0.002	0.003	8.3	9.6	0.07	0.09	0.01	0.01	2	11
	Lake Emma	0.03	0.07	ND <0.002	ND <0.002	36.0	120.0	0.08	0.18	0.02	0.02	2	23
	Lake Ames	0.03	0.03	0.002	0.006	16.0	7.7	0.08	0.08	0.01	0.01	3	3
	White Meadow Lake	0.01	0.02	ND <0.002	ND <0.002	3.6	5.8	0.05	0.05	ND <0.01	ND <0.01	3	6
	Mt Hope Pond	0.02	0.03	ND <0.002	ND <0.002	18.0	19.0	0.08	0.08	ND <0.01	ND <0.01	7	7
	Durham Pond	0.04	0.04	ND <0.002	0.002	11.0	11.0	0.05	0.05	0.01	0.01	3	4
	Camp Lewis Lake	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Mt Hope Lake/Mill Pond	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Fox's Pond	0.04	0.04	ND <0.002	ND <0.002	15.0	18.0	0.53	0.63	ND <0.01	ND <0.01	4	5	
September-21	Lake Telemark	0.01	0.02	ND <0.002	ND <0.002	3.7	ND <0.5	0.11	0.11	ND <0.01	ND <0.01	4	2
	Green Pond	0.04	0.03	ND <0.002	ND <0.002	1.8	ND <0.5	0.02	0.01	ND <0.01	ND <0.01	ND <2	ND <2
	Egbert Lake	0.04	0.03	ND <0.002	0.002	2.2	24.0	0.05	0.04	ND <0.01	ND <0.01	3	2
	Lake Emma	0.01	0.02	ND <0.002	ND <0.002	6.9	8.6	0.02	0.02	ND <0.01	ND <0.01	3	2
	Lake Ames	0.01	0.04	ND <0.002	0.003	1.5	5.7	0.07	0.09	ND <0.01	ND <0.01	ND <2	5
	White Meadow Lake	0.04	0.05	ND <0.002	ND <0.002	7.4	5.8	0.08	0.04	ND <0.01	ND <0.01	4	5
	Mt Hope Pond	0.03	0.06	ND <0.002	ND <0.002	4.6	26.0	0.04	0.06	ND <0.01	ND <0.01	2	5
	Durham Pond	0.02	0.06	ND <0.002	ND <0.002	15.0	17.0	0.12	0.15	ND <0.01	ND <0.01	4	7
	Camp Lewis Lake	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Mt Hope Lake/Mill Pond	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Fox's Pond	0.05	0.06	ND <0.002	ND <0.002	22.0	6.3	0.10	0.09	ND <0.01	ND <0.01	4	5	

Discrete Monitoring Data for Rockaway Lake Inlets - 2021					
Date	Station	NO3-N (mg/L)	SRP (mg/L)	TP (mg/L)	TSS (mg/L)
May-21	Lake Telemark	0.21	ND <0.002	0.01	ND <2
	Green Pond	NO NATURAL INLET			
	Egbert Lake	0.38	0.004	0.02	ND <2
	Lake Emma	NO NATURAL INLET			
	Lake Ames	0.22	0.003	0.01	ND <2
	White Meadow Lake	0.48	0.019	0.05	5
	Mt Hope Pond	0.09	0.019	0.03	6
	Durham Pond	0.18	ND <0.002	0.04	9
	Camp Lewis Lake	N/A			
	Mt Hope Lake/Mill Pond	N/A			
	Fox's Pond	1.30	0.011	0.03	ND <2
September-21	Lake Telemark	0.25	0.002	0.02	2
	Green Pond	NO NATURAL INLET			
	Egbert Lake	0.25	0.008	0.02	ND <2
	Lake Emma	NO NATURAL INLET			
	Lake Ames	0.08	0.006	0.01	2
	White Meadow Lake	0.23	0.012	0.01	2
	Mt Hope Pond	0.16	0.018	0.03	12
	Durham Pond	0.06	ND <0.002	0.04	10
	Camp Lewis Lake	N/A			
	Mt Hope Lake/Mill Pond	0.11	0.002	0.04	5
	Fox's Pond	1.30	0.017	0.02	ND <2

APPENDIX V:
PLANKTON SAMPLE DATA

Phytoplankton and Zooplankton Community Composition Analysis												
Sampling Location: Rockaway Lakes				Sampling Date: 5/11/2021								
Site 1: White Meadow Lake - 1.5m tow			Site 2: Mt. Hope Pond - 3.5m tow			Site 3: Durham Pond						
Phytoplankton												
Bacillariophyta (Diatoms)				Chlorophyta (Green Algae)				Cyanophyta (Blue-Green Algae)				
Asterionella	A	R		Actinostrum	1	2	3	Dolichospermum (formerly Anabaena)				
Aulacoseira				Ankistrodesmus				Amphizomen				
Cocconeis				Chlamydomonas				Aphanocapsa		P		
Cyclotella				Botryococcus				Chroococcus				
Cymatopleura				Chlorella		R		Cylindrospermum				
Cymbella				Coelastrum				Lyngbya				
Denticula				Eudarina				Microcystis		R		R
Fragilaria	R	R		Gloeoecystis				Nostoc				
Frustulia				Dictyosphaerium				Pseudoanabaena				
Gyrosigma				Hydrodictyon				Oscillatoria				
Melosira	C	A	A	Monoraphidium				Coelosphaerium				
Nedum				Mougeotia				Spirulina				
Stauroneis				Microspora				Aphanothece				
Stephanodiscus				Ochromonas								
Surirekka				Oedogonium				Euglenophyta (Euglenoids)				
Synedra			R	Oocystis				Colacium				
Tabellaria		R	P	Scenedesmus				Phacus				
Pinnularia				Spirogya				Euglena sp				
Navicula				Treubaria				Trachelomonas		R	P	C
Mastogloia												
Chrysophyta (Golden Algae)				Desmids (Green Algae)				Cryptomonads				
Dinobryon	B	P	C	Microsterias				Chroomonas				
Chromulina				Staurastrum								
Mallomonas				Spondylium								
				Closterium								
				Desmidium								
				Staurodesmus		R						
Unknown filaments												
Zooplankton												
Cladocera (Water Fleas)				Copepoda (Copepods)				Rotifera (Rotifers)				
Bosmina sp.	R	R	P	Cyclops sp.				Keratella sp.		P	P	
Daphnia sp.		C	P	Dipatomus (H)				Kellicottia sp.			P	
Eubosmina sp.				Nauplii	R	A	C	Asplanchna sp.				P
Chydorus				Skistodiaptomus sp.		R		Polarthra		R		P
Diaphanosoma				Microcyclops sp.		P	C	P	Hexarthra mira		R	
Caridaphnia		P		Limnocalanus macrurus				Conochilus			P	A
Leptodora kindtii				Leptodiaptomus sp.				Tricocerca				
Scapholeberis mucronata				Unknown Cyclopod				Bipalpus				
Bosmina longirostris				Unknown Calanoid				Arthropoda (Arthropods)				
Diaphanosoma brachyurum				Mesocyclops				Chaoborus punctipennis				
Diaphanosoma birgei				Dia-cyclops				Ostracoda			R	
				Tropocyclops								
Sites:				Notes: Durham Pond sample is zooplankton-dominated								
Total Phytoplankton Genera	6	12	8	0	0	0	0					
Total Zooplankton Genera	5	10	8	0	0	0	0					
Phytoplankton Key: Bloom (B), Common (C), Present (P), and Rare (R)												
Zooplankton Key: Dominant (D), Abundant (A), Present (P), and Rare (R); Herbivorous (H) or Carnivorous (C)												
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Phytoplankton and Zooplankton Community Composition Analysis																						
Sampling Location: Rockaway Lakes								Sampling Date: 5/12/2021														
Site 1: Lake Telemark - 1.5m tow																						
Phytoplankton																						
Bacillariophyta (Diatoms)								Chlorophyta (Green Algae)								Cyanophyta (Blue-Green Algae)						
Asterionella								Actinostrum								Dolichospermum (formerly Anabaena)						
Aulacoseira								Ankistrodesmus								Amphizomen						
Cocconeis								Chlamydomonas								Aphanocapsa	R					
Cyclotella								Botryococcus								Chroococcus						
Cymatopleura								Chlorella								Cylindrospermum						
Cymbella								Coelastrum								Lyngbya						
Denticula								Eudarina								Microcystis						
Fragilaria	P							Gloeoecystis								Nostoc						
Frustulia								Dictyosphaerium	R							Pseudoanabaena						
Gyrodinium								Hydrodictyon								Oscillatoria						
Melosira	P							Monoraphidium								Coelosphaerium						
Nedum								Mougeotia								Spirulina						
Stauroneis																Aphanothece						
Stephanodiscus	R							Microspora														
Surirekka								Ochromonas														
Synedra	P							Oedogonium								Euglenophyta (Euglenoids)						
Tabellaria	R							Oocystis								Colacium						
Pinnularia								Scenedesmus								Phacus						
Navicula								Spirogya	R							Euglena sp						
Mastogloia																Trachelomonas	C					
								Treubaria														
Chrysophyta (Golden Algae)																Pyrrhophyta (Dinoflagellates)						
Dinobryon	C							Pediastrum	R							Ceratium	R					
Chromulina								Valvex								Peridinium						
Mallomonas								Zygnema								Cystodinium						
								Sphaerocystis														
								Ulothrix								Cryptomonads						
Synurophytes								Desmids (Green Algae)								Chroomonas	P					
Chrysochaerella								Microsterias														
								Staurastrum														
								Spondylium														
								Closterium														
								Desmidium														
Unknown filaments								Staurodesmus	R													
Zooplankton																						
Cladocera (Water Fleas)								Copepoda (Copepods)								Rotifera (Rotifers)						
Bosmina sp.	R							Cyclops sp.							Keratella sp.	R						
Daphnia sp.								Dipatomus (H)							Kellicottia sp.	R						
Eubosmina sp.								Nauplii	P						Asplanchna sp.							
Chydorus	R							Skistodiaptomus sp.							Polarthra							
Diaphanosoma								Microcyclops sp	R						Hexarthra mira							
Caridodaphnia								Limnocalanus macrurus							Conochilus							
Leptodora kindtii								Leptodiaptomus sp.							Tricocerca							
Scapholeberis mucronata								Unknown Cyclopod							Bipalpus							
Bosmina longirostris								Unknown Calanoid							Arthropoda (Arthropods)							
Diaphanosoma brachyurum								Mesocyclops							Chaoborus punctipennis							
Diaphanosoma birgei								Diaicyclops							Ostracoda	R						
								Tropocyclops							Chironomidae	R						
Sites:	1	2	3	4				Notes:														
Total Phytoplankton Genera	14	0	0	0	0	0	0	Phytoplankton Key: Bloom (B), Common (C), Present (P), and Rare (R) Zooplankton Key: Dominant (D), Abundant (A), Present (P), and Rare (R); Herbivorous (H) or Carnivorous (C)														
Total Zooplankton Genera	7	0	0	0	0	0	0															
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Phytoplankton and Zooplankton Community Composition Analysis												
Sampling Location: Rockaway Lakes				Sampling Date: 7/12/2021								
Site 1: Lake Ames				Site 2: Lake Emma				Site 3: Green Pond				
Phytoplankton												
Bacillariophyta (Diatoms)				Chlorophyta (Green Algae)				Cyanophyta (Blue-Green Algae)				
<i>Asterionella</i>				<i>Actinostrium</i>				<i>Dolichospermum (formerly Anabaena)</i>				P
<i>Aulacoseira</i>				<i>Ankistrodesmus</i>				<i>Amphizomenon</i>				
<i>Cocconeis</i>				<i>Chlamydomonas</i>				<i>Aphanocapsa</i>				
<i>Cyclotella</i>				<i>Botryococcus</i>				<i>Chroococcus</i>				
<i>Cymatopleura</i>				<i>Chlorella</i>				<i>Cylindrospermum</i>				
<i>Cymbella</i>				<i>Coelastrum</i>				<i>Lyngbya</i>		R		R
<i>Denticula</i>				<i>Eudorina</i>				<i>Microcystis</i>		R		C
<i>Fragilaria</i>	R		R	<i>Gloeocystis</i>				<i>Nastoc</i>				
<i>Frustula</i>				<i>Dictyosphaerium</i>				<i>Pseudoanabaena</i>				
<i>Gyrosigma</i>				<i>Hydrodictyon</i>				<i>Oscillatoria</i>				
<i>Melosira</i>				<i>Monoraphidium</i>				<i>Coelosphaerium</i>				
<i>Nedium</i>				<i>Mougeotia</i>		P		<i>Spirulina</i>				
<i>Stauroneis</i>								<i>Aphanothece</i>				
<i>Stephanodiscus</i>				<i>Microspora</i>				<i>Snowella</i>				
<i>Surirekka</i>				<i>Ochromonas</i>				Euglenophyta (Euglenoids)				
<i>Synedra</i>		A		<i>Oedogonium</i>				<i>Colacium</i>				
<i>Tabellaria</i>				<i>Oocystis</i>				<i>Phacus</i>		P		
<i>Pinnularia</i>				<i>Scenedesmus</i>				<i>Euglena sp</i>				R
<i>Navicula</i>				<i>Spirogya</i>				<i>Trachelomonas</i>		R	P	
<i>Mastogloia</i>				<i>Treubaria</i>				Pyrrhophyta (Dinoflagellates)				
Chrysophyta (Golden Algae)				<i>Pediastrum</i>				<i>Ceratium</i>				
<i>Dinobryon</i>	P		P	<i>Volvox</i>			R		A			R
<i>Chromulina</i>				<i>Zygnema</i>				<i>Peridinium</i>				
<i>Mallomonas</i>				<i>Sphaerocystis</i>			R	<i>Cystodinium</i>				
<i>Ochromonas</i>		R		<i>Ulothrix</i>				Cryptomonads				
Synurophytes				Desmids (Green Algae)				<i>Chroomonas</i>				
<i>Chrysochaerella</i>	P			<i>Microsterias</i>				<i>Cryptomonas</i>		A		
				<i>Hyalotheca</i>			P					
				<i>Spondylosium</i>								
				<i>Clasterium</i>								
				<i>Desmidium</i>								
Unknown filaments				<i>Staurodesmus</i>								
Zooplankton												
Cladocera (Water Fleas)				Copepoda (Copepods)				Rotifera (Rotifers)				
<i>Bosmina sp.</i>	P		C	<i>Cyclops sp.</i>				<i>Keratella sp.</i>		R		
<i>Daphnia sp.</i>		R		<i>Dipodomus (H)</i>				<i>Kellicottia sp.</i>				
<i>Eubosmina sp.</i>				<i>Nauplii</i>	P	C	P	<i>Asplanchna sp.</i>				P
<i>Chydorus</i>	R			<i>Skistodiaptomus sp.</i>				<i>Polyarthra</i>		R		R
<i>Diaphanosoma</i>				<i>Microcyclops sp.</i>			P	<i>Hexarthra mira</i>				
<i>Ceriodaphnia</i>			P	<i>Limnocalanus macrurus</i>				<i>Conochilus</i>				
<i>Leptodora kindti</i>				<i>Leptodiaptomus sp.</i>				<i>Conochiloides</i>				
<i>Scapholeberis mucronata</i>				<i>Unknown Cyclopod</i>				<i>Branchionus</i>				
				<i>Orthocyclops</i>			R	<i>Tricercera</i>		R		R
<i>Bosmina longirostris</i>				<i>Unknown Calanoid</i>			R	R	Arthropoda (Arthropods)			
<i>Diaphanosoma brachyurum</i>				<i>Mesocyclops</i>					<i>Chaoborus punctipennis</i>			
<i>Diaphanosoma birgei</i>				<i>Diacyclops</i>					<i>Ostracoda</i>		R	
									<i>Water Mite</i>			R
				<i>Tropocyclops</i>					<i>Chironomidae</i>		R	
Sites:	1	2	3	4	Notes:							
Total Phytoplankton Genera	7	8	8	0	Phytoplankton Key: Bloom (B), Common (C), Present (P), and Rare (R) Zooplankton Key: Dominant (D), Abundant (A), Present (P), and Rare (R); Herbivorous (H) or Carnivorous (C)							
Total Zooplankton Genera	5	7	6	0								
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Phytoplankton and Zooplankton Community Composition Analysis																
Sampling Location: Rockaway Lakes					Sampling Date: 10/11/2021											
Site 1: Egbert 1.5 m tow					Site 2: Lake Emma 1 m tow					Site 3: Lake Telemark 1.2m tow		Site 4: Green Pond 8.5m tow				
Phytoplankton																
Bacillariophyta (Diatoms)					Chlorophyta (Green Algae)					Cyanophyta (Blue-Green Algae)						
Asterionella	R			R	Actinostrium					Dolichospermum (formerly Anabaena)	R	R				
Aulacoseira					Ankistrodesmus					Amphizomena	R					
Cocconeis					Chlamydomonas					Aphanocapsa						
Cyclotella					Botryococcus					Chroococcus						
Cymatopleura					Chlorella	P				Cylindrospermum						
Cymbella					Coelastrum					Lyngbya	P					
Denticula					Eudorina					Microcystis	P	P	R	R		
Fragilaria	P	R			Gloeocystis					Nostoc						
Frustulia					Dictyosphaerium					Pseudoanabaena						
Gyrosigma					Hydrodictyon					Oscillatoria				R		
Melosira		P	R		Monoraphidium					Coelosphaerium						
Nedum					Mougeotia	P	P			Spirulina						
Stauroneis										Aphanothece						
Stephanodiscus					Microspora											
Surirekka					Ochromonas					Euglenophyta (Euglenoids)						
Synedra			R	R	Oedogonium					Colacium						
Tabellaria					Oocystis					Phacus						
Pinnularia					Scenedesmus					Euglena sp						
Navicula	R	R			Spirogya			R		Trachelomonas	C	R	R			
Mastoglaia																
					Treubaria											
Chrysophyta (Golden Algae)					Desmids (Green Algae)					Pyrrhophyta (Dinoflagellates)						
Dinobryon	C	P	P	C	Pediastrum			R		Ceratium	R	R	R	R		
Chromulina					Volvox					Peridinium						
Mallomonas					Zygnema					Cystodinium						
Ochromonas		A			Sphaerocystis											
					Ulothrix					Cryptomonads						
Synurophytes					Micrasterias					Chroomonas						
Chrysohaerella	R			R	Micrasterias			R								
					Staurastrum			R	R							
					Spondyliolum			R	P							
					Closterium			P	R							
					Desmidium											
					Staurodesmus											
Unknown filaments																
Zooplankton																
Cladocera (Water Fleas)					Copepoda (Copepods)					Rotifera (Rotifers)						
Bosmina sp.	P	R		P	Cyclops sp.					Keratella sp.	R		R	C		
Daphnia sp.					Dipatomus (H)					Kellicottia sp.		R		R		
Eubosmina sp.					Nauplii	C	P	P	P	Asplanchna sp.	R		C			
Chydorus					Skistodiptomus sp.					Polyarthra	R		P	R		
Diaphanosoma					Microcyclops sp.	P	P	R	R	Hexarthra mira						
Ceriodaphnia	P				Limnocalanus macrurus					Conochilus	P					
Leptodora kindti					Leptodiptomus sp.					Tricocerca				P		
Scapholeberis mucronata					Unknown Cyclopoid					Bipalpus						
Bosmina longirostris					Unknown Calanoid	P	R			Arthropoda (Arthropods)						
Diaphanosoma brachyurum					Mesocyclops					Chaoborus punctipennis						
Diaphanosoma birgei					Diacyclops					Ostracoda						
					Tropocyclops					Chironomidae	R	R				
Sites:																
Total Phytoplankton Genera	16	13	8	8	0	0										
Total Zooplankton Genera	9	5	5	7	0	0										
Phytoplankton Key: Bloom (B), Common (C), Present (P), and Rare (R)																
Zooplankton Key: Dominant (D), Abundant (A), Present (P), and Rare (R); Herbivorous (H) or Carnivorous (C)																
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