TOWNSHIP OF BYRAM LAKES AND WATERSHEDS MANAGEMENT PLAN

TOWNSHIP OF BYRAM, SUSSEX COUNTY, NEW JERSEY

MAY 2024 - DRAFT

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1.0 INTRODUCTION

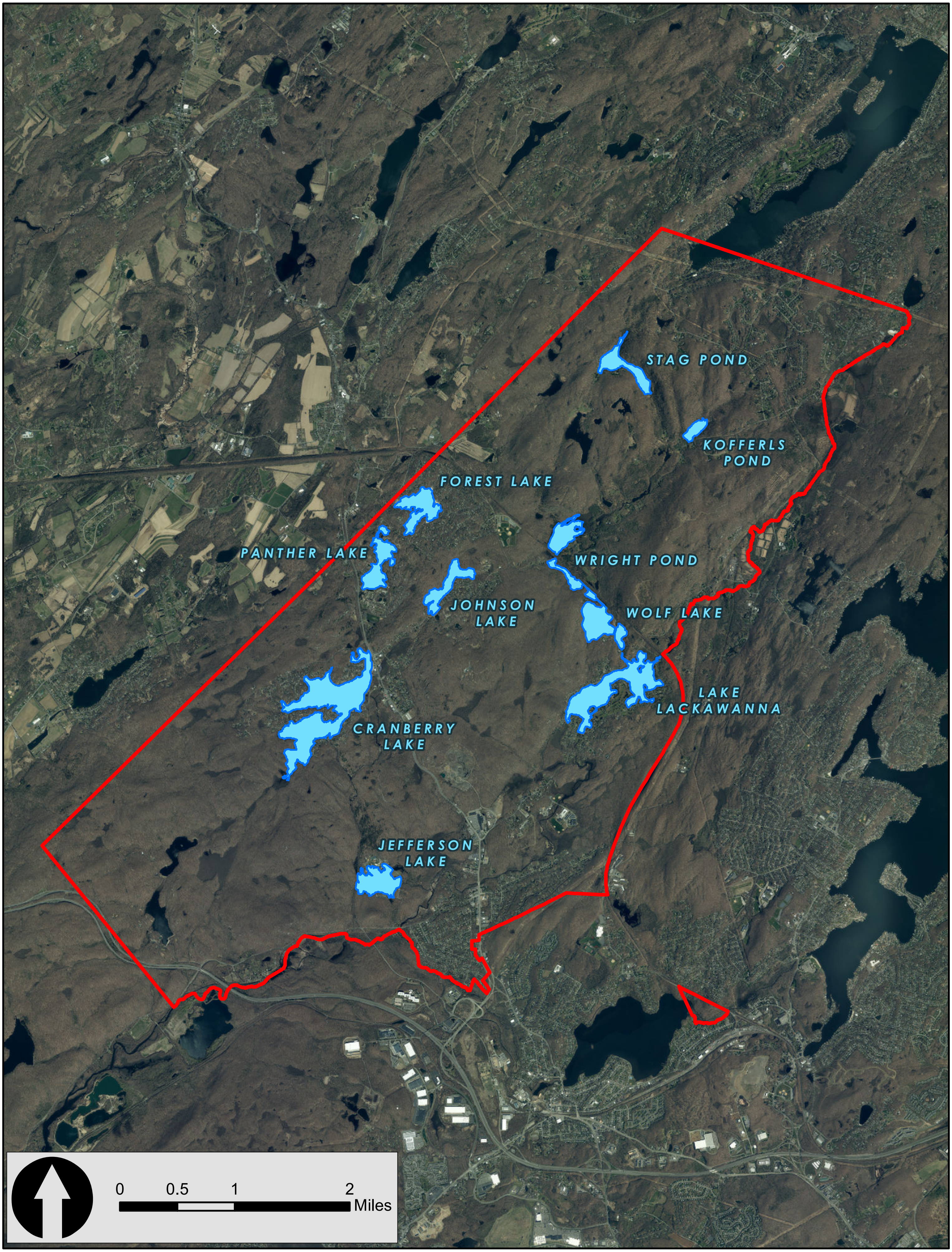
The Township of Byram (Township) includes multiple lakes and their respective lake associations (if private) within the Township limits and is locally known as "The Township of Lakes". Although these lakes are both public and private, the Township wished to take an active role in the management of the surrounding watersheds of these lakes, as the private lakes themselves are managed by their respective associations. This regional approach to lake management has recently been recommended by staff of both the New Jersey Department of Environmental Protection (NJDEP) and the New Jersey Highlands Council (NJHC) and has been implemented in other New Jersey Highland communities such as Ringwood Borough, Rockaway Township, West Milord Township, Byram Township and Vernon Township.

Given the large number of lakes in Byram Township, and in an effort to keep this first phase of an overall Township study to a reasonable scope of the funding already provided by the NJHC ($150,000.00), a selection process of which lakes to include occurred with input from the Township offices, the Township Environmental Commission, Princeton Hydro and ultimately, 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 or surrounded by permanently preserved land, including state-owned lakes, were eliminated from the study. Any reservoirs owned by private water utilities and lakes present on Federal facilities were also not included in the study. Finally, it is important to note that Lakes less than 10 acres that possessed a swimming beach WERE included due to the potential impacts of harmful algal blooms on the recreational use of these lakes. As a result of these conditions described above, the agreed upon list of lakes listed in this project were:

- Cranberry Lake
- Lake Lackawanna
- Johnson Lake
- Forest Lake
- Panther Lake
- Wolf Lake
- Wright Pond
- Jefferson Lake
- Stag Pond
- Kofferls Pond

A map of these lakes can be found in the subsequent page. This project aimed to identify the steps necessary for restoration and future management of these waterbodies. The following report is a Lake and Watershed Management Plan as based on the nine (9) minimum components of watershed plans by the USEPA.


STAG POND
KOFFERLS POND
FOREST LAKE
PANTHER LAKE
WRIGHT POND
JOHNSON LAKE
WOLF LAKE
LAKE LACKAWANNA
CRANBERRY LAKE
JEFFERSON LAKE
0
0.5
1
2
Miles

2.0 HISTORICAL DATA REVIEW

Historical data has been obtained from the Township, as well as other regulatory agencies, (such as NJDEP, NJDOT and the USGS), and reviewed in advance of the watershed assessment outlined in Sections 3.0, 4.0 and 5.0. By doing so, a capitalization on established water quality trends, problems and issues raised through any past sampling efforts, and evaluation of the relative success of any past restoration efforts was accomplished. All of the streams within each watershed that may feed these lakes was also included in a review of all available surface water data available through the USGS. This information is the foundation of the watershed assessment. This is part of a standard study approach for any aquatic system; integration of reliable data developed in past studies. Making use of these supplemental data collected by others to compliment the field efforts is beneficial, (with the assumption that the data were collected by properly trained personnel in a manner consistent with standard NJDEP quality assurance protection plan protocols). Princeton Hydro gave particular attention to any historical files with regards to the coliform testing required to maintain a swimming beach, if provided, from each of the lakes, whether they be public or private.

A brief review of historical data collected at the lakes is detailed in the sections below.

2.1 CRANBERRY LAKE

Cranberry Lake is an approximately 190-acre lake located within Byram Township, created by damming the area and flooding two kettle lakes in the 1830s to help serve as a feeder for the Morris Canal. This waterbody is located within the Highlands Preservation area. This waterbody is fueled by the two tributaries Ledge Run and Cranberry Bog Run, which are located in the northwest and southwest arms of the lake, respectively. The lake itself is classified as a FW2-TMC1, while its tributaries are considered FW2-NT (Ledge Run) and FW2-NTC1 (Cranberry Bog Run). Cranberry Lake is mainly utilized for recreational purposes, including fishing, boating and swimming. This lake shoreline is developed and contains both year-round and seasonal homeowners.

BATHYMETRIC SURVEY (NJFW)

A bathymetric map of Cranberry Lake was created by NJ Fish and Wildlife. This map, attached in Appendix I, details the shallow and deep pockets of the lake. The average lake depth across the entirety of the waterbody is approximately 7’. The deepest point according to this survey is 15’ and located in the northern end of the lake.

1992 PHASE I DIAGNOSTIC FEASIBILITY (COASTAL)

A Phase I Diagnostic Feasibility Study was conducted in 1992 utilizing grant funding through the 314 Clean Lakes Program grant. The purpose of this study was to characterize the waterbody, identify and quantify the issues causing eutrophication and degradation to the lake’s health and develop a restoration and management plan in response to these issues. Estimated annual nutrient loads for phosphorus, nitrogen and sediments were calculated and used to tailor recommendations.

Water quality monitoring, macrophyte surveys, fishery surveys and a variety of other investigations were conducted to determine the overall health and trophic state of the waterbody. Based on this data collection, Cranberry Lake was classified as eutrophic and under its current phosphorus loading conditions, it is expected to continue to support excessive productivity. In response to this discovery, this study dictates that long-term management of the lake will require implementation of nutrient and sediment removal techniques through septic management, soil erosion control, stormwater management, land use ordinances and product modifications. In-lake restoration measures including aquatic vegetation removal, spot dredging and hypolimnetic applications of nutrient inactivants.

1998 PHASE II IMPLEMENTATION (PRINCETON HYDRO)

Upon completion of the Phase I study mentioned above, Byram Township was awarded grant funding from NJDEP for the consideration for USEPA Phase II Implementation. This funding went towards the reduction of non-point source pollutant loading to Cranberry Lake, examining feasibility of aquatic vegetation harvesting and further public education on septic management, fertilizer use and other initiatives to improve water quality as well as the implementation of a water quality monitoring program.

Mechanical harvesting trials were conducted, and it was determined hydroraking and harvesting, in concert with selective herbicide treatments were an effective means of aquatic vegetation control. Highlights from the stormwater management portion of this plan include the replacements of over 50 catch basins with water quality basins, continued cleaning schedules for these basins, repair of eroding shoreline area utilizing a bulkhead, creation o a roadside swale and the construction of a multi-chambered sedimentation basin. The water quality monitoring program consisted of monthly sampling of the lake between 1993 and 1996. A detailed sensitive land management plan was prepared to identify the watershed's sensitive natural resources and determine where developing in the area would have the highest impacts.

1998 MTBE AND OTHER VOLATILE COMPOUNDS (USGS)

A study conducted by USGS, specifically Baehr and Zapecza, studied the occurrence of methyl tert-butyl ether (MTBE) and other volatile organic compounds in four lakes within Byram Township, including Cranberry Lake, Lake Lackawanna, Forest Lake and Stag Pond. By this study, NJDEP had set a maximum human health threshold for MTBE of 70 µg/L. MTBE concentrations varied between the June and September sampling events, with measures between 1.6 µg/L and 29.0 µg/L. While the concentrations noted at Cranberry Lake did not contravene the 70 µg/L threshold, other agencies/states have set lower thresholds, such as 20 µg/L at the EPA to as low as 14 µg/L in California. Other VOCs including tert-amyl-methyl ether (TAME) and benzene, toluene, ethylbenzene and xylenes (BTEX) were also identified in higher densities.

2003 TMDL FOR PHOSPHORUS (NJDEP)

In accordance with the Federal Clean Water Act, NJDEP developed the 2002 Integrated List of waterbodies to address the overall water quality of the State's waters and identify impaired waterbodies for which TMDLs may be required. This document established that Cranberry Lake required a TMDL for phosphorus. This TMDL requires a reduction to a steady state phosphorus concentration of 0.03 mg/L to avoid contravening the 0.05 mg/L phosphorus NJ Surface Water Quality Standards criteria. Target TP conditions of 0.02 mg/L with a maximum upper bound condition of 0.03 mg/L were established to restore compliance within this lake. A reduction of approximately 73% of the overall TP load is needed to be in compliance.

CRANBERRY LAKE MANAGEMENT PROGRAM (CLCC)

A lake management program was released by the Cranberry Lake Community Club in concert with Aquatic Technologies Inc. This document consists of vegetation control measures and water testing at the lake, projects to improve water quality in the lake, State approved lake regulations, and information for the public including bulletins, educational programs, boating safety courses and more.

2004 NORTH SHORE WATER ASSOCIATION SWAR/SUMMARY (NJDEP)

In accordance with the Safe Drinking Water Act, NJDEP conducted a source water assessment for North Shore Water Association (NSWA). The goal of this assessment was to identify the source water assessment area that supplies water to the NSWA drinking water system, inventorying any significant potential sources of contamination in the area and analyzing how susceptible the drinking water source is to the potential sources of contamination. NSWA consists of one well and the system's source water comes from igneous and metamorphic rocks. Overall, Low susceptibility ratings were observed for pathogens, pesticides, VOCs and inorganics, Medium susceptibility ratings were observed for radionuclides/radon and DBPs (Disinfectant Byproduct Precursors) and high susceptibility ratings were noted for nutrients.

2004 STRAWBERRY POINT PROPERTY OWNERS ASSOCIATION/SUMMARY (NJDEP)

In accordance with the Safe Drinking Water Act, NJDEP conducted a source water assessment for Strawberry Point Property Owners Association (SPPOA). The goal of this assessment was to identify the source water assessment area that supplies water to the SPPOA drinking water system, inventorying any significant potential sources of contamination in the area and analyzing how susceptible the drinking water source is to the potential sources of contamination. SPPOA consists of two wells and the system's source water comes from igneous and metamorphic rocks. Both wells yielded Low susceptibility ratings for pesticides, VOCs and inorganics, while both wells yielded Medium susceptibility ratings for radionuclides, radon and DBPs. Differences were observed in terms of pathogen and nutrient contamination, with Low or Medium susceptibility to pathogens and Medium to High susceptibility to nutrients.

2010 TMDL FOR MERCURY (NJDEP)

Cranberry Lake currently has a Total Maximum Daily Load (TMDL) designation for mercury in fish tissue. This TMDL is listed for Cranberry Lake, Jefferson Lake and its tributaries. It should be noted that the mercury in fish tissue TMDL applies to the majority of lakes in northern New Jersey and is the result of historical atmospheric deposition. The target for the TMDL is a concentration of 0.18 μg/g in fish tissue, which is the concentration at which the recommended rate of fish consumption for the high-risk population is not more than 1 meal per week of top trophic level fish.

2016 FISHERY SURVEY (NJFW)

The NJ Department of Fish and Wildlife (NJFW) conducted fishery surveys utilizing a variety of collection techniques on a total of twelve (12) waterbodies for target species during the 2016 season. Surveys at Cranberry Lake were funded under the Sport Fish Restoration Federal Grant F-48-R to perform cool water fisheries assessments. Northern pike were targeted at this waterbody and were collected utilizing a total of 15 trap nets over four sampling days. A very low catch rate was observed (two pike), indicating low population abundance within the lake. While Northern pike densities were low, the native game species chain pickerel were identified in healthy population sizes.

WQDE MONITORING LOCATION

The New Jersey Department of Environmental Protection (NJDEP) and the affiliated Bureau of Freshwater and Biological Monitoring (BFBM) established a total of three water quality monitoring sites within Cranberry Lake, including Station IDs NJLM-0918-1, NJLM-0918-2 and NJLM-0918-3. The dataset contains water quality data from 2016 - 2018 and include a large variety of parameters: temperature, turbidity, alkalinity, chlorophyll a, hardness, ammonia-nitrogen, inorganic nitrogen, Kjeldahl nitrogen, phosphate-phosphorus, Secchi clarity, dissolved oxygen, pH, and specific conductance. The BFBM also established the fishery sampling station FTM041. This station collected and analyzed fish tissue samples for weight, length, mercury content and a variety of polychlorinated biphenyls (PCBs).

BYRAM TOWNSHIP § 272-15

According to septic management requirements set by Byram Township, minimum pumping requirements must be met within the Cranberry Lake program area. Unless a request for an extension or an application for an exemption has been granted in accordance with the provisions of this article, each individual subsurface sewage disposal system in the program areas must be pumped at least every three years. Homeowners may adopt a one- or two-year pumping schedule, or the Township may require such a schedule where there is evidence that a system is substandard or functioning poorly.

2.2 LAKE LACKAWANNA

Lake Lackawanna is an approximately 117-acre lake in Byram Township created in 1910 by damming Lubbers Run stream. This waterbody is located within the Highlands Preservation area. This waterbody is fueled by two tributaries of Lubbers Run, which are located in the northern end of the lake. Lake Lackawanna is classified as a FW2-NTC1 waterbody while its inlets and outlets are classified as FW2-TMC1. Lake Lackawanna is mainly utilized for recreational purposes, including fishing, boating and swimming. This lake shoreline is heavily developed.

1998 MTBE AND OTHER VOLATILE COMPOUNDS (USGS)

A study conducted by USGS, specifically Baehr and Zapecza, studied the occurrence of methyl tert-butyl ether (MTBE) and other volatile organic compounds in four lakes within Byram Township, including Cranberry Lake, Lake Lackawanna, Forest Lake and Stag Pond. By this study, NJDEP had set a maximum human health threshold for MTBE of 70 µg/L. While the concentrations noted at Lake Lackawanna (between 3.7 µg/L and 14.0 µg/L) remained below this recommended threshold, other agencies/states have set much lower thresholds as low as 14 µg/L (California). Another VOC, tert-amyl-methyl ether (TAME) was also identified in higher densities.

TMDL FOR FECAL COLIFORMS 2007 (NJDEP)

In accordance with the Federal Clean Water Act, NJDEP developed the 2006 Integrated List of waterbodies to address the overall water quality of the State's waters and identify impaired waterbodies for which TMDLs may be required. This document established that Lake Lackawanna required a TMDL for pathogens, such as fecal coliforms and E. coli. Lake Lackawanna would require a land-based load allocation reduction of 93% to be compliant with the TMDL.

RULES AND REGULATIONS FOR THE USE OF THE FACILITIES OF LAKE LACKAWANNA INVESTMENT COMPANY, INC

This document sets forth the rules and regulations set by Lake Lackawanna Investment Company Inc for the members of Lake Lackawanna. A variety of rules are enforced to improve the quality of the lake and surrounding areas, including avoiding phosphorus-based products, septic management, and picking up after pets. Additionally, lake-based programs such as catch and release fishing and lake drawdowns every four drawdowns.

BYRAM TOWNSHIP § 272-15

According to septic management requirements set by Byram Township, minimum pumping requirements must be met within the Lake Lackawanna program area. Unless a request for an extension or an application for an exemption has been granted in accordance with the provisions of this article, each individual subsurface sewage disposal system in the program areas must be pumped at least every three years. Homeowners may adopt a one- or two-year pumping schedule, or the Township may require such a schedule where there is evidence that a system is substandard or functioning poorly.

FISH INDEX OF BIOTIC INTEGRITY (NJDEP BUREAU OF GIS)

The Fish Index of Biotic Integrity network was created as a biomonitoring network to supplement the current Ambient Biomonitoring Network. A FIBI is an index that measures the health of a stream based on multiple attributes of the resident fish assemblage. A stream site within Lubbers Run north of Lake Lackawanna contains a Fish Index of Biotic Integrity rating. It is classified as IBI rating round 1 'good' and habitat rating round 2 'optimal'.

2.3 JOHNSON LAKE

Johnson Lake is an approximately 38-acre lake located in Byram Township. This waterbody is located within the Highlands Preservation area. This lake contains two tributaries, located in the northeastern and southeastern portions of the lake. Both the tributaries and the lake itself were classified as FW2-NT.

2010 TMDL FOR MERCURY (NJDEP)

Johnson Lake currently has a Total Maximum Daily Load (TMDL) designation for mercury in fish tissue. This TMDL is listed for Cranberry Lake, Jefferson Lake and its tributaries. It should be noted that the mercury in fish tissue TMDL applies to the majority of lakes in northern New Jersey and is the result of historical atmospheric deposition. The target for the TMDL is a concentration of 0.18 µg/g in fish tissue, which is the concentration at which the recommended rate of fish consumption for the high-risk population is not more than 1 meal per week of top trophic level fish.

2017 MONITORING REPORT (PRINCETON HYDRO AND NJCF)

The New Jersey Conservation Foundation (NJCF) contracted Princeton Hydro to conduct a water quality monitoring study, that included in-situ, discrete and biological monitoring, a vegetation survey, a bathymetric study, as well as a historical data search and pollutant load analyses.

While the lake was not thermally stratified during this sampling period, anoxic conditions (DO<1 mg/L) were present in the deeper reaches of the Lake. This is likely due to the inability of the lake to have wind and wave action due to the heavy emergent vegetation present lake-wide. Deep-water TP concentrations exceeded state thresholds, an indication that internal loading of P is likely occurring. The vegetation survey showed that the majority of the waterbody (80-90%) is covered in floating emergent species, such as watershield *(Brasenia schreberi*), yellow waterlily (*Nuphar spp*) and white waterlily *(Nuphar odorata)*. The few open areas were populated by the invasive species Eurasian watermilfoil (*Myriophyllum spicatum*).

The pollutant loading analysis show that the greatest external nutrient control improvements could be achieved through stormwater management efforts implemented within the developed areas of the watershed, including the use of both structural and non-structural stormwater management measures. Also, the pond at the end of Ghost Pony Brook, one of the main tributaries, should be maintained in order to achieve the highest efficiency of pollutant load removal before these pollutants can move into Johnson Lake. The bathymetric survey conducted on this waterbody detailed an average water depth of approximately 5’, with maximum depths of 9.5’ identified. A total of 258,224 cubic yards of unconsolidated sediment was estimated to be within Johnson Lake. Sediment deposition was heavier at the entering tributaries. Maximum deposition was observed in the northernmost portion of the lake and the southwestern cove, reaching maximum sediment depths of 10’.

2.4 FOREST LAKE

Forest Lake is an approximately 44-acre lake in Byram Township that was created in the 1950s as a private lake community. This waterbody is located within the Highlands Preservation area. Forest Lake is mainly utilized for recreational purposes, including fishing, boating and swimming by the members of the Forest Lakes Club. Unlike a lot of the waterbodies in this area, the direct shoreline is mainly forested with the exception of a few beach areas. The majority of housing development around this lake is located 150’ off the shoreline.

1998 MTBE AND OTHER VOLATILE COMPOUNDS (USGS)

A study conducted by USGS, specifically Baehr and Zapecza, studied the occurrence of methyl tert-butyl ether (MTBE) and other volatile organic compounds in four lakes within Byram Township, including Cranberry Lake, Lake Lackawanna, Forest Lake and Stag Pond. Forest Lake. All VOC concentrations at this waterbody were below 0.2 µg/L, and not at a level for concern.

TMDL FOR FECAL COLIFORMS 2007 (NJDEP)

In accordance with the Federal Clean Water Act, NJDEP developed the 2006 Integrated List of waterbodies to address the overall water quality of the State's waters and identify impaired waterbodies for which TMDLs may be required. This document established that Forest Lake required a TMDL for pathogens, such as fecal coliforms and E. coli. Forest Lake would require a land-based load allocation reduction of 98% to be compliant with the TMDL.

2010 TMDL FOR MERCURY (NJDEP)

In accordance with the Federal Clean Water Act, NJDEP developed the 2006 Integrated List of waterbodies to address the overall water quality of the State's waters and identify impaired waterbodies for which TMDLs may be required. This document established that Forest Lake is considered part of the New Wawayanda Lake and Andover Pond tributaries streamshed, which is designated as being impaired for total phosphorus.

2020 TMDL FOR MERCURY (NJDEP)

A Total Maximum Daily Load (TMDL) designation for mercury in fish tissue for New Wawayanda Lake and Andover Pond tributaries. While Forest Lake is not directly listed under this TMDL, it is considered a part of the streamshed for these waterbodies. It should be noted that the mercury in fish tissue TMDL applies to the majority of lakes in northern New Jersey and is the result of historical atmospheric deposition. The target for the TMDL is a concentration of 0.18 μg/g in fish tissue, which is the concentration at which the recommended rate of fish consumption for the high risk population is not more than 1 meal per week of top trophic level fish.

2.5 PANTHER LAKE

Panther Lake is an approximately 40-acre lake in Byram Township. This lake is located within the Highlands Preservation area. This waterbody is a kettle lake that formed approximately 10-12,000 years ago from retreating glaciers and was dammed in the 1800s. Panther Lake is mainly utilized for recreational purposes, including fishing, boating and swimming. The waterbody is directly fueled by the dammed Cub Lake upstream.

BATHYMETRIC SURVEY (NJFW)

A bathymetric map of Panther Lake was created by NJ Fish and Wildlife. This map, attached in Appendix I, details the shallow and deep pockets of the lake. While smaller than some of the other waterbodies, maximum depths of this lake reach 40'. The average water depth for this lake is approximately 9'.

WQDE MONITORING LOCATION

The New Jersey Department of Environmental Protection (NJDEP) and the affiliated Bureau of Freshwater and Biological Monitoring (BFBM) established a total of two water quality monitoring sites within Panther Lake, including Station IDs NJW04459-289-1 and NJW04459-289-2. The dataset contains water quality data from the 2009 and 2014 seasons and include a large variety of parameters: temperature, turbidity, alkalinity, chlorophyll a, hardness, ammonia-nitrogen, inorganic nitrogen, Kjeldahl nitrogen, phosphate-phosphorus, Secchi clarity, dissolved oxygen, pH, and specific conductance.

2010 BATHYMETRIC SURVEY AND IMPOUNDMENT ASSESSMENT (PRINCETON HYDRO)

Princeton Hydro completed a bathymetric survey and geomorphic assessment of Panther Lake and Cub Lake on behalf of the Panther Lake Camping Resort, Inc. (PLCR). The bathymetric survey conducted by Princeton Hydro yielded very similar results to the survey conducted by NJFW, with maximum depths of 39.9' and an average depth of 10.4'. Alongside the bathymetric survey, an analysis of the Panther and Cub Lake dams was conducted to determine their impacts on each waterbody if the dams were removed. It was determined that Panther Lake would exist without the presence of the Panther Lake dam or Cub Lake dam, just at a lower water level. Maximum depths would only decline from 40' to approximately 34' if the dams were removed. If the Cub Lake dam was removed the lake would cease to exist, while it would still be present if the Panther dam was removed.

2010 TMDL FOR MERCURY (NJDEP)

In accordance with the Federal Clean Water Act, NJDEP developed the 2006 Integrated List of waterbodies to address the overall water quality of the State's waters and identify impaired waterbodies for which TMDLs may be required. This document established that Panther Lake is considered part of the New Wawayanda Lake and Andover Pond tributaries streamshed, which is designated as being impaired for total phosphorus.

2020 TMDL FOR MERCURY (NJDEP)

A Total Maximum Daily Load (TMDL) designation for mercury in fish tissue for New Wawayanda Lake and Andover Pond tributaries. While Panther Lake is not directly listed under this TMDL, it is considered a part of the streamshed for these waterbodies. It should be noted that the mercury in fish tissue TMDL applies to the majority of lakes in northern New Jersey and is the result of historical atmospheric deposition. The target for the TMDL is a concentration of 0.18 μg/g in fish tissue, which is the concentration at which the recommended rate of fish consumption for the high risk population is not more than 1 meal per week of top trophic level fish.

2.6 WOLF LAKE

Wolf Lake is an approximately 45-acre lake located in Byram Township. This lake is situated between Wright Pond and Lackawanna Lake and is classified as FW2-NTC1. This waterbody is located within the Highlands Preservation area.

TMDL FOR FECAL COLIFORMS FOR LACKAWANNA LAKE 2007 (NJDEP)

In accordance with the Federal Clean Water Act, NJDEP developed the 2006 Integrated List of waterbodies to address the overall water quality of the State's waters and identify impaired waterbodies for which TMDLs may be required. This document established that Lake Lackawanna required a TMDL for pathogens, such as fecal coliforms and E. coli. Lake Lackawanna would require a land-based load allocation reduction of 93% to be compliant with the TMDL. While not directly identified under this TMDL, Wolf Lake is considered to be in the Lackawanna lakeshed and falls under the TMDL.

2.7 WRIGHT POND

Wright Pond is an approximately 32-acre lake located in Byram Township. This waterbody has three tributaries of Lubbers Run entering the northern end of the lake. The Lake itself is classified as FW2-NTC1, while each tributary is classified as FW2-TMC1. This waterbody is located within the Highlands Preservation area.

TMDL FOR FECAL COLIFORMS FOR LACKAWANNA LAKE 2007 (NJDEP)

In accordance with the Federal Clean Water Act, NJDEP developed the 2006 Integrated List of waterbodies to address the overall water quality of the State's waters and identify impaired waterbodies for which TMDLs may be required. This document established that Lake Lackawanna required a TMDL for pathogens, such as fecal coliforms and E. coli. Lake Lackawanna would require a land-based load allocation reduction of 93% to be compliant with the TMDL. While not directly identified under this TMDL, Wright Pond is considered to be in the Lackawanna lakeshed and falls under the TMDL.

WQDE MONITORING LOCATION

The New Jersey Department of Environmental Protection (NJDEP) and the affiliated Bureau of Freshwater and Biological Monitoring (BFBM) established a single water quality monitoring sites within Wright Pond, including Station IDs NJLM-1010-1. The dataset contains water quality data from the 2018 season and include a large variety of parameters: temperature, turbidity, alkalinity, chlorophyll a, hardness, ammonia-nitrogen, inorganic nitrogen (nitrate+nitrite), Kjeldahl nitrogen, total phosphorus, Secchi clarity, dissolved oxygen, pH, and specific conductance.

2.8 JEFFERSON LAKE

Jefferson Lake is an approximately 43-acre lake in Byram Township. Jefferson Lake contains multiple tributaries, including the Cranberry Lake outlet stream and a variety of Jefferson Lake tributaries entering around the waterbody. This waterbody is classified as FW2-NTC1. For the most part, all tributaries were also FW2-NTC1, with a tributary of the Musconetcong River listed as FW2-TM. This waterbody is located within the Highlands Preservation area.

2010 TMDL FOR MERCURY (NJDEP)

Jefferson Lake currently has a Total Maximum Daily Load (TMDL) designation for mercury in fish tissue. This TMDL is listed for Cranberry Lake, Jefferson Lake and its tributaries. It should be noted that the mercury in fish tissue TMDL applies to the majority of lakes in northern New Jersey and is the result of historical atmospheric deposition. The target for the TMDL is a concentration of 0.18 µg/g in fish tissue, which is the concentration at which the recommended rate of fish consumption for the high risk population is not more than 1 meal per week of top trophic level fish.

2.9 STAG POND

Stag Pond is an approximately 33-acre lake located in Byram Township. This lake is located within the Highlands Preservation area and is fueled by a tributary of Lubbers Run. The waterbody itself is classified as FW2-NTC1 while its tributary is classified as FW2-TMC1.

1998 MTBE AND OTHER VOLATILE COMPOUNDS (USGS)

A study conducted by USGS, specifically Baehr and Zapecza, studied the occurrence of methyl tert-butyl ether (MTBE) and other volatile organic compounds (VOCs) in four lakes within Byram Township, including Cranberry Lake, Lake Lackawanna, Forest Lake and Stag Pond. All VOC concentrations at this waterbody were below 0.2 µg/L, and not at a level for concern.

TMDL FOR FECAL COLIFORMS FOR LACKAWANNA LAKE 2007 (NJDEP)

In accordance with the Federal Clean Water Act, NJDEP developed the 2006 Integrated List of waterbodies to address the overall water quality of the State's waters and identify impaired waterbodies for which TMDLs may be required. This document established that Lake Lackawanna required a TMDL for pathogens, such as fecal coliforms and E. coli. Lake Lackawanna would require a land-based load allocation reduction of 93% to be compliant with the TMDL. While not directly identified under this TMDL, Stag Pond is considered to be in the Lackawanna lakeshed and falls under the TMDL.

WQDE MONITORING LOCATION

The New Jersey Department of Environmental Protection (NJDEP) and the affiliated Bureau of Freshwater and Biological Monitoring (BFBM) established a total of two water quality monitoring sites within Stag Pond, including Station IDs NJW04459-177-1 and NJW04459-177-2. The dataset contains water quality data from the 2009 and 2014 seasons and include a large variety of parameters: temperature, turbidity, alkalinity, chlorophyll a, hardness, ammonia-nitrogen, inorganic nitrogen (nitrate+nitrite), Kjeldahl nitrogen, phosphate- phosphorus, Secchi clarity, dissolved oxygen, pH, and specific conductance.

2.10 KOFFERLS POND

Kofferls Pond is an approximately 12-acre lake located in Byram Township and is situated in the Highlands Preservation area. This lake is fueled by a Lubbers Run tributary located on the northern end of the waterbody. Kofferls Pond is considered a FW2-NTC1 waterbody, while its inlet is classified as FW2-TMC1.

TMDL FOR FECAL COLIFORMS FOR LACKAWANNA LAKE 2007 (NJDEP)

In accordance with the Federal Clean Water Act, NJDEP developed the 2006 Integrated List of waterbodies to address the overall water quality of the State's waters and identify impaired waterbodies for which TMDLs may be required. This document established that Lake Lackawanna required a TMDL for pathogens, such as fecal coliforms and E. coli. Lake Lackawanna would require a land-based load allocation reduction of 93% to be compliant with the TMDL. While not directly identified under this TMDL, Kofferls Pond is considered to be in the Lackawanna lakeshed and falls under the TMDL.

3.0 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. Sub-watersheds were edited in ESRI's ArcMAP and QGIS Desktop. 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 II. GIS shapefiles for each sub-watershed and total watershed were imported into Model My Watershed, which produced a .gms file containing hydrologic and nutrient data for a 30-year period. This file was subsequently entered into Penn State's Generalized Watershed Loading Functions-Enhanced (GWLF-E) tool. Edits to the .gms file were made in Model my Watershed prior to export and in GWLF-E. In order to assess septic system loading, all houses within each watershed were counted (excluding sewered locations), with the number of houses with 15 m of a lake or stream also noted. Populations within 15m of the lake or any inflowing waterways, as well as 5% of the total population, were assumed to "short circuit" or contribute nutrients to waterways and/or groundwater prematurely; these systems usually contribute higher amounts of nutrients than systems with no issues.

Many of the lakes in Byram Township are inhabited by a population of Canada goose (*Branta canadensis*) or other waterfowl. While these birds can be a nuisance to lake users for several reasons, their droppings can also negatively impact water quality by adding excess phosphorus and nitrogen. These loads were estimated using GWLF-E's farm animal module, as well as coefficients for each nutrient yielded by each goose each day (Manny et al., 1975). Bacterial loads contributed to Canada geese were modeled using the same estimated loading rate use in the GWLF-E model for turkeys. Each lake was estimated to contain at least two Canada geese and were modeled for larger numbers of birds if field observations indicated a larger population. A migratory population of an estimated three times the resident population. For each lake, an average was calculated of geese numbers, assuming a year-round number for 11 months and a migration population for 1 month. Goose-based nutrient modeling was only applied to full watersheds. It should be noted that the Canada goose population numbers in each scenario are estimates; this model may be fine-tuned in the future using Canada goose and other waterfowl count data collected in Byram Township.

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

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

In addition to watershed-based loading, internal loading of phosphorus in each lake was calculated using a loading coefficient of 6 mg TP/m^2/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/m^2/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 Wolf Pond or Wright Lake, as in-field measurements and observations could not be collected due to a lack of property access.

3.2 RESULTS

CRANBERRY LAKE

Cranberry Lake is an approximately 187.72-acre impoundment located in the southern portion of the township. The lake's 1510.8-acre watershed is over 75% forested, with wetlands and low-density open space making up a majority of the remaining space. The lake receives most of its flow from its two main inlets: Ledge Run entering the northwestern corner of the lake and Cranberry Bog Run entering the southern-most tip of the lake. The lake's outlet stream leaves the lake along the eastern edge, quickly joining Ghost Pony Brook and continuing south to Jefferson Lake, Lubbers Run, and the Musconetcong River.
Descriptions of the waterbody's subwatersheds are as follows:

- **Cabin Spring:** This subwatershed is located in the northwestern portion of the lake and covers an area of about 85.7 acres. Approximately 63% of this area consists of low-density open space, with forested land comprising an additional approximately 34%.
- **Bog Run:** This subwatershed is located off the southern tip of Cranberry Lake and contains the inlet stream Cranberry Bog Run, covering an area of approximately 491.5 acres. This watershed is approximately 85% forested.
- **French Grove:** This subwatershed abuts the northern shoreline of Cranberry Lake and contains a small inlet and some small wetlands. As with most of the other subwatersheds, French Grove is mostly forested, with wetlands and low-density open space comprising the remaining space.
- **Hilltop:** This smaller 21.3-acre subwatershed is located along the southern edge of the waterbody and is 100% forested.
- **Laurel Cove:** This is the northern-most of Cranberry Lake's subwatersheds and covers an area of approximately 87.1 acres. Over 50% of the area is forested, with urbanized landcover making up a notable area towards the lake's shoreline. A small inlet is also present.
- **Ledge Run:** This is the largest of Cranberry Lake's subwatersheds at approximately 586.1 acres. As its name suggests, it contains the major inlet Ledge Run. The area is over 80% covered in forested land, with notable amounts of wetland and urnabized land also present.
- **Meteor Trail:** This subwatershed is located along the northern shoreline of Cranberry Lake and is largely urbanized, with a total area of approximately 20.2 acres.
- **Northeast:** This small, 13-acre subwatershed contains Route 206 and some of the immediately adjacent urbanized areas. Approximately 5.9 acres of the area are also forested.
- **Southeast:** This small, 23.4-acre subwatershed contains mostly forested land cover, with small amounts of wetland and open space also present.
- **Southwest:** This 53.3-acre subwatershed is largely forested, with small amounts of wetlands and urbanized landcover also present.
- **Strawberry Point:** This subwatershed encompasses the point seperating the northern and southern basins of Cranberry Lake, comprising an area of approximately 28.6 acres. Most of this land consists of residential urbanized landcover, with some forested land and wetlands also present.
- **Waramung:** This 22.7-acre subwatershed is located along the eastern edge of the waterbody and contains the lake's dam. The area is over 60% urbanized.

According to the USDA's Gridded Soil Survey Geographic (SSURGO) 2016 hydrologic soil groups data, the Cranberry Lake watershed consists largely of the soil type "C – slow infiltration", with approximately 28.1% of the area featuring soil type "D – very slow infiltration". These soils allow for relatively low infiltration of rainwater into the water table, generating relatively high runoff during rain events and thus increased erosion. The Northeast subwatershed features the highest percentage (52.6%) of soil type D.

Variations in elevation change in a watershed can determine the impact water runoff has on soil erosion, with steeper slopes causing higher erosion rates, especially if little vegetation is present. While the percent slope in the full watershed averages approximately 12.4%, the maximum percent slope is approximately 53.2%, which occurs in both the French Grove and Laurel Cove subwatersheds. The Northeast subwatershed featured the highest average percent slope, at approximately 17.2%.

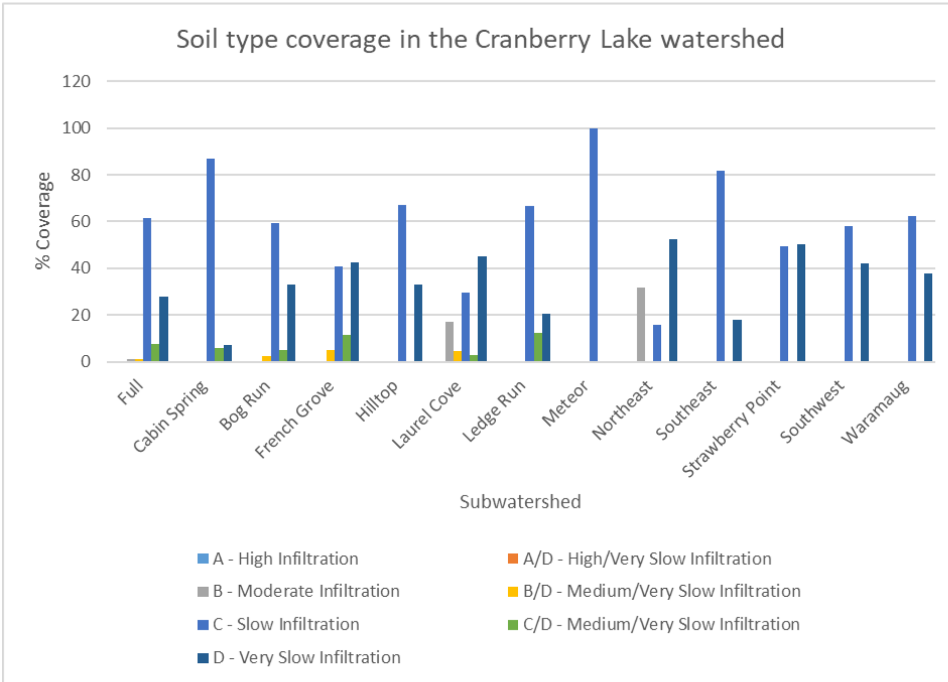


Figure 3.1. Percent coverage of the Cranberry Lake watershed and subwatersheds by different hydrologic soil groups.

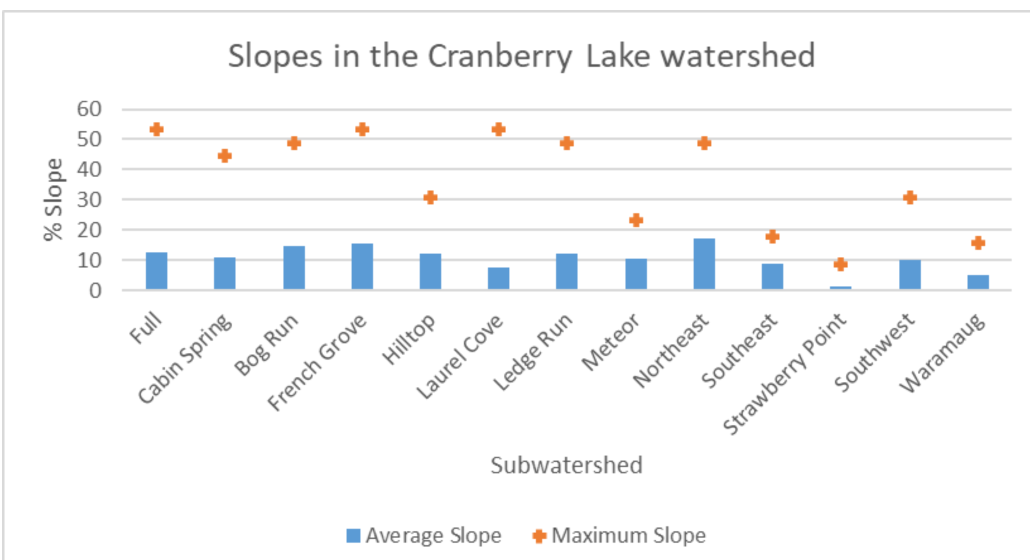


Figure 3.2. Variation in average and maximum percent slope between subwatersheds in the Cranberry Lake watershed.

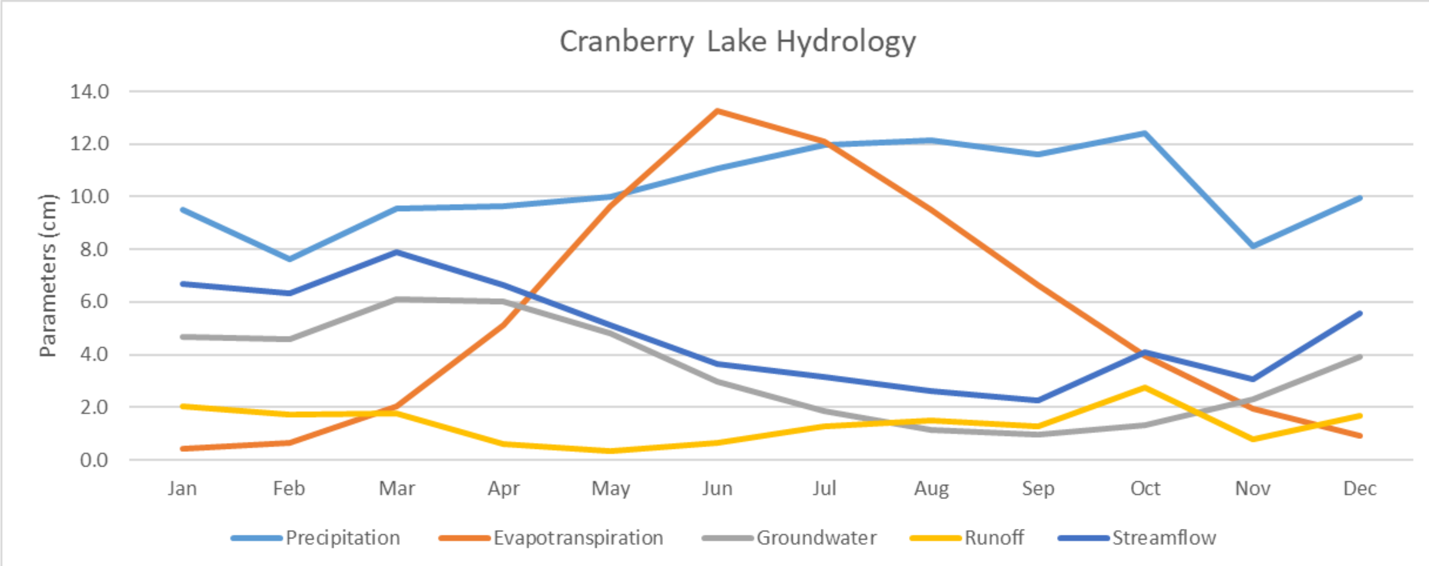


Figure 3.3. Estimated seasonal changes in hydrology in the Cranberry Lake Watershed

Table 3.1. Total hydrological parameters in the Cranberry Lake watershed

Month	Precipitation	Evapotranspiration	Groundwater	Runoff	Streamflow	
	cm	cm	cm	cm	cm	cfs
Jan	9.5	0.4	4.7	2.0	6.7	5.4
Feb	7.7	0.6	4.6	1.7	6.3	5.6
Mar	9.6	2.1	6.1	1.8	7.9	6.4
Apr	9.7	5.1	6.0	0.6	6.6	5.5
May	10.0	9.6	4.8	0.3	5.1	4.1
Jun	11.1	13.3	3.0	0.6	3.6	3.0
Jul	12.0	12.1	1.9	1.3	3.2	2.5
Aug	12.1	9.5	1.1	1.5	2.6	2.1
Sep	11.6	6.7	1.0	1.3	2.3	1.9
Oct	12.4	4.0	1.3	2.8	4.1	3.3
Nov	8.1	2.0	2.3	0.8	3.1	2.6
Dec	10.0	0.9	3.9	1.7	5.6	4.5
Total	123.6	66.2	40.7	16.4	57.1	3.9

Runoff varied between the different subwatersheds, with the Northeast subwatershed yielding a notably higher runoff throughout the year. This is likely due to its relatively high acreage of impervious landcover, very slow-infiltration soil, and relatively steep average slope.

As displayed in Table 3.1, most hydrologic data is presented in the one-dimensional unit of centimeters, in order to relate these metrics back to precipitation, the base of a watershed's hydrology. This allows for a simpler comparison between watersheds. The total amount of water in m^3 each of these values represents can be calculated by multiplying the value by 0.01 (in order to convert the unit to m^2) and multiplying this product by the total watershed area in m^2. 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 waterbody itself are factored in, Cranberry Lake is estimated to receive approximately 3,928,319.9 m³ or 1,037.8 million gallons of water a year.

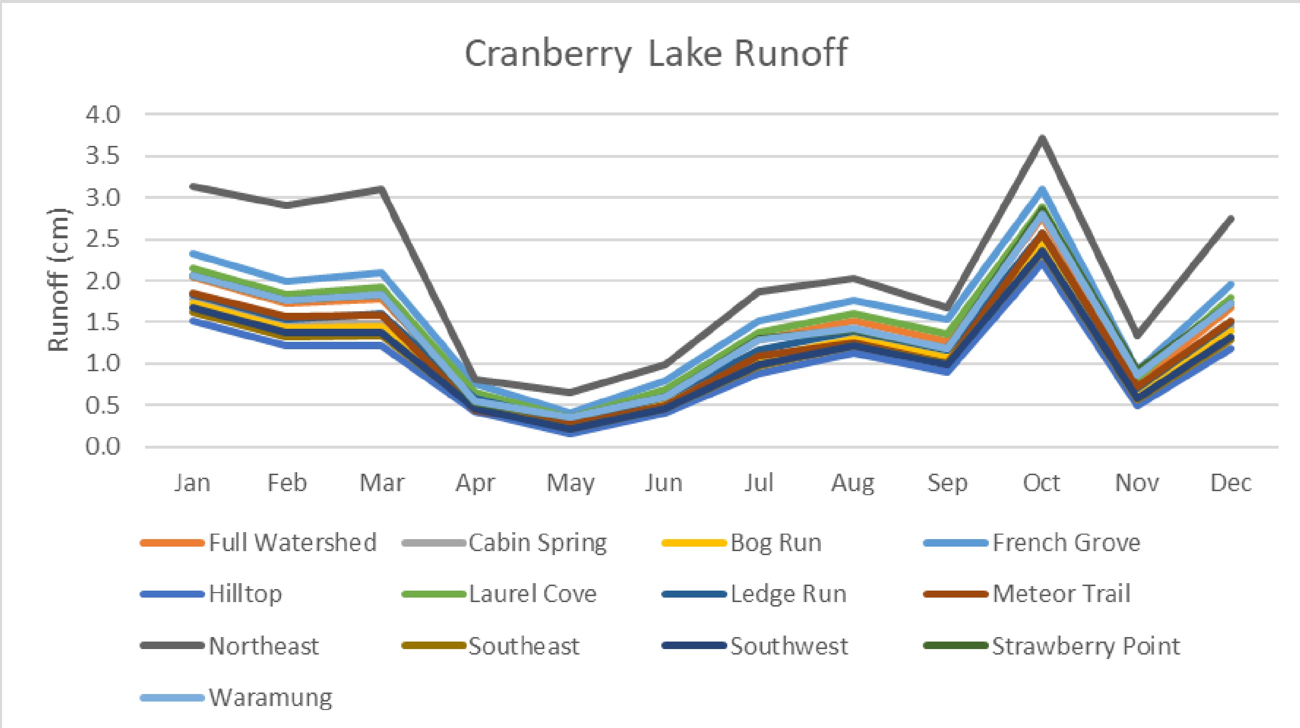


Figure 3.4. Average monthly runoff occurring by sub-watershed in the Cranberry Lake watershed

Bathymetric data was digitized from an NJDEP map using ArcGIS. Using this data, Cranberry Lake's volume was estimated to be approximately 1,519,992 m³ or 401.5 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.

Based on its modeled hydraulic load and lake volume, Cranberry Lake is estimated to flush approximately 2.6 times a year. Accordingly, the hydraulic retention time, or how long water takes to move through the lake, is estimated to be approximately 141.3 days.

Due to variations in monthly precipitation, the annual flushing rate and retention times can be further broken down into monthly annualized estimates. Figure 3.5 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.

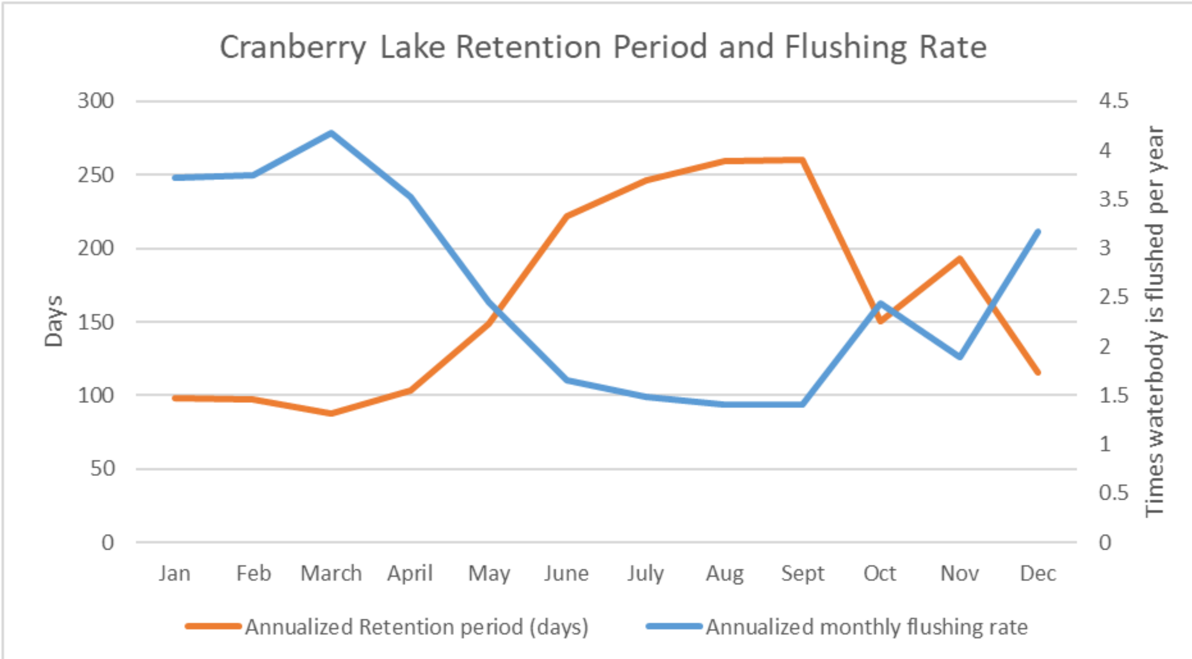


Figure 3.5. Variations in annualized flushing rates and retention periods over the course of a hypothetical year for Cranberry Lake, based on variations in hydraulic loads.

The annual estimated nitrogen load for Cranberry Lake is estimated to occur largely from septic systems in the watershed, with groundwater inputs also yielding a significant annual load. It should be noted that groundwater typically contains naturally higher concentrations of nitrogen than most surface waters, due to the high solubility of nitrogen in water. Septic leachate also usually enters into the groundwater when present, further influencing this, as can be observed in the results from the watersheds with more houses. Runoff from forested land also contributed a notable annual estimated load, however this is likely a product of the largely forested nature of this watershed; per unit area, forests have low nitrogen loading rates. The Ledge Run subwatershed yielded the highest overall annual nitrogen load at approximately 622 kg. On a per-unit-area basis, however, the Meteor Trail subwatershed yielded a higher rate at 12.7 kg nitrogen per acre. This is likely due to the high density of septic systems in a relatively small area. The full watershed is estimated to yield approximately 3024.6 kg of nitrogen per year, or approximately 2.0 kg/acre.

Influences from septic systems are estimated to contribute to over 85% of the estimated annual phosphorus load in the Cranberry Lake watershed. This is common for many lakes in northern New Jersey, particularly those with numerous houses along the shoreline. Forested areas yielded the highest runoff-based phosphorus load, however this was due to this being the dominant land-use type in the watershed. The Strawberry Point subwatershed was estimated to contribute the largest overall yearly load of phosphorus to the lake, with almost all of this originating from septic systems. The Waramung subwatershed was estimated to contribute the highest phosphorus load per-acre at 2.95 kg/acre. The entire Cranberry Lake watershed is estimated to contribute approximately 369.76 kg of phosphorus per year to the lake, or approximately 0.24 kg/acre.

While external (watershed-based) loading of phosphorus into a lake occurs, a waterbody can also receive internal phosphorus loading. One of the major sources for this in many deeper northeastern lakes is the release of phosphorus from sediment under anoxic conditions. For most of the year when water above the bottom sediments of a lake contains dissolved oxygen, phosphorus is bound to metals in sediment in a form that that does not easily dissolve into water. However, during periods of anoxia in the warmer summer months, the lack of dissolved oxygen in the water results in a redox reaction causing phosphorus to become soluble in water. On a large scale, this can result in measurably higher concentrations in the deeper waters of a lake than those obtained at the surface. When mixed towards the top of the water column, this increased phosphorus load can trigger blooms of algae and cyanobacteria. This internal load can be modeled using water quality data obtained in the field, which provides an approximate depth at which anoxia occurs and concentrations of phosphorus at the surface and at depth. A deep phosphorus concentration that is notably higher than those obtained from the surface paired with the presence of anoxia at the bottom of the water column can suggest that increased internal phosphorus loading may be occurring.

During the course of the 2023 sampling season, Cranberry Lake was not observed to feature anoxia in its northern basin, where phosphorus samples were collected. These samples also did not yield large differences in phosphorus concentrations between surface and deep waters. Due to these conditions, internal loading was modeled for Cranberry Lake using the lower loading rate of 0.6 mg TP/m²/day. Using this rate for an assumed 153-day growing season, internal loading was calculated to result in approximately 69.7 kg of phosphorus per year being added to the water column.

It should be noted that a degree of anoxia was observed in the southern basin's water quality profile. While the present study models internal loads based on data collected from the northern basin, it is possible that the two basins may behave somewhat differently from one another in regard to internal phosphorus loading. Future studies may benefit from phosphorus samples also being collected from the surface and deeper portions of the water column in the south basin in order to further assess these differences.

Table 3.2 below compares Cranberry Lake's yearly estimated phosphorus loads from external and internal sources, totaling approximately 439.5 kg/year.

Table 3.2: Total estimated annual phosphorus loads for Cranberry Lake from external and internal sources

Source	**Phosphorus (kg/yr)**
External (Runoff, Groundwater, Septic Systems)	369.8
Internal	69.7
Total	**439.5**

Over 90% of the estimated annual load of sediment is modeled to originate from streambank erosion. Runoff from agricultural land and urbanized areas are also estimated to contribute notable annual loads. As mentioned above, the soils in Cranberry Lake's watershed largely only allow for slow infiltration of water, causing runoff to occur at a relatively high rate, carrying higher amounts of sediment and other material. While the Ledge Run subwatershed yielded a higher estimated sediment load (4,468 kg/yr) than the other subwatersheds did, the Strawberry Point subwatershed yielded the highest load of sediment on a per-acre basis, at 15.5 kg/acre each year. The overall watershed was estimated to yield approximately 29,478 kg of sediment annually, or approximately 19.5 kg/acre.

Due to the largely forested nature of Cranberry Lake's watershed, a majority of bacteria originates from wildlife, while approximately 15.1% is generated from urban area runoff and a fraction of a percent is estimated to be contributed by waterfowl. The Ledge Run subwatershed was estimated to yield the highest estimated annual load of bacteria, likely as a product of its large area.

LAKE LACKAWANNA

Lake Lackawanna is an approximately 112.4-acre waterbody located near Byram Township's eastern border. The lake is relatively shallow, with an average depth of approximately 1.1 meters. The watershed for Lake Lackawanna is relatively large at approximately 8211.5 acres, encompassing Wolf Lake, Wright Pond, Kofferls

Pond, and Stag Pond and their respective watersheds. A majority of the Lake's flow enters from two inlets on the northern end of the waterbody: The outlet of Wolf Lake, which enters Lake Lackawanna near its northwestern corner, and Lubber's Run, which enters Lake Lackawanna from the northeast. The Lake's outlet stream is a continuation of Lubber's Run, which flows southwest before its confluence with the Musconetcong River. The Lake's subwatersheds are as follows:

- **Carpenter:** This is the smallest of Lake Lackawanna's subwatersheds at 7.6 acres. It mostly consists of low-density open space, with forested land also comprising approximately 26.3% of the area.
- **Cove:** This 21.9-acre subwatershed abuts the southern shoreline of Lake Lackawanna and consists mainly of forested land with an additional notable presence of urbanized land-cover.
- **Dam:** As its name suggests, this 10.1-acre subwatershed contains the Lake's dam, as well as its swimming beach. It is located at the southernmost end of Lake Lackawanna and is 41.6% forested, with the remaining 58.4% consisting of urbanized land-cover.
- **Golf Course:** This 23.2-acre subwatershed comprises the peninsula and island in the middle of the lake and part of the associated golf club. Most of the area is classified as low-density open space, with notable amounts of wetland and low-density mixed housing also present.
- **Lubbers Run:** This is the largest of Lake Lackawanna's subwatersheds at 5,012 acres and contains one of the lake's main inlets. The area is 67.5% forested, with 12.8% classified as wetlands and 10.6% classified as low-density open space.
- **North:** This 19.5-acre subwatershed contains the norther intersection of Lake Dr. and Lackawanna Dr.. The area consists mostly of forested land, as well as wetlands and low-density open space.
- **Orchard St.:** This 152.4-acre subwatershed is located along the lake's northern shoreline. Over 85% of the area is forested.
- **Pine Pt.:** This 12.9-acre subwatershed is located along the eastern portion of the lake. It is classified as mostly containing low-density open space and forested land.
- **Richmond:** Located at the southern end of the lake, this 11.3-acre subwatershed consists mostly of urbanized landcover, with the remaining area being forested.
- **Roseville:** This 17.9-acre subwatershed is located along the northern shoreline of the lake. Approximately half of its area consists of urbanized land while the other half consists of forested land and a small area of agricultural land.
- **South:** This 33.8-acre subwatershed contains a part of the golf club property located near the southern portion of the lake. The area is classified as approximately 57% low-density open space, with an additional 35.2% classified as forested land.
- **Southeast:** This 66-acre subwatershed contains over 65% forested land, as well as a notable amount of wetlands and urbanized landcover. It also features a small inlet.
- **West:** This 44.2-acre subwatershed consists mainly of forested land, with smaller amounts of urbanized landcover also present.
- **Wolf:** Located near the northwest corner of the waterbody, this large (2,774 acres) subwatershed contains Wolf Lake, Wright Pond, Kofferls Pond, and Stag Pond. Over 75% of the area is forested, with a notable amount of wetlands also present.

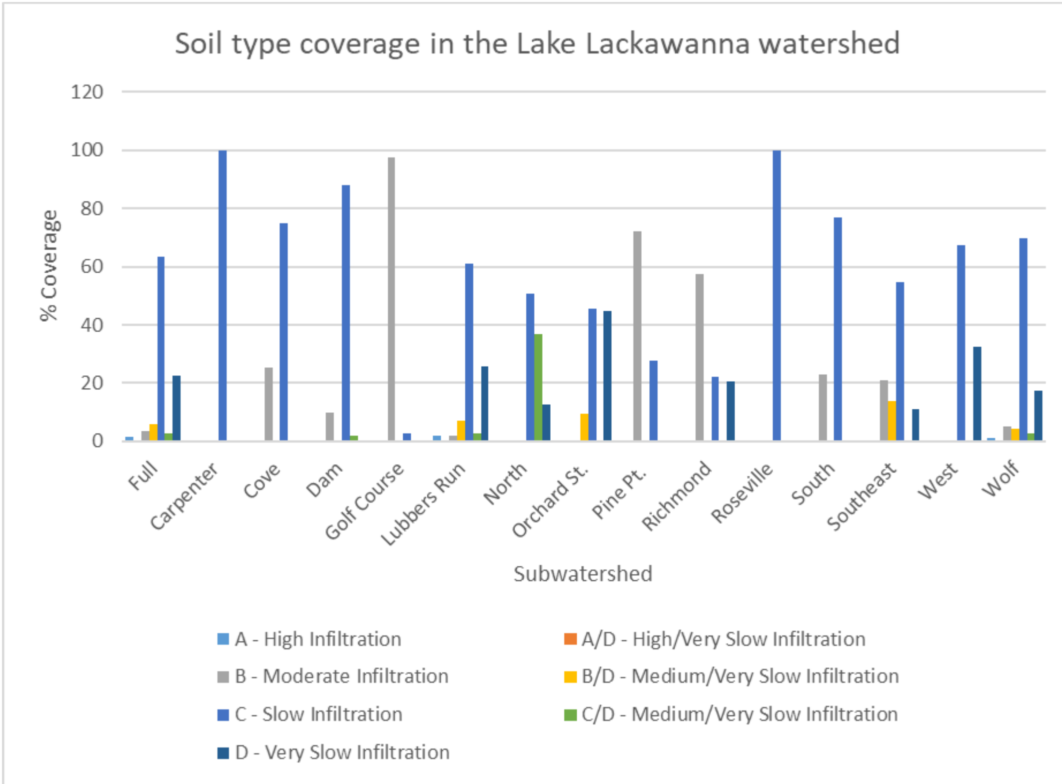


Figure 3.6. Percent coverage of Lake Lackawanna's Watersheds by different hydrologic soil groups

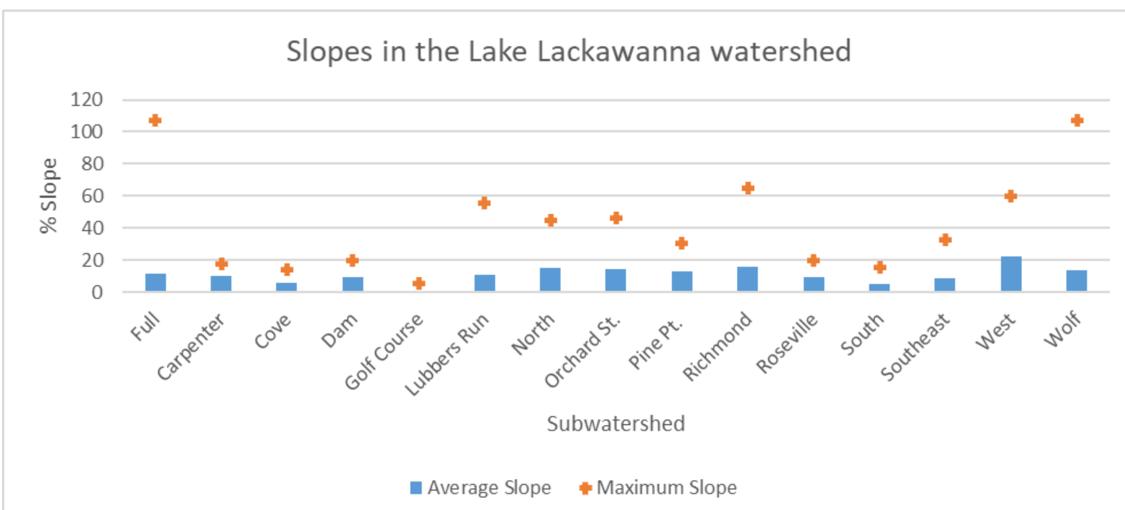


Figure 3.7. Variation in average and maximum percent slope between subwatersheds in the Lake Lackawanna Watershed.

Lake Lackawanna's watershed generally was dominated by the soil groups "C – Slow Infiltration" and "D – Very Slow Infiltration". Some subwatersheds, however, featured notable coverage with the group "B – Moderate Infiltration", with the Golf Course, Pine Pt., and Richmond subwatersheds being dominated by this group. While the subwatersheds featuring high coverage with C- and D-group soils may generate more runoff and more resulting erosion, subwatersheds with a high coverage with B-group soils may allow additional rainwater to infiltrate the groundwater prior to generating runoff.

Slopes in the full Lake Lackawanna watershed averaged approximately 11.8%, with a steep maximum slope of approximately 107%, which occurred in the Wolf subwatershed. The West subwatershed featured the highest average slope at approximately 22.6%.

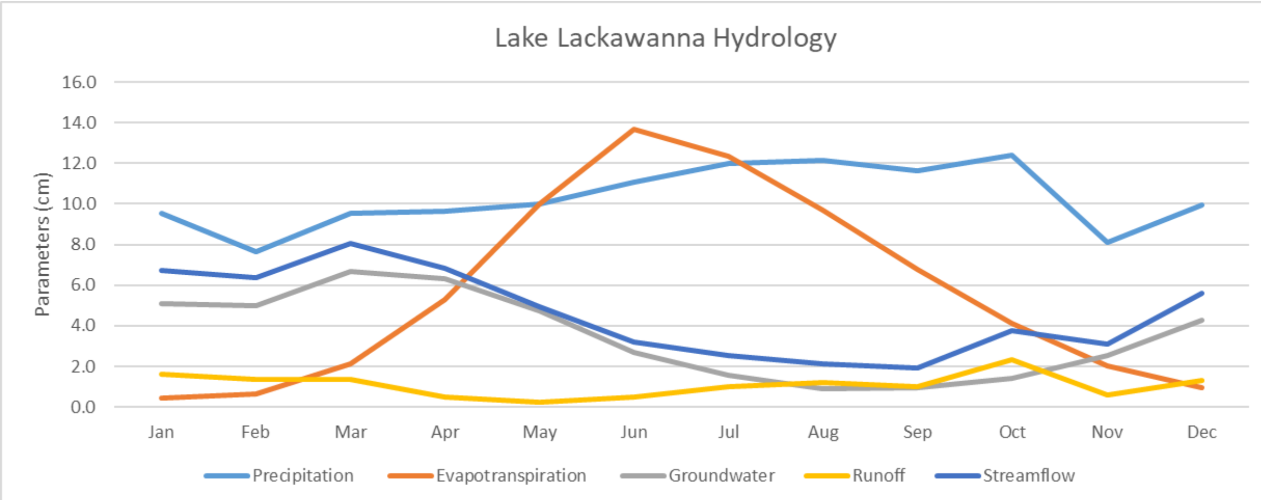


Figure 3.8. Estimated seasonal changes in hydrology in the Lake Lackawanna watershed

Table 3.3: Total hydrological parameters in the full Lake Lackawanna watershed over the course of a simulated year

Month	Precipitation	Evapotranspiration	Groundwater	Runoff	Streamflow	
	cm	cm	cm	cm	cm	cfs
Jan	9.5	0.5	5.1	1.6	6.7	29.5
Feb	7.7	0.7	5.0	1.4	6.4	30.6
Mar	9.6	2.1	6.7	1.4	8.1	35.3
Apr	9.7	5.3	6.3	0.5	6.8	30.8
May	10.0	10.0	4.7	0.2	5.0	21.7
Jun	11.1	13.7	2.7	0.5	3.2	14.4
Jul	12.0	12.4	1.6	1.0	2.6	11.2
Aug	12.1	9.7	0.9	1.2	2.1	9.3
Sep	11.6	6.8	0.9	1.0	1.9	8.6
Oct	12.4	4.1	1.4	2.3	3.7	16.4
Nov	8.1	2.0	2.5	0.6	3.1	14.1
Dec	10.0	1.0	4.3	1.3	5.6	24.5
Total	123.6	68.2	42.2	13.0	55.2	20.5

Runoff was modeled to be the highest in the North and Orchard St. subwatersheds. After factoring in direct precipitation and evaporation to the lake itself, the Lake Lackawanna is estimated to receive approximately 18,582,222.9 m³ or 4,909 million gallons of water a year.

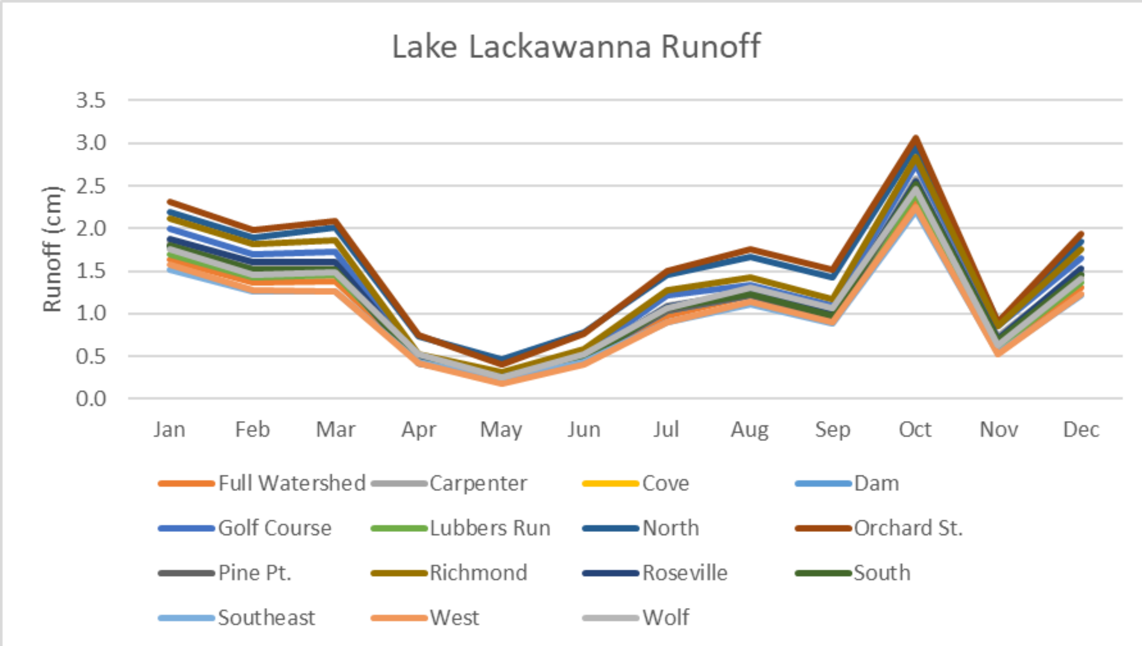


Figure 3.9. Average monthly runoff within sub-watersheds of the Lake Lackawanna watershed

Bathymetric data was digitized from an NJDEP map using ArcGIS. Using this data, Lake Lackawanna's volume was estimated to be approximately 490,518 m^3 or 129.6 million gallons of water. As a relatively shallow body of water, Lake Lackawanna flushes relatively quickly, at approximately 38 times a year, with a retention period of 9.6 days. The annualized monthly flushing rate for Lake Lackawanna typically reaches its lowest point during August, while the highest annualized flushing rate is estimated to occur in March.

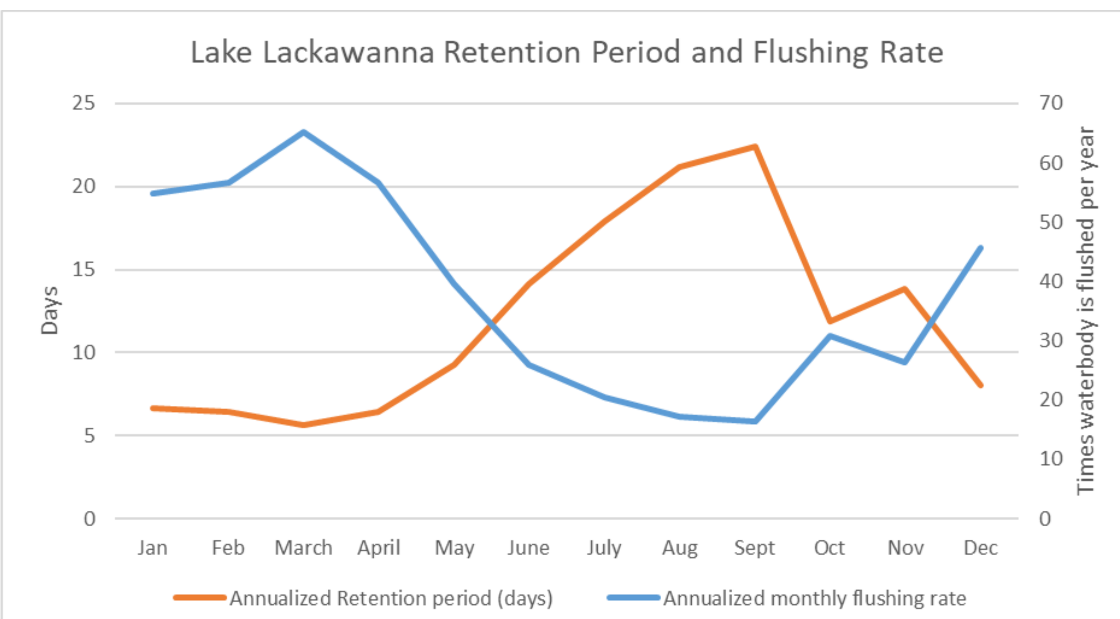


Figure 3.10. Variations in annualized flushing rates and retention periods over the course of a hypothetical year for Lake Lackawanna, based on variations in hydraulic loads.

A majority of Lake Lackawanna's nitrogen load originates from septic systems and groundwater. Forested land and wetlands were estimated to yield the largest runoff-based nitrogen loads. The Lubbers Run subwatershed yielded the largest amount of nitrogen per average year, likely due to its large area and high number of septic systems. The Pine Pt. subwatershed yielded the highest load per acre due to the number of houses close to the waterbody. The full watershed is estimated to yield an annual nitrogen load of approximately 11,864.9 kg, or approximately 1.4 kg/acre.

Septic systems, groundwater, and stream bank erosion were estimated to be the largest sources of phosphorus to Lake Lackawanna, with septic systems yielding approximately 49% of the total estimated load. Runoff-based phosphorus was estimated to largely originate from forested areas, agricultural land, and areas of low-density open space. The Lubbers Run subwatershed is estimated to yield the highest annual phosphorus load at 237.02 kg, however it should be noted that this watershed produces one of the lowest amounts of phosphorus per acre, suggesting that the overall high annual load can be largely attributed to the subwatershed's large area. The golf course subwatershed is estimated to yield the highest annual amount of phosphorus per acre, with a large majority of phosphorus originating from septic systems. The entire Lake Lackawanna watershed is estimated to yield a total of 479.51 kg annually or 0.06 kg/acre.

During field sampling events in 2023, Lake Lackawanna was not measured to exhibit anoxia at any point during the season. While there were small differences between surface and deep phosphorus samples during the spring and summer events, these are small disparities and may be due to decomposition of organic matter. Internal loading was calculated using the assumption that anoxic loading does not typically occur in Lake Lackawanna and only the reduced oxic loading rate (approximately 0.6 mg TP/m²/day) was used. Lake Lackawanna is estimated to receive approximately 41.8 kg each year due to internal loading.

Table 3.4 below displays the external and internal loads of phosphorus for Lake Lackawanna, as well as the grand total, which is estimated to be approximately 521.3 kg/year. External loading is estimated to be the primary source of phosphorus loading in Lake Lackawanna, representing over 90% of the entire annual load.

Table 3.4: Total estimated annual phosphorus loads for Lake Lackawanna from external and internal sources

Source	Phosphorus (kg/yr)
External (Runoff, Groundwater, Septic Systems)	479.51
Internal	41.75
Total	**521.26**

A majority of sediment entering Lake Lackawanna is estimated to originate from stream bank erosion. Runoff-based sediment loads were significantly lower, with urbanized land and agricultural land yielding the highest annual loads. Lubbers Run yielded the highest annual total sediment load at 24,139 kg. As with phosphorus, the golf course subwatershed yielded the highest amount of sediment per acre at 7.6 kg/acre. The full watershed was estimated to yield approximately 57,741 kg of sediment annually, or 7 kg/acre.

More than 80% of the total bacterial load estimated to enter Lake Lackawanna each year is estimated to originate from wildlife in the watershed, with approximately 16% of the load estimated to occur from urbanized areas. The Lubbers Run subwatershed is estimated to yield the highest annual bacteria load.

JOHNSON LAKE

Johnson Lake is an approximately 36.9-acre impoundment located near the center of Byram Township. The lake is largely dominated with aquatic macrophytes and is relatively shallow, with a maximum depth of approximately 2.4 m. The lake's watershed covers an area of approximately 369 acres. Two small inlets enter the lake at its northeastern end, and a southern inlet enters the lake from a pond directly across Tamarack Road. The lake's outlet, Ghost Pony Brook, is located at its southern-most end and flows southwest until its confluence with the Cranberry Lake outlet stream. Johnson Lake's subwatersheds are as follows:

- **East Inlet:** This 54.1-acre subwatershed is mostly classified as forested land with a notable amount of low-density open space also present.
- **Hunters:** This 24.7-acre subwatershed is located along the southeastern shoreline of Johnson Lake and contains some of the residential area to the east of Hunters Ln. It is mostly classified as forested land and low-density open space.
- **Manu Trail:** This 25.4-acre subwatershed is located along the southern shoreline of the lake and contains the residential area surrounding Manu Trail and the majority of Hunters Ln. Approximately 60% of the area is classified as low-density open space, with forested land also comprising a notable amount of the area.
- **Northeast:** This 14.3-acre subwatershed is located between the two small inlets at the eastern end of the waterbody and consists entirely of forested land and wetlands.
- **North:** This 25.9-acre subwatershed almost entirely consists of forested land and wetlands, with the northern edge of the subwatershed approaching the residential area south of Crows Nest Rd.
- **Northwest:** This 8.2-acre subwatershed is classified as entirely forested. A single residence is present at the northern edge.
- **Southeast:** This is the largest of Johnson Lake's subwatersheds at 190.8 acres. As mentioned above, it contains a pond directly south of Tamarack Road connected to Johnson Lake via a culvert. This pond is itself fed by a stream at its southern end. As with much of the other subwatersheds, the area is mostly forested, with a notable amount of low-density open space also present.
- **South:** This 10.6-acre subwatershed is classified as entirely forested land and wetlands. It also contains some small parking areas for park users and a length of driveway.
- **Southwest:** This is the smallest of Johnson Lake's subwatersheds at 5.4 acres. As with many of the other subwatersheds for the lake, the area consists entirely of forested land and wetlands.
- **West:** This 9.9-acre subwatershed is entirely forested and is located across Johnson Lake from Manu Trail.

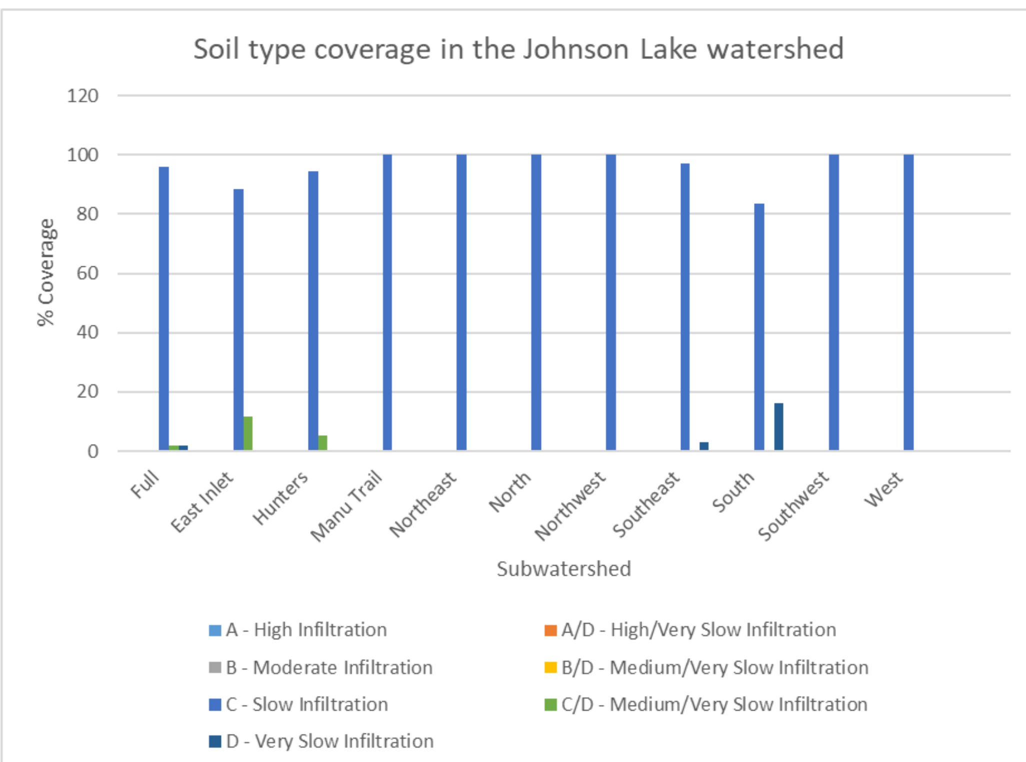


Figure 3.11. Percent coverage of Johnson Lake Watershed and subwatersheds by different hydrologic soil groups

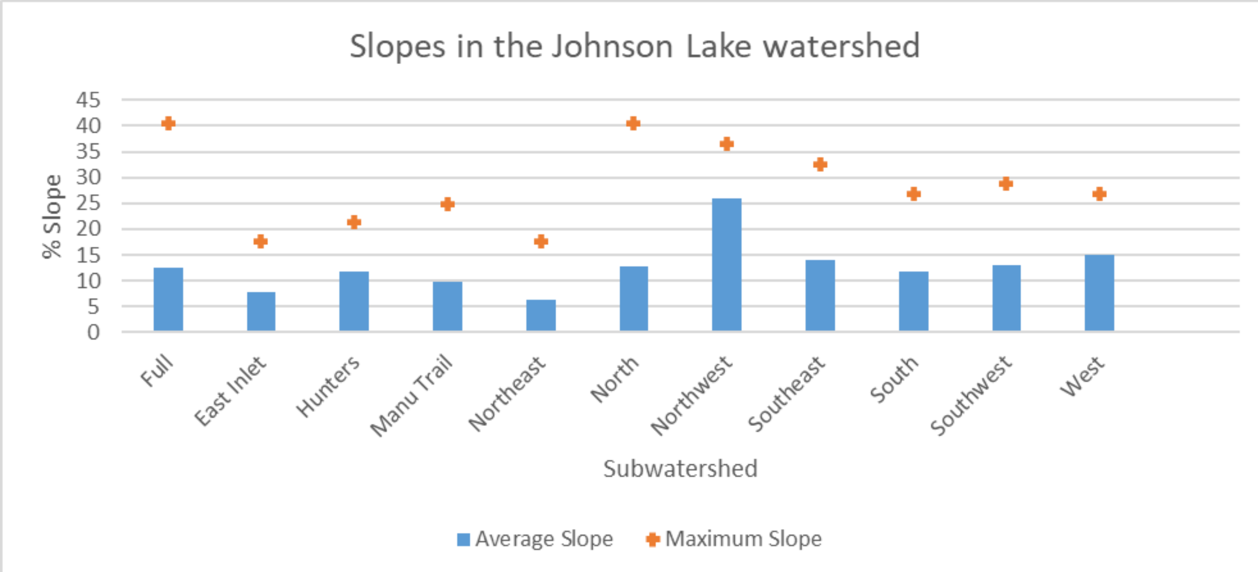


Figure 3.12. Variation in average and maximum percent slope between subwatersheds in the Johnson Lake Watershed.

Johnson Lake's watershed generally was dominated by the soil group "C – Slow Infiltration". Subwatersheds featuring high coverage with C -group soils may generate more runoff and more resulting erosion. Slopes in the full Johnson Lake watershed averaged approximately 12.5%, with a maximum slope of approximately 40.4%, which occurred in the North subwatershed. The Northwest subwatershed featured the highest average slope at approximately 25.9%.

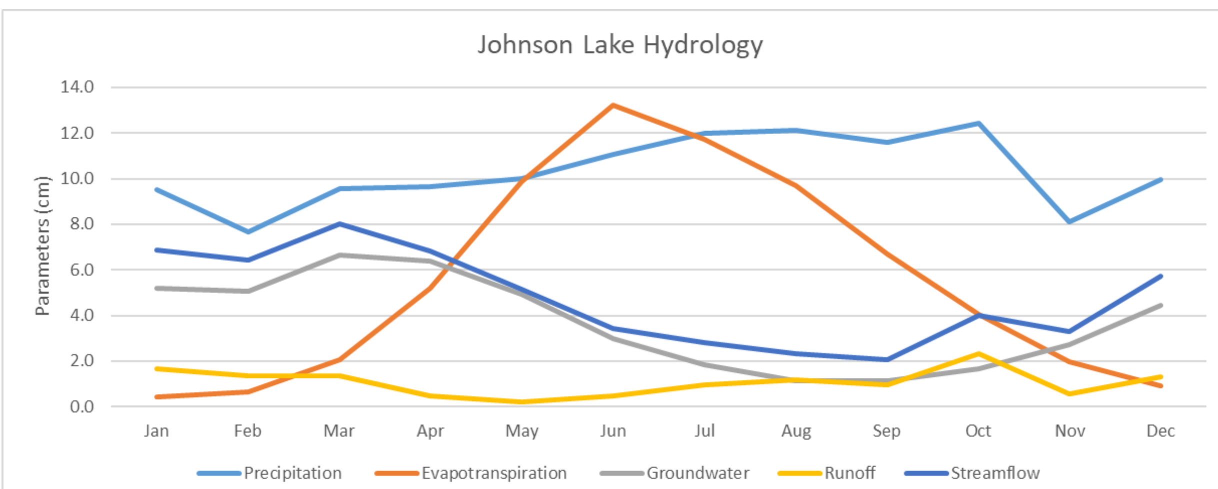


Figure 3.13. Estimated seasonal changes in hydrology in the Johnson Lake watershed

Table 3.5: Total hydrological parameters in Johnson Lake watershed over the course of a simulated year

Month	Precipitation	Evapotranspiration	Groundwater	Runoff	Streamflow	
	cm	cm	cm	cm	cm	cfs
Jan	9.5	0.4	5.2	1.6	6.9	1.3
Feb	7.7	0.6	5.1	1.4	6.4	1.4
Mar	9.6	2.1	6.7	1.4	8.0	1.6
Apr	9.7	5.2	6.4	0.5	6.8	1.4
May	10.0	9.9	4.9	0.2	5.2	1.0
Jun	11.1	13.2	3.0	0.5	3.4	0.7
Jul	12.0	11.7	1.8	1.0	2.8	0.6
Aug	12.1	9.7	1.1	1.2	2.3	0.5
Sep	11.6	6.7	1.1	1.0	2.1	0.4
Oct	12.4	4.1	1.7	2.3	4.0	0.8
Nov	8.1	2.0	2.7	0.6	3.3	0.7
Dec	10.0	0.9	4.4	1.3	5.7	1.1
Total	123.6	66.5	44.2	12.7	56.9	1.0

Simulated runoff for the individual subwatersheds showed only a small degree of variation, with the North subwatershed yielding the overall highest amount of runoff. After factoring in direct precipitatiojn and evaporation to the lake itself, Johnson Lake is estimated to receive approximately 934,913 m³ or approximately 247 million gallons of water a year.

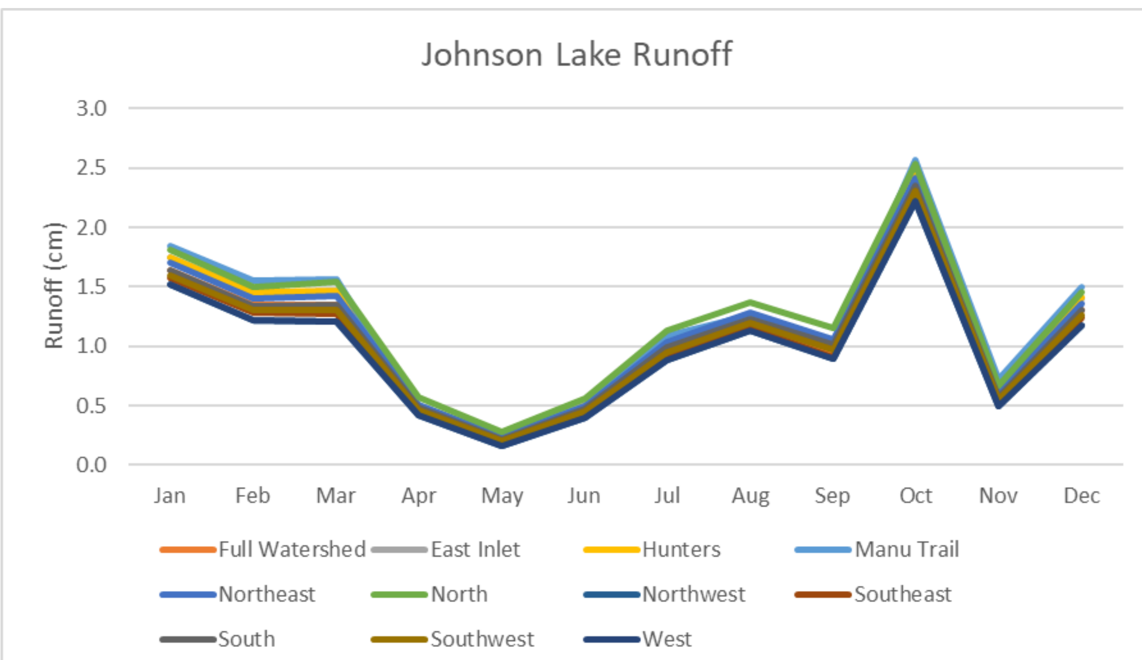


Figure 3.14. Average monthly runoff within sub-watersheds of the Johnson Lake watershed

Previous bathymetric data was available for Johnson Lake, and as such, the lake's volume was approximately 189,911.7 m³ or 50.2 million gallons. Johnson Lake is estimated to flush approximately 4.9 times a year, with a retention period of 74.2 days. The annualized monthly flushing rate for Johnson Lake typically reaches its lowest point during August, while the highest annualized flushing rate is estimated to occur in March.

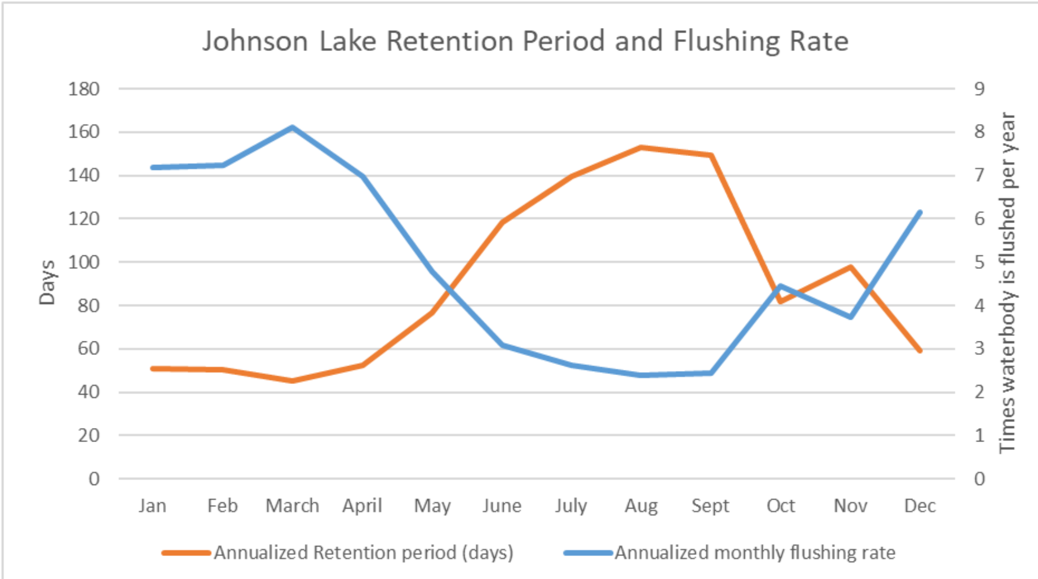


Figure 3.15. Variations in annualized flushing rates and retention periods over the course of a hypothetical year for Johnson Lake, based on variations in hydraulic loads.

A majority of Johnson Lake's nitrogen load originates from septic systems and groundwater. Forested land, wetlands, and low-density open space were estimated to yield the largest runoff-based nitrogen loads. The southeast subwatershed yielded the highest overall estimated annual nitrogen load, while the Hunters subwatershed yielded the largest amount of nitrogen per acre. The entire Johnson Lake watershed is estimated to receive 735.8 kg of nitrogen each year, or 2 kg/acre.

Septic systems and groundwater were estimated to be the largest watershed-based sources of phosphorus to Johnson Lake, with septic systems yielding approximately 57% of the total estimated load. Runoff-based phosphorus was estimated to largely originate from forested areas. The Southeast subwatershed was estimated to yield the overall highest annual phosphorus load at 237.02 kg, while the Manu Trail subwatershed was estimated to yield the largest phosphorus load on a per-acre basis at 0.10 kg/acre. The full watershed is estimated to yield 22.85 kg of phosphorus or 0.06 kg/acre annually.

During field sampling events in 2023, Johnson Lake was not observed to feature bottom anoxia at its deepest station during the Spring and Summer events. While anoxia was observed during the Fall event, phosphorus concentrations in the deep sample were no different from those occurring at the surface, suggesting that increased anoxic loading was not occurring. Internal loading was therefore calculated using the assumption that anoxic loading does not typically occur in Johnson Lake and only the reduced oxic loading rate (approximately 0.6 mg TP/m^2/day) was used. Johnson Lake's water column is estimated to receive approximately 13.7 kg of phosphorus annually from internal loading. Table 3.6 below displays the external and internal loads of phosphorus for Johnson Lake, as well as the grand total, which is estimated to be approximately 36.6 kg/year. External loading is estimated to be the primary source of phosphorus loading in Johnson Lake.

Table 3.6: Total estimated annual phosphorus loads for Johnson Lake from external and internal sources

Source	Phosphorus (kg/yr)
External (Runoff, Groundwater, Septic Systems)	22.85
Internal	13.71
Total	**36.56**

A majority (approximately 84%) of sediment entering Johnson Lake is estimated to originate from stream bank erosion. Runoff-based sediment loads were significantly lower and were represented entirely by sediment originating from urbanized land. While the East Inlet subwatershed was estimated to yield the overall highest annual sediment load, the Manu Trail subwatershed was estimated to yield the highest load per acre at 4.5 kg/acre. The full watershed was estimated to yield an annual sediment load of approximately 1,467 kg or 4 kg/acre.

More than 80% of the total bacterial load estimated to enter Johnson Lake each year is estimated to originate from wildlife in the watershed, with approximately 19% of the load estimated to occur from urbanized areas. The Southeast subwatershed is estimated to yield the highest annual bacteria load.

FOREST LAKE

Forest Lake is an approximately 47-acre impoundment located close to the northern border of Byram Township. The lake features moderate depths compared to some of the other lakes in this study, with a maximum depth of approximately 5.2 meters. The lake's 145.5-acre watershed is classified as 70% low-density open space, with forested land also comprising a notable amount of the area. The lake's inlets mostly consist of small ephemeral stormwater streams in various locations along the eastern side of the lake, with an additional small perennial stream entering near the southern point of the lake. The lake's outlet travels northwest, passing through various smaller waterbodies and confluences with other streams until meeting the Pequest River. Forest Lake's subwatersheds are as follows:

- **Dam:** This 7.6-acre subwatershed is located in the northwest corner of the waterbody and contains the lake's outlet and a small length of Hemlock Rd. While a majority of the area is classified as urbanized, approximately 42% of the area is classified as forested.
- **East:** This 32.9-acre subwatershed contains lengths of Cresent Dr. S, Woodland Rd., Old Stage Coach Rd., Sleepy Hollow Rd., and Crows Nest Rd. It is classified as over 87% low-density open-space.
- **Northeast:** This 16.1-acre subwatershed contains lengths of Cresent Dr. N and Deer Run, as well as one of the lake's beaches and swimming areas. As with most of the other Forest Lake subwatersheds, the area is classified as mostly low-density open space, with some forested land also present.
- **North:** This 22.2-acre subwatershed contains the intersections of Hemlock Rd. with Woodlawn Dr. and Winding Way, as well as a length of Harbor-View Drive and one of the lake's beaches. Approximately 59% of the area is classified with urban land-use types, with the remaining 41% of the area being classified as forested.
- **Southeast:** This 25.9-acre subwatershed contains lengths of Old Stage Coach Rd., Lake View Dr., and Woodland Dr., as well as one of the lake's beaches. Over 80% of the area is classified as low-density open space, with an additional 10% of the area being forested.
- **South:** This 25.7-acre subwatershed contains lengths of Sleepy Holow Rd. and Glen Cove Rd., as well as the small perennial inlet stream from which stream-based sampling occurred. As with many of the other subwatersheds around the lake, the area largely consists of 66.5%.
- **Southwest:** This is the smallest of Forest Lake's subwatersheds at 4 acres in area. The area is classified as half forested and half low-density open space.
- **West:** This 11.5-acre watershed contains a length of Forest Lake Dr. N. The area is classified as approximately 57.4% urbanized land-use types, with the remaining area consisting of forested land and wetlands.

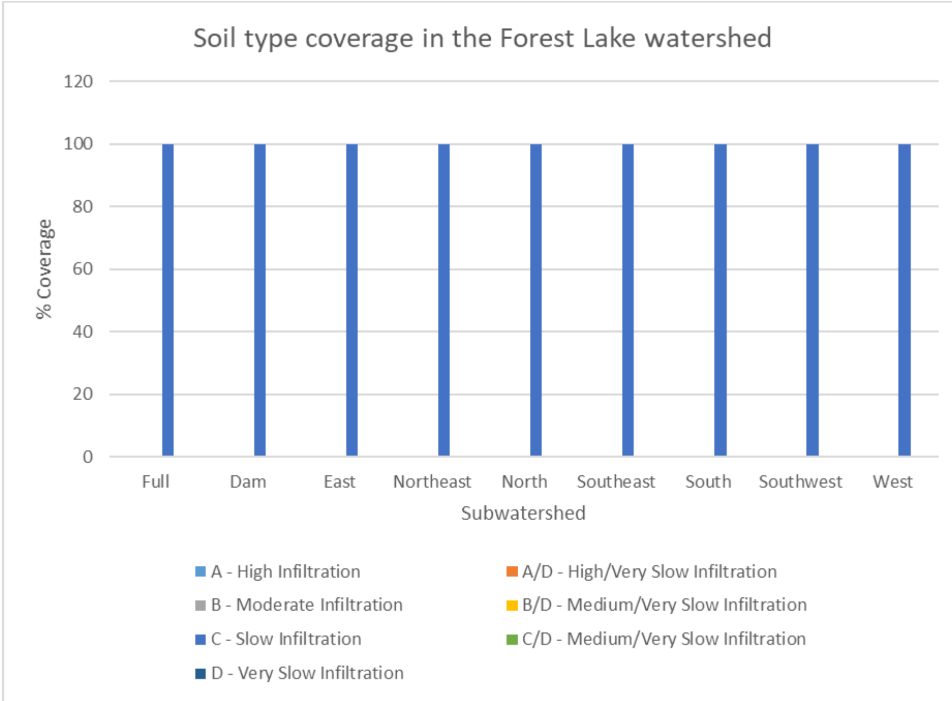
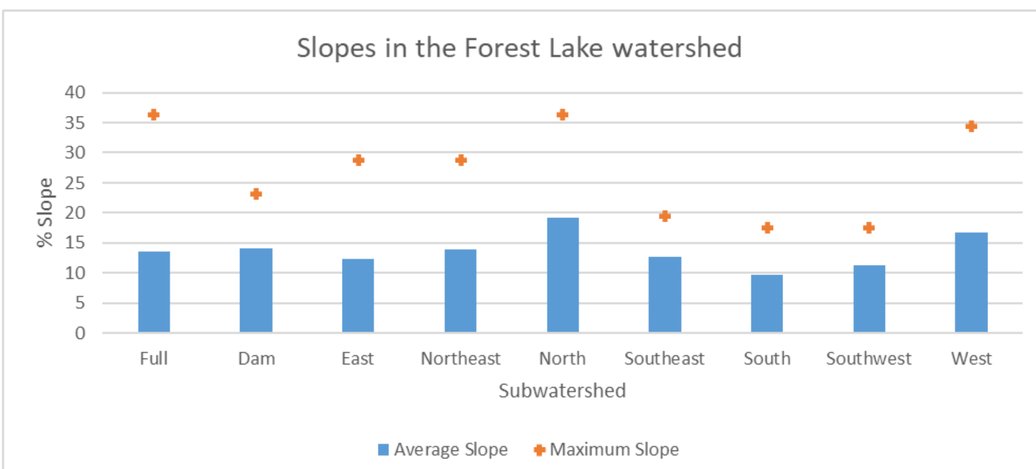


Figure 3.16. Percent coverage of Forest Lake Watershed and subwatersheds by different hydrologic soil groups

Figure 3.17. Variation in average and maximum percent slope between subwatersheds in the Forest Lake Watershed.



Forest Lake's watershed is entirely covered by the soil group "C – Slow Infiltration". Subwatersheds featuring high coverage with C -group soils may generate more runoff and more resulting erosion.

Slopes in the full Forest Lake watershed averaged approximately 13.5%, with a maximum slope of approximately 36.4%, which occurred in the North subwatershed. The North subwatershed also featured the highest average slope at approximately 19.2%.

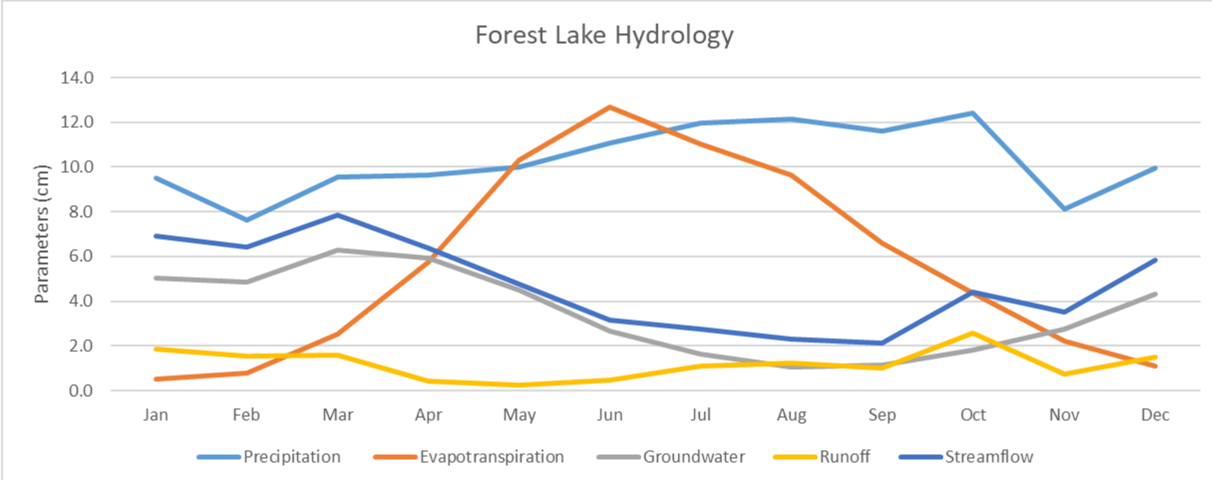


Figure 3.18. Estimated seasonal changes in hydrology in the Forest Lake watershed

Table 3.7: Total hydrological parameters in the full Forest Lake watershed over the course of a simulated year

Month	Precipitation	Evapotranspiration	Groundwater	Runoff	Streamflow	
	cm	cm	cm	cm	cm	cfs
Jan	9.5	0.5	5.0	1.9	6.9	0.5
Feb	7.7	0.8	4.9	1.6	6.4	0.5
Mar	9.6	2.6	6.3	1.6	7.9	0.6
Apr	9.7	5.8	5.9	0.4	6.4	0.5
May	10.0	10.3	4.5	0.3	4.8	0.4
Jun	11.1	12.7	2.7	0.5	3.1	0.3
Jul	12.0	11.0	1.6	1.1	2.7	0.2
Aug	12.1	9.7	1.1	1.3	2.3	0.2
Sep	11.6	6.6	1.2	1.0	2.2	0.2
Oct	12.4	4.4	1.8	2.6	4.4	0.3
Nov	8.1	2.2	2.8	0.8	3.5	0.3
Dec	10.0	1.1	4.3	1.5	5.9	0.5
Total	123.6	67.6	42.1	14.4	56.5	0.4

Simulated runoff for the individual subwatersheds showed only a small degree of variation, with the Southeast subwatershed yielding the overall highest amount of runoff. After factoring in direct precipitation and evaporation to the lake itself, Forest Lake is estimated to receive approximately 438,992.2 m^3 or approximately 116 million gallons of water a year.

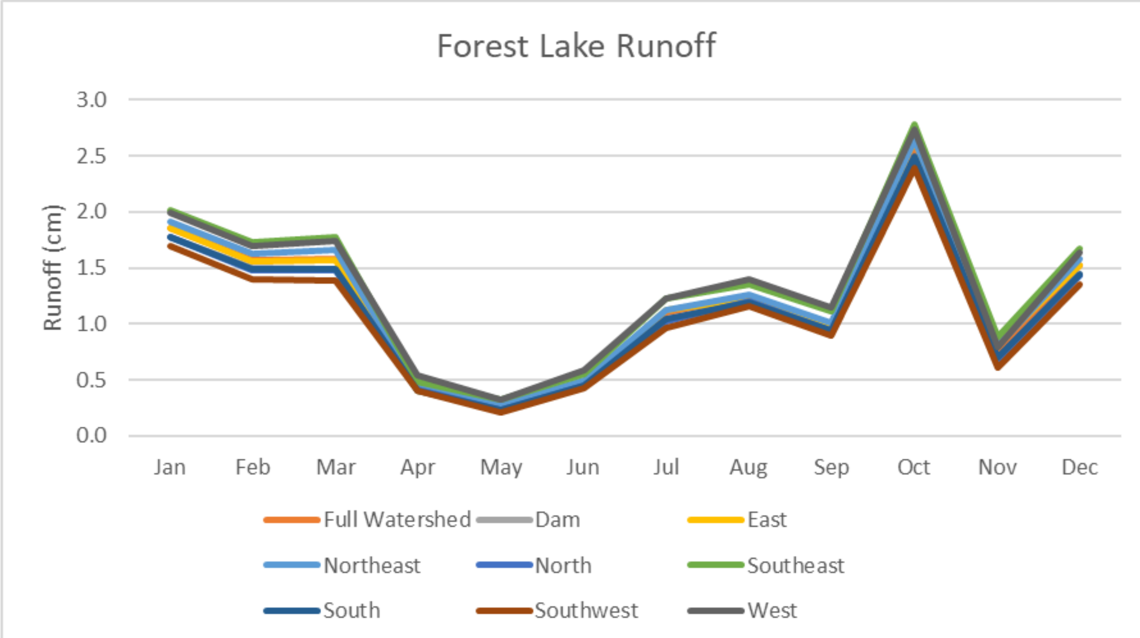


Figure 3.19. Average monthly runoff within sub-watersheds of the Forest Lake watershed

Bathymetric data was not available for Forest Lake, and as such, the lake's volume was estimated using depths collected when collecting water quality data. Forest Lake is estimated to feature a volume of approximately 610,802.9 m³ or 161.4 million gallons of water. Using this volume and the estimated annual discharge mentioned above, Forest Lake is estimated to flush approximately 0.7 times a year, or once every 508.1 days. The lowest annualized monthly flushing rate for the lake is estimated to occur in June during an average year, with the highest rate occurring in March.

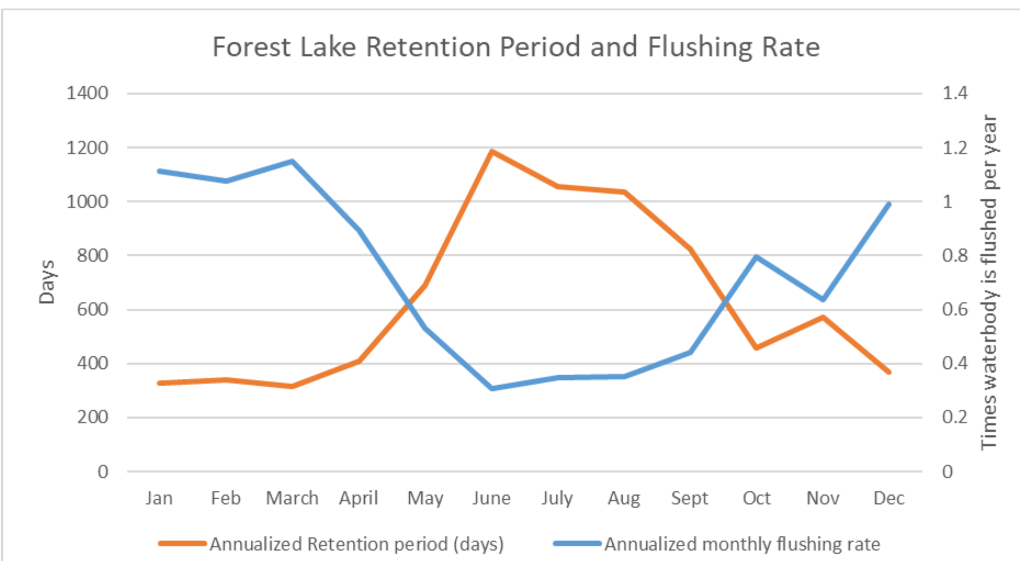


Figure 3.20. Variations in annualized flushing rates and retention periods over the course of a hypothetical year for Forest Lake, based on variations in hydraulic loads.

A majority of Forest Lake's nitrogen load originates from septic systems and groundwater. Low-density open space was estimated to yield the largest runoff-based nitrogen loads. The east subwatershed yielded both the highest overall estimated annual nitrogen load as well as the largest amount of nitrogen per acre. The entire Forest Lake watershed is estimated to receive 817.6 kg of nitrogen each year, or 5.6 kg/acre.

Septic systems and groundwater were estimated to be the largest watershed-based sources of phosphorus to Forest Lake, with septic systems yielding approximately 81% of the total estimated load. Runoff-based phosphorus was estimated to largely originate from areas of low-density open space. The South subwatershed was estimated to yield both the overall highest annual phosphorus load and the largest phosphorus load on a per-acre basis. The full watershed is estimated to yield 28.01 kg of phosphorus or 0.19 kg/acre annually.

During field sampling events in 2023, Forest Lake was observed to feature bottom anoxia at its deepest station during all three events. Additionally, deep phosphorus concentrations were notably higher than surface concentrations during the Spring and Summer events, suggesting that increased internal phosphorus loading may have been occurring. Given the data collected in the field in 2023, Forest Lake is estimated to undergo increased internal phosphorus loading (6 mg TP/m²/day) from late-Spring through mid-Summer, approximately 3 months or 92 days. When oxic loading at the lower rate of 0.6 mg TP/m²/day in shallower areas of the lake and during other parts of the growing season is accounted for, Forest Lake is estimated to receive an annual internal phosphorus load of approximately 59.97 kg. If a year were to occur without internal phosphorus loading at the advanced rate, the estimated annual internal load would be 17.46 kg.

While anoxia was observed during the Fall event, phosphorus concentrations in the deep sample were no different from those occurring at the surface, suggesting that increased anoxic loading was not occurring. Internal loading was therefore calculated using the assumption that anoxic loading does not typically occur in Forest Lake and only the reduced oxic loading rate (approximately 0.6 mg TP/m²/day) was used. Forest Lake's water column is estimated to receive approximately 13.7 kg of phosphorus annually from internal loading.

Table 3.8 below displays the external and internal loads of phosphorus for Forest Lake, as well as the grand total, which is estimated to be approximately 87.98 kg/year. Internal loading is estimated to be the primary source of phosphorus loading in Forest Lake, constituting approximately 68% of the total annual load.

Table 3.8: Total estimated annual phosphorus loads for Forest Lake from external and internal sources

Source	Phosphorus (kg/yr)
External (Runoff, Groundwater, Septic Systems)	28.01
Internal	59.97
Total	**87.98**

Forest Lake's annual sediment load is estimated to largely (almost 87%) originate as runoff from low-density open space. The East subwatershed is estimated to yield the largest overall annual sediment load, while the northeast subwatershed is estimated to yield the largest amount per acre. The full watershed was estimated to yield an annual sediment load of approximately 725 kg or 5 kg/acre.

More than 90% of the total bacterial load estimated to enter Forest Lake each year is estimated to originate from urban areas, with most of the remaining load estimated to occur from wildlife. The East subwatershed is estimated to yield the highest annual bacteria load.

PANTHER LAKE

Panther Lake is an approximately 43.36-acre natural lake located close to Forest Lake and the northern border of Byram Township. As a glacial lake, the waterbody is the deepest in this study, with a maximum depth of approximately 11.6 meters. The lake's 215.5-acre watershed is approximately 76% forested, with an additional 17.2% of the area being classified as an urban land-use type. The lake's main inlet enters at the southeastern shoreline. An outlet leaves the lake at a dam at the northernmost point of the waterbody in a somewhat isolated cove known as Cub Lake. For the purposes of this study, Cub Lake is considered to be part of Panther Lake. Panther Lake's subwatersheds are as follows:

- **Cub Lake:** As its name suggests, this 2.2-acre subwatershed is located along the northeastern shoreline of the area corner of the waterbody known as Cub Lake. It is classified as entirely forested.
- **Forest:** This 2.7-acre subwatershed is located along the northeastern shoreline of the main portion of the lake. It is classified as almost completely forested, with a fraction of an acre of land classified and Hay/Pasture.
- **Jans Way:** This 9.2-acre subwatershed is located along the northwestern edge of Panther Lake. The area is almost entirely classified as forested land with one acre of low-density open space also present.
- **Northeast:** This 63.9-acre subwatershed contains the northern end of the Panther Lake Camping Resort, stretching northeast along Sleepy Hollow Rd. It is largely forested with a small amount of urbanized land also present.
- **North:** This is the smallest of Panther Lake's subwatersheds at 1.7 acres. The area is almost entirely forested.
- **Northwest:** This 3.7-acre subwatershed contains a length of Jans Way. Like many of the other subwatersheds, the area is almost entirely classified as forested.
- **Outlet:** This 2.4-acre subwatershed encompasses the peninsula between Cub Lake and the main portion of Panther Lake. The area is classified as mostly forested and features a small pond.
- **Rose Marie Ln:** This 5.9-acre subwatershed is located along the western shoreline of the lake. The area is mostly classified as urbanized, with a notable portion of the area being forested.
- **Southeast:** This is the largest of Panther Lake's subwatersheds at 116.2 acres and contains a majority of the campground. The area is mostly forested with a notable presence of urbanized land-use type.
- **Southwest:** This 4.9-acre subwatershed is located along Rt. 206 and contains the campground entrance. The area is mostly urbanized, while an additional approximately 25% of the area is classified as forested.
- **West:** This 1.9-acre subwatershed is location along the Lake's southwestern shoreline. The area classified as approximately 63.2% urbanized and 36.8% forested.

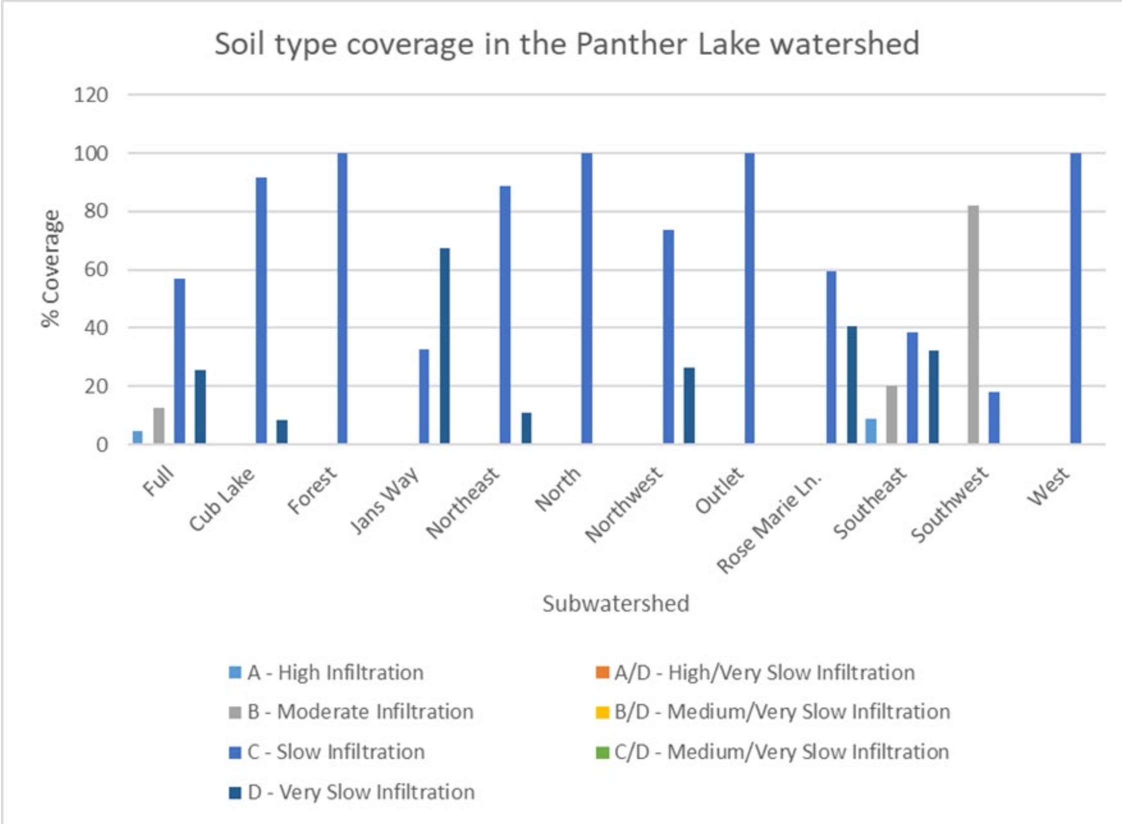


Figure 3.21. Percent coverage of the Panther Lake Watershed and subwatersheds by different hydrologic soil groups

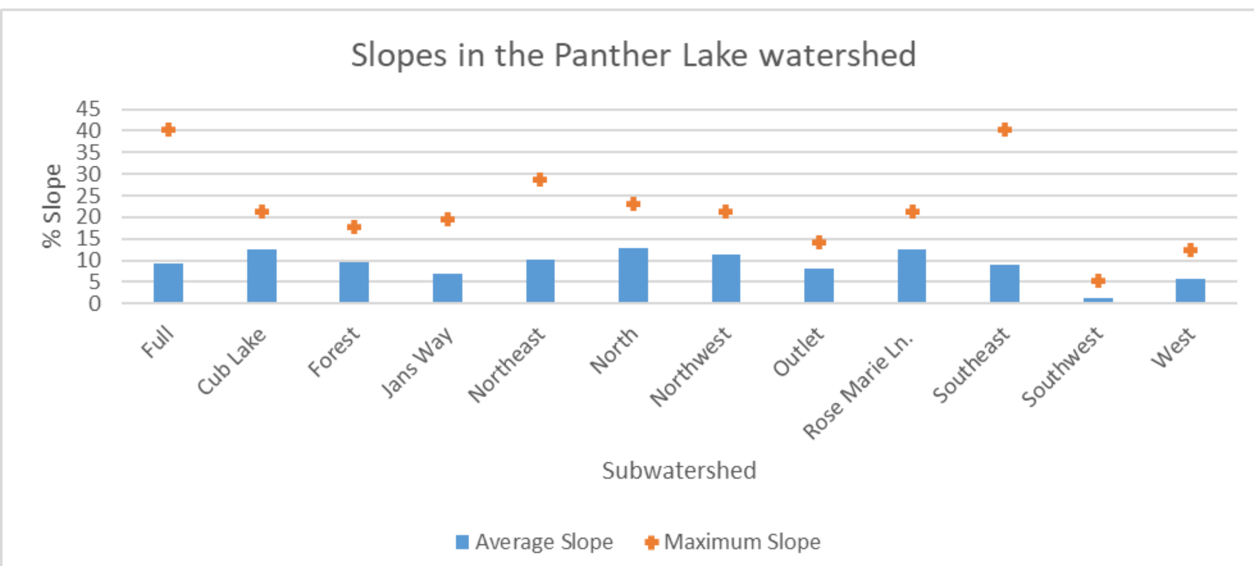


Figure 3.22. Variation in average and maximum percent slope between subwatersheds in the Panther Lake Watershed.

Panther Lake's watershed is largely dominated by the soil group "C – Slow Infiltration". Subwatersheds featuring high coverage with C -group soils may generate more runoff and more resulting erosion. It should be noted that the Southwest subwatershed is dominated by the soil group "B – Moderate Infiltration". This suggests that soils in this area of the watershed may allow for increased infiltration to groundwater by precipitation, leading to reduced runoff. Conversely, the Jans Way subwatershed is dominated by the soil group "D – Very Slow Infiltration", suggesting that this subwatershed may experience somewhat increased runoff due to reduced ability of rainwater to quickly infiltrate into groundwater.

Slopes in the full Panther Lake watershed averaged approximately 9.3%, with a maximum slope of approximately 40.4%, which occurred in the southeast subwatershed. The North subwatershed featured the highest average slope at approximately 12.9%.

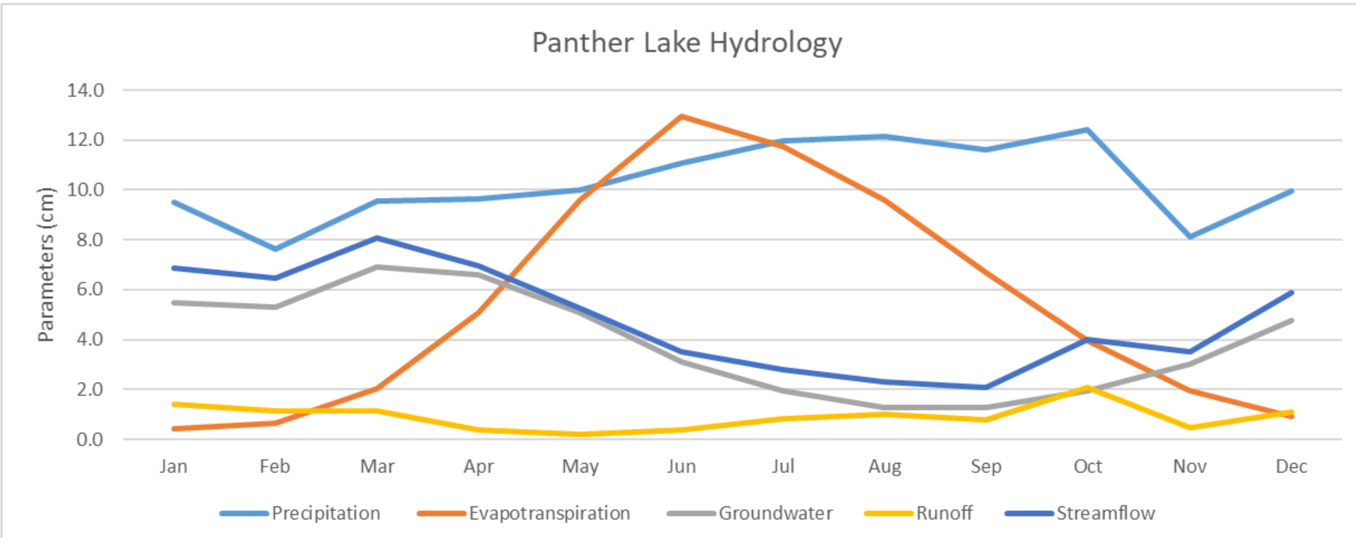


Figure 3.23. Estimated seasonal changes in hydrology in the Panther Lake watershed

Table 3.9: Total hydrological parameters in the full Panther Lake watershed over the course of a simulated

Month	Precipitation	Evapotranspiration	Groundwater	Runoff	Streamflow	
	cm	cm	cm	cm	cm	cfs
Jan	9.5	0.4	5.5	1.4	6.9	0.8
Feb	7.7	0.6	5.3	1.2	6.5	0.8
Mar	9.6	2.0	6.9	1.2	8.1	0.9
Apr	9.7	5.1	6.6	0.4	7.0	0.8
May	10.0	9.6	5.1	0.2	5.3	0.6
Jun	11.1	13.0	3.1	0.4	3.5	0.4
Jul	12.0	11.7	2.0	0.8	2.8	0.3
Aug	12.1	9.6	1.3	1.0	2.3	0.3
Sep	11.6	6.7	1.3	0.8	2.1	0.2
Oct	12.4	4.0	1.9	2.1	4.0	0.5
Nov	8.1	1.9	3.0	0.5	3.5	0.4
Dec	10.0	0.9	4.8	1.1	5.9	0.7
Total	123.6	65.6	46.7	11.0	57.8	0.6

Simulated runoff for the individual subwatersheds varied by approximately 40.3% at most, with the Jans Way subwatershed yielding the highest estimated annual runoff. This is likely a product of this subwatershed's higher area of very low-infiltrating soils, as discussed above. After factoring in direct precipitation and evaporation to the lake itself, Panther Lake is estimated to receive approximately 605,462.6 m³ or approximately 160 million gallons of water a year.

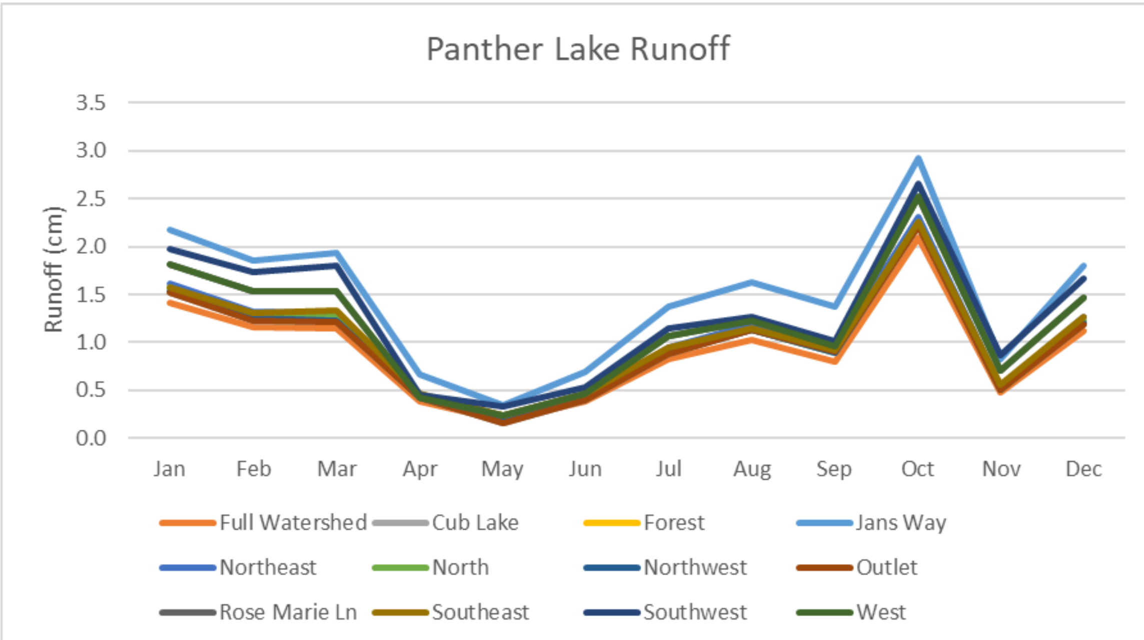


Figure 3.24. Average monthly runoff within sub-watersheds of the Panther Lake watershed

Panther Lake's volume was estimated by digitizing an older NJDEP map in ArcGIS; this produced an estimate of approximately 381,471.3 m³ or 100.8 million gallons of water. Using this volume and the estimated annual discharge mentioned above, Panther Lake is estimated to flush approximately 1.6 times a year, or once every 230.1 days. The lowest annualized monthly flushing rates for the lake are estimated to occur in July and August during an average year, with the highest rate occurring in March.

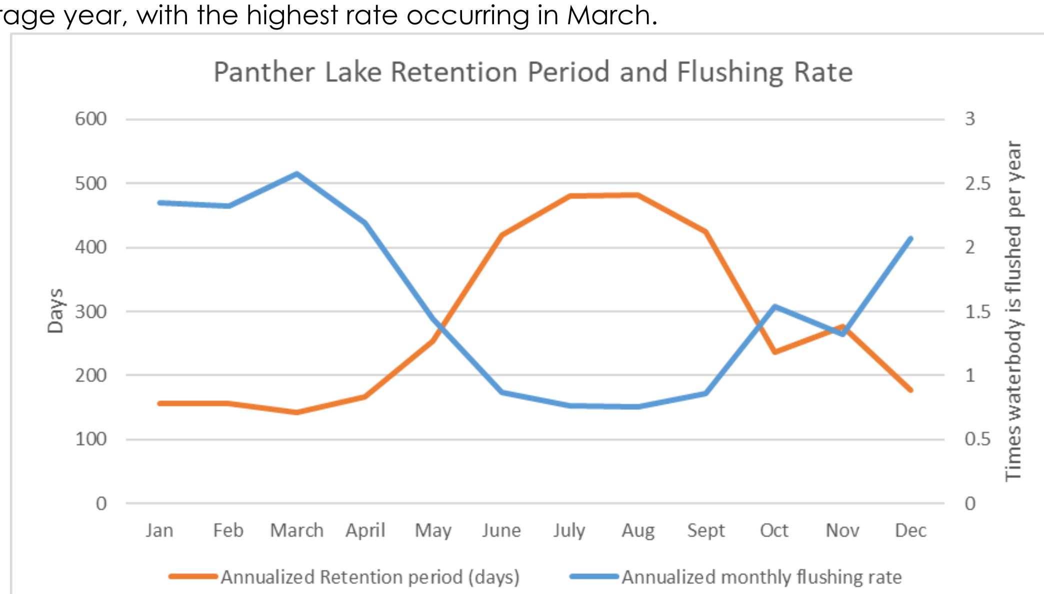


Figure 3.25. Variations in annualized flushing rates and retention periods over the course of a hypothetical year for Panther Lake, based on variations in hydraulic loads.

A majority of Panther Lake's nitrogen load originates from septic systems and groundwater. Forested Land, wetland, and urbanized land were estimated to yield the largest runoff-based nitrogen loads. The northeast subwatershed yielded the highest overall estimated annual nitrogen load, while the West subwatershed yield a disproportionately high amount of nitrogen per acre. The entire Panther Lake watershed is estimated to receive 349.7 kg of nitrogen each year, or 1.6 kg/acre.

Septic systems and groundwater were estimated to be the largest watershed-based sources of phosphorus to Panther Lake, with septic systems yielding approximately 82% of the total estimated load. Runoff-based phosphorus was estimated to largely originate from areas classified as hay/pasture. The West subwatershed was estimated to produce both the highest overall annual phosphorus load and the highest load per acre. This is likely due to the number of houses that are present within 15 meters of the lake. The full watershed is estimated to yield 41.59 kg of phosphorus or 0.19 kg/acre annually.

During field sampling events in 2023, Panther Lake was observed to feature bottom anoxia at its deepest station during all three events. Additionally, deep phosphorus concentrations were notably higher than surface concentrations during the Summer and Fall events, suggesting that increased internal phosphorus loading may have been occurring. Given the data collected in the field in 2023, Panther Lake is estimated to undergo increased internal phosphorus loading (6 mg TP/m²/day) from approximately mid-June through the beginning of October, approximately 3.5 months or 107 days. When oxic loading at the lower rate of 0.6 mg TP/m²/day in shallower areas of the lake and during other parts of the growing season is accounted for, Panther Lake is estimated to receive an annual internal phosphorus load of approximately 68.03 kg. If a year were to occur without internal phosphorus loading at the advanced rate, the estimated annual internal load would be 41.75 kg.

Table 3.10 below displays the external and internal loads of phosphorus for Panther Lake, as well as the grand total, which is estimated to be approximately 109.62 kg/year. Internal loading is estimated to be the primary source of phosphorus loading in Panther Lake, constituting approximately 62% of the total annual load.

Table 3.10: Total estimated annual phosphorus loads for Panther Lake from external and internal sources

Source	Phosphorus (kg/yr)
External (Runoff, Groundwater, Septic Systems)	41.59
Internal	68.03
Total	**109.62**

Approximately half of Panther Lake's annual sediment load is estimated to originate as runoff from land classififed as hay/pasture. The Southeast subwatershed is estimated to yield the largest overall annual sediment load, while the Southwest subwatershed is estimated to yield the largest amount per acre. The full watershed was estimated to yield an annual sediment load of approximately 533 kg or 2.3 kg/acre.

Approximately 74% of the total bacterial load estimated to enter Panther Lake each year is estimated to originate from wildlife in forested areas, with most of the remaining load estimated to occur from urbanized areas. The Southeast subwatershed is estimated to yield the highest annual bacteria load.

WOLF LAKE

Wolf Lake is an approximately 52.3-acre waterbody located in the approximate center of Byram township, immediately northwest of Lake Lackawanna. The waterbody's approximately 2,697-acre watershed is classified as over 79% forested, with wetlands and urbanized areas also comprising a notable percentage of the area. Wright, Stag, and Kofferls Ponds and their respective watersheds are all part of the Wolf Lake watershed. The waterbody receives most of its incoming flow from its northern inlet, which flows from Wright Pond to the north.

The lake's outlet is located at its southern end and flows a short distance into Lake Lackawanna. As Wolf Lake was not sampled during the 2023 season, it received only a desktop-based watershed assessment. The waterbody's subwatersheds are as follows:

- **North:** This 27.9-acre subwatershed is classified largely as forested. It contains a length of Roseville Road, as well as a small waterbody directly across the road from Wolf Lake.
- **Northeast:** This 33.1-acre subwatershed is classified mostly as forested, with a small amount of open land also present. It is located to the north of the southern basin of the lake.
- **South:** This 39.7-acre subwatershed contains the lake's outlet and largely consists of forested land.
- **Southwest:** This 75.8-acre subwatershed largely consists of forested land and contains the small drive known as Nail Road and an adjacent residence.
- **Wright:** This is the largest of Wolf Lake's subwatersheds at 2,520.1 acres. It contains the watersheds of Wright, Stag and Kofferls Ponds and is 78.5% forested, with wetlands comprising an additional 10.9%.

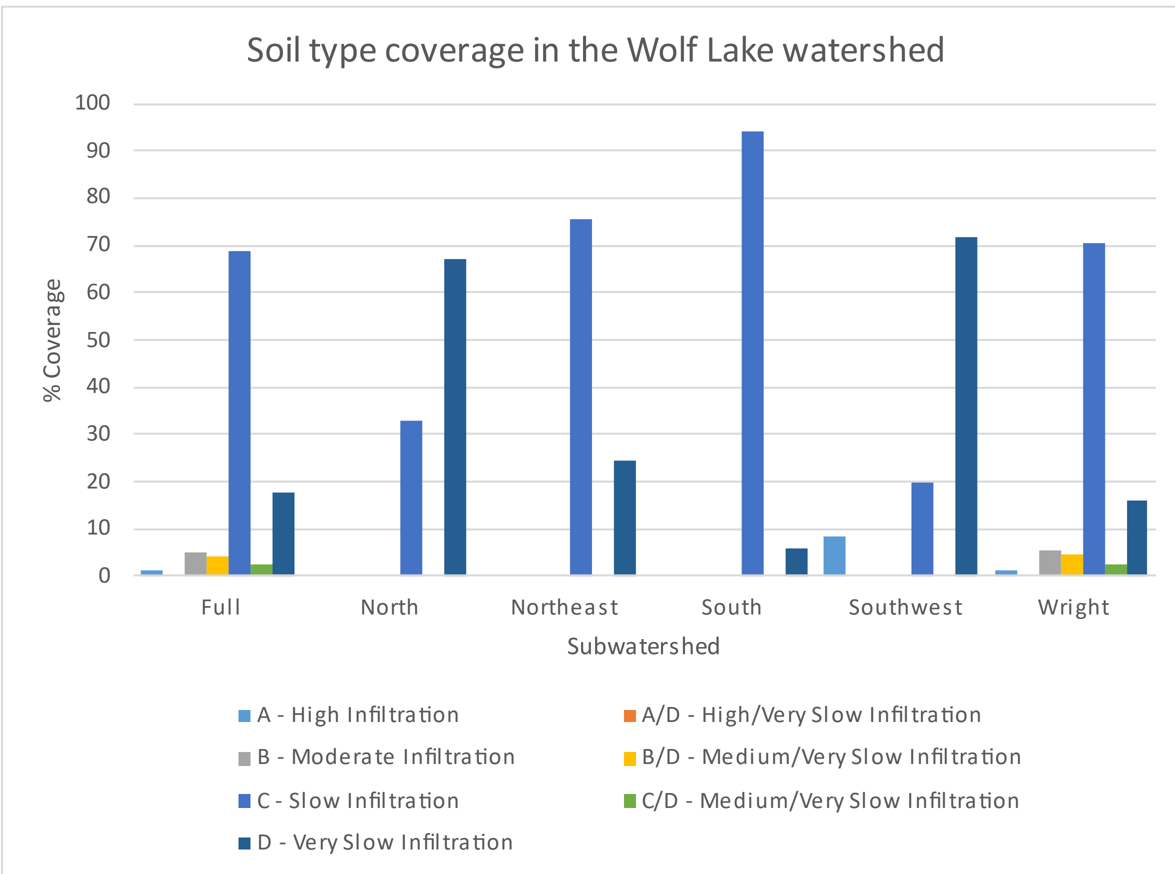


Figure 3.26. Percent coverage of Wolf Lake Watershed and subwatersheds by different hydrologic soil groups

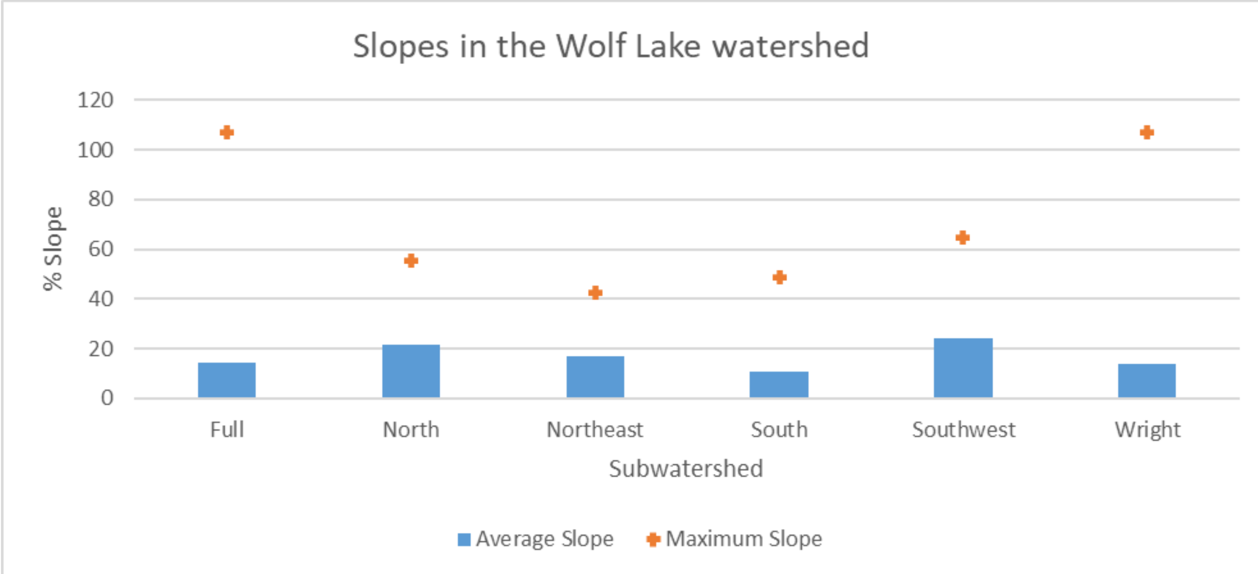


Figure 3.27. Variation in average and maximum percent slope between subwatersheds in the Wolf Lake Watershed.

Wolf Lake's watershed consists largely of the soil groups "C – Slow Infiltration" and "D – Very Slow Infiltration. The North and Southwest subwatersheds feature the highest coverage in type D soils. Subwatersheds featuring high coverage with C- and D-group soils may generate more runoff and more resulting erosion.

Slopes in the full Wolf Lake watershed averaged approximately 14.2%, with a steep maximum slope of approximately 107%, which occurred in the Wright subwatershed. The Southwest subwatershed featured the highest average slope at approximately 24.1%.

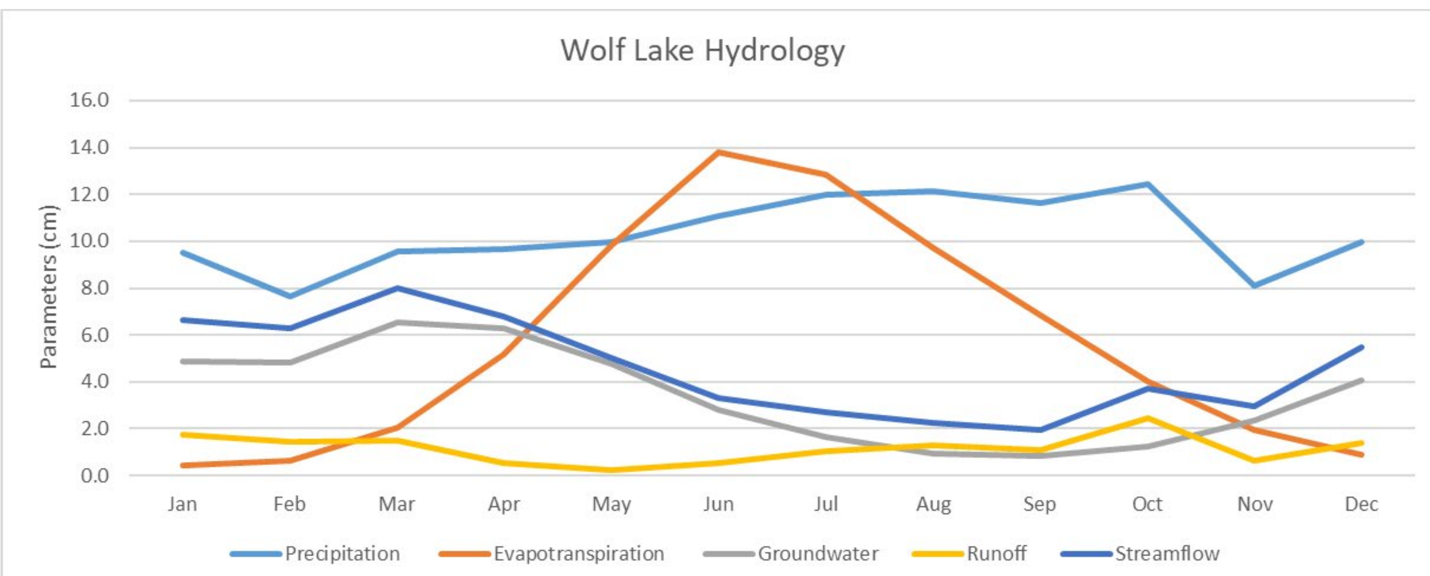


Figure 3.28. Estimated seasonal changes in hydrology in the Wolf Lake watershed

Table 3.11: Total hydrological parameters in the full Wolf Lake watershed over the course of a simulated year

Month	Precipitation	Evapotranspiration	Groundwater	Runoff	Streamflow	
	cm	cm	cm	cm	cm	cfs
Jan	9.5	0.4	4.9	1.7	6.6	9.5
Feb	7.7	0.6	4.8	1.5	6.3	9.9
Mar	9.6	2.0	6.5	1.5	8.0	11.5
Apr	9.7	5.2	6.3	0.5	6.8	10.1
May	10.0	9.8	4.8	0.3	5.0	7.2
Jun	11.1	13.8	2.8	0.5	3.3	4.9
Jul	12.0	12.9	1.7	1.1	2.7	3.9
Aug	12.1	9.7	0.9	1.3	2.2	3.2
Sep	11.6	6.9	0.9	1.1	1.9	2.9
Oct	12.4	4.0	1.2	2.5	3.7	5.3
Nov	8.1	2.0	2.3	0.6	3.0	4.4
Dec	10.0	0.9	4.1	1.4	5.5	7.9
Total	123.6	68.2	41.2	13.9	55.1	6.7

Simulated runoff showed only a small degree of variation between most of the subwatersheds, however the North and Southwest subwatersheds yielded notably higher runoff rates, likely due to these subwatersheds featuring higher coverage with slower infiltrating soils. After factoring in direct precipitation and evaporation to the lake itself, Wolf Lake is estimated to receive approximately 6,126,992.4 m³ or approximately 1,618.6 million gallons of water a year.

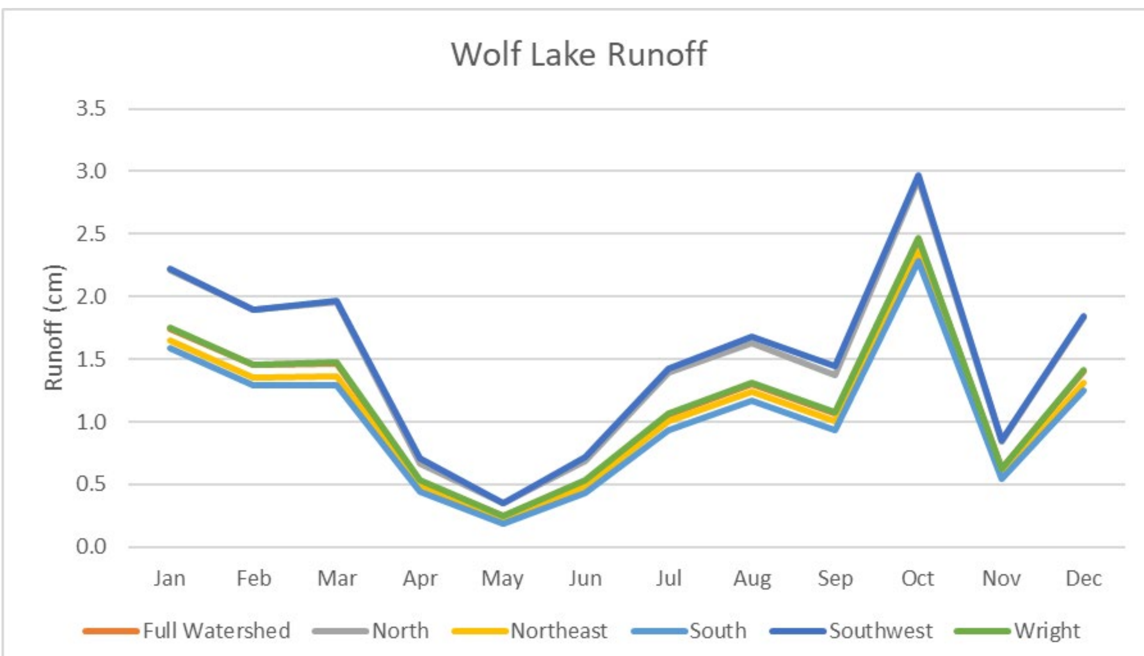


Figure 3.29. Average monthly runoff within sub-watersheds of the Wolf Lake watershed

As depth measurements were not collected in Wolf Lake in 2023, the lake's volume could not be estimated. It may be inferred, however, that the lake is overall shallow due to its coverage with floating vegetation. Given the relatively high watershed discharge, as mentioned above, and this apparently shallow depth, Wolf Lake likely flushes relatively quickly.

A majority of Wolf Lake's nitrogen load originates from septic systems, groundwater, and dryfall. Areas classified as forested land were estimated to yield the largest runoff-based nitrogen loads. The Wright subwatershed yielded the highest overall estimated annual nitrogen load, while the south subwatershed yielded as the largest amount of nitrogen per acre. The entire Wolf Lake watershed is estimated to receive 2650 kg of nitrogen each year, or 1.0 kg/acre.

Septic systems and groundwater were estimated to be the largest watershed-based sources of phosphorus to Wolf Lake. Runoff-based phosphorus was estimated to largely originate from forested land and areas classififed as hay/pasture. The Wright subwatershed was estimated to yield the overall highest annual phosphorus load, while the North subwatershed was estimated to yield the highest load per acre. The full watershed is estimated to yield 78.46 kg of phosphorus or 0.03 kg/acre annually.

Approximately 85% of Wolf Lake's annual sediment load is estimated to originate as stream bank erosion. An additional approximately 11% of the total load is estimated to originate as runoff from areas classified as hay/pasture. The Wright subwatershed is estimated to yield the highest overall annual sediment load, while the North subwatershed is estimated to yield the highest amount of sediment per acre. The full watershed was estimated to yield an annual sediment load of approximately 6,162 kg or 2.3 kg/acre.

More than 90% of the total bacterial load estimated to enter Wolf Lake each year is estimated to originate from wildlife within the forested areas of the watershed. The Wright subwatershed is estimated to yield the highest annual bacteria load.

WRIGHT POND

Wright Pond, also known as Roseville Pond, is an approximately 32.35-acre waterbody located near the center of Byram Township to the north of Wolf Lake. The waterbody's 805.5-acre watershed contains Stag and Kofferls Ponds and their respective watersheds, and is classified as 76% forested, with an additional 10.7% of the area classified as wetlands. The pond receives a majority of its flow from its northeast inlet Punkhorn Creek, a tributary to Lubbers Run, as well as a smaller inlet that enters along the northwestern shoreline. The Pond's outlet exits at its southern end and travels south through a wetland into Wolf Lake. As with Wolf Lake, Wright Pond was not sampled during the 2023 season, and thus only received a desktop-based watershed assessment. The waterbody's subwatersheds are as follows:

- **East:** This 9.40 acre subwatershed encompasses most of the southeastern shoreline of Wright Pond. The area is classified as mostly forested. While no land in the area is classified as hay pasture, a horse farm is also present.
- **Island:** As its name suggests, this small (0.5 acres) subwatershed consists of an island near the pond's inlet. It is classified as entirely wetlands and open land.
- **Lubbers Run:** This is the largest of Wright Pond's subwatersheds at 1,779.9 acres. The area contains Stag and Kofferls Pond and their respective watersheds, as well as the tributary to Lubbers Run known as Punkhorn Creek, which enters the pond via the wetland at its northeastern end. The subwatershed is classified as 77.8% forested, with wetlands making up an additional 10.9%.
- **Sparta Mt.**: This 117.8-acre subwatershed is located along the northwestern shoreline of Wright Pond and features a smaller inlet that originates from a smaller pond to the north. The area consists entirely of forest and wetlands.
- **West:** This 19.1-acre subwatershed contains a length of railroad and is entirely classified as forested land and wetlands.

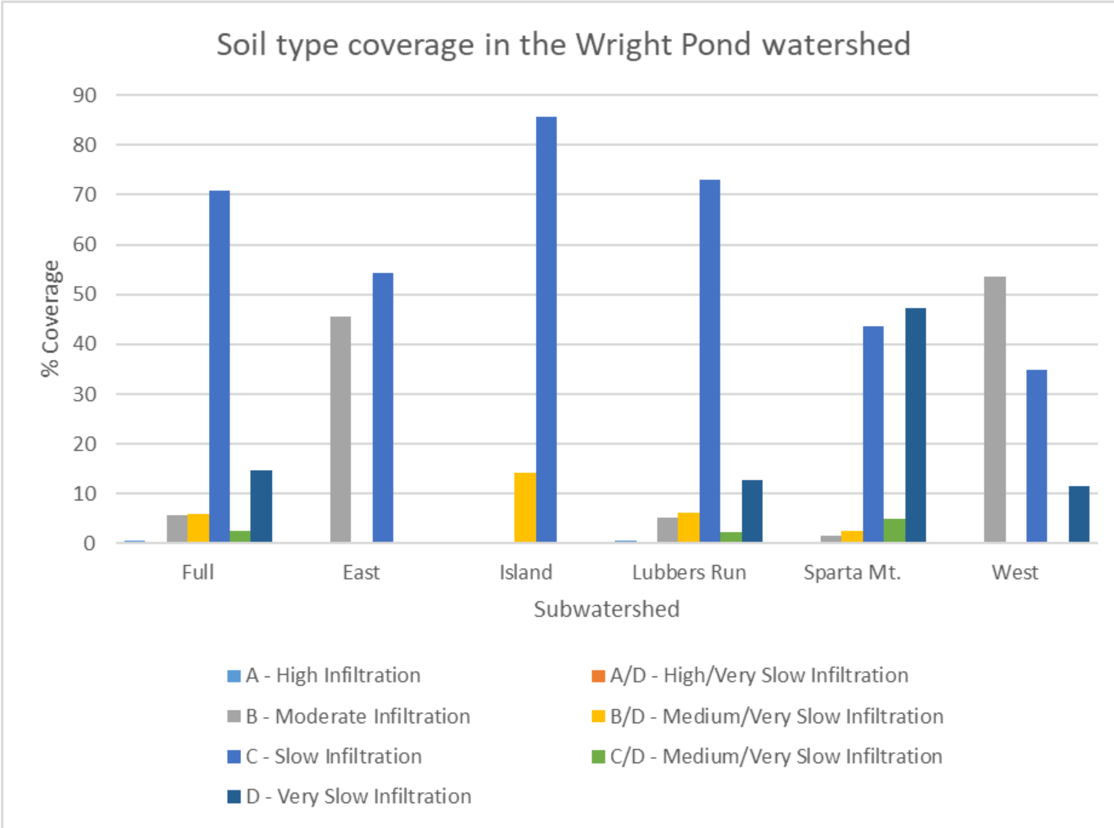


Figure 3.30. Percent coverage of Wright Pond's Watershed and subwatersheds by different hydrologic soil groups

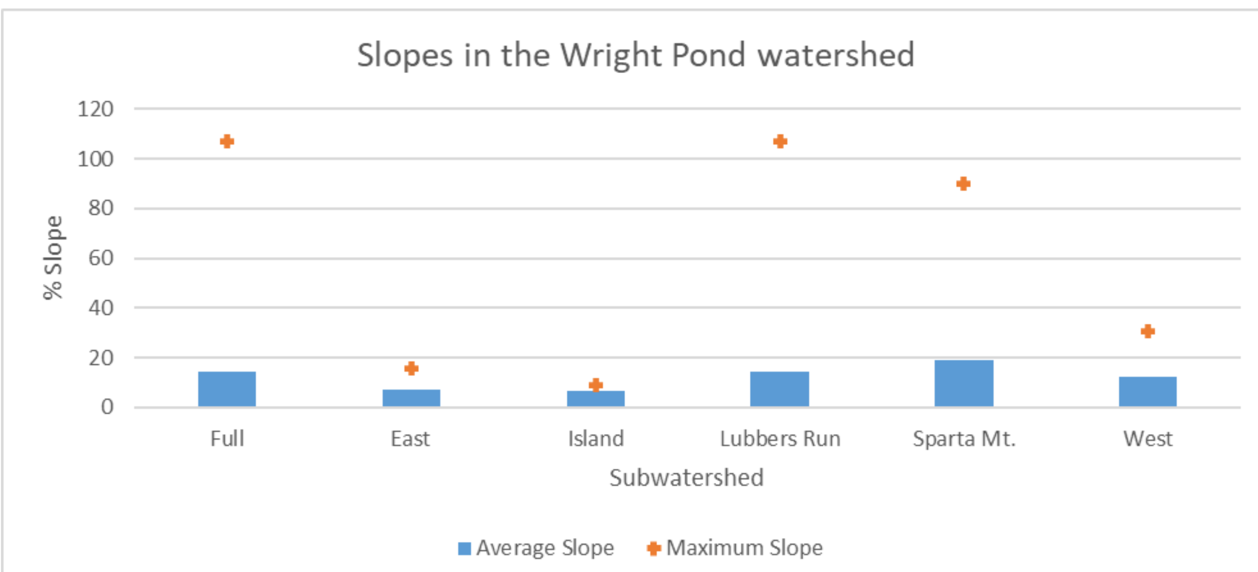


Figure 3.31. Variation in average and maximum percent slope between subwatersheds in the Wright Pond Watershed.

Wright Pond's watershed is mostly covered by the soil group "C – Slow Infiltration". The Sparta Mt. subwatershed is approximately half covered with the soil group "D – Very Slow Infiltration", while the East and West subwatersheds feature notable coverage with the soil group "B – Moderate Infiltration". Subwatersheds featuring high coverage with C- and D-group soils may generate more runoff and more resulting erosion, while those featuring higher coverage with B-group soils may allow better infiltration of precipitation into the groundwater and generate less runoff.

Slopes in the full Wright Pond watershed averaged approximately 14.5%, with a steep maximum slope of approximately 107%, which occurred in the Lubbers Run subwatershed. The Sparta Mt. subwatershed featured the highest average slope at approximately 18.9%.

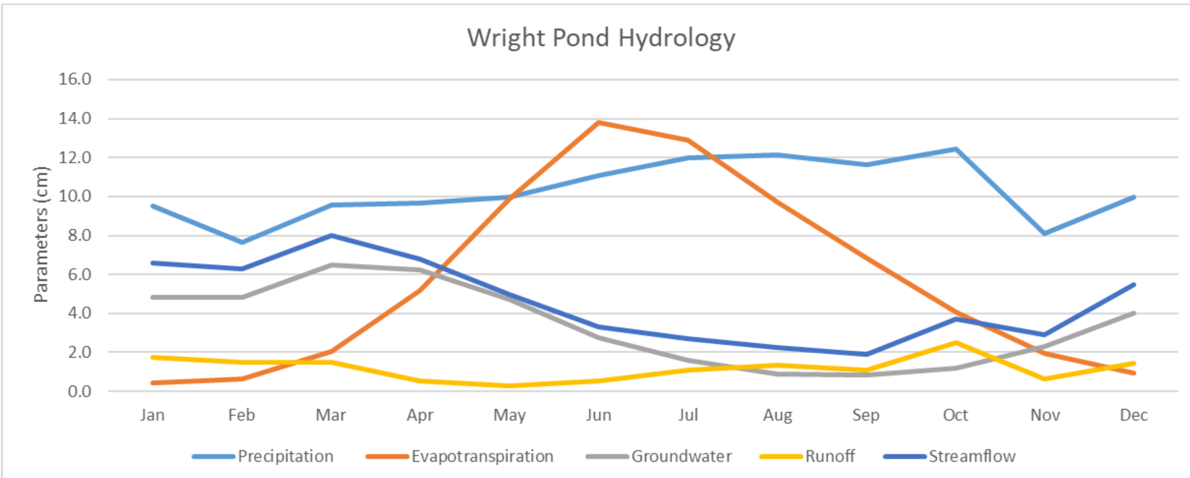


Table 3.12: Total hydrological parameters in the full Wright Pond watershed over the course of a simulated

Figure 3.32. Estimated seasonal changes in hydrology in the Wright Pond watershed

Month	Precipitation	Evapotranspiration	Groundwater	Runoff	Streamflow	
	cm	cm	cm	cm	cm	cfs
Jan	9.5	0.4	4.8	1.8	6.6	2.8
Feb	7.7	0.6	4.8	1.5	6.3	3.0
Mar	9.6	2.1	6.5	1.5	8.0	3.4
Apr	9.7	5.2	6.3	0.5	6.8	3.0
May	10.0	9.9	4.7	0.3	5.0	2.1
Jun	11.1	13.8	2.8	0.5	3.3	1.5
Jul	12.0	12.9	1.6	1.1	2.7	1.2
Aug	12.1	9.7	0.9	1.3	2.2	1.0
Sep	11.6	6.9	0.8	1.1	1.9	0.9
Oct	12.4	4.1	1.2	2.5	3.7	1.6
Nov	8.1	2.0	2.3	0.6	2.9	1.3
Dec	10.0	0.9	4.0	1.4	5.5	2.3
Total	123.6	68.4	40.8	14.1	54.9	2.0

Simulated runoff showed a large degree of variation (as much as 97.7%) between the subwatersheds, with the island subwatershed modeled to produce a notably higher runoff rate than the other subwatersheds. This may be due to the area consisting largely of group-C soils, as well as a portion of the area classified as open land. As the island subwatershed is very small, it likely does not produce a large total amount of runoff. After factoring in direct precipitation and evaporation to the pond itself, Wright Pond is estimated to receive approximately 1,860,899.5 m³ or approximately 491.6 million gallons of water a year.

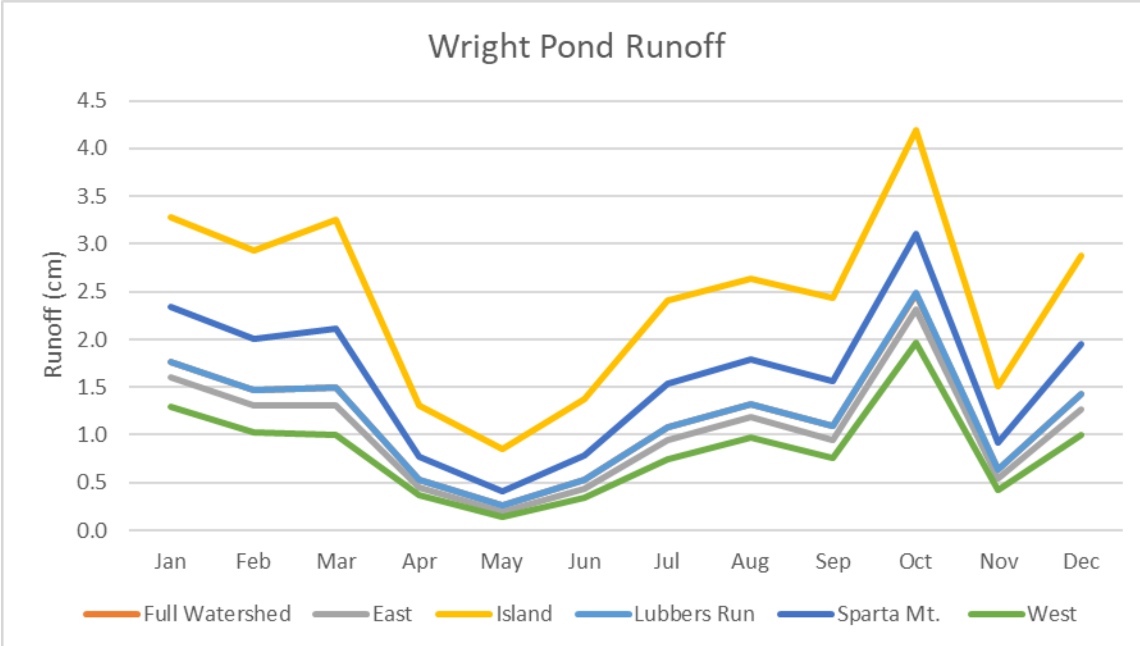


Figure 3.33. Average monthly runoff within sub-watersheds of the Wright Pond watershed

A majority of Wright Pond's nitrogen load originates from septic systems, groundwater, and dryfall. Areas classified as forested land were estimated to yield the largest runoff-based nitrogen loads. The Lubbers Run subwatershed yielded the highest overall estimated annual nitrogen load, while the East subwatershed yielded as the largest amount of nitrogen per acre. The entire Wright Pond watershed is estimated to receive 1819.4 kg of nitrogen each year, or 2.3 kg/acre.

Septic systems and groundwater were estimated to be the largest watershed-based sources of phosphorus to Wolf Lake. Runoff-based phosphorus was estimated to largely originate from forested land and areas classififed as hay/pasture. The Lubbers Run subwatershed was estimated to yield the overall highest annual phosphorus load, while the East subwatershed was estimated to yield the highest load per acre. The full watershed is estimated to yield 60.45 kg of phosphorus or 0.08 kg/acre annually.

Approximately 86% of Wright Pond's annual sediment load is estimated to originate as stream bank erosion. An additional approximately 7.8% of the total load is estimated to originate as runoff from areas classified as hay/pasture. The Lubbers Run subwatershed is estimated to yield the highest overall annual sediment load, while the West subwatershed is estimated to yield the highest amount of sediment per acre. The full watershed was estimated to yield an annual sediment load of approximately 4,375 kg or 5.4 kg/acre.

More than 90% of the total bacterial load estimated to enter Wright Pond each year is estimated to originate from wildlife within the forested areas of the watershed. The Lubbers Run subwatershed is estimated to yield the highest annual bacteria load.

JEFFERSON LAKE

Jefferson Lake is an approximately 48.8-acre impoundment in the southern portion of Byram Township. The lake's 3,245.8-acre watershed contains Cranberry Lake and Johnson Lake and their respective watersheds. The watershed is approximately 71% forested, with notable amounts of wetlands and urbanized areas also present. The lake features a maximum depth of approximately 3.7 meters. Jefferson Lake's inlet stream, Ghost Pony Brook, enters the basin at its northwestern corner. The lake features two outlets along its eastern shoreline which quickly join each other before their confluence with Lubber's Run, which flows south until its confluence with the Musconetcong River. The lake also features a small overflow outlet feature in its southwest corner. Jefferson Lake's subwatersheds are as follows:

- **Dam:** This is the smallest of Jefferson Lake's subwatersheds at 5.4 acres. The area contains a length of the access road for the Jeff Lake Camp, as well as an athletic field and the lake's two eastern outlet streams. The subwatershed is classified as a mix of forested land, hay/pasture, wetlands, and low-density developed open space.
- **Ghost Pony:** This is the largest of Jefferson Lake's subwatersheds at 2,929.4 acres. As its name suggests, it contains the lake's inlet Ghost Pony Brook. The subwatershed also stretches north to include the Cranberry Lake and Johnson Lake watersheds, as well as a length of Rt. 206 and some of the surrounding urbanized areas. The area is approximately 69% forested, with wetlands and low-density urbanized open space.
- **Northeast:** This 73.6-acre subwatershed is 95% forested, with a small amount of wetlands also present. The area also contains a length of the Jeff Lake Camp access road.
- **North:** This 29.1-acre subwatershed contains a majority of the Jeff Lake Camp area. Approximately 62.9% of the area is classified as forested, with developed land contributing to an additional 29.6% of the area.
- **Northwest:** This 174.4-acre subwatershed is almost entirely forested and contains a hiking trail along the western edge of the lake.
- **Southeast:** This 22.7-acre subwatershed is 74% forested, with a notable area of low-density developed open space also present. It contains a length of Jefferson Lake Road South and a small wetland.
- **South:** This 9.9-acre subwatershed is located adjacent to the southwest corner of Jefferson Lake. The area is classified as 100% forested.

Jefferson Lake's watershed is largely covered by the soil groups "C – Slow Infiltration" and "D – Very Slow Infiltration". The Dam, North, Southeast, and South subwatersheds also feature notable coverage with the soil group "A – High Infiltration". Subwatersheds featuring high coverage with C- and D-group soils may generate more runoff and more resulting erosion, while subwatersheds with higher coverage is A-group soils likely allow more precipitation to enter into the groundwater through the soil and may reducing runoff.

Slopes in the full Jefferson Lake watershed averaged approximately 11.4%, with a maximum slope of approximately 62.5%, which occurred in the Ghost Pony subwatershed. The Northwest subwatershed featured the highest average slope at approximately 14.2%.

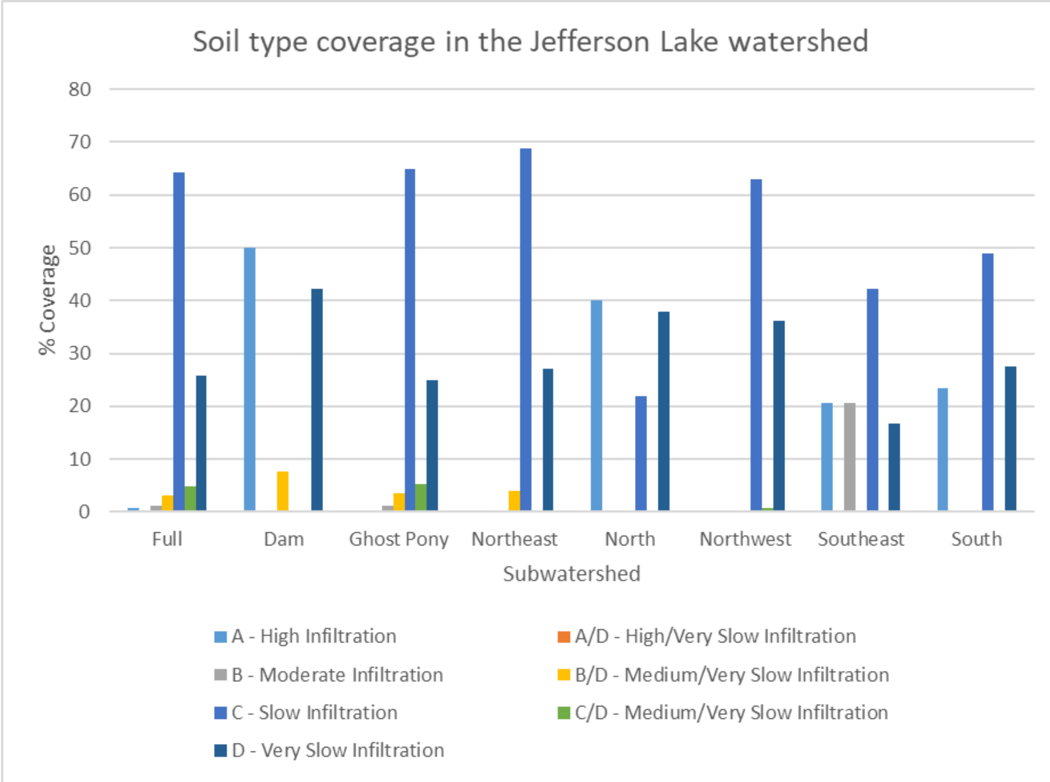


Figure 3.34. Percent coverage of Jefferson Lake Watershed and subwatersheds by different hydrologic soil groups

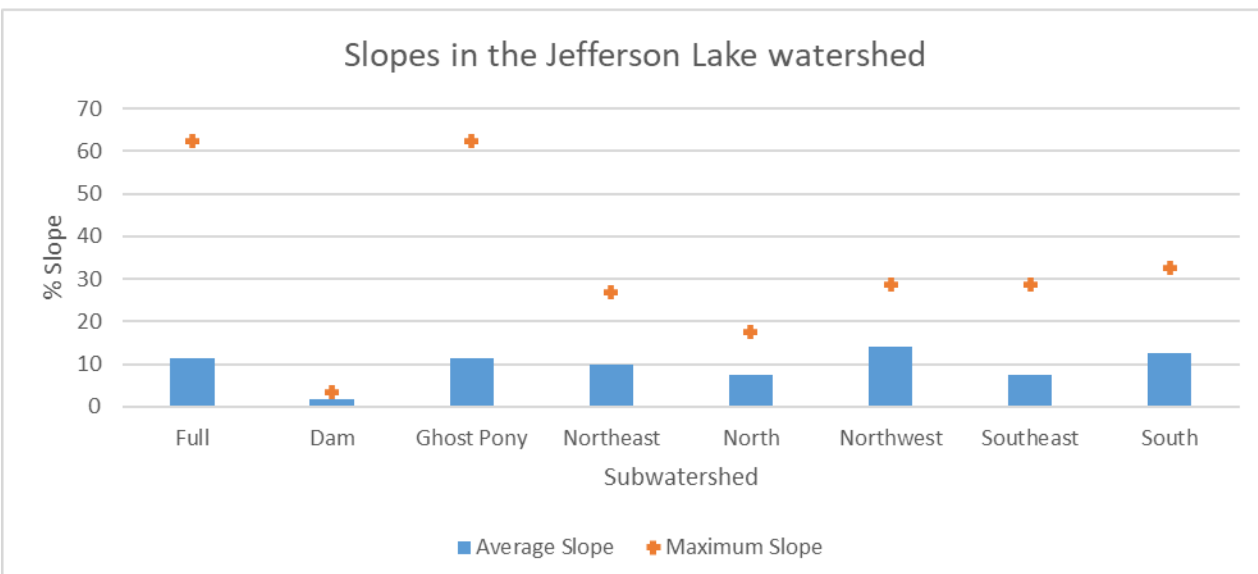


Figure 3.35. Variation in average and maximum percent slope between subwatersheds in the Jefferson Lake Watershed.

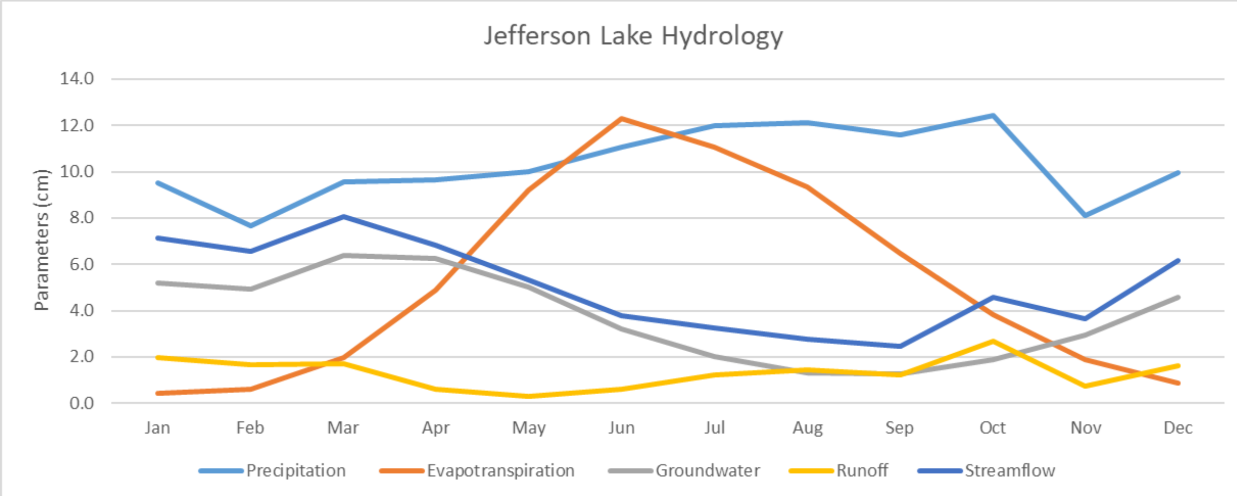


Figure 3.36. Estimated seasonal changes in hydrology in the Jefferson Lake watershed

Table 3.13: Total hydrological parameters in the full Jefferson Lake watershed over the course of a simulated year

Month	Precipitation	Evapotranspiration	Groundwater	Runoff	Streamflow	
	cm	cm	cm	cm	cm	cfs
Jan	9.5	0.4	5.2	2.0	7.1	12.4
Feb	7.7	0.6	4.9	1.7	6.6	12.5
Mar	9.6	2.0	6.4	1.7	8.1	14.0
Apr	9.7	4.9	6.2	0.6	6.8	12.2
May	10.0	9.2	5.0	0.3	5.3	9.2
Jun	11.1	12.3	3.2	0.6	3.8	6.8
Jul	12.0	11.1	2.0	1.2	3.2	5.6
Aug	12.1	9.3	1.3	1.5	2.8	4.8
Sep	11.6	6.5	1.3	1.2	2.5	4.4
Oct	12.4	3.8	1.9	2.7	4.6	7.9
Nov	8.1	1.9	2.9	0.7	3.7	6.5
Dec	10.0	0.9	4.6	1.6	6.2	10.7
Total	123.6	62.8	44.9	15.7	60.6	8.9

Simulated runoff between the individual subwatersheds varied at most by approximately 23.4%. The North subwatershed yielded the highest runoff rate. After factoring in direct precipitation and evaporation to the lake itself, Jefferson Lake is estimated to receive approximately 8,081,448 m³ or approximately 2,134.9 million gallons of water a year.

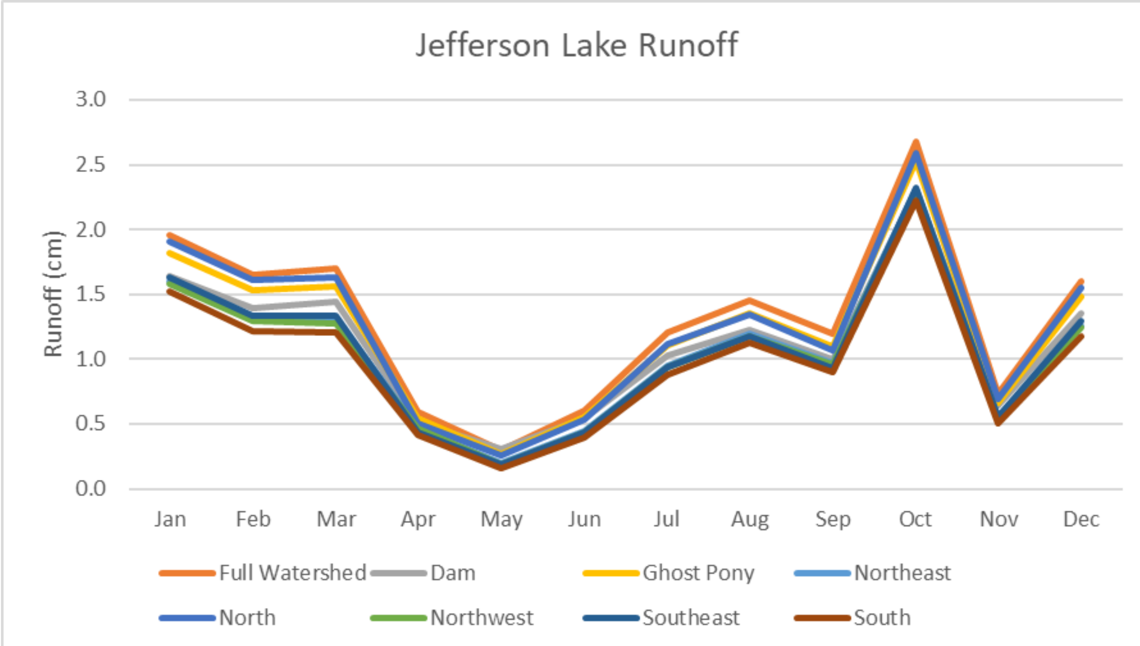


Figure 3.37. Average monthly runoff within sub-watersheds of the Jefferson Lake watershed

Bathymetric data was not available for Jefferson Lake, and as such, the lake's volume was estimated using depths collected when collecting water quality data. Jefferson Lake is estimated to feature a volume of approximately 395,725.3 m³ or 104.5 million gallons of water. Using this volume and the estimated annual discharge mentioned above, Jefferson Lake is estimated to flush approximately 20.4 times a year, or once every 17.9 days. The lowest annualized monthly flushing rate for the lake is estimated to occur in September during an average year, with the highest rate occurring in March.

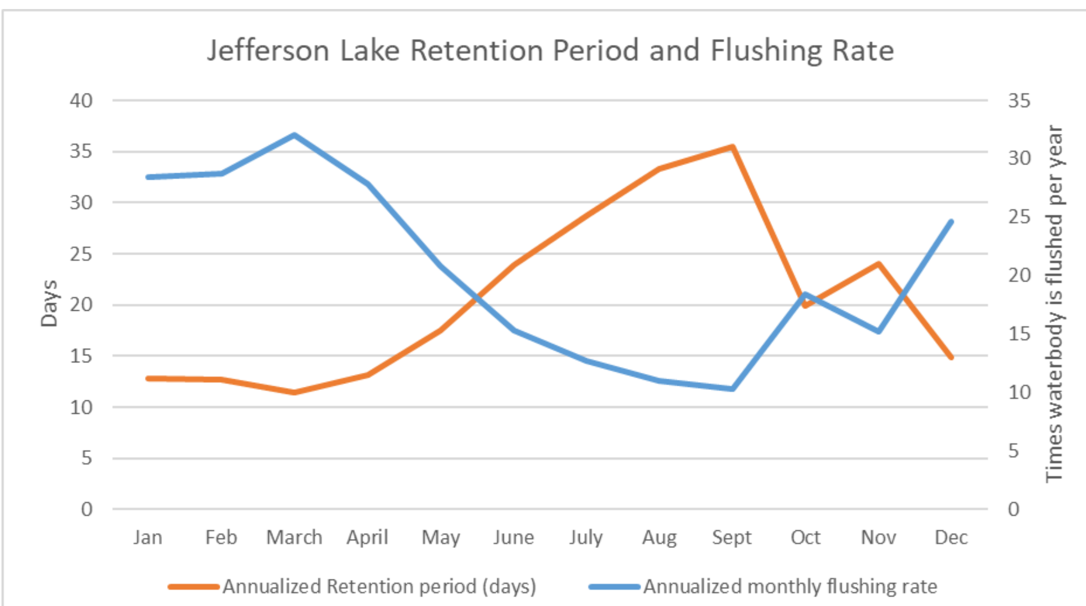


Figure 3.38. Variations in annualized flushing rates and retention periods over the course of a hypothetical year for Jefferson Lake, based on variations in hydraulic loads.

Most of Jefferson Lake's nitrogen load originates from septic systems and groundwater. Forested land and wetlands were estimated to yield the largest runoff-based nitrogen loads. The Ghost Pony subwatershed yielded both the highest overall estimated annual nitrogen load as well as the largest amount of nitrogen per acre. The entire Jefferson Lake watershed is estimated to receive 5,435.8 kg of nitrogen each year, or 1.7 kg/acre.

Septic systems and groundwater were estimated to be the largest watershed-based sources of phosphorus to Jefferson Lake, with septic systems yielding approximately 72.4% of the total estimated load. Runoff-based phosphorus was estimated to largely originate from forested areas. The Ghost Pony subwatershed was estimated to yield both the overall highest annual phosphorus load and the largest phosphorus load on a per-acre basis. The full watershed is estimated to yield 356.80 kg of phosphorus or 0.11 kg/acre annually.

During field sampling events in 2023, Jefferson Lake was observed to feature bottom anoxia during the 21 June event. Deep phosphorus concentrations during this date were somewhat higher than those obtained at the surface, suggesting that increased internal phosphorus loading may have been occurring. Given these observations, Jefferson Lake is estimated to undergo increased internal phosphorus loading (6 mg TP/m^2/day) for one month during the growing season, approximately 31 days. When oxic loading at the lower rate of 0.6 mg TP/m^2/day in shallower areas of the lake and during other parts of the growing season is accounted for, Jefferson Lake is estimated to receive an annual internal phosphorus load of approximately 20.44 kg. If a year were to occur without internal phosphorus loading at the advanced rate, the estimated annual internal load would be 18.13 kg.

Table 3.14 below displays the external and internal loads of phosphorus for Jefferson Lake, as well as the grand total, which is estimated to be approximately 377.24 kg/year. External loading is estimated to be the primary source of phosphorus loading in Jefferson Lake, constituting approximately 94.6% of the total annual load.

Table 3.14: Total estimated annual phosphorus loads for Jefferson Lake from external and internal sources

Source	**Phosphorus (kg/yr)**
External (Runoff, Groundwater, Septic Systems)	356.80
Internal	20.44
Total	**377.24**

Jefferson Lake's annual sediment load is estimated to largely (over 96%) originate as streambank erosion. The Ghost Pony subwatershed is estimated to yield both the largest overall annual sediment load and the largest amount per acre. The full watershed was estimated to yield an annual sediment load of approximately 42,866 kg or 13.2 kg/acre.

Approximately 85% of the total bacterial load estimated to enter Jefferson Lake each year is estimated to originate from wildlife in forested areas, with most of the remaining load estimated to occur from urban areas. The Ghost Pony subwatershed is estimated to yield the highest annual bacteria load.

STAG POND

Stag Pond is an approximately 36.79-acre waterbody in the northern portion of Byram Township. The pond's 237.9-acre watershed is almost entirely covered by forests and wetlands, with only 4.6 acres of land classified as urbanized. It should be noted that most of the residences around the pond are only used during the summer; as such, septic modeling reflected use only during the summer months. The waterbody is somewhat deep compared to most of the other waterbodies in the study, with a maximum depth of approximately 7.6 meters. Two inlets enter the body; one of these enters the northernmost cove while a second small inlet enters the lake along the western shoreline. The pond's outlet flows south from its southernmost cove, traveling south for a short distance before its confluence with Punkhorn Creek, which continues southwest towards Wright Pond. Stag Pond's subwatersheds are as follows:

- **East:** This 24.2-acre subwatershed is classified as 100% forested. No residences are present in this area.
- **North:** This is the largest of Stag Pond's subwatersheds at 124.8-acres. The area consists entirely of wetlands and forested land and contains the north inlet.
- **Outlet:** This 21-acre subwatershed lies at the southernmost point of the full watershed. It contains a length of Stag Lake East Road and is otherwise entirely forested with a small amount of wetland present.
- **South:** This is the smallest of Stag Pond's subwatersheds at 13.2 acres. The area contains four summer cottages and is largely forested.
- **Southeast:** This 13.8-acre subwatershed contains a part of the pond's dam, as well as one of the only year-round residences in the lake's community. The area is almost entirely classified as forested land.
- **Southwest:** This 7.9-acre subwatershed contains an area of low-density developed open space, containing two summer cottages. The remainder of the area is otherwise classified as forested.
- **West:** This 33.1-acre subwatershed contains the smaller of the lake's two inlet streams and a length of Stag Pond Rd. (an unpaved gravel trail in this area). Like the other subwatersheds, it is largely classified as forested.

Stag Pond's watershed is largely covered by the soil group "C – Slow Infiltration". The East and Southeast subwatersheds also feature notable coverage with the soil group "D – High Infiltration". Subwatersheds featuring high coverage with C- and D-group soils may generate more runoff and more resulting erosion. Slopes in the full Stag Pond watershed averaged approximately 18.3%, with a maximum slope of approximately 67.5%, which occurred in the East subwatershed. This subwatershed also featured the highest average slope at approximately 14.2%.

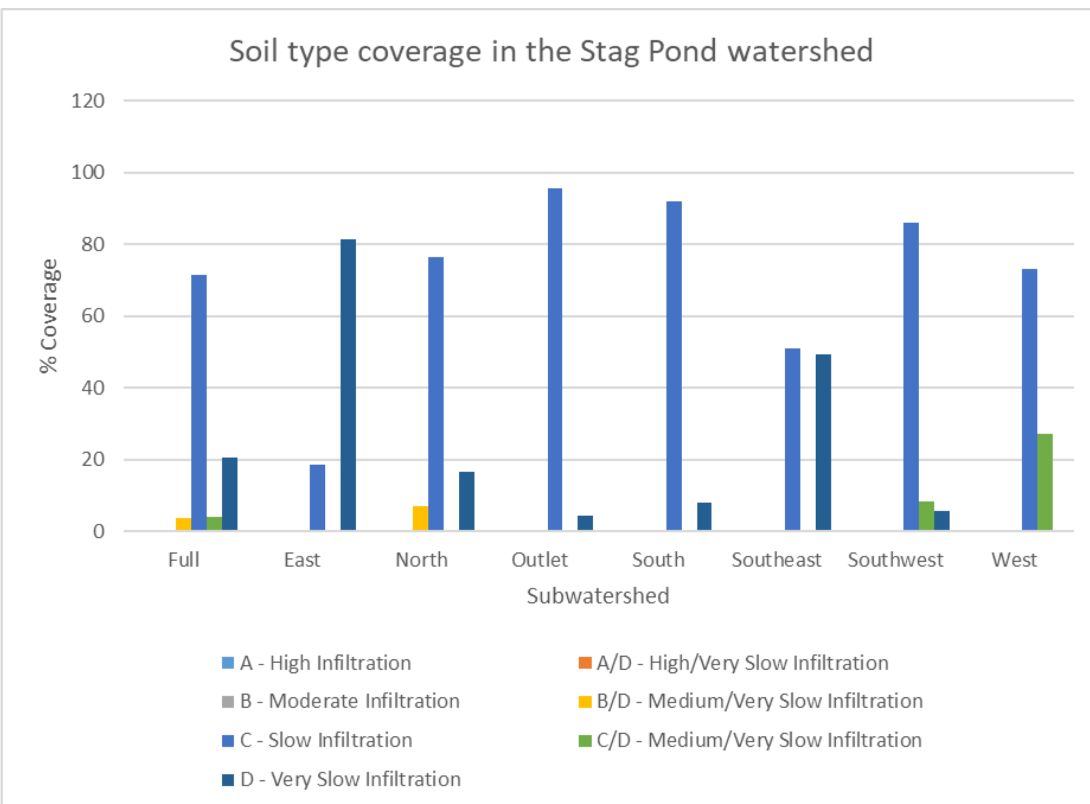


Figure 3.39. Percent coverage of Stag Pond Watershed and subwatersheds by different hydrologic soil groups

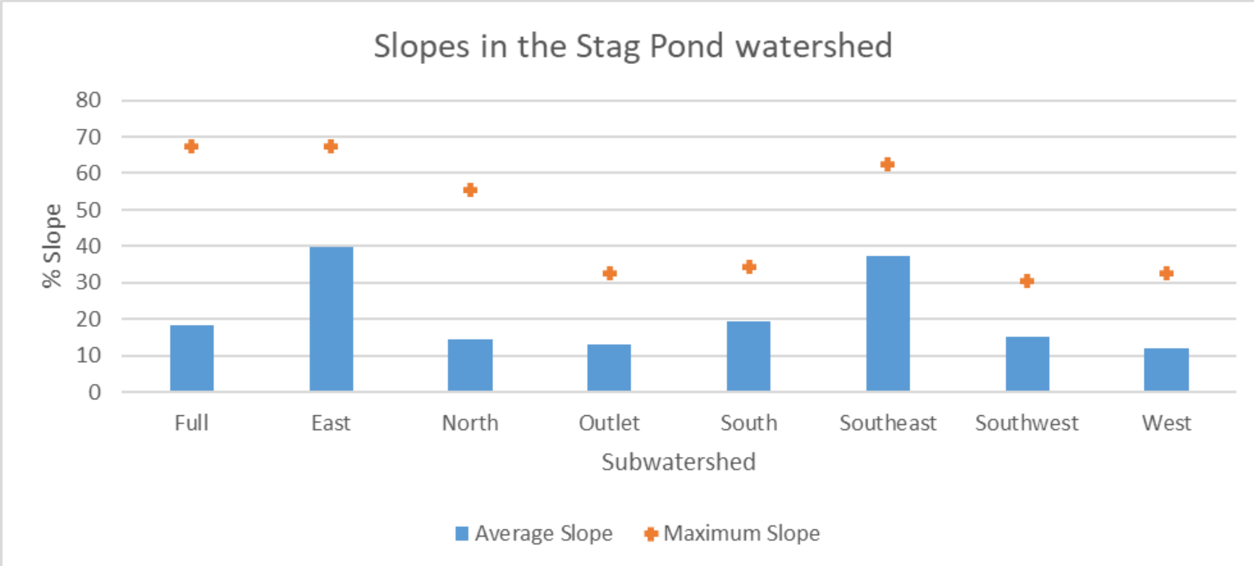


Figure 3.40. Variation in average and maximum percent slope between subwatersheds in the Stag Pond Watershed.

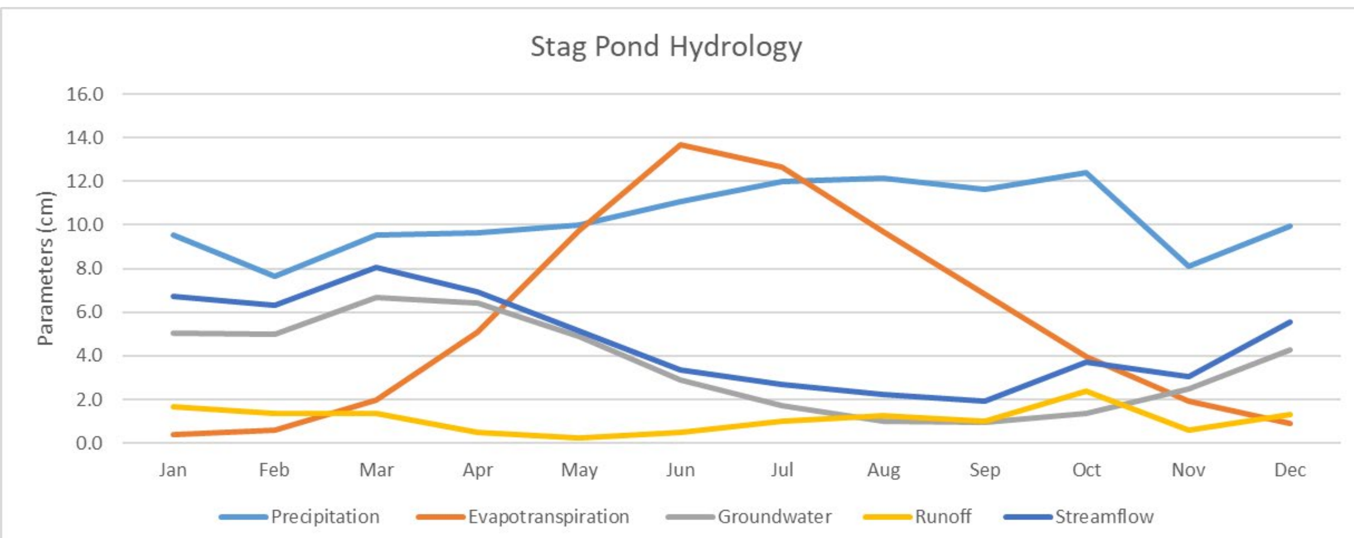


Figure 3.41. Estimated seasonal changes in hydrology in the Stag Pond watershed

Table 3.15: Total hydrological parameters in the full Stag Pond watershed over the course of a simulated year

Month	Precipitation	Evapotranspiration	Groundwater	Runoff	Streamflow	
	cm	cm	cm	cm	cm	cfs
Jan	9.5	0.4	5.1	1.7	6.7	0.9
Feb	7.7	0.6	5.0	1.4	6.3	0.9
Mar	9.6	2.0	6.7	1.4	8.1	1.0
Apr	9.7	5.1	6.4	0.5	6.9	0.9
May	10.0	9.8	4.9	0.2	5.1	0.6
Jun	11.1	13.7	2.9	0.5	3.4	0.4
Jul	12.0	12.7	1.7	1.0	2.7	0.3
Aug	12.1	9.7	1.0	1.2	2.2	0.3
Sep	11.6	6.9	0.9	1.0	1.9	0.3
Oct	12.4	4.0	1.4	2.4	3.7	0.5
Nov	8.1	1.9	2.5	0.6	3.1	0.4
Dec	10.0	0.9	4.3	1.3	5.6	0.7
Total	123.6	67.5	42.7	13.1	55.8	0.6

Simulated runoff between most of the individual subwatersheds displayed little variation. The East subwatershed, however, displayed higher runoff rates, likely due to its higher coverage with very low-infiltration soils. After factoring in direct precipitation and evaporation to the pond itself, Stag Pond is estimated to receive approximately 620,447.9 m³ or approximately 163.9 million gallons of water a year.

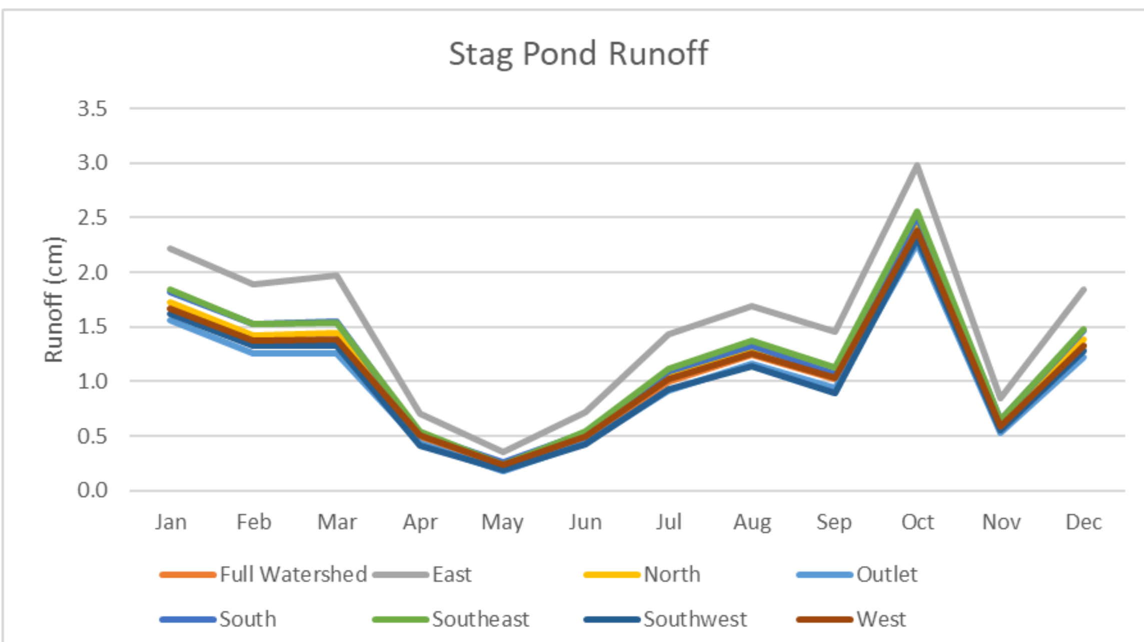


Figure 3.42. Average monthly runoff within sub-watersheds of the Stag Pond watershed

Bathymetric data was not available for Stag Pond, and as such, the Pond's volume was estimated using depths collected when collecting water quality data. Stag Pond is estimated to feature a volume of approximately 330,341.2 m³ or 87.3 million gallons of water. Using this volume and the estimated annual discharge mentioned above, Stag Pond is estimated to flush approximately 1.9 times a year, or once every 194.4 days. The lowest annualized monthly flushing rate for the lake is estimated to occur in July and August during an average year, with the highest rate occurring in March.

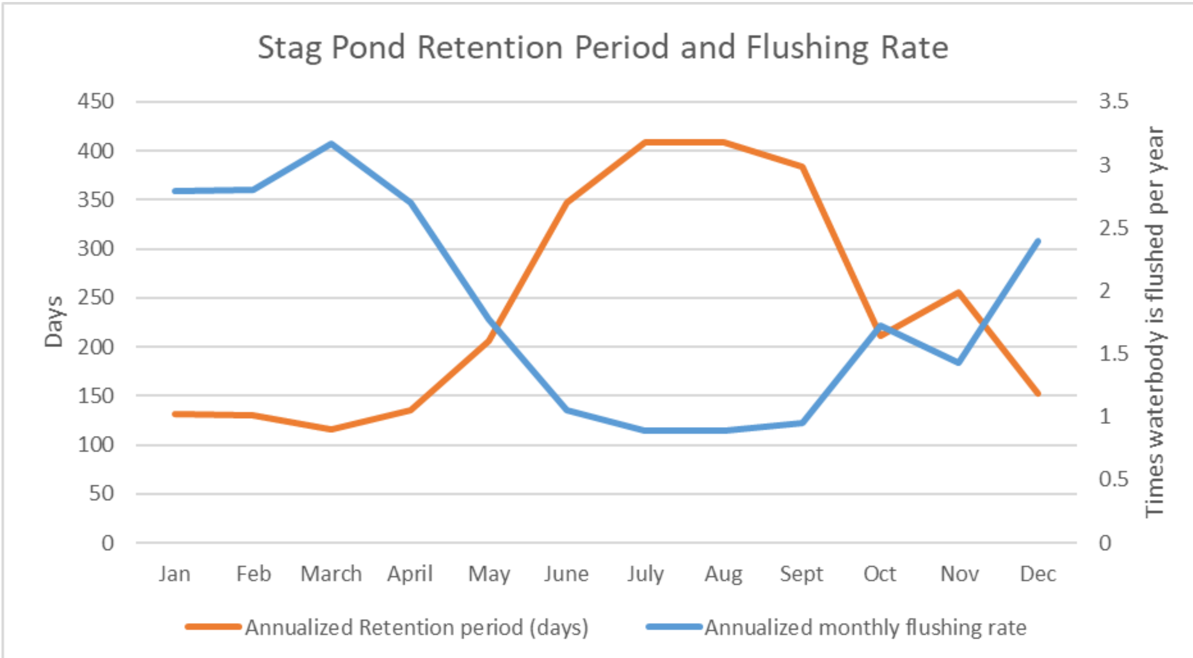


Figure 3.43. Variations in annualized flushing rates and retention periods over the course of a hypothetical year for Stag Pond, based on variations in hydraulic loads.

Most of Stag Pond's nitrogen load originates from groundwater and dryfall. Forested land was estimated to yield the largest runoff-based nitrogen loads. The North subwatershed yielded the highest overall estimated annual nitrogen load, while the South subwatershed yielded the largest amount of nitrogen per acre. The entire Stag Pond watershed is estimated to receive 219.9 kg of nitrogen each year, or 0.9 kg/acre.

Septic systems and groundwater were estimated to be the largest watershed-based sources of phosphorus to Stag Pond. Runoff-based phosphorus was estimated to largely originate from forested areas. The Southeast subwatershed was estimated to yield both the overall highest annual phosphorus load and the largest phosphorus load on a per-acre basis. The full watershed is estimated to yield 8.48 kg of phosphorus or 0.04 kg/acre annually.

During field sampling events in 2023, Stag Pond was measured to feature bottom anoxia during all three sampling events. Deep phosphorus concentrations were notably higher than those collected at the surface during each event also, suggesting that increased internal phosphorus loading may have been occurring. Given these measurements, Stag Pond is estimated to undergo increased internal phosphorus loading (6 mg TP/m²/day) for 3.5 months or approximately 92 days at a depth of approximately 7 meters, and for 2 months or approximately 61 days at 5 meters. When oxic loading at the lower rate of 0.6 mg TP/m²/day in shallower areas of the lake and during other parts of the growing season is accounted for, Stag Pond is estimated to receive an annual internal phosphorus load of approximately 30.87 kg. If a year were to occur without internal phosphorus loading at the advanced rate, the estimated annual internal load would be 13.67 kg.

Table 3.16 below displays the external and internal loads of phosphorus for Stag Pond, as well as the grand total, which is estimated to be approximately 39.35 kg/year. Internal loading is estimated to be the primary source of phosphorus loading in Stag Pond, constituting approximately 78.5% of the total annual load.

Table 3.16: Total estimated annual phosphorus loads for Stag Pond from external and internal sources

Source	Phosphorus (kg/yr)
External (Runoff, Groundwater, Septic Systems)	8.48
Internal	30.87
Total	**39.35**

Stag Pond's annual sediment load is generally estimated to be very low. The largest contributor of sediment is estimated to be low-density developed open space, and the Southwest subwatershed is estimated to yield both the highest overall annual sediment load and the highest annual load per acre. The full watershed is estimated to yield approximately 50 kg of sediment per year or 0.2 kg/acre.

Almost all of the total bacterial load estimated to enter Stag Pond each year is estimated to originate from wildlife in forested areas. The North subwatershed is estimated to yield the highest annual bacteria load.

KOFFERLS POND

Kofferls Pond is an approximately 12.47-acre impoundment in the northern portion of Byram Township. Similarly to other waterbodies in this study, the pond's 361.97-acre watershed is mostly (approximately 75%) forested, with an additional 17.4% of the area being urbanized. The waterbody is relatively shallow, with a maximum depth of approximately 3 meters. The pond's main inlet (Punkhorn Creek) enters from the northeast, while the outlet stream leaves the pond at its southwest corner, joining Stag Pond's outlet stream and flowing southwest towards Wright Pond. Kofferls Pond's subwatersheds are as follows:

- **East:** This 24.2-acre subwatershed is classified as 100% forested. It contains a single residence.
- **Northeast:** This is the largest of Kofferls pond's subwatersheds at 232.1 acres. The area is 65.8% forested, with a notable portion of developed land on the northern side of Rt. 671. It also contains the pond's inlet stream.
- **North:** This 97.8-acre subwatershed features few residences, with most of the land being otherwise forested.
- **Northwest:** This 7.4-acre subwatershed is classified as entirely forested.
- **Southeast:** This 5.2-acre subwatershed contains a length of Amity Road and is classified as mostly forested with a notable area of low-density developed open space also present.
- **South:** This is the smallest of Kofferls Pond's subwatersheds at 2 acres. The area contains a length of Amity Road and is approximately 75% forested and 25% classified as urban land.
- **West:** This 6.7-acre subwatershed is classified as entirely forested.

Kofferls Pond's watershed is largely covered by the soil group "C – Slow Infiltration". The East and Southeast subwatersheds also feature notable coverage with the soil group "D – High Infiltration". Subwatersheds featuring high coverage with C- and D-group soils may generate more runoff and more resulting erosion.

Slopes in the full Kofferls Pond watershed averaged approximately 18.3%, with a maximum slope of approximately 67.5%, which occurred in the East subwatershed. This subwatershed also featured the highest average slope at approximately 14.2%.

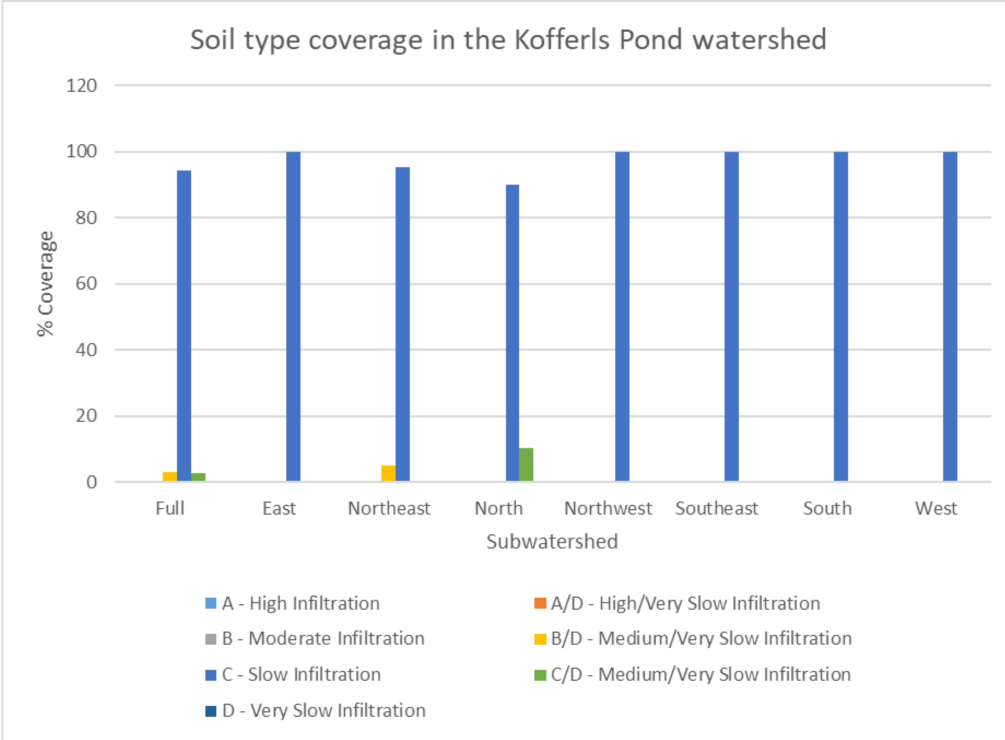


Figure 3.44. Percent coverage of Kofferls Pond Watershed and subwatersheds by different hydrologic soil groups

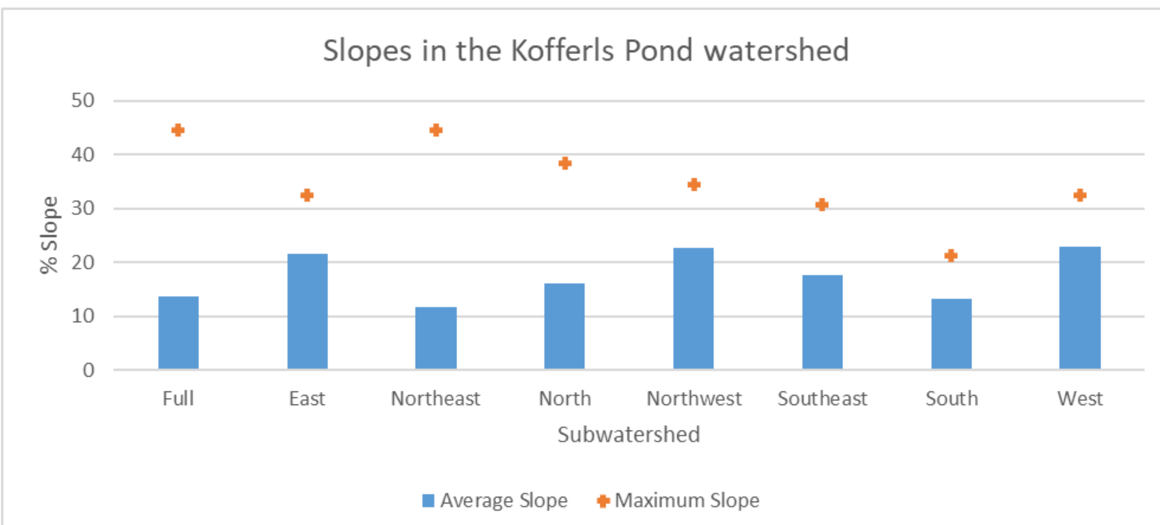


Figure 3.45. Variation in average and maximum percent slope between subwatersheds in the Kofferls Pond Watershed.

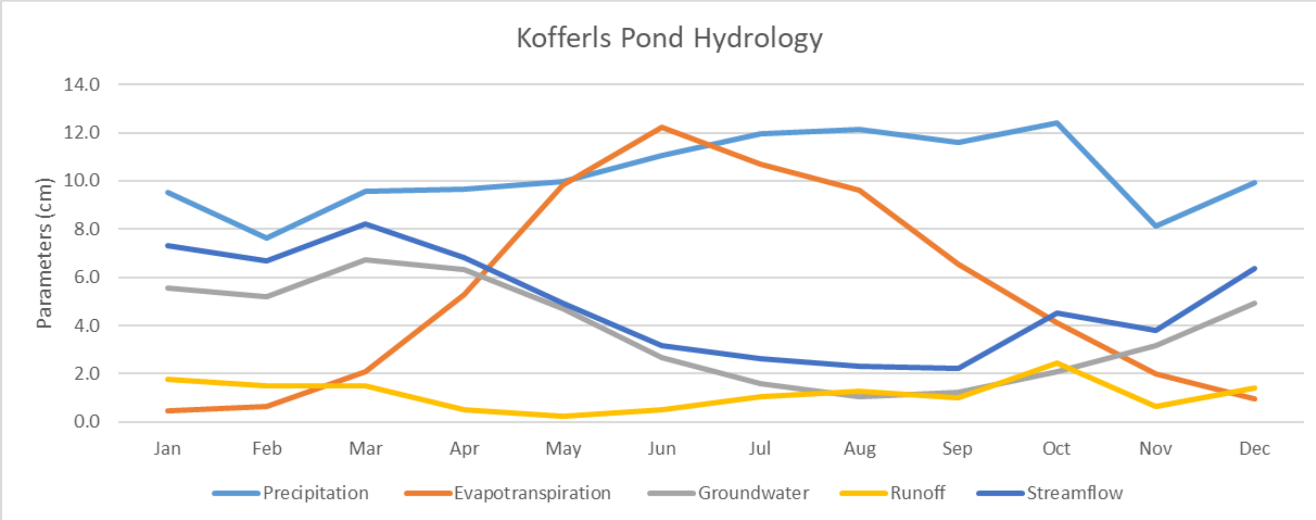


Figure 3.46. Estimated seasonal changes in hydrology in the Kofferls Pond watershed

Table 3.17: Total hydrological parameters in the full Kofferls Pond watershed over the course of a simulated year

Month	Precipitation	Evapotranspiration	Groundwater	Runoff	Streamflow	
	cm	cm	cm	cm	cm	cfs
Jan	9.5	0.5	5.5	1.8	7.3	1.4
Feb	7.7	0.7	5.2	1.5	6.7	1.4
Mar	9.6	2.1	6.7	1.5	8.2	1.6
Apr	9.7	5.3	6.3	0.5	6.8	1.4
May	10.0	9.8	4.7	0.3	4.9	1.0
Jun	11.1	12.2	2.7	0.5	3.2	0.6
Jul	12.0	10.7	1.6	1.1	2.6	0.5
Aug	12.1	9.6	1.0	1.3	2.3	0.4
Sep	11.6	6.6	1.2	1.0	2.2	0.4
Oct	12.4	4.1	2.1	2.5	4.5	0.9
Nov	8.1	2.0	3.2	0.6	3.8	0.8
Dec	10.0	0.9	4.9	1.4	6.4	1.2
Total	123.6	64.4	45.2	13.9	59.0	1.0

Simulated runoff between most of the individual subwatersheds displayed little variation, with the Northeast subwatershed yielding the highest runoff rate. After factoring in direct precipitation and evaporation to the pond itself, Kofferls Pond is estimated to receive approximately 894,413 m^3 or approximately 236.2 million gallons of water a year.

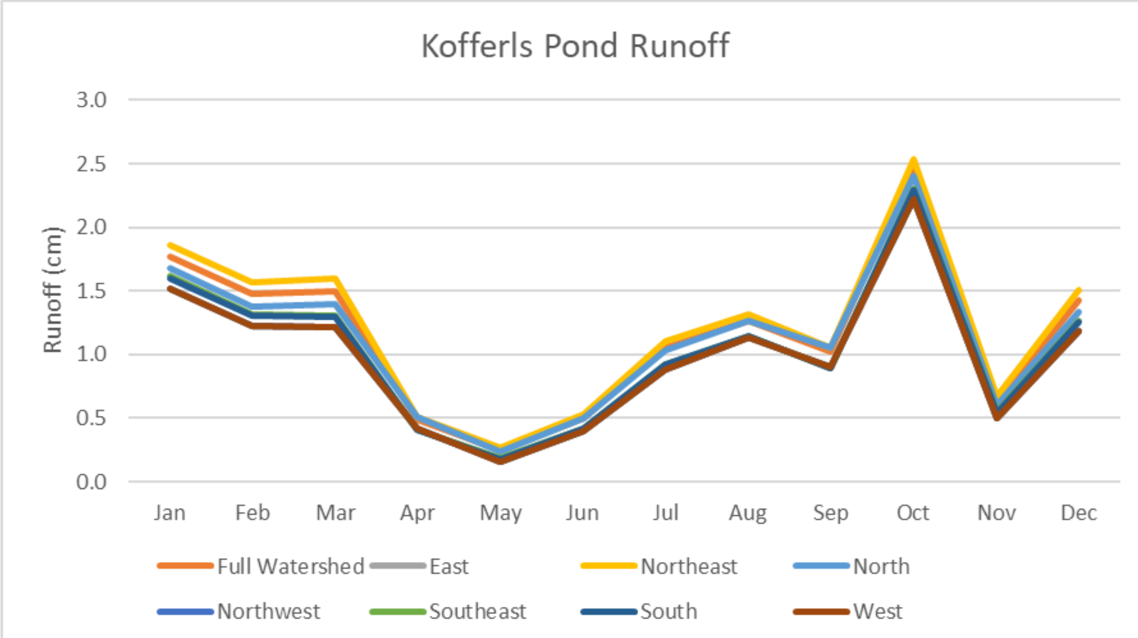


Figure 3.47. Average monthly runoff within sub-watersheds of the Kofferls Pond watershed

Bathymetric data was not available for Kofferls Pond, and as such, the Pond's volume was estimated using depths collected when collecting water quality data. Kofferls Pond is estimated to feature a volume of approximately 95,089.38 m³ or 25.1 million gallons of water. Using this volume and the estimated annual discharge mentioned above, Kofferls Pond is estimated to flush approximately 9.4 times a year, or once every 38.8 days. The lowest annualized monthly flushing rate for the lake is estimated to occur in August and September during an average year, with the highest rate occurring in April.

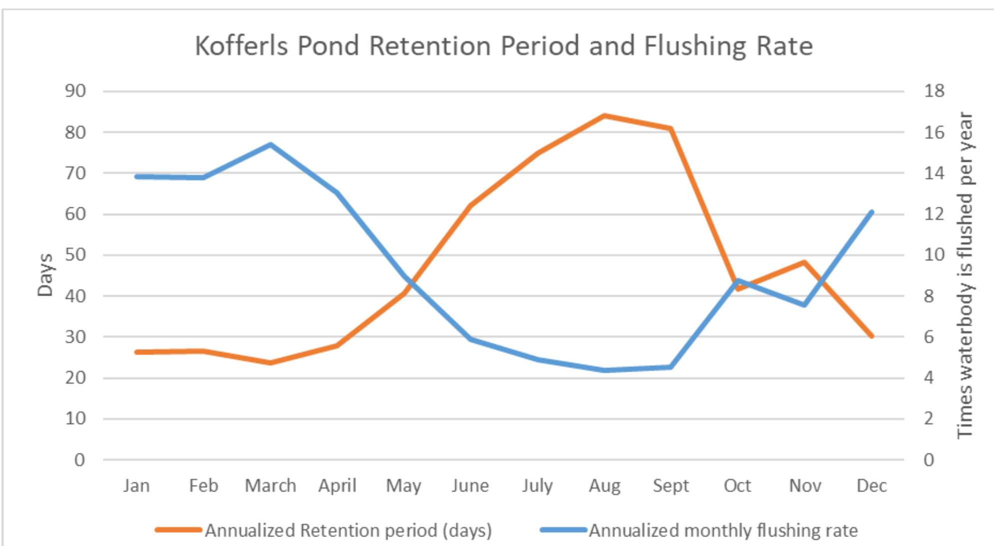


Figure 3.48. Variations in annualized flushing rates and retention periods over the course of a hypothetical year for Kofferls Pond, based on variations in hydraulic loads.

Most of Kofferls Pond's nitrogen load originates from septic systems and groundwater. Forested land was estimated to yield the largest runoff-based nitrogen loads. The Northeast subwatershed yielded both the highest overall estimated annual nitrogen load and the highest load per acre. The entire Kofferls Pond watershed is estimated to receive 658.6 kg of nitrogen each year, or 1.8 kg/acre.

Septic systems and groundwater were estimated to be the largest watershed-based sources of phosphorus to Kofferls Pond. Runoff-based phosphorus was estimated to largely originate from forested and urbanized areas. The Northeast subwatershed was estimated to yield both the overall highest annual phosphorus load, while the West subwatershed was estimated to yield the largest phosphorus load on a per-acre basis. The full watershed is estimated to yield 24.52 kg of phosphorus or 0.07 kg/acre annually.

During field sampling events in 2023, Kofferls Pond was only measured to have anoxia at the bottom of the water column during the 22 June event. Deep phosphorus concentrations from this event were not higher than those obtained near the top, suggesting that increased internal load was likely not occurring. Internal loading was therefore calculated using the assumption that anoxic loading does not typically occur in Kofferls Pond and only the reduced oxic loading rate (approximately 0.6 mg TP/m^2/day) was used. Kofferls Pond's water column is estimated to receive approximately 4.63 kg of phosphorus annually from internal loading.

Table 3.18 below displays the external and internal loads of phosphorus for Kofferls Pond, as well as the grand total, which is estimated to be approximately 39.35 kg/year. Internal loading is estimated to be the primary source of phosphorus loading in Kofferls Pond, constituting approximately 78.5% of the total annual load.

Table 3.18: Total estimated annual phosphorus loads for Kofferls Pond from external and internal sources

Source	Phosphorus (kg/yr)
External (Runoff, Groundwater, Septic Systems)	24.52
Internal	4.63
Total	**29.15**

Kofferls Pond's annual sediment load is estimated to largely originate from streambank erosion in the watershed. The Northeast subwatershed is estimated to yield both the highest overall annual sediment load and the highest sediment load per acre. The full watershed is estimated to yield approximately 2,518 kg of sediment or approximately 7 kg/acre.

Approximately 72.5% of the total bacterial load estimated to enter Kofferls Pond each year is estimated to originate from wildlife in forested areas, with bacteria originating in urbanized areas estimated to comprise most of the remaining annual load. The Northeast subwatershed is estimated to yield the highest annual bacteria load.

4.0 WINTER WATERSHED-BASED WATER QUALITY DATA (INLET STREAMS)

4.1 METHODS

Water samples were collected in streams within each lake's primary sub-watershed under snowfall conditions in order to assess the potential impacts of road salt use on water quality. Two (2) sampling events were conducted during the winter season of 2024 on 26 January and 28 February. An additional third event was conducted during 22 June in order to obtain baseline data with respect to salt use. During each event, both *in-situ* and discrete water quality data were collected. *In-situ* data consisted of temperature, dissolved oxygen (DO), pH, and specific conductivity, all of which were measured with a calibrated AquaTROLL 500 multi-probe water quality meter. In-Situ data can be found in Appendix IV. Princeton Hydro is certified by NJDEP (#10006) in these parameters. Discrete water quality samples (Table 4.1) were collected at each site and analyzed for sodium (Na) and chlorides (Cl). Following collection, all chloride samples were delivered to the laboratory Environmental Compliance Monitoring in Hillsborough Township, NJ for analysis. Sodium samples were delivered to Integrated Analytical Laboratories in Randolph, NJ.

Comparisons were made between January and February values and values obtained during the baseline event in June.

4.2 RESULTS

All surface water classifications for the streams discussed in this section are identified in N.J.A.C. 7:9B. In most cases, chloride concentrations remained within compliance of surface water quality standards except for where noted. N.J.A.C. 7:9B does not possess standards for sodium.

CRANBERRY LAKE

Ledge Run, which enters the northwestern cove of Cranberry Lake, was measured to feature 89.72 µS/cm and 149.4 µS/cm during the January and February events, respectively. The June baseline event yielded an unexpectedly higher conductivity of 277.0 µS/cm. The increase in conductivity between the January and February event may be attributable to road salt runoff occurring during the heavier snow event in February. It is not known what caused the further increase in June, however.

Both Na and Cl saw increases in Ledge Run between the January and February events, particularly Na, which increased from 7 mg/L in January to 8460 mg/L in February. In June, Na and Cl were measured at 160 mg/L and 8 mg/L, respectively. This represents a decrease in these parameters from February, but not to the low concentrations observed in January.

LAKE LACKAWANNA

The northeast branch of Lubbers Run, which enters Lake Lackawanna shortly after crossing under Lake Dr., featured a similar seasonal pattern of conductivity measurements as those observed in Cranberry Lake's inlet, with measurements increasing from January to February and further increasing by late June. Na and Cl concentrations featured a pattern more expected to reflect winter road salting, with February yielding higher values of both parameters than January. June yielded a lower concentration of sodium than those obtained in both January and February and a lower value of chlorides than that obtained in February, but yielded a higher concentration of chloride in June than that obtained in January.

JOHNSON LAKE

The inlet entering the small pond connected across Tamarack Road to Johnson Pond yielded a seasonal pattern of specific conductivity opposite that observed in the inlets to Cranberry Lake and Lake Lackawanna, with January yielding the highest concentration of conductivity before decreasing slightly in February and decreasing further in June. Na and Cl featured a pattern in this inlet similar to that of Cranberry Lake's inlet, with concentrations increasing to their seasonal maximum in February and dropping slightly in June, but not to the low concentrations observed in January.

FOREST LAKE

The small inlet entering the southernmost cove of Forest Lake shortly after crossing under Forest Lakes Dr. featured an increasing pattern of specific conductivity throughout the three sampling events, with June yielding a notable concentration of 1,255 µS/cm. Na concentrations in this inlet saw their seasonal high in February with a concentration of 123,000 mg/L and a seasonal low of 3.2 mg/L in June. Cl concentrations, however, saw an increase throughout the season, increasing from 120 mg/L in January to 200 mg/L in February, and increasing further to 230 mg/L in June. It should be noted that 230 mg/L (230,000 µg/L) is the NJ Surface Water Quality standard for human health (chronic exposure).

PANTHER LAKE

Specific conductivity concentrations in the small inlet stream entering Panther Lake at its southeastern shoreline were measured to be relatively low in January at 78.77 µg/L before increasing to 234.62 µg/L in February and further increasing to 425.00 µg/L in June. Na concentrations in this inlet displayed a notable increase from 1.8 mg/L in January to 2820 mg/L in February before decreasing to 20 mg/L in June. Cl concentrations increased from 1.4 mg/L in January to 6.2 in February before increasing further to 9.0 mg/L in June. It should be noted that the two discrete parameters in this inlet were measured at concentrations lower than those sampled at most of the other waterbodies' inlets in 2023. This is likely due to the lower number of public roads upstream of this location than those present upstream of many of the other inlet locations (it is not known to what extent the roads in the Panther Lake Campground are treated with salt to reduce snow and ice, if at all).

WRIGHT LAKE

Wright Lake's inlet stream was sampled approximately 0.5 miles upstream of the pond from Stag Pond Road. This stream was unexpectedly measured to feature its lowest specific conductivity of the three winter sampling events during the February event before yielding its highest concentration in June. Additionally, this inlet featured its highest Cl concentration of 83 mg/L during the January event before decreasing to 51 mg/L in both February and June. Na was measured in January at 50.5 mg/L before increasing sharply to 25,000 mg/L in February. By June, this inlet stream's Na concentration had decreased to 2 mg/L.

JEFFERSON LAKE

Jefferson Lake's inlet stream, Ghost Pony Brook, featured a similar seasonal pattern of winter specific conductivity, with January featuring the lowest concentration of 207.43 µS/cm and June featuring the highest concentration of 589.0 µS/cm. Na concentrations in this inlet stream were at their lowest during the January sampling event at 21.4 mg/L. This increased sharply to 27,100 mg/L in February before decreasing to 44 mg/L in June. The inlet's Cl concentrations increased through the winter season into the summer, with the January event yielding the lowest concentration of 33 mg/L and the June event yielding the highest concentration of 82 mg/L.

STAG POND

The small inlet stream that enters the northwestern shoreline of Stag Pond yielded relatively low specific conductivity values through the winter stream study, with the lowest value of 59.86 µS/cm occurring in January and the highest value of 174 µS/cm occurring in June. Similarly to Panther Lake's inlet, this inlet features a drainage area with few roads, and as such featured some of the lowest NA and Cl concentrations in the study. Na concentrations were at their lowest in January at 1.5 mg/L before increasing to 1720 mg/L in February. Na concentrations decreased again by June to 32 mg/L. Cl concentrations were below the minimum detectable value during the January and June events, with the February event yielding a concentration of 0.88 mg/L.

KOFFERLS POND

The inlet stream that enters Kofferls Pond at its northeastern end yielded specific conductivity values consistently higher than the inlets of many of the other lakes in this study, with a low concentration of 527.72 µS/cm occurring in January and a high concentration of 770 µS/cm occurring in June. The inlet's highest concentration of Na occurred in February at 56,800 mg/L, while the lowest was measured in the June sample at 24 mg/L. Cl concentrations were measured at their lowest in January at 110 mg/L and at their highest in June at 140 mg/L.

Table 4.1 – Winter Discrete Sampling Results

Winter Discrete Monitoring Data for Byram Inlet Streams - 2023				
Date	**Station**	**Sodium (mg/L)**	**Chloride (mg/L)**	**Snowfall (Inches)**
January-23	Jefferson	21.4	33.0	1.2
	Cranberry	7.0	5.6	
	Lackawanna	28.1	49.0	
	Forest	72.0	120.0	
	Panther	1.8	1.4	
	Johnson	16.5	28.0	
	Stag	1.5	ND	
	Kofferls	61.7	110.0	
	Wright	50.5	83.0	
February-23	Jefferson	27100	42.0	3.8
	Cranberry	8460	12.0	
	Lackawanna	34400	70.0	
	Forest	123000	200.0	
	Panther	2820	6.2	
	Johnson	39000	63.0	
	Stag	1720	0.9	
	Kofferls	56800	120.0	
	Wright	25000	51.0	
June-23	Jefferson	44.0	82.0	N/A
	Cranberry	160.0	8.0	
	Lackawanna	8.7	58.0	
	Forest	3.2	230.0	
	Panther	20.0	9.0	
	Johnson	68.0	32.0	
	Stag	32.0	ND <3	
	Kofferls	24.0	140.0	
	Wright	2.0	51.0	

5.0 BASELINE WATERSHED-BASED WATER QUALITY DATA (INLET STREAMS)

5.1 METHODS

Water samples were collected in streams within each lake's primary sub-watershed with regards to pollutant and hydrologic loading under base-flow conditions in order to assess the nutrient load contributed by these streams during baseline conditions. Three sampling events were conducted throughout the growing season on 6 April, 29 June, and 19 September. During each event, both *in-situ* and discrete water quality data were collected. *In-situ* data consisted of temperature, dissolved oxygen (DO), pH, and specific conductivity, all of which were measured with a calibrated AquaTROLL 500 multi-probe water quality meter. Princeton Hydro is certified by NJDEP (#10006) in these parameters. In-Situ data can be found in Appendix V. Discrete water quality samples (Table 5.1) were collected at each site and analyzed for toral phosphorus (TP), soluble reactive phosphorus (SRP), nitrate-nitrogen (NO_3-N), and total suspended solids (TSS). Additionally, for a road salt comparison, chlorides and sodium were also analyzed during one baseline event. 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:

Comparisons were made between the measured values and concentrations derived from modeled data. Concentrations based on modeled data were calculated using the modeled stream flow, nitrogen, phosphorus, and sediment rates for the months of May and October in the subwatershed sampled.

5.2 RESULTS

The following water quality results are compared with the New Jersey Surface Water Quality Standards (N.J.A.C. 7:9B), where applicable. All surface water classifications for the streams discussed in this section are identified in N.J.A.C. 7:9B.

CRANBERRY LAKE

The Cranberry Lake inlet stream (Ledge Run) is located in the Musconetcong River watershed and is classified as an FW2-NT stream. Temperatures in the inlet stream increased throughout the 2023 season, ranging from 11.49 °C in April up to 20.07 °C in September. Temperatures remained below the NJDEP daily maximum threshold of 31.00 °C for FW2-NT waters during all three sampling events. DO remained relatively consistent throughout the first two sampling events, with concentration of 11.26 mg/L and 11.08 mg/L, respectively. There was a dip in DO in September with a concentration of 7.76 mg/L; however, DO concentrations remained above the minimum threshold for FW2-NT waters. pH remained consistent throughout the sampling season, ranging from 7.43 in September up to 8.00 in June. Values stayed within NJDEP recommended range of 6.5-8.5 during these events. Specific conductance was also relatively consistent during the year, ranging from 160.46 µS/cm in April to 277.00 µS/cm in June.

TP concentrations were low throughout the season and remained well below the NJDEP Non-Tidal Stream threshold of 0.10 mg/L; TP concentrations ranged between 0.03 mg/L and 0.04 mg/L. SRP concentrations were low in April with a concentration of 0.006 mg/L but increased during the June and September sampling events, with respective concentrations of 0.016 mg/L and 0.028 mg/L. TSS was variable in the stream ranging from 2 mg/L in June to 24 mg/L in April but remained below the threshold of 40 mg/L of FW2-NT waters. Similar to the other nutrients sampled, nitrate-N concentrations were low throughout the season and did not exceed 0.07 mg/L.

LAKE LACKAWANNA

The Lake Lackawanna inlet stream (Lubbers Run) is located in the Musconetcong River watershed and is classified as a FW2-TM(C1) stream. Temperatures in the inlet stream followed expected seasonal variation throughout the year, ranging from 14.04 °C in April to 16.18 °C in September. Temperatures remained below the NJDEP daily maximum threshold of 25.00 °C for FW2-TM waters. DO concentrations remained relatively consistent throughout the season, ranging from 9.26 mg/L in June up to 10.30 mg/L in April. DO concentrations also remained above the minimum threshold for FW2-TM waters during all sampling events in 2023. pH stayed relatively consistent during the year, ranging from 7.79 in June up to 8.01 in April and remaining within the NJDEP recommended range of 6.5 to 8.5 throughout the year. Specific conductance was more variable during the sampling events and ranged from 349.63 µS/cm in September up to 424.47 µS/cm in April.

TP concentrations were low during all sampling events, ranging from non-detectable (<0.02 mg/L) in September to 0.03 mg/L in June. TP remained below the NJDEP Non-Tidal Stream threshold of 0.10 mg/L during all of the sampling events in 2023. SRP was low at the beginning of the season, with a concentration below the lab detection limit (<0.003mg/L) in April before increasing to 0.008 mg/L in September. Nitrate-N was low throughout the 2023 season, ranging from 0.06 mg/L in April to 0.07 mg/L in June. TSS also remained low during all sampling events, ranging from non-detectable (<2 mg/L) in June up to 7 mg/L in April. These concentrations were well below the 25 mg/L threshold for FW2-TM waters.

JOHNSON LAKE

The Johnson Lake inlet stream, a tributary to Ghost Pond Brook, is located in the Musconetcong River watershed and is classified as an FW2-NT stream. Temperatures in the inlet remained relatively cool during the 2023 season, ranging from 12.75 °C in April up to 15.89 °C in September. Temperatures remained well below the NJDEP daily maximum threshold of 31.00 °C for FW2-NT waters during all three sampling events. DO concentrations remained relatively consistent during the sampling events, ranging from 9.78 mg/L in September up to 10.70 mg/L in June; thus, DO concentrations remained above the minimum threshold for FW2-NT waters. pH was consistent throughout the year, ranging from 7.60 in April to 7.88 in June and staying within the recommended NJDEP threshold. Specific conductance varied between 170.47 µS/cm in September and 296.00 µS/cm in June.

TP concentrations were low throughout the sampling season and did not exceed 0.02 mg/L. SRP concentrations were low in April, with a concentration below the lab detection limit (<0.003 mg/L), but increased as the season progressed, peaking at 0.009 mg/L in September. Nitrate-N was low in April, with a concentration below the lab detection limit of 0.03 mg/L. However, concentrations were much higher during the last two events of the year, with respective concentrations of 0.29 mg/L and 0.23 mg/L in June and September. TSS was highest during the April event, with a concentration of 14 mg/L, before declining to non-detectable (< 2mg/L) concentrations during the last two sampling events. These concentrations remained below the threshold of 40 mg/L of FW2-NT waters.

FOREST LAKE

The Forest Lake inlet stream does not have a surface water classification but falls within the Pequest River watershed. Temperatures in the stream followed expected seasonal variation, ranging from 12.71 °C in April to 16.76 °C in September. DO concentrations were variable throughout the year, ranging from 5.01 mg/L in June up to 9.24 mg/L in April. pH was relatively consistent throughout the year, ranging from 7.21 in June to 7.45 in September, and remaining within the NJDEP recommended threshold of 6.5 – 8.5. Specific conductance was variable through the season, ranging from 125.50 µS/cm in June up to 935.55 µS/cm in April. This may have been due to remnants of winter salting operations.

TP concentrations remained relatively low and ranged from 0.03 mg/L in April up to 0.05 mg/L in June and September. SRP concentrations were low in April, with a concentration below the lab detection limit (<0.003 mg/L), but increased as the season progressed, peaking at 0.009 mg/L in June and September. Nitrate-N concentrations were elevated during the 2023 sampling season, ranging from 0.10 mg/L in April up to 0.83 mg/L in June. TSS concentrations were below the lab detection limit during the last two events but was slightly higher in April, with a concentration of 14 mg/L.

PANTHER LAKE

The Panther Lake inlet stream does not have a surface water classification but falls within the Pequest River watershed. Temperatures in the stream remained low throughout the season, ranging from 12.01 °C in June to 14.12 °C in September. DO concentrations were consistent during the season, ranging from 7.00 mg/L in April up to 7.67 mg/L in September. pH was also consistent during the sampling season, ranging from 7.41 in April and September to 7.58 in June. Specific conductance was more variable during the 2023 season, ranging from 125.50 µS/cm in June to 227.03 µS/cm in April. All *in-situ* data was within recommended ranges per N.J.A.C. 7:9B.

TP concentrations were low in 2023, ranging from 0.02 mg/L in April to 0.04 mg/L in September. SRP concentrations were more variable throughout the year, ranging from 0.005 mg/L in April to 0.024 mg/L in September; 0.024 mg/L is elevated for SRP. Nitrate-N concentrations remained consistent and low throughout the year, with concentrations of 0.06 mg/L in April and 0.08 mg/L during the last two events of the season. TSS concentrations were below the lab detection limit during the last two events but was slightly higher in April, with a concentration of 16 mg/L.

WOLF LAKE

Permission to access the inlet was not granted. There is no access from public property.

WRIGHT LAKE

The Wright Lake inlet stream (Lubbers Run) is located in the Musconetcong River watershed and is classified as an FW2-TM(C1) stream. Temperatures ranged from a minimum of 12.46 °C in June to a maximum of 17.39 °C in September. Temperatures remained below the NJDEP daily maximum threshold of 25.00 °C for FW2-TM waters. DO ranged from 6.12 mg/L in June to 8.82 mg/L in April, remaining above the minimum threshold for FW2-TM waters during all sampling events in 2023. pH was consistent throughout the year, ranging from 7.05 in September to 7.33 in June and staying within the recommended NJDEP threshold. Specific conductance had a wide range of values, from a minimum of 163.74 µS/cm in September up to a maximum of 447.00 µS/cm in June.

TP concentrations were low and consistent during the 2023 season, being measured at 0.02 mg/L during all sampling events; TP remained below the NJDEP Non-Tidal Stream threshold of 0.10 mg/L. SRP was more variable, ranging from 0.001 mg/L in September up to 0.014 mg/L in April; thus, SRP was the dominant form of phosphorus in April. Nitrate-N was variable throughout the year, ranging from non-detectable (<0.07 mg/L) to 0.23 mg/L in April. TSS concentrations were below the lab detection limit during the last two events but was slightly higher in April, with a concentration of 8 mg/L. These concentrations were well below the 25 mg/L threshold for FW2-TM waters.

JEFFERSON LAKE

The Jefferson Lake inlet stream (Jefferson Lake Tributary) is classified as an FW2-NT(C1) stream and falls within the Musconetcong River watershed. Temperatures in the stream were variable throughout the season, ranging from 11.27 °C in April to 16.04 °C in September. Temperatures remained below the NJDEP daily maximum threshold of

31.00 °C for FW2-NT waters during all three sampling events. DO concentrations were elevated throughout the season, ranging from 9.23 mg/L in June to 10.95 mg/L in April; thus, DO concentrations remained above the minimum threshold for FW2-NT waters. pH was consistent during the season, ranging from 7.81 in September to 7.95 in April and staying within the recommended NJDEP threshold. Specific conductance was more variable, ranging from 279.48 µS/cm in September to 589.00 µS/cm in June.

TP concentrations were consistently low throughout the season, ranging from 0.01 mg/L in April and September to 0.02 mg/L in June; TP remained below the NJDEP Non-Tidal Stream threshold of 0.10 mg/L. SRP was also low throughout the season, ranging from non-detectable (<0.003 mg/L) in April to 0.007 mg/L during the last two sampling events of the year. Nitrate-N was measured at 0.33 mg/L in April before declining to 0.06 mg/L and non-detectable (<0.07 mg/L) in September. TSS concentrations were low, ranging from non-detectable (<2mg/L) in June to 9 mg/L in April. These concentrations remained below the threshold of 40 mg/L of FW2-NT waters.

STAG POND

The Stag Pond inlet stream (Lubbers Run) is located in the Musconetcong River watershed and is classified as a FW2-TM(C1) stream. Temperatures remained low throughout the season and ranged from 10.87 °C in April to 13.89 °C in September. Temperatures remained below the NJDEP daily maximum threshold of 25.00 °C for FW2-TM waters. DO was high throughout the season, ranging from 9.96 mg/L in September to 10.63 mg/L in April, remaining above the minimum threshold for FW2-TM waters during all sampling events in 2023. pH was consistent throughout the season, ranging from 7.18 in April to 7.82 in September and staying within the recommended NJDEP threshold. Specific conductance was low during all the sampling events, ranging from 57.68 µS/cm in April to 174.00 µS/cm in June.

TP concentrations were consistently low in 2023, ranging from 0.01 mg/L in June to 0.02 mg/L during the other two sampling events; TP remained below the NJDEP Non-Tidal Stream threshold of 0.10 mg/L. SRP concentrations were also low, ranging from 0.004 mg/L in April to 0.007 mg/L in September. Nitrate-N was very low during 2023 season, ranging from non-detectable (<0.03 mg/L) to 0.04 mg/L in June. TSS was low in 2023, ranging from non-detectable (<2 mg/L) up to 6 mg/L. These concentrations remained below the threshold of 25 mg/L threshold for FW2-TM waters.

KOFFERLS POND

The Kofferls Pond inlet stream (Lubbers Run) is classified as a FW2-TM(C1) stream and is located in the Musconetcong River watershed. Temperatures in the stream remained low, ranging from 12.79 °C in June to 14.79 °C in September. Temperatures remained below the NJDEP daily maximum threshold of 25.00 °C for FW2-TM waters. DO concentrations varied between 9.77 mg/L in September and 10.66 mg/L in June, remaining above the minimum threshold for FW2-TM waters. pH was relatively consistent during the season, ranging from 7.79 in June up to 8.01 in April and staying within the recommended NJDEP threshold. Specific conductance was moderately elevated during the season, ranging from 474.37 µS/cm in September up to 770.00 µS/cm in June.

TP concentrations in the stream were low throughout the year, varying from non-detectable (<0.02 mg/L) in September to 0.04 mg/L in April; TP remained below the NJDEP Non-Tidal Stream threshold of 0.10 mg/L. SRP was also low throughout the season, ranging from non-detectable (<0.003 mg/L) in April up to 0.006 mg/L in September. Nitrate-N concentrations were moderately elevated, ranging from 0.52 mg/L in June up to 0.80 mg/L in April. TSS concentrations were relatively low throughout the season, ranging between non-detectable (<2 mg/L) up to 10 mg/L. These concentrations remained below the threshold of 25 mg/L threshold for FW2-TM waters.

Table 5.1 – Baseline Watershed Discrete Sampling Results

Discrete Monitoring Data for Byram Inlet Streams - 2023							
Date	Station	NO3-N (mg/L)	SRP (mg/L)	TP (mg/L)	TSS (mg/L)	Sodium (mg/L)	Chloride (mg/L)
May-23	Jefferson	0.33	ND <0.003	0.01	9	X	X
	Cranberry	0.06	0.006	0.03	24	X	X
	Lackawanna	0.06	ND <0.003	0.02	7	X	X
	Forest	0.10	0.011	0.03	10	X	X
	Panther	0.06	0.005	0.02	16	X	X
	Johnson	ND <0.03	ND <0.003	0.01	14	X	X
	Stag	ND <0.03	0.004	0.02	6	X	X
	Kofferls	0.8	ND <0.003	0.01	9	X	X
	Wright	0.23	0.014	0.02	8	X	X
July-23	Jefferson	0.06	0.007	0.02	ND <2	44.00	82
	Cranberry	0.06	0.016	0.04	2.00	160.00	8
	Lackawanna	0.07	0.007	0.03	ND <2	8.70	58
	Forest	0.83	0.037	0.05	ND <2	3.20	230
	Panther	0.08	0.015	0.03	ND<2	20.00	9
	Johnson	0.29	0.004	0.02	ND <2	68.00	32
	Stag	0.04	0.005	0.01	ND <2	32.00	ND <3
	Kofferls	0.52	0.003	0.04	10.00	24.00	140
	Wright	0.05	ND <0.003	0.02	ND <2	0.02	51
September-23	Jefferson	ND <0.07	0.007	ND <0.02	7	X	X
	Cranberry	ND <0.07	0.028	0.03	4	X	X
	Lackawanna	ND <0.07	0.008	ND <0.02	3	X	X
	Forest	0.42	0.032	0.05	ND<2	X	X
	Panther	0.08	0.024	0.04	ND<2	X	X
	Johnson	0.23	0.009	0.02	ND<2	X	X
	Stag	ND <0.07	0.007	0.02	ND<2	X	X
	Kofferls	0.57	0.006	ND <0.02	ND<2	X	X
	Wright	ND <0.07	0.001	0.02	ND<2	X	X

6.0 LAKE-BASED WATER QUALITY DATA

6.1 METHODS

Sampling events were conducted at each lake three different times over the course of the 2023 growing season in order to collect data during spring, summer, and autumn conditions. 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 analyzing *In-situ* water quality data (State ID #10006). This data was collected throughout the water column in half-meter to one-meter increments in order to generate full profiles of the water column. The parameters sampled as part of *In-situ* water quality sampling include water temperature (°C), dissolved oxygen (mg/L), specific conductivity (µS/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 (State ID #18630) in Hillsborough, 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)
- 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, SAV or algae growth, and watercolor.

6.2 PARAMETER DESCRIPTIONS

IN-SITU WATER QUALITY

Thermal stratification is a common phenomenon that occurs in lakes with sufficient depth. Thermal stratification typically begins to form sometime between mid-spring to early summer, depending on several factors. 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 VI.

The reduction of dissolved oxygen (DO) 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, DO 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.

Transparency in lakes is generally determined through the use of a Secchi disk. The Secchi disk is a contrasting white and black disk that is lowered into the lake until it is no longer visible, then retrieved until visible again. The average of those two lengths is termed the Secchi depth. This depth may be influenced by algal density, suspended inorganic particles, organic acid staining of the water, or more commonly a combination of all three. This parameter is often times used to calculate the trophic status (productivity) of a lake, and as such is a critical tool in lake evaluation. Secchi depths less than 1.0 m are generally associated with reduced water quality due to high concentrations of algae or suspended inorganic sediments and are generally associated with impaired quality.

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.

The current concentration threshold recommended by Princeton Hydro for TP concentrations in lakes and ponds to preclude nuisance algal and macrophyte growth is 0.03 mg/L. The New Jersey Department of Environmental Protection (NJDEP) Surface Water Quality Standard (SWQS) for TP is 0.05 mg/L (N.J.A.C. 7:9B). There is no standard for SRP in N.J.A.C. 7:9B but Princeton Hydro recommends concentrations not to exceed 0.005 mg/L to prevent nuisance algal blooms.

While phosphorus can enter a water body 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-N. While 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-N. 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-N 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 water body.

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.

6.3 RESULTS

CRANBERRY LAKE

IN-SITU WATER QUALITY

Cranberry Lake was sampled three times during the 2023 season on 24 April, 21 June, and 19 September. Water clarity remained high throughout the 2023 growing season with all Secchi depths exceeding the recommended 1.0 m threshold during all of the sampling events. Water clarity at the south end of the lake ranged between 1.4 m and 1.6 m while the north end of the lake had higher visibility ranging between 2.1 m and 2.7 m. Surface temperatures followed expected seasonal variation throughout the year ranging between 16.79 °C in April and 22.59 °C in June. DO varied throughout the year and water column in 2023. Overall, DO was higher in the north end of the lake where it stayed above the 4.0 mg/L recommended threshold for supporting warm water fisheries. The south end of the lake had lower DO ranging from 8.53 mg/L in April down to 0.02 mg/L at the bottom of the water column in June; DO concentrations were low throughout the water column in September, ranging from 3.10 mg/L at the surface down to 1.09 mg/L at 3.0 m. The pH in the lake remained relatively consistent throughout the growing season ranging from 6.68 in June up to 8.03 in June. This is within the recommended range of 6.50 to 8.50. Specific conductance varied throughout the season ranging from 137.43 µS/cm in September up to 238.31 µS/cm in April.

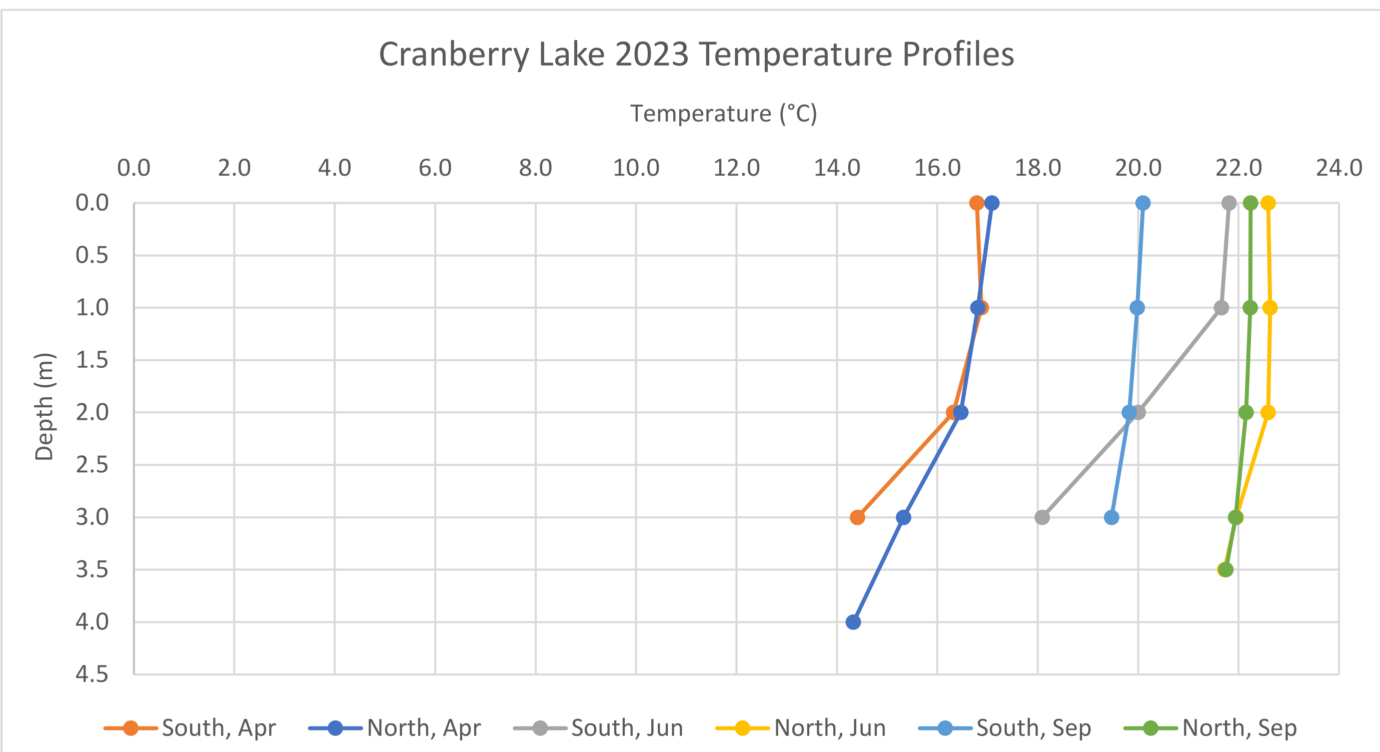


Figure 6.1: Cranberry Lake temperature profiles throughout the 2023 growing season

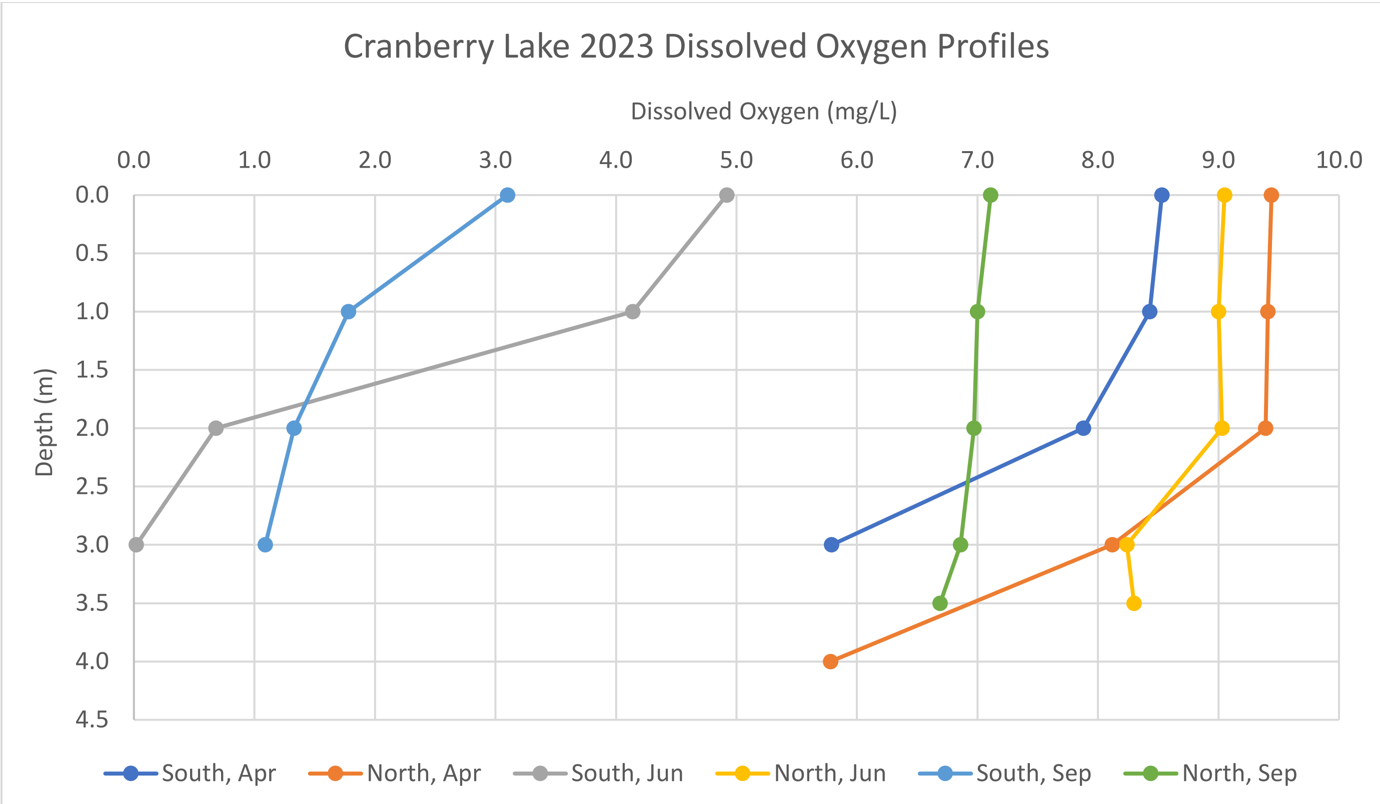


Figure 6.2: Cranberry Lake dissolved oxygen profiles throughout the 2023 growing season

DISCRETE WATER QUALITY

Samples for the analysis of discrete parameters were collected throughout the growing season at the deepest spot of Cranberry Lake. TP concentrations in Cranberry Lake remained relatively consistent throughout the 2023 growing season. Concentrations ranged from 0.01 mg/L up to 0.02 mg/L remaining well below the 0.05 mg/L NJDEP SWQS and the Princeton Hydro recommended threshold of 0.03 mg/L to preclude nuisance algal blooms. SRP levels remained very low throughout the season and never exceeded 0.002 mg/L. TSS concentrations had more variation during the year, ranging from non-detectable (<2 mg/L) up to 12 mg/L. Nitrate-N concentrations also remained low throughout the season ranging from non-detectable (<0.03 mg/L) in June up to 0.07 mg/L in June. Ammonia-N concentrations also remained low during the season ranging from non-detectable (0.01 mg/L) to 0.04 mg/L in September. Surface chlorophyll *a* concentration had minimal variation throughout the season, ranging from 2.7 µg/L in June up to 6.3 µg/L in April.

PLANKTON AND MACROPHYTES

The community composition in April showed a diversity of phytoplankton in Cranberry Lake. There was a total of fifteen genera identified with the majority of them being diatoms with five different genera. *Aterionella* and *Synura* were both seen in abundance in the April sample, while a majority of the other genera were observed as present or rare. There was a decrease in overall diversity in June with ten genera identified. There was a relatively even distribution between the different groups of phytoplankton in this sample, with the dinoflagellate genus *Ceratium* observed to be abundant. There was an increase in genera richness during the September sampling with twenty-two genera which was the highest of the season. Diatoms were the most abundant group of phytoplankton in this sample with many genera being observed as either common or present.

The zooplankton community in Cranberry Lake was healthy throughout the year with representation from eleven different genera across the three major groups: cladocerans, copepods, and rotifers. The cladoceran genus *Bosmina,* the rotifer genus *Keratella,* and the copepod genus *Cyclops sp.* were co-dominant in this sample with most of the other genera observed to be common or present. There was a slight decrease in abundance during June with ten genera observed. Copepod nauplii, *Cyclops sp*., as well as Bosmina, were all co-dominant in this sample. September saw the peak in seasonal richness with thirteen different genera identified. Copepod nauplii and *Conochilus* were co-dominant in this sample with a majority of genera observed as present or common.

Cranberry Lake was observed to contain a prevalent community of submerged aquatic vegetation; however these were largely not at densities that would impact use of the main body of the lake. The southern basin was observed to feature large densities of floating plants in shallower areas such as watershield (*Brasenia schreberi*), white water lily *(Nymphaea odorata*), and yellow pond lilies (*Nuphar sp.*). Both basins also featured a species of the submerged carnivorous plant genus bladderwort (*Utricularia sp.*). Dense bigleaf pondweed (*Potamogeton amplifolius*) was also observed in some areas. The invasive species Eurasian watermilfoil (*Myriophyllum spicatum*) and curlyleaf pondweed (*Potamogeton* crispus) were also noted in some shallower areas, while southern naiad (*Najas guadalupensis*) was observed on the anchor at the deep station in the northern basin.

LAKE LACKAWANNA

IN-SITU WATER QUALITY

Lake Lackawanna was sampled three times during the 2023 season on 24 April, 21 June, and 19 September. Surface temperatures followed expected trends during the 2023 growing season with a seasonal minimum of 16.67 °C in May and a seasonal maximum of 23.99 °C in June. DO varied throughout the year ranging from 7.24 mg/L in September to 10.34 mg/L in June, remaining sufficiently oxygenated to support aquatic life. Water clarity remained above the recommended 1.0 m threshold throughout the year, and the Secchi disk reached the bottom of the water column at a majority of the sites. pH varied between 7.57 in September to 8.80 in April. Specific conductance had more variation throughout the year ranging from 290.21 µS/cm in September up to 368.79 µS/cm in June.

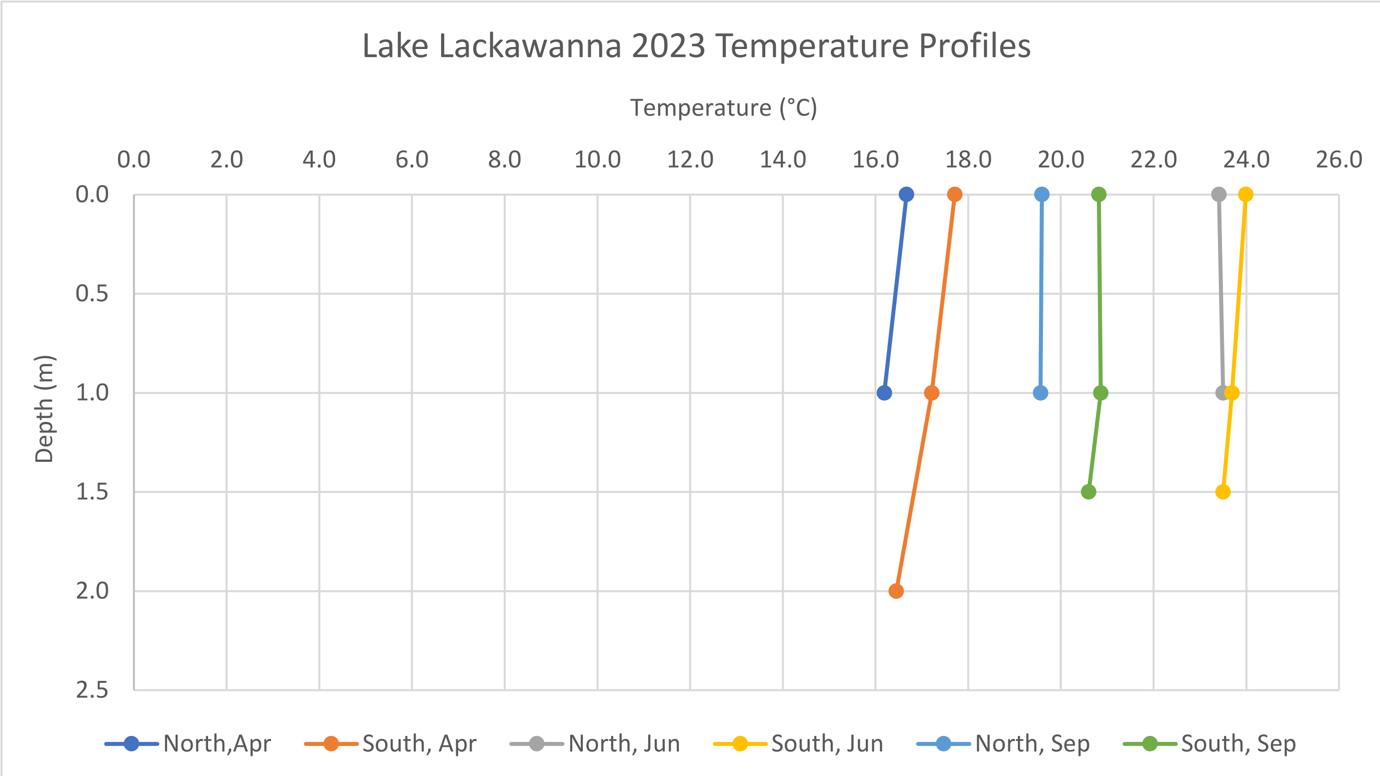


Figure 6.3 Lackawanna Lake temperature profiles throughout the 2023 growing season

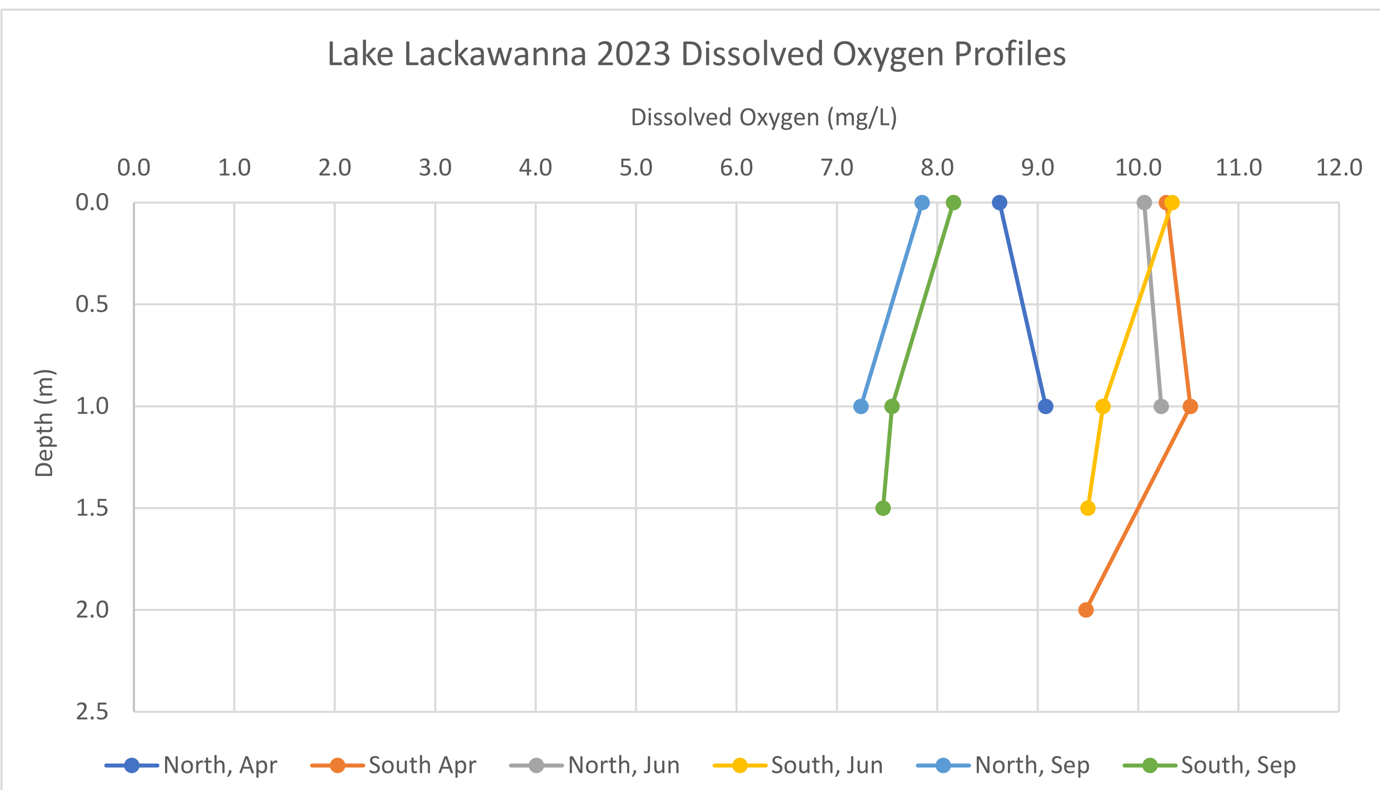


Figure 6.4: Lackawanna Lake dissolved oxygen profiles throughout the 2023 growing season

DISCRETE WATER QUALITY

TP concentrations remained low throughout the season, with a maximum concentration of 0.03 mg/L measured at the bottom of the water column in April and June. There were non-detectable TP concentrations (<0.02 mg/L) at both the surface and bottom of the water column in September. SRP was undetectable (<0.003 mg/L) in Lake Lackawanna during the first two events and was 0.001 mg/L and 0.002 mg/L in the surface and deep samples, respectively, in September. Nitrate-N concentrations were also low throughout the season throughout the water column. Concentrations ranged from non-detectable (<0.03 mg/L) to a maximum of 0.03 mg/L. Chlorophyll *a* remained low throughout the season, ranging from 3.5 µg/L in September to 7.6 µg/L in April. TSS ranged from 2 mg/L in September up to 7 mg/L in April, with all concentrations remaining below 20 mg/L which is often the threshold that can result in turbid water.

PLANKTON AND MACROPHYTES

Lake Lackawanna had a wide diversity of phytoplankton in 2023 and April yielded the greatest diversity with sixteen genera identified. A majority of these were green algae that were observed to be present or rare. However, there was a bloom of the golden algae *Uroglena*; a bloom of *Uroglena* was also seen in a few other lakes in Byram township. In June there was a slight decrease with fourteen genera identified in the sample. Again, a majority of these were green algae but the diatom genus *Asterionella* was the most common genera seen in this sample. September saw the lowest diversity of the year with eleven genera identified. The benthic cyanobacteria genus *Lyngbya* was identified in this sample.

The zooplankton community was comprised of a variety of rotifers, copepods, and cladocerans. During the April sampling event, there were ten genera identified with *Keratella* and *Bosmina* co-dominating the phytoplankton community. Diversity was similar in June with nine genera being identified across the three different groups. In this sample, two Cladocera were co-dominant with *Bosmina* and *Ceriodaphnia* being abundant in this sample. In September there were twelve different genera of zooplankton identified, with the majority being cladocerans.

Lake Lackawanna was observed during the Spring event to feature dense, nuisance populations of Eurasian watermilfoil, as well as more localized patches of curlyleaf pondweed. By the summer event, curlyleaf pondweed was the dominant species in shallow areas. Bigleaf pondweed was also observed in small densities at the boat launch as well during this date. By the September event, most plants had senesced. White water lily were observed in some of the coves during this date, however. Small amounts of milfoil were also observed in the southern portion of the lake during this event.

JOHNSON LAKE

IN-SITU WATER QUALITY

Johnson Lake was sampled three times during the 2023 season on 24 April, 21 June, and 19 September. Surface temperatures in Johnson Lake varied throughout the year with a seasonal minimum of 15.97 °C in April and a seasonal maximum of 19.71 °C in September at the north station. DO also varied during the season, declining as the season went on. Surface DO was recorded as 8.01 mg/L at the south sampling station in April and 7.03 mg/L in June; the surface DO concentration at the north station was 4.71 mg/L in June. However, in September DO decreased significantly to 0.76 mg/L at the surface of the south station and 1.39 mg/L at the surface of the north station; DO concentrations were anoxic (DO <1.0 mg/L) below the surface at both stations. These DO concentrations are extremely low and pose a risk to all aquatic life in the water body. Water clarity remained good throughout the season, ranging from 1.3 m to 2.4 m; thus, remaining above the 1.0 m threshold throughout the season. pH remained relatively consistent during the 2023 season, ranging from 6.43 in September to 7.44 in April. Specific conductance varied during the season from 222.79 µS/cm up to 404.00 µS/cm.

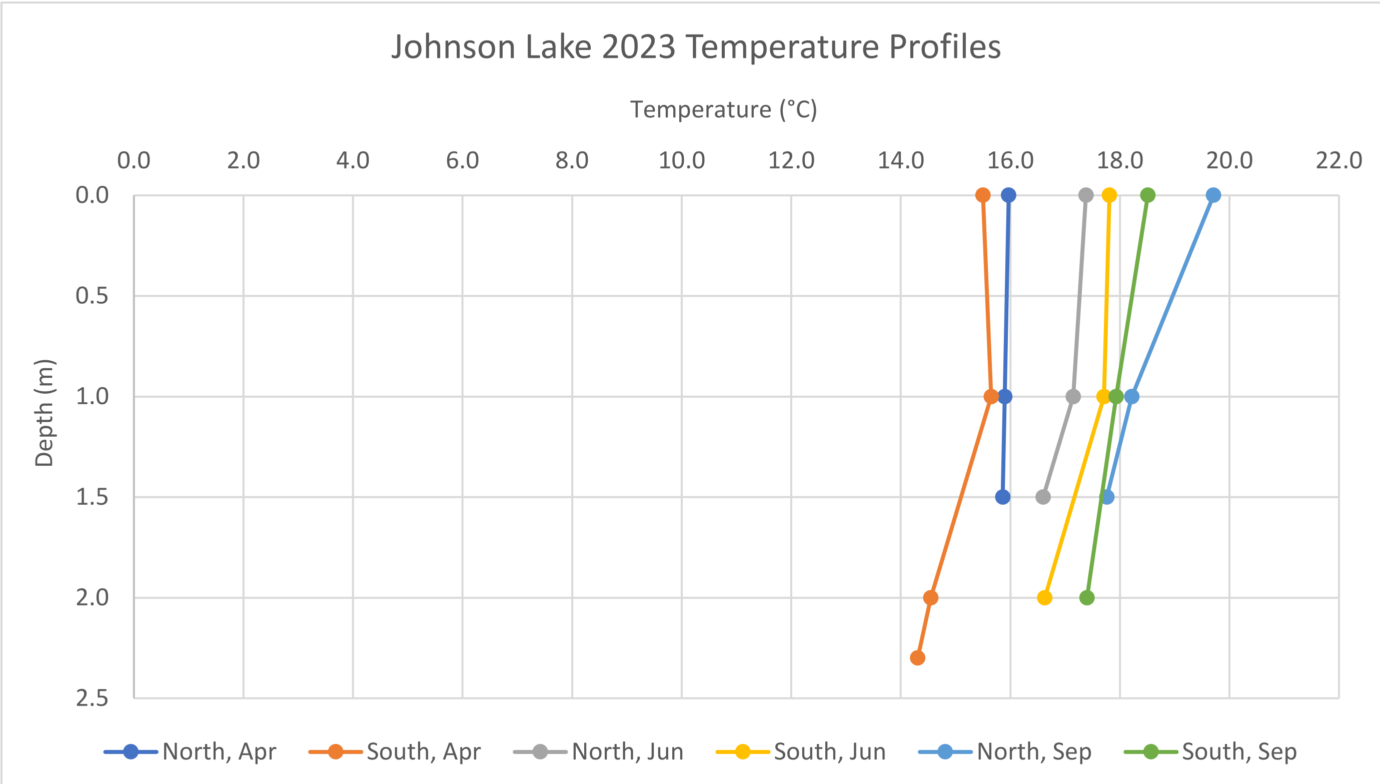


Figure 6.5: Johnson Lake temperature profiles throughout the 2023 growing season

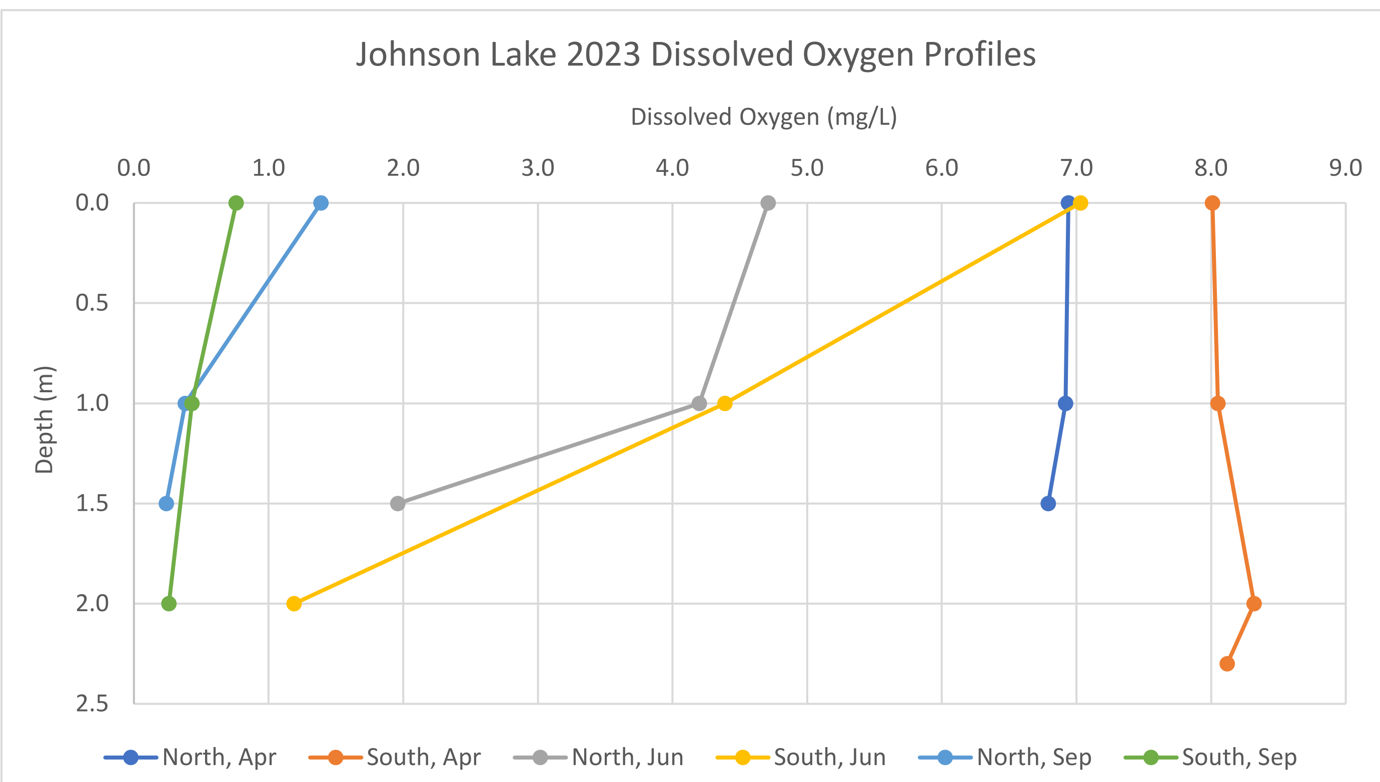


Figure 6.6: Johnson Lake dissolved oxygen profiles throughout the 2023 growing season

DISCRETE WATER QUALITY

TP was low throughout the season, ranging between 0.01 mg/L and 0.02 mg/L. SRP was also low throughout the season and was non-detectable (<0.003 mg/L) during the first two events of the year and was measured at 0.001 mg/L in September. Chlorophyll *a* concentrations were low in 2023, ranging from 2.2 µg/L in June to 5.9 µg/L in September. Nitrate-N concentrations were higher overall in the deep-water samples ranging from 0.04 mg/L to 0.10 mg/L; ammonia-N concentrations remained very low. TSS ranged from 3 mg/L to 9 mg/L during the season. All discrete parameters had low concentrations throughout the season, indicative of a low productivity system in 2023.

PLANKTON AND MACROPHYTES

The plankton community in Johnson Lake followed seasonal variation throughout the year, similar to the other Byram Township lakes. In April there were sixteen total genera identified, but the sample was dominated by a bloom of *Synura* which is a golden algae. In June there were nineteen genera identified with an abundance of the golden algae genus *Uroglena*. Genera diversity decreased in September, with only nine genera identified. Cyanobacteria diversity increased in September with three different genera identified as being present or rare.

The zooplankton community also followed a seasonal decline in diversity. In April there was a peak in diversity with eleven genera identified. The rotifer genus *Polyartha* and copepod nauplii were both seen in abundant quantities. In June there was a slight decrease with nine genera observed. During the June sampling event, the dominant organism was copepod nauplii but the rotifers were the most diverse. Zooplankton diversity decreased in September with five genera identified and no cladocerans. There were two types of copepods and three genera of rotifers identified in this sample, all of which were observed to be present or rare.

Due to Johnson Lake's relatively shallow water depth, the lake is over 90% covered with macrophytes during the peak of the growing season. Floating vegetation such as white waterlily, watershield, and yellow pond lily dominate most of the lake, however the lake also features a diversity of native submerged species. These include swollen bladderwort (*Utricularia inflata*), eastern purple bladderwort (*Utricularia purpurea*), humped bladderwort (*Utricularia* gibba), white water crowfoot (*Ranunculus aquatilis*), and floating-leaf pondweed (*Potamogeton natans*). The invasive curlyleaf pondweed was also observed during the spring event. The high coverage of the lake with macrophytes would likely be a nuisance to boaters and, at times, shoreline anglers.

FOREST LAKE

IN-SITU WATER QUALITY

Forest Lake was sampled three times during the 2023 season on 24 April, 21 June, and 19 September. Surface temperatures in Forest Lake followed seasonal variation, with a minimum temperature of 15.55 °C in April and a maximum temperature of 23.99 °C in June. Surface DO concentrations decreased as the season progressed, with a concentration of 11.09 mg/L in April and a concentration of 6.18 mg/L in September. There were sharp declines in DO with depth throughout the year. Anoxia (DO <1.0 mg/L) was seen at the bottom of the water column during all of the sampling events in Forest Lake. Clarity was variable in 2023 ranging from 1.1 m up to 2.7 M. Clarity remained above the recommended 1.0 m threshold throughout the season. pH remained relatively consistent during the 2023 season, ranging from 6.97 in September to 8.62 in April. Specific conductance was elevated, ranging from 729.90 µS/cm in September up to 899.56 µS/cm in June; this is likely a natural occurrence based on the geology of the drainage basin.

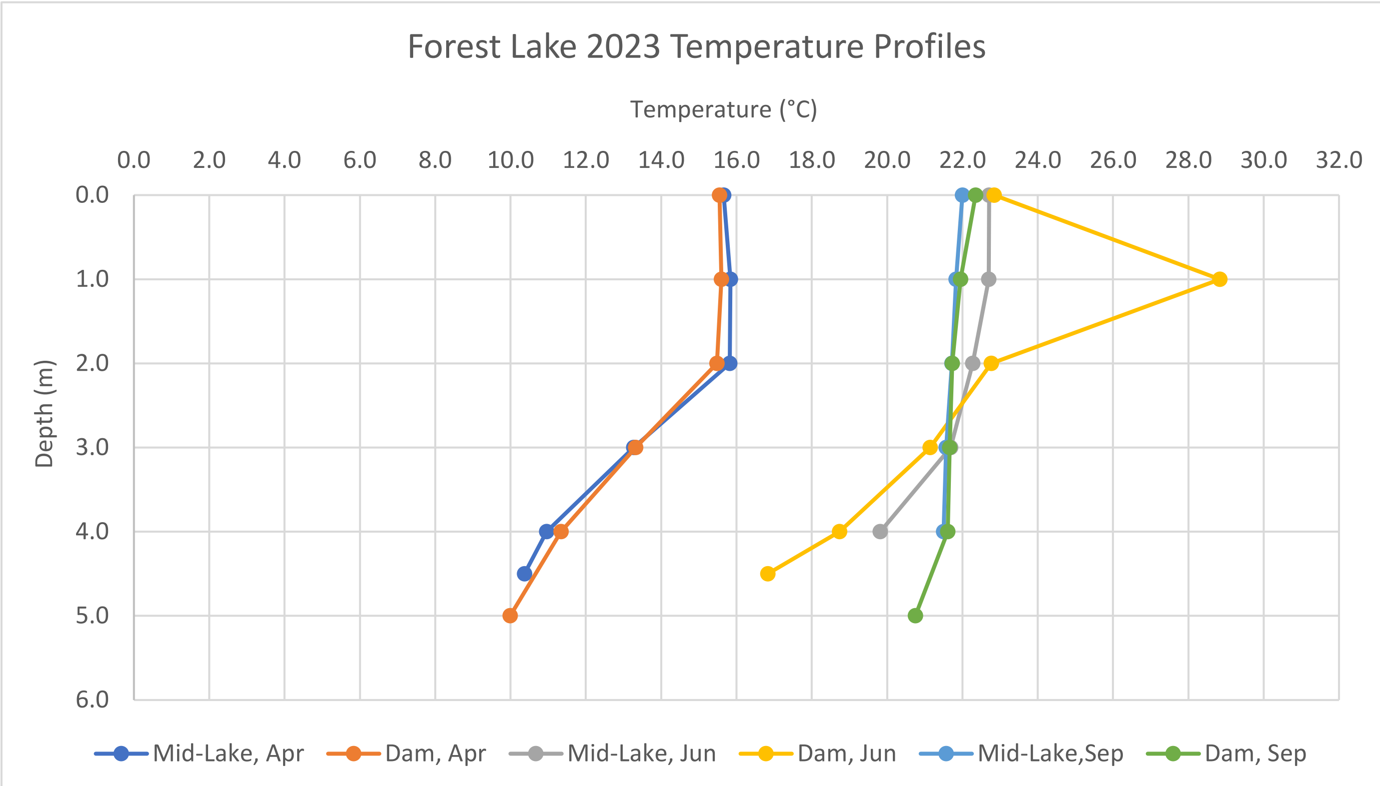


Figure 6.7: Forest Lake temperature profiles throughout the 2023 growing season

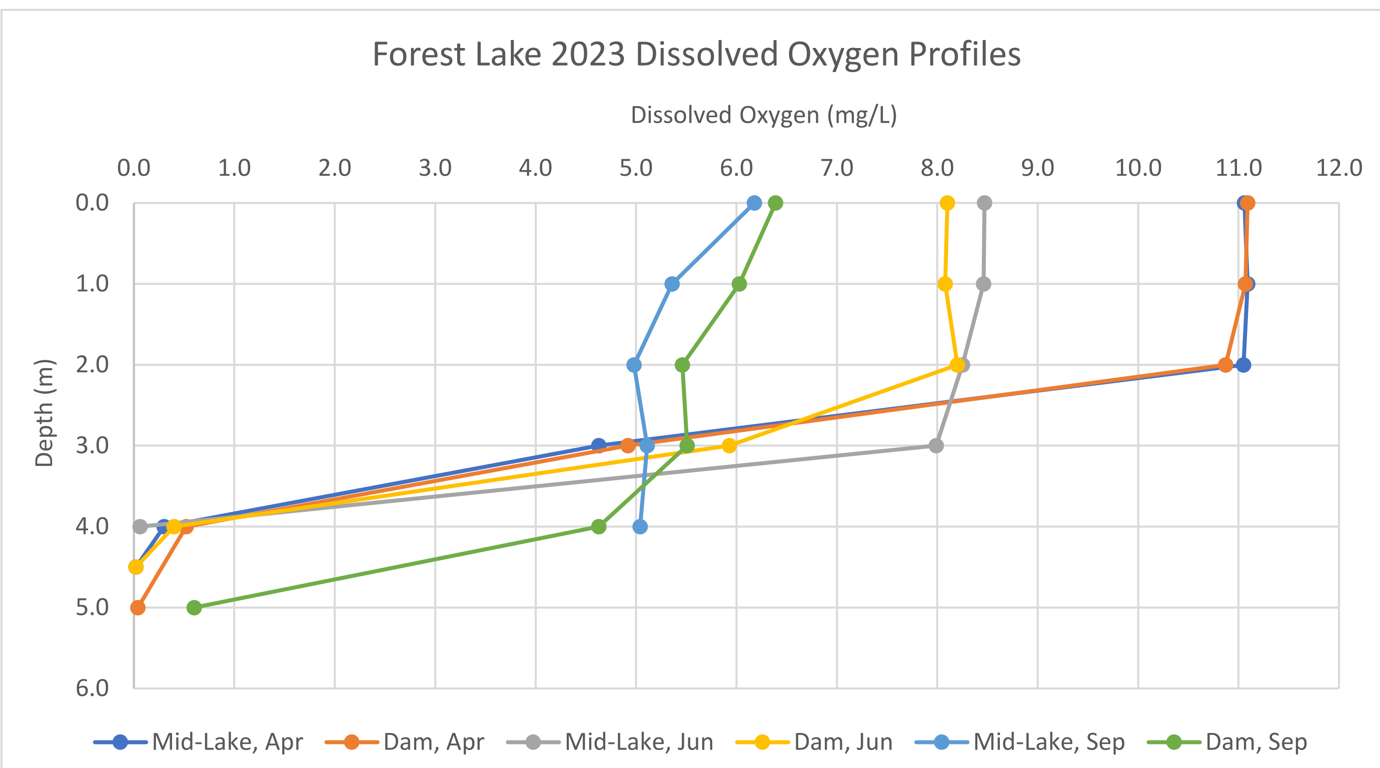


Figure 6.8: Forest Lake dissolved oxygen profiles throughout the 2023 growing season

DISCRETE WATER QUALITY

Surface TP in Forest Lake remained low throughout the 2023 season, ranging from 0.01 mg/L in June up to 0.03 mg/L in September. Deep water TP was slightly higher throughout the season, ranging between 0.03 mg/L in June and September up to 0.06 mg/L in April. SRP was non-detectable (<0.003 mg/L) during the first two sampling sessions and 0.001 mg/L in September. TSS remained relatively consistent throughout the season ranging from 6 mg/L in April and September up to 9 mg/L in June. Nitrate-N concentrations were low in Forest Lake, ranging from non-detectable (<0.07 mg/L)in September up to 0.10 mg/L in April. Chlorophyll *a* concentrations were variable throughout the 2023 season in Forest Lake. Surface concentrations ranged from 7.4 µg/L April up to 23.0 µg/L in June. There was also a wide range of chlorophyll *a* concentrations in the deep samples, with a minimum of 3.6 µg/L in June up to 30.0 µg/L in April.

PLANKTON AND MACROPHYTES

Phytoplankton diversity was relatively low at the beginning of the season with nine genera observed in April. There was a bloom of the golden algae genus *Dinobryon* in this early-season sample. In June the peak diversity was observed with fourteen genera identified. This was the first sample of the year where dinoflagellates were observed, and the dinoflagellate genus *Ceratium* was abundant. In September there was a slight increase with eleven genera identified and cyanobacteria were identified for the first time in 2023. Three different cyanobacteria genera were observed in common, present, and rare abundances.

Eight zooplankton genera were observed in April across the three main groups: cladocerans, copepods, and rotifers. Copepod nauplii and *Cyclops sp.* were both found in abundance in this sample. Diversity increased in June, with 12 genera identified. Copepod nauplii and the cladoceran genus *Daphnia* were co-dominant in the June sample with a majority of the other genera observed to be common or present. In September there were again 12 genera observed, all of which were common or present.

Most of the lake's macrophyte populations were observed relatively close to shore, with the shoreline near the dam featuring beds of *Chara,* curlyleaf pondweed, Eurasian watermilfoil, and filamentous algae. As most of the central area of the lake is relatively deep, macrophytes were not observed in this area. During the summer event, however, filamentous algae was observed around the edges of the waterbody.

PANTHER LAKE

IN-SITU WATER QUALITY

Panther Lake was sampled three times during the 2023 season on 24 April, 21 June, and 19 September. Surface temperatures in Panther Lake followed seasonal variation, with a minimum temperature of 15.92 °C in April and a maximum temperature of 20.67 °C in September. DO concentrations decreased with depth below the thermocline during each monitoring event. This is common in deep lakes that stratify during the growing season, as the bottom layer of water, known as the hypolimnion, is cut off from the surface layer of water, known as the epilimnion, that is in direct contact with the atmosphere. The bottom 2.5 meters of the water column was anoxic (DO < 1.0 mg/L) at the south station in April and the bottom 6.0+ meters was anoxic in June and September. Water clarity remained above the 1.0 m threshold throughout the season with the best clarity recorded in September at a depth of 2.6 m at the south station. pH declined with depth at the deep south station during each sampling event. This is common in deeper lakes where there is no photosynthetic activity in the darker hypolimnion; photosynthesis in the epilimnion causes an increase in pH.

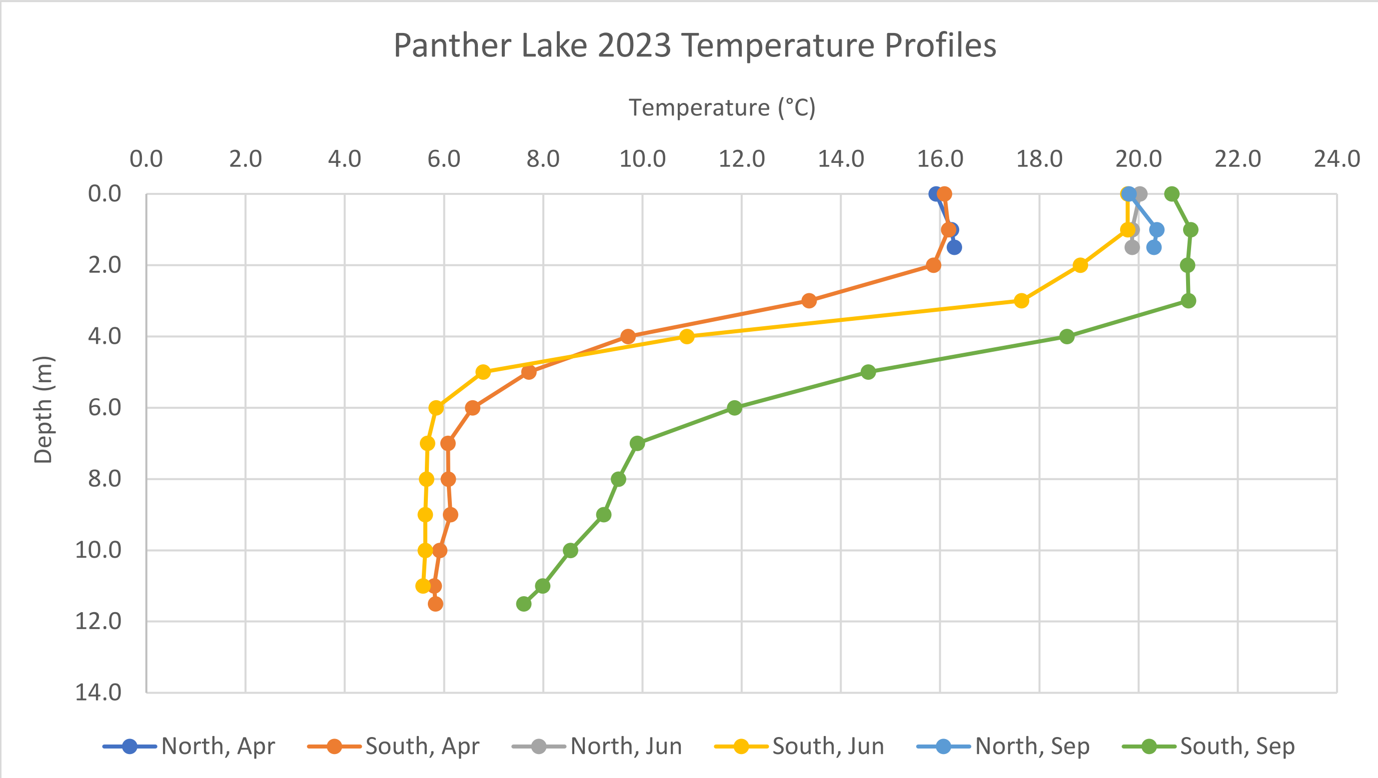


Figure 6.9: Panther Lake temperature profiles throughout the 2023 growing season

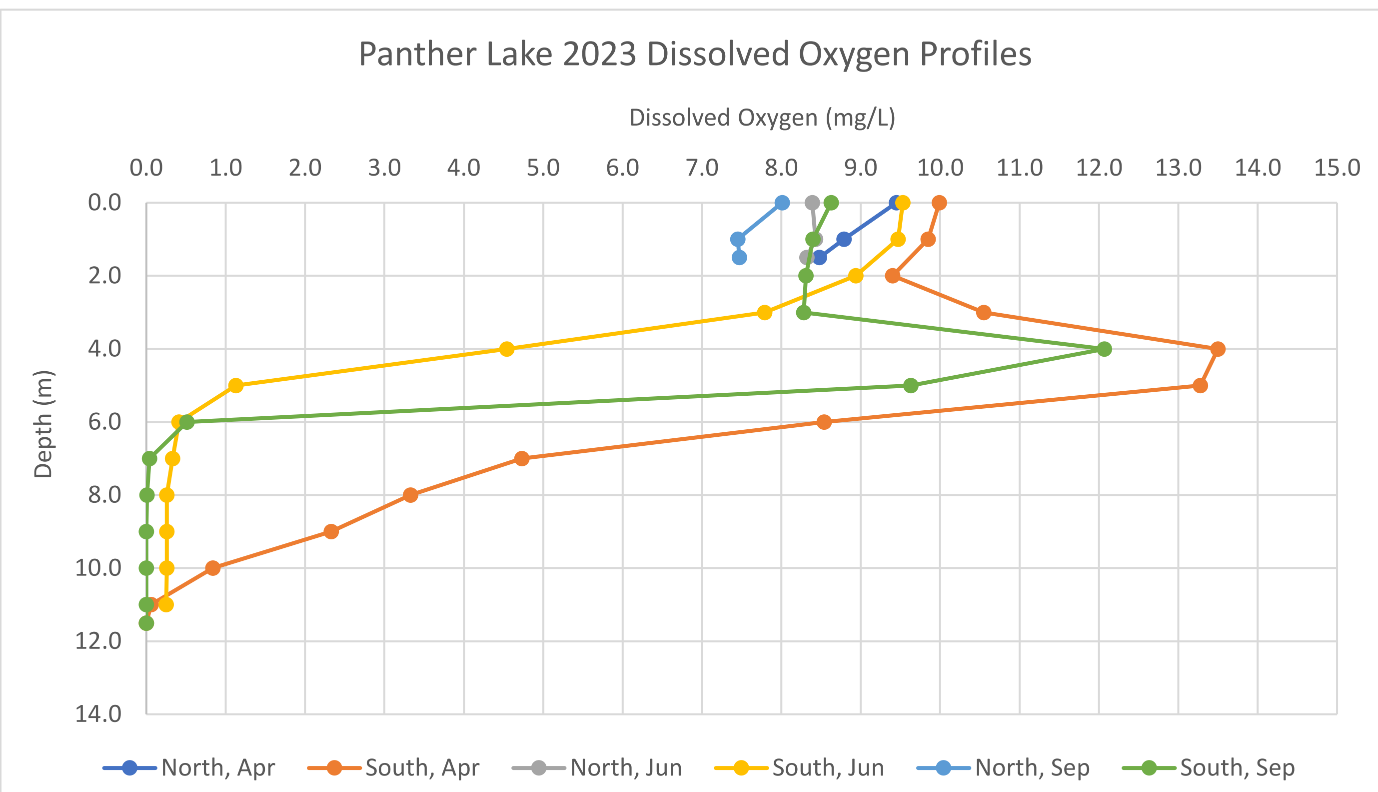


Figure 6.10: Panther Lake dissolved oxygen profiles throughout the 2023 growing season

DISCRETE WATER QUALITY

Surface TP concentrations remained low throughout the season, ranging between 0.02 mg/L and 0.03 mg/L. Deep water TP concentrations became elevated as the season progressed. In April, the deep TP concentration was 0.04 mg/L. The deep TP concentration increased significantly in June and remained elevated into September, with respective concentrations of 0.12 mg/L and 0.11 mg/L. These increases in deep TP concentrations can be attributed to the internal release of phosphorus from the anoxic sediments as the lake remained stratified and the hypolimnion was void of oxygen.

Similar to TP concentrations, SRP was low at the surface but elevated in the deeper waters in June and September. Deep SRP concentrations ranged from non-detectable (<0.003 mg/L) in April up to 0.032 mg/L in June, followed by a slight decline to 0.028 mg/L in September. Ammonia-N concentrations were low for most of the season before increasing to 0.63 mg/L in the September deep sample. It is not uncommon for deep water ammonia-N concentrations to increase during the summer stratification period due to the absence of oxygen; under oxic conditions, ammonia is converted to nitrite and nitrate by bacteria in the environment which can then be assimilated by plants and algae. Nitrate-N concentrations were moderately elevated in the deep samples in April and June. Concentrations ranged from non-detectable (<0.03 mg/L) at the surface to 0.18 mg/L in the April deep sample. TSS was variable in 2023 with surface concentrations ranging from 3 mg/L in September to 10 mg/L in June. Surface chlorophyll *a* concentrations ranged from 3.3 µg/L in June to 8.7 µg/L in April.

PLANKTON AND MACROPHYTES

The plankton community in Panther Lake had a very diverse population and had the greatest species richness in April with seventeen genera identified. There was also a bloom of the golden algae genus *Uroglena*. In June there was a decrease in diversity but it remained high with thirteen genera identified, with the majority being green algae. In September there were nine genera identified, including the only cyanobacteria genus, *Oscillatoria,* that was observed in 2023.

Zooplankton genera richness remained relatively consistent as the season progressed in Panther Lake. In April there were thirteen genera identified across the three major groups. There were both rotifers and copepods that were observed in abundance, while most of the other genera were observed to be common or present. In June, diversity remained similar with twelve genera identified. *Kellicottia* and *Bosmina* were co-dominant in this sample, but the rotifers were still the most common group in the sample. Fourteen genera were identified in September, representing the seasonal peak in diversity. The rotifer genus *Conochilus* was the dominant genus in September, and most of the other genera were observed to be common or rare.

While Panther Lake was observed to contain some nuisance densities of the invasive species curlyleaf pondweed during the spring event, the lake also was observed to contain several beneficial native species of plants. Of important note is the presence of the New Jersey State Endangered species Illinois pondweed (*Potamogeton illinoensis*), as well as the state-listed rare species Robbin's pondweed (*Potamogeton robbinsii*). Shallower areas of the lake were also observed to feature white water lily and yellow pond lily. The plant-like macroalgae *Chara* was also observed growing at the bottom of the waterbody in the boat launch cove; this area also contained patches of leafy pondweed (*Potamogeton foliosus*).

WOLF LAKE

Did not give permission to access the lake.

WRIGHT LAKE

Did not give permission to access the lake.

JEFFERSON LAKE

IN-SITU WATER QUALITY

Jefferson Lake was sampled three times during the 2023 season on 24 April, 21 June, and 19 September. Surface temperatures followed typical seasonal variation, with a minimum temperature of 15.42 °C in April and a seasonal maximum of 22.54 °C in June. Surface temperatures declined slightly by September, with temperatures of 20.57 °C and 19.70 °C at the dam and west locations, respectively. DO concentrations also had seasonal variation, declining with depth during each sampling event and declining slightly at the surface as the season progressed. The highest DO concentrations were observed in April at the dam location with a surface concentration of 9.85 mg/L. Anoxic conditions (DO < 1.0 mg/L) were present in the bottom meter of both stations in June. Secchi depths decreased as the season progressed, with a seasonal maximum of 2.4 m at both stations in April and a seasonal minimum of 1.2 m at the dam station in September. pH remained consistent throughout the year ranging from 7.25 in June up to 8.08 in April.

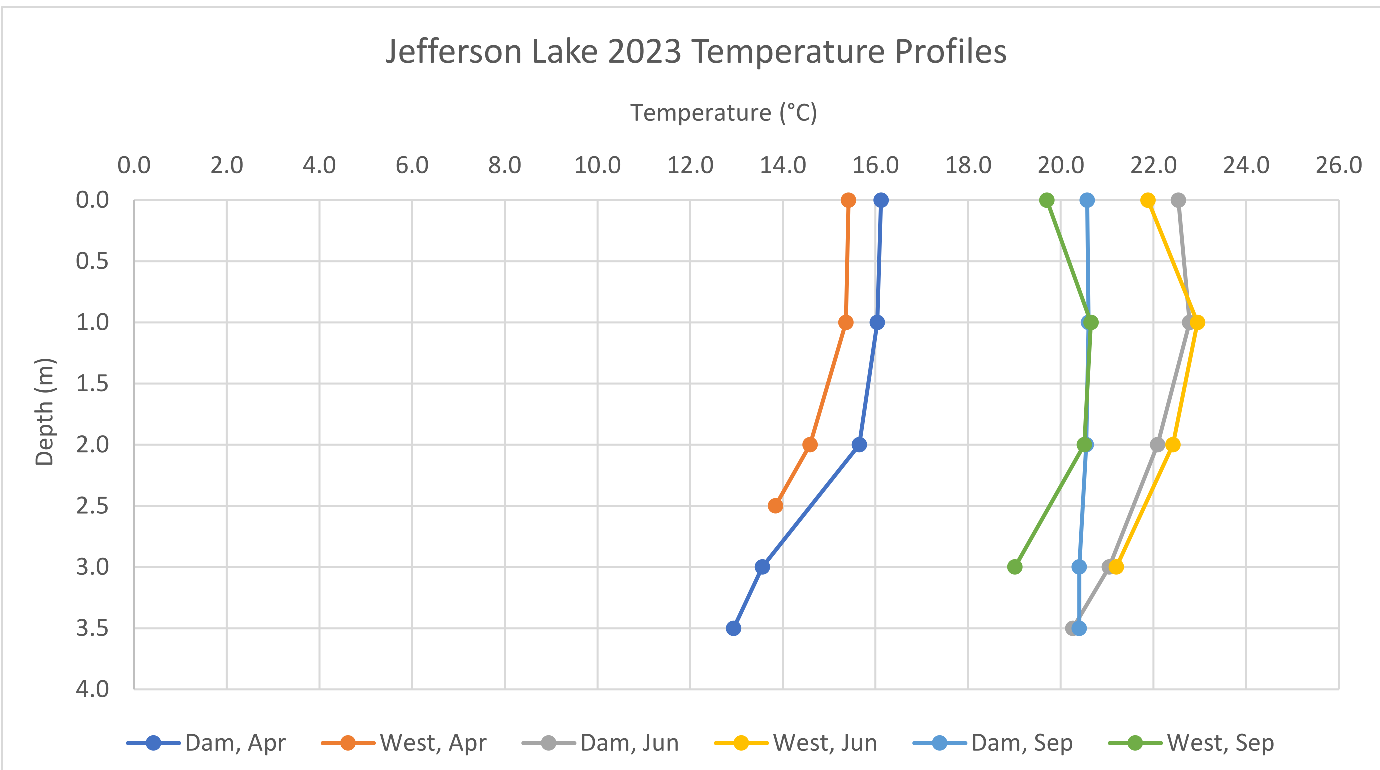


Figure 6.11: Jefferson Lake temperature profiles throughout the 2023 growing season

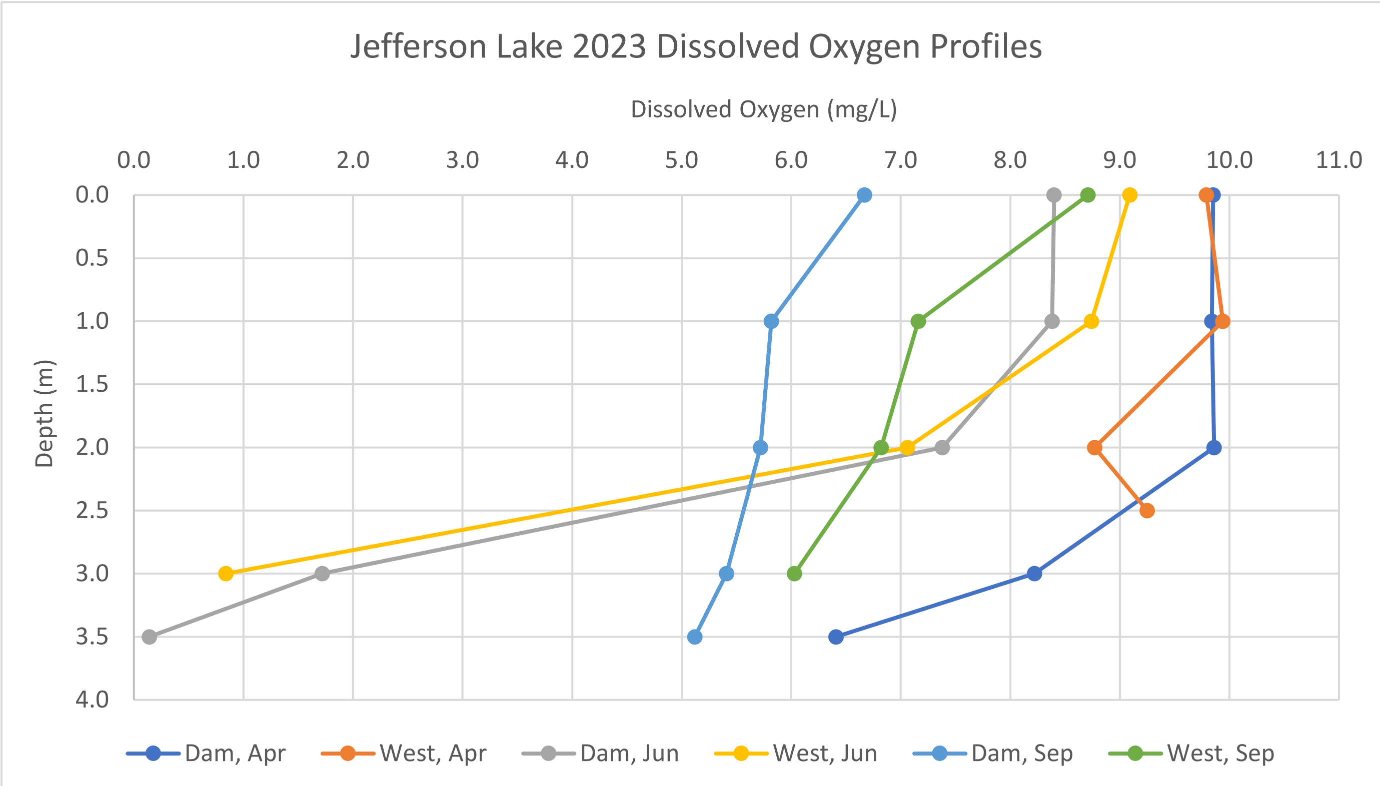


Figure 6.12: Jefferson Lake dissolved oxygen profiles throughout the 2023 growing season

DISCRETE WATER QUALITY

TP concentrations remained low throughout the season, ranging from 0.01 mg/L at the surface in April up to 0.04 mg/L in the deep sample in June. SRP concentrations remained very low throughout the season and never exceeded 0.002 mg/L. Nitrate-N concentrations also remained low during the 2023 growing season, varying between non-detectable (<0.03 mg/L) in April up to 0.08 mg/L in the deep sample in June. Surface chlorophyll *a* concentration increased as the season progressed, ranging from 3.3 µg/L in April to a maximum of 18.0 µg/L in September. TSS concentrations remained low for most of the season but were highest in April, with respective surface and deep concentrations of 12 and 13 mg/L.

PLANKTON AND MACROPHYTES

Phytoplankton diversity in Jefferson Lake was variable throughout the 2023 season. In April there were nine genera identified. A majority of the genera were diatoms, with both *Asterionella* and *Fragilaria* observed to be abundant. In June there was an increase in diversity, with twelve genera identified. There was a bloom of the golden algae genus *Dinobryon* in the June sample. There was a seasonal high in diversity during the September event with sixteen genera observed in the sample. The green algae genus *Phacotus* and the diatom genus *Melosira* were co-dominant in this sample with additional representation from diatoms, green algae, cyanobacteria, euglenoids, cryptomonads, and dinoflagellates.

Zooplankton diversity was also variable throughout the year; however, there was a mix of rotifers, copepods, and cladocerans during all three sampling events. In April, ten genera were identified in Jefferson Lake with an abundance of *Bosmina, Cyclops,* and *Keratella.* A majority of the other genera were observed to be present or rare. Diversity was similar in June with nine genera identified across the three major groups. The June sample was dominated by the cladoceran genera *Bosmina* and *Ceriodaphnia,* both identified as abundant, while *Daphnia* was recorded as common. Genera richness reached a seasonal maximum in September with twelve genera identified. A majority of the genera were identified as common or present in this sample with no dominance by any one particular genus. Most of Jefferson Lake's macrophyte community was observed in the shallower western half of the lake. During the spring event, this area was dominated by the invasive species curlyleaf pondweed, with trace amounts of Eurasian watermilfoil, sparse bigleaf pondweed, and some yellow pond lily also present in the southwest corner. By the summer event, most of the curlyleaf pondweed had senesced. During the September event, dense Eurasian watermilfoil was observed in the northwest cove. This location also featured the invasive species brittle naiad (*Najas minor*). The inlet area also contained yellow pond lily, while bigleaf pondweed was again observed near the western shoreline.

STAG POND

IN-SITU WATER QUALITY

Stag Pond was sampled three times during the 2023 season on 24 April, 21 June, and 19 September. Surface temperatures in Stag Pond varied throughout the seasons in 2023 and were typically slightly cooler at the inlet station than at the mid-lake station. Temperatures at the mid-lake station varied from 15.09 °C in April to 19.98 °C in September, while the inlet station ranged from 14.44 °C in April to 19.28 °C in June. Surface DO concentrations at the mid-lake station also varied depending on the time of year, ranging from 7.45 mg/L in September to 9.83 mg/L in April. However, anoxia (DO <1.0 mg/L) was observed at the bottom of the mid-lake station during all three sampling events. Water clarity was great throughout the entirety of the 2023 sampling season. At the inlet station, Secchi depths reached the bottom of the lake during each event. Water clarity exceeded 2.5 m at the mid-lake station during all three sampling events. pH varied throughout the season and water column, decreasing with depth at the mid-lake station. This is common in deeper lakes where there is no photosynthetic activity in the darker hypolimnion; photosynthesis in the epilimnion causes an increase in pH. Surface pH ranged from 7.05 in September to 7.84 in April, while deep water pH was lower, varying between 7.24 and 5.27. Specific conductance was low during the 2023 season, ranging from 51.72 µS/cm up to 187.00 µS/cm.

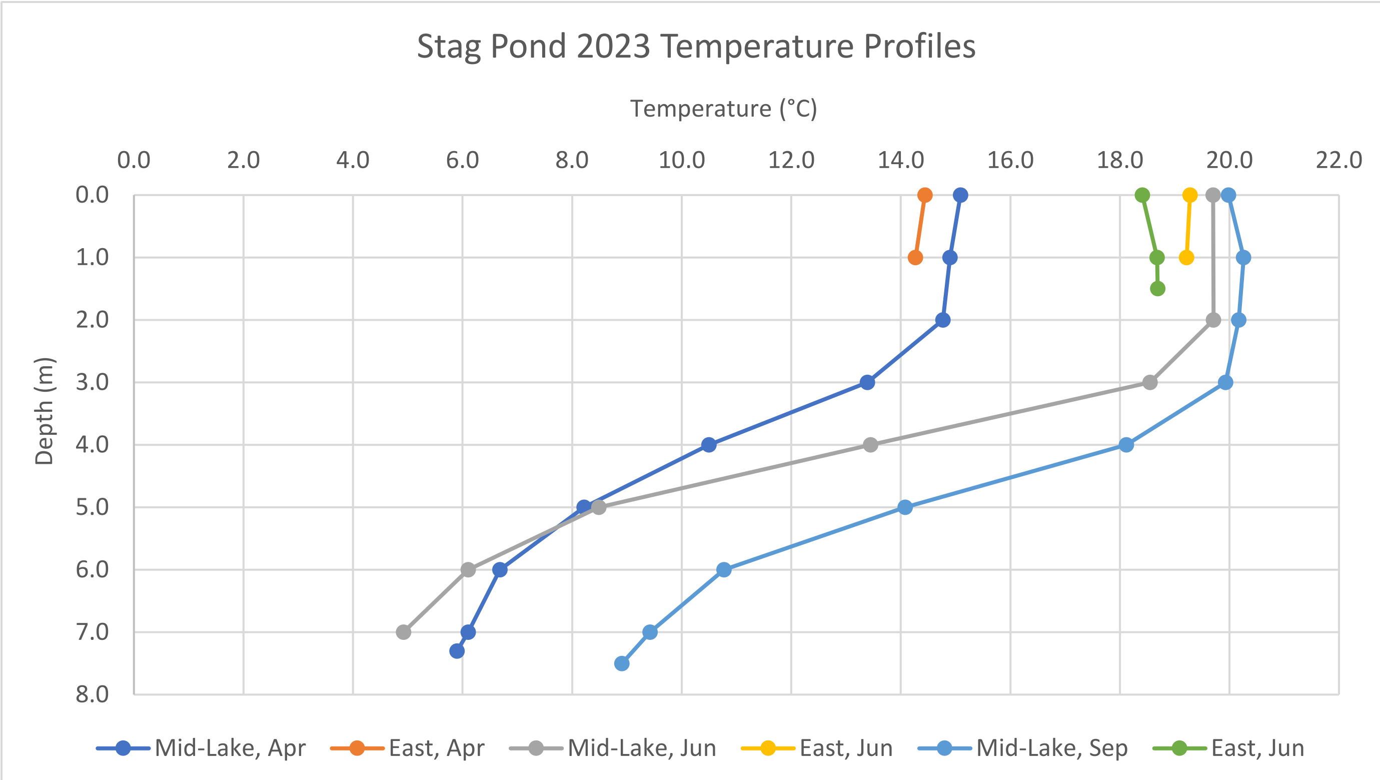


Figure 6.13: Stag Pond temperature profiles throughout the 2023 growing season

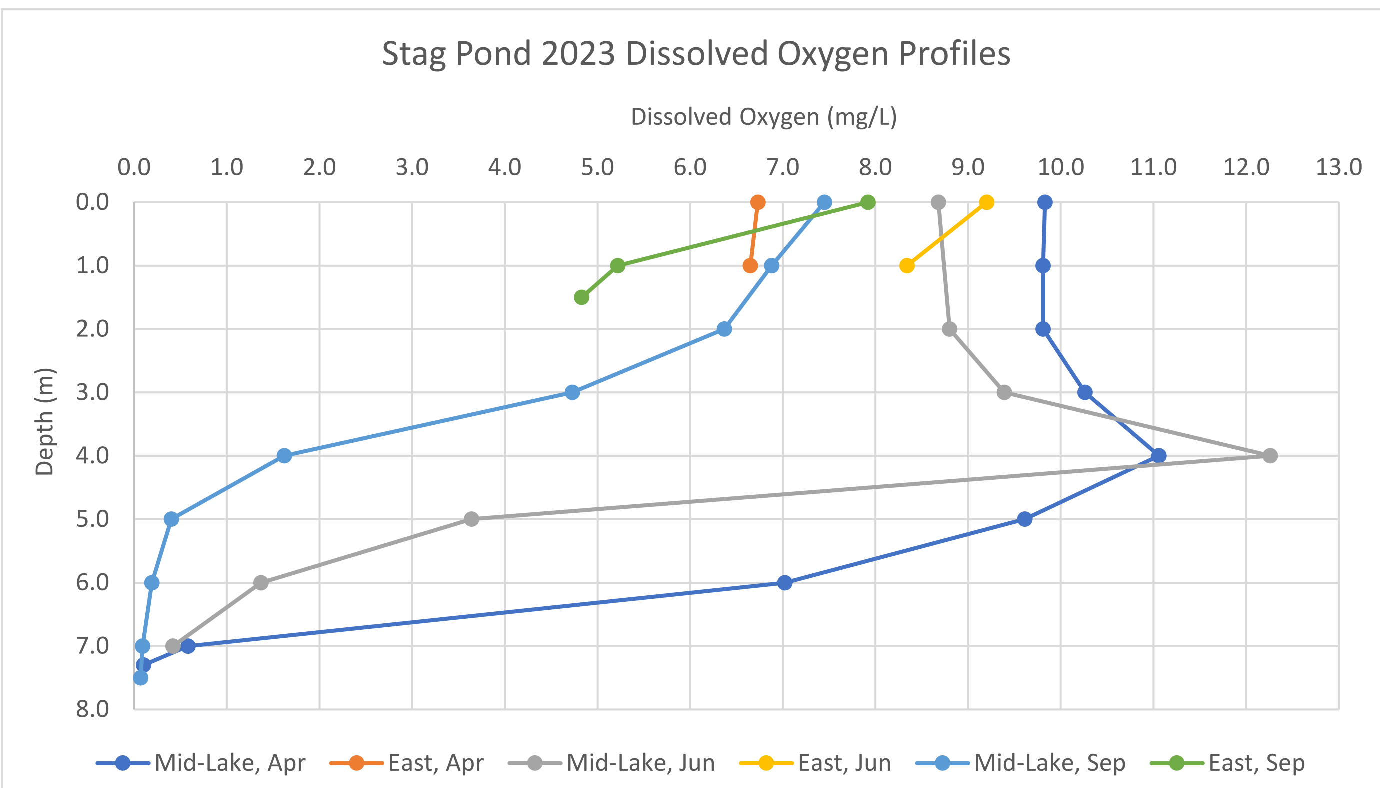


Figure 6.14: Stag Pond dissolved oxygen profiles throughout the 2023 growing season

DISCRETE WATER QUALITY

Surface TP in Stag Pond stayed low during the 2023 season ranging from non-detectable (<0.01 mg/L) in June to 0.02 mg/L in April and September. However, deep water TP concentrations became elevated as the season progressed. In April, the deep TP concentration was 0.08 mg/L. The deep TP concentration increased significantly in June and September, with respective concentrations of 0.14 mg/L and 0.34 mg/L. These increases in deep TP concentrations can be attributed to the internal release of phosphorus from the anoxic sediments as the lake remained stratified and the hypolimnion was void of oxygen.

Surface SRP concentrations remained extremely low, never exceeding 0.002 mg/L. However, similar to deep TP concentrations, deep SRP concentrations also increased as the season progressed, with respective June and September concentrations of 0.004 mg/L and 0.056 mg/L. Deep water chlorophyll *a* was consistently elevated throughout the season, averaging 36.0 µg/L across the three sampling events. However, surface chlorophyll a concentrations remained very low in April and June, with respective concentrations of 3.4 µg/L and 1.7 µg/L, before increasing to a concentration of 18.0 µg/L in September. Nitrate-N concentrations like many of the other lakes were low during the 2023 season. Concentrations ranged from non-detectable (<0.03 mg/L) to 0.07 mg/L during the year. TSS varied during the season, ranging from non-detectable (<2 mg/L) up to 15 mg/L in April.

PLANKTON AND MACROPHYTES

The Stag Pond plankton community remained diverse throughout the 2023 season, with sixteen genera of phytoplankton identified in April. The sample was characterized by a bloom of *Uroglena* which is a golden algae. In June there was a decrease in richness with ten genera identified in the sample. In this sample, there was again an abundance of golden algae but the dominant genus was *Dinobryon.* There was also an abundance of the cyanobacteria genus *Dolichospermum* which has the potential to form harmful algal blooms. In September there were thirteen genera identified, and there was another bloom of the golden algae genus *Dinobryon* in Stag Pond. Four genera of cyanobacteria were identified in the sample.

The zooplankton community was also variable during the season, with seven genera identified in April. This sample consisted of rotifers, copepods, and cladocerans observed in varying abundances. In June there were again seven genera identified and *Daphnia* was the most abundant genera. Zooplankton richness reached a seasonal maximum in September with nine genera identified. *Conochilus* was the dominant genus in this later-season sample.

Stag Pond was observed to contain a diversity of native macrophytes, particularly in the shallower southeastern portion of the waterbody. Of particular note is the presence of the New Jersey Rare Species flat-leaf bladderwort (*Utricularia intermedia*), which grew to moderate densities at the peak of the season. Also present were the species watershield, white water lily, yellow pond lily, tapegrass (*Vallisneria americana*), coontail (*Ceratophyllum demersum*), floating-leaf pondweed, and ribbonleaf pondweed (*Potamogeton epihydrus*). The invasive species Eurasian watermilfoil is also present and is managed via seasonal lake drawdowns. Of particular concern was the observation of dense beds of the invasive plant brittle naiad in the southeastern arm of the lake. While drawdowns appear to effectively manage milfoil densities, they may encourage growth of brittle naiad. The overall plant communities are relatively dense in the southeastern arm and may pose a nuisance to boaters and swimmers.

KOFFERLS POND

IN-SITU WATER QUALITY

Kofferls Pond was sampled three times during the 2023 season on 24 April, 21 June, and 19 September. Surface temperatures in Kofferls Pond varied throughout the 2023 season and it was coldest in April with a temperature of 14.27 °C and was warmest in September with a temperature of 19.22 °C. DO was variable during the 2023 season with surface readings ranging from 3.30 mg/L in September to 14.50 mg/L in April. Water clarity in Kofferls pond was excellent in 2023, remaining above the recommended 1.0 m threshold throughout the season. Most of the Secchi depths exceeded 2.0 m unless the Secchi disk was covered by plants prior to reaching that depth. pH was slightly elevated at times, ranging from 6.77 in June to 9.47 in April which is outside of the optimal range of 6.5 to 8.5.

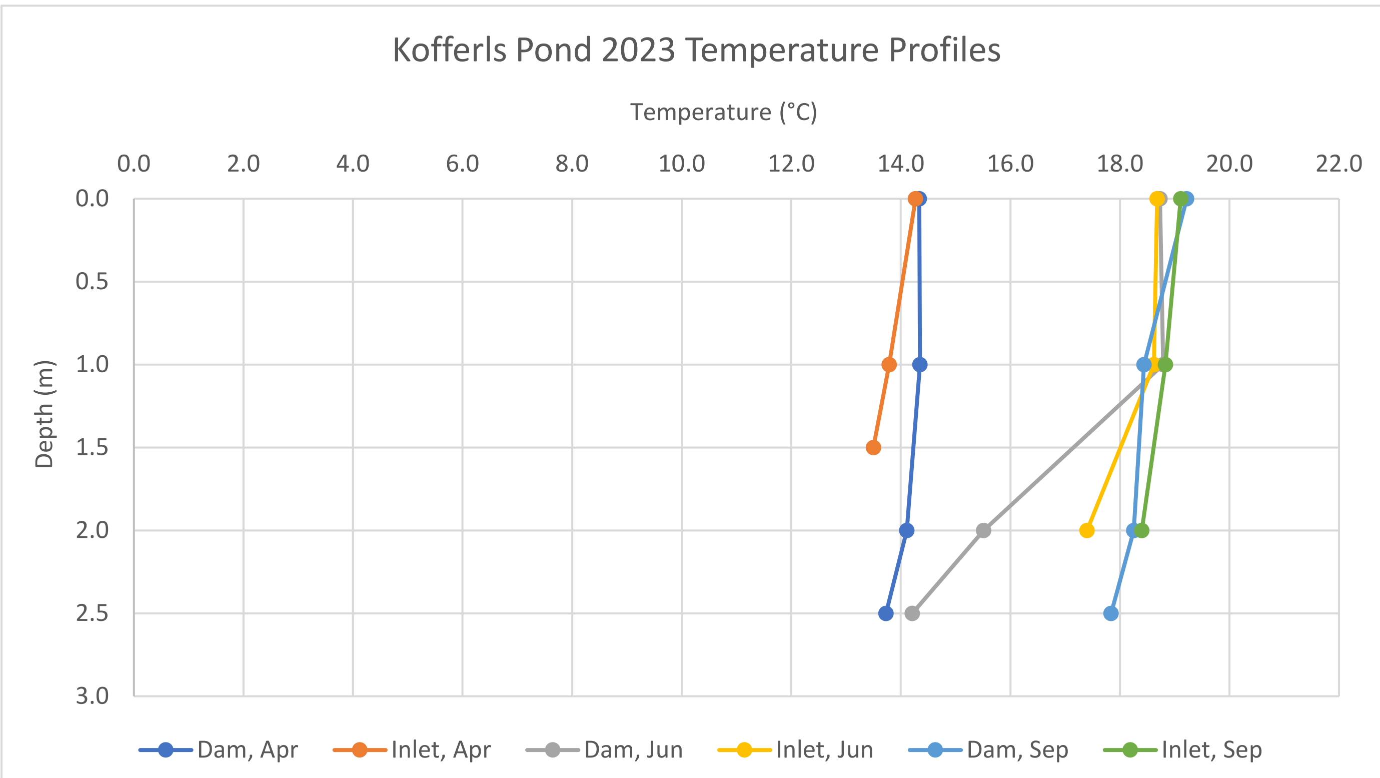


Figure 6.15: Kofferls Pond temperature profiles throughout the 2023 growing season

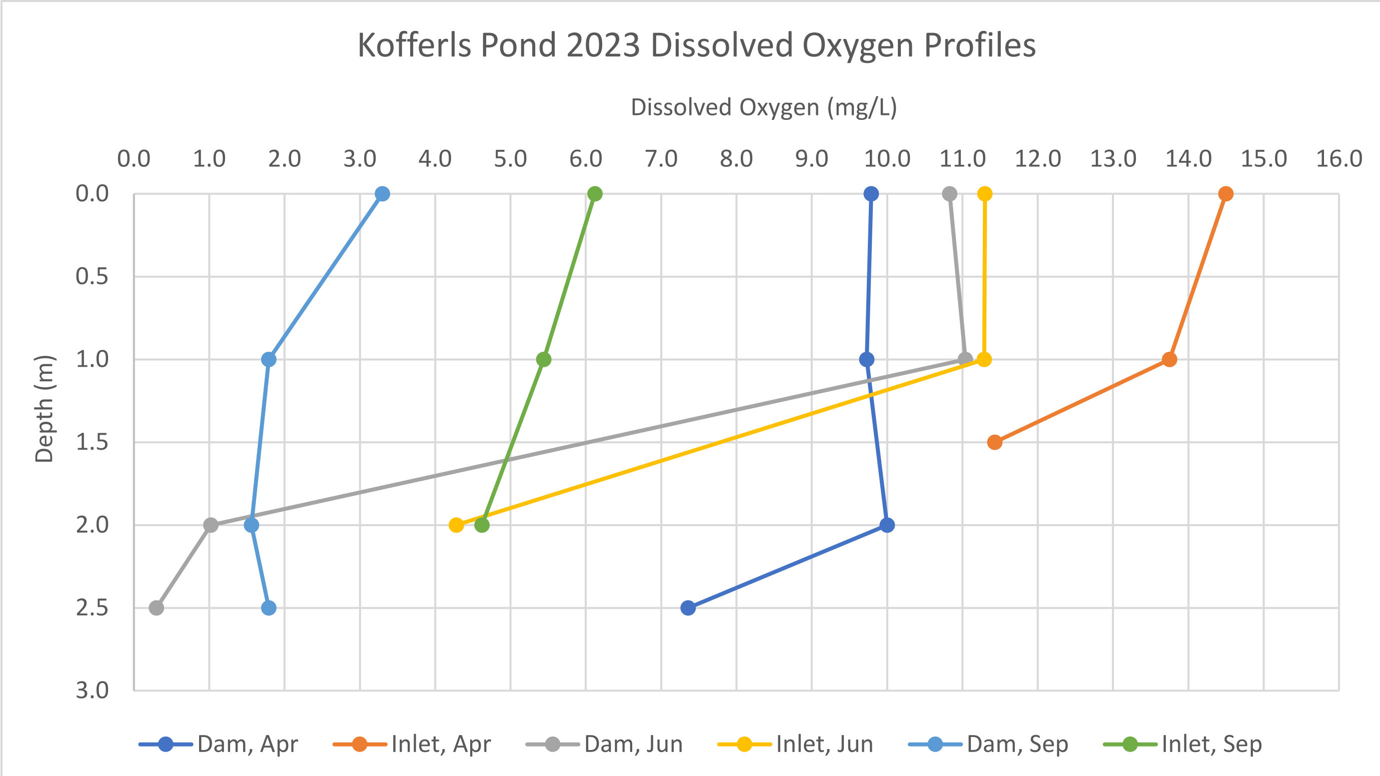


Figure 6.16: Kofferls Pond dissolved oxygen profiles throughout the 2023 growing season

DISCRETE WATER QUALITY

TP remained low during the 2023 season and did not exceed 0.03 mg/L. SRP remained below 0.003 mg/L during all of the sampling events in surface and deep samples, staying well within the recommended limits. Nitrate-N was variable throughout the water column in 2023 and surface samples remained low and at or below 0.03 mg/L, while the highest concentration (0.15 mg/L) was found at depth.

Chlorophyll *a* was consistently minimal throughout the season, never exceeding 9.6 µg/L across the three sampling events. TSS varied during the season, ranging from non-detectable (<2 mg/L) up to 8 mg/L in April.

PLANKTON AND MACROPHYTES

The plankton community in Kofferls Pond remained diverse and consistent throughout the 2023 season. In April the community was comprised of sixteen different genera across the major groups. The June sample showed a seasonal high genera richness, with eighteen genera identified across all of the major groups. In September there were sixteen genera present, but an abundant amount of *Lyngbya* which is a cyanobacteria were identified. This was the only lake that *Mougeotia* was found in during 2023.

The zooplankton community was also variable during the season, with ten genera being observed in April. There was an abundance of *Chydorus* in this sample which was considerably more than in other lakes in Byram township. In June there were eleven genera identified and *Chydorus* remained abundant. In September there was the lowest amount of diversity with six different genera. The most abundant genera in this sample was the rotifer *Kellicottia* while most of the other genera were seen in rare or present quantities.

The macrophyte community in Kofferls Pond is dominated by the invasive species Eurasian watermilfoil, which develops dense mats over the surface of most of the waterbody. This likely poses a nuisance to boaters and, at times, anglers. These mats often also contained filamentous algae. The native species coontail was also observed growing along the bottom in many areas. Leafy pondweed was also occasionally observed, and the edges of the northeastern half of the waterbody contained dense white water lily and watershield. Smaller amounts of duckweed (*Lemna sp.*) were also present in mats of these species.

7.0 TROPHIC STATE MODELING

7.1 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:

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

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:

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

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:

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

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 or reduced productivity and yields a lower value; the reverse is also true and lower clarity equates to higher index values.

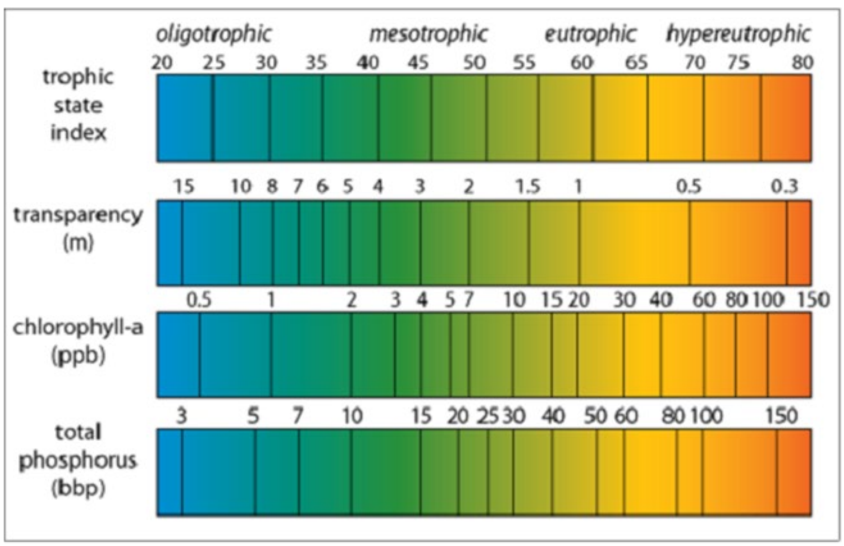


Figure 7.1. Ranges of trophic states for the three components of Carlson's TSI.

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 7.2 by Carlson and Havens (2005), the location of events in one of the "quadrats" on the graph, relative to the axes, may suggest differences in conditions during those particular events.

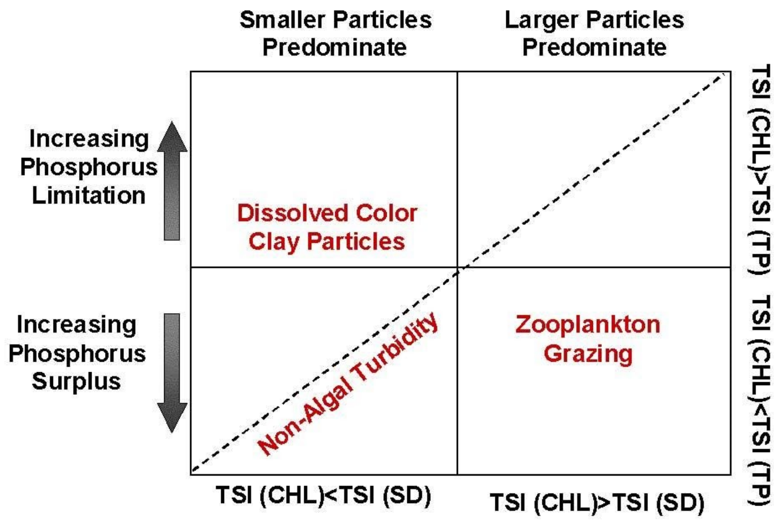


Figure 7.2. Carlson and Havens (2005) display possible interpretations for differences in trophic state indices when plotted on an axis.

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:

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

Where [TP] = annual mean phosphorus concentration (mg/L), L = areal phosphorus loading ($g/m^2/yr$), 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 Log_{10} 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 log_{10} 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.

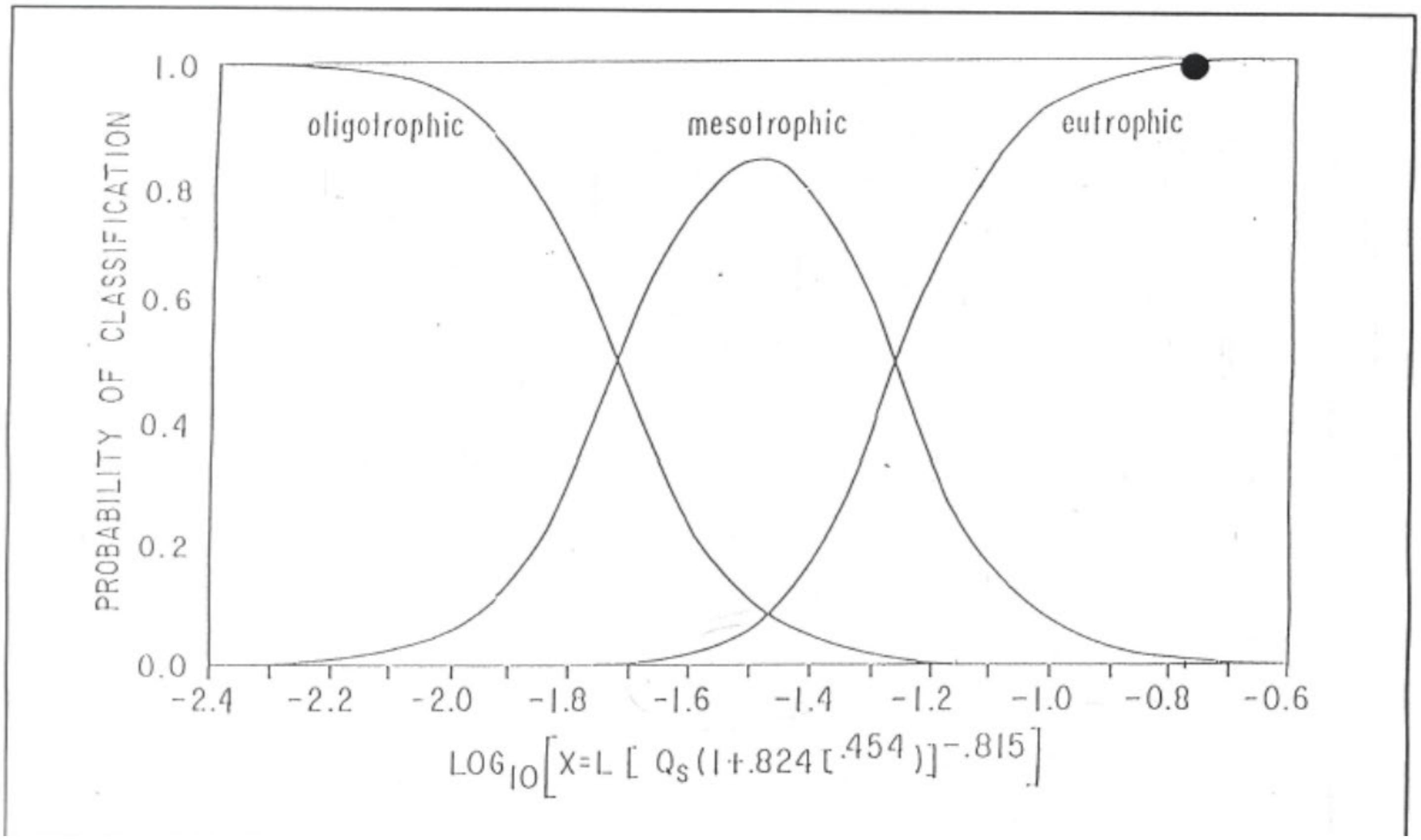


Figure 7.3. Walker (1977) displays how to interpret the log_{10} of spring phosphorus concentrations in order to assess the trophic state of a waterbody.

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 (1976) 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 (1988) 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.

7.2 RESULTS

CRANBERRY LAKE

Surface concentrations of total phosphorus collected in Cranberry Lake during the 2023 season were relatively low, yielding a mid-summer phosphorus-based TSI of 37.35, suggesting late-oligotrophic conditions. Chlorophyll *a* concentrations were also relatively low, yielding a mid-summer Chl. *a*-based TSI of 40.34, suggestive of mesotrophic conditions. Secchi depths typically were moderate, and the Secchi-based TSI for the middle of the summer was calculated to be approximately 45.7, suggesting mesotrophic conditions. It should be noted that Cranberry Lake features a low-to-moderate degree of macrophyte group, particularly in the southern end of the lake. Carlson's TSI assumes that phosphorus and resulting primary productivity results mostly in phytoplanktonic algal growth, and thus these results may not fully capture phosphorus used in multicellular plant growth. If the nutrients used for plant growth in Cranberry Lake were instead utilized solely by phytoplanktonic algae, the results of in-field sampling and thus the Carlson's TSI Model may reflect a system that leans closer to eutrophic rather than mesotrophic conditions.

Residuals of TSI values for each sampling date are plotted below in Figure 7.4. The points representing the April and June events are located in the upper-left quadrat; this suggests that chlorophyll was limited by phosphorus concentrations at these times and water clarity was impacted either by small-celled algae or by suspended clay particles or other non-algal particulates in the water column. TSS concentrations during the April event were somewhat elevated and may partially explain this. This coincided with an abundance of the diatom *Asterionella* and the golden algae genus *Synura,* which likely also impacted the water clarity. The point representing the September event is located in the upper-right quadrat close to the y-axis. The location of the point in the upper half of the chart suggests that phosphorus was limiting algae growth, while the proximity to the y-axis suggests that Secchi depth was largely the product of this algae growth.

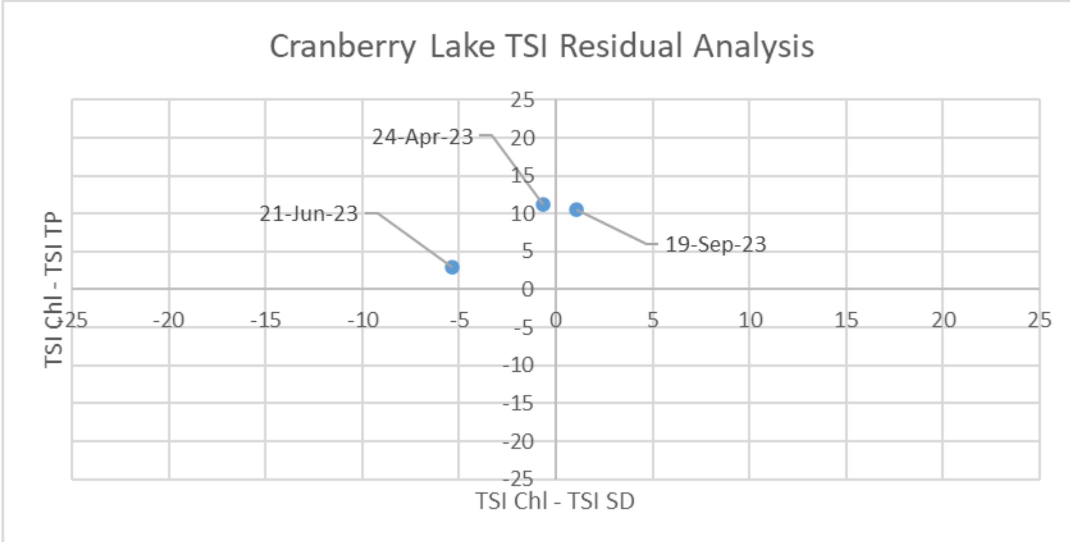


Figure 7.4. Residuals from TSI values obtained over the course of the 2022 growing season in Algonquin Waters.

When assessed with Kirchner and Dillon's phosphorus retention model, Cranberry Lake yielded an R value of 0.65, suggesting that approximately 2/3rds of the phosphorus that enters the waterbody is retained on an annual basis and not flushed from the waterbody. When this value is entered into the Dillon-Rigler predictive phosphorus model, Cranberry Lake is predicted to have a Spring phosphorus concentration of approximately 0.03 mg/L, or 0.04 mg/L if the internal load is included in the calculation. These are overestimations when compared to the total phosphorus concentration of 0.01 mg/L obtained at the lake's surface during the April event. The Walker model yielded a closer value of approximately 0.05 mg/L or 0.06 mg/L if the internal phosphorus load is accounted for. According to Walker's trophic state analysis, Cranberry Lake has approximately a 100% likelihood of being Oligotrophic, or a 95% chance of being Oligotrophic and a 5% chance of being mesotrophic when the internal load is considered. This is a departure from the Carlson's TSI values, which suggested the lake is generally mesotrophic. Carlson's estimated summertime chlorophyll *a* model predicted a chlorophyll concentration of approximately 13.7 µg/L or 17.6 µg/L, an overestimation of the actual concentration obtained during the June event of 2.7 µg/L. Vollenweider's predicted phosphorus model yield an estimated phosphorus concentration of approximately 0.03 mg/L (0.04 mg/L when the internal load is accounted for), while Reckhow's predicted phosphorus model yielded a similar estimated value of approximately 0.05 mg/L for both model runs. The models generally yield somewhat overestimated results, suggesting that the watershed-based pollutant model may slightly overestimate incoming phosphorus loads. Alternatively, as described above, a large portion of the phosphorus modeled to enter the waterbody may be assimilated by macrophytes rather than algae, and thus may not be captured when analyzing water samples.

LAKE LACKAWANNA

During the 2023 sampling season, Lake Lackawanna yielded relatively low surface total phosphorus concentrations, with the mid-summer phosphorus-based TSI calculated to be 47.35, characteristic of mesotrophy. Chlorophyll *a* concentrations were also relatively low, with the mid-summer Chl. *a*-based TSI value calculated to be 43.70, also characteristic of mesotrophy. Secchi depths were relatively high during the summer event, reaching the bottom of the water column, yielding a Secchi-based TSI value of 50.01, characteristic of a eutrophic water body. As noted with Cranberry Lake, Lake Lackawanna typically features notable macrophyte densities that may sequester a significant amount of phosphorus, and thus the lake may be more eutrophic than this model suggests.

TSI value residuals are plotted below in Figure 7.5. The points representing the April and June sampling events are located in the left-hand side of the y-axis close to the x-axis. The point representing the September sampling event is also to the left of the y-axis but is above the x-axis. This suggests that Secchi depths may have been limited by factors other than algal growth. This may simply be an effect of the Secchi disk reaching the bottom of the lake before disappearing from view. The proximity of the first two sampling events' points to the x-axis suggests that algal growth was largely explained by phosphorus concentrations, while the location of the point representing the September event above the x-axis suggests that algal growth was limited by phosphorus during this event.

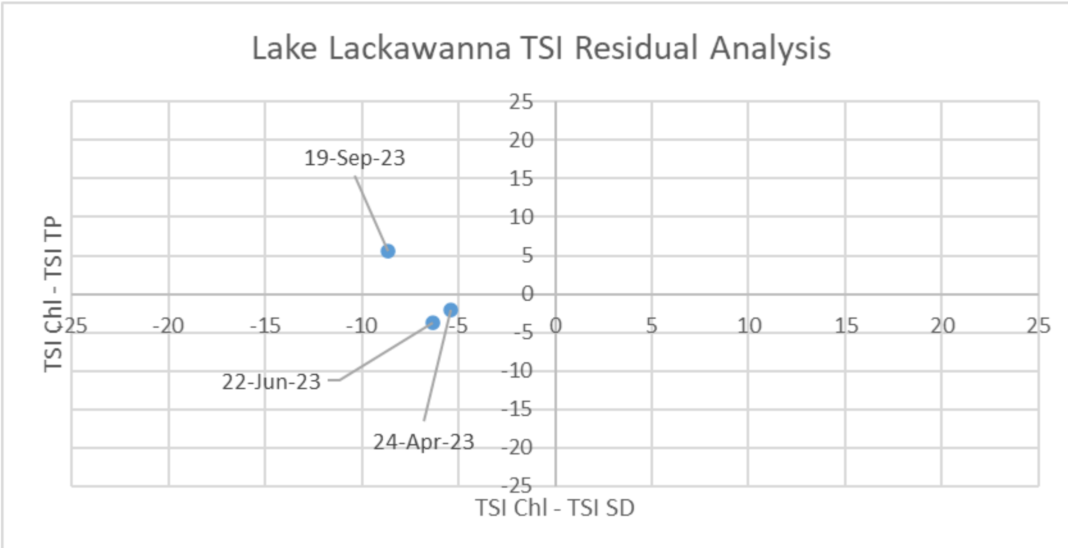


Figure 7.5. Residuals from TSI values obtained over the course of the 2023 growing season in Lake Lackawanna.

When assessed with Kirchner and Dillon's phosphorus retention model, Lake Lackawanna yields an *R*-value of approximately 0.39, suggesting that the lake retains slightly over a third of the incoming 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, Lake Lackawanna is predicted to yield a spring-time phosphorus concentration of approximately 0.02 mg/L, aligning with the surface concentration of 0.02 mg/L obtained during the Spring sampling event. Walker's predicted spring phosphorus model yielded similar results of 0.02 mg/L. The results of Walker's trophic state analysis suggest that the pond has 100% likelihood of being Oligotrophic. This result differs from the results of Carlson's TSI, which suggested that the lake is mesotrophic-to-eutrophic. Carlson's predicted summertime chlorophyll model yielded an estimated concentration of approximately 4.73 µg/L or 5.33 µg/L if internal loads are included. These are relatively close to the chlorophyll *a* concentration of 3.8 µg/L obtained during the summer event. Vollenweider's model predicted a phosphorus concentration of approximately 0.02 mg/L when using both the external load only and when factoring for the internal load, while Reckhow's model predicted similar results of 0.02 mg/L. These two models also align with the phosphorus concentrations obtained in the field.

JOHNSON LAKE

Surface total phosphorus concentrations collected in Johnson Lake were consistently low, particularly during the summer event, which yielded a phosphorus-based TSI value of 37.35, characteristic of an oligotrophic-to-mesotrophic waterbody. Surface chlorophyll *a* concentrations were also relatively low, with the mid-summer concentration yielding a chl. *a*-based TSI value of 38.33, also characteristic of an Oligotrophic waterbody. The summer event's Secchi depth yielded a Secchi-based TSI value of 53.23, which is suggestive of eutrophic conditions, while the Spring event yielded a higher Secchi depth, yielding a Secchi-based TSI value of 47.39, an indicator of mesotrophic conditions. Johnson lake is largely a macrophyte-dominated system, and as such may be more eutrophic than these results suggest.

Johnson Lake's TSI residuals are plotted below in Figure 7.6. The point representing the April event is located close to the graph's origin, suggesting that, during this date, algae populations were largely explained as a product of phosphorus concentrations, and Secchi depths were largely a product of algae density. The points representing the June and September events are both located to the left of the y-axis and are relatively close to the x-axis. This suggests that algae densities were largely a product of phosphorus concentrations, but Secchi depths were not solely limited by algae in the water column. This may be due to the presence of fine sediment in the water column.

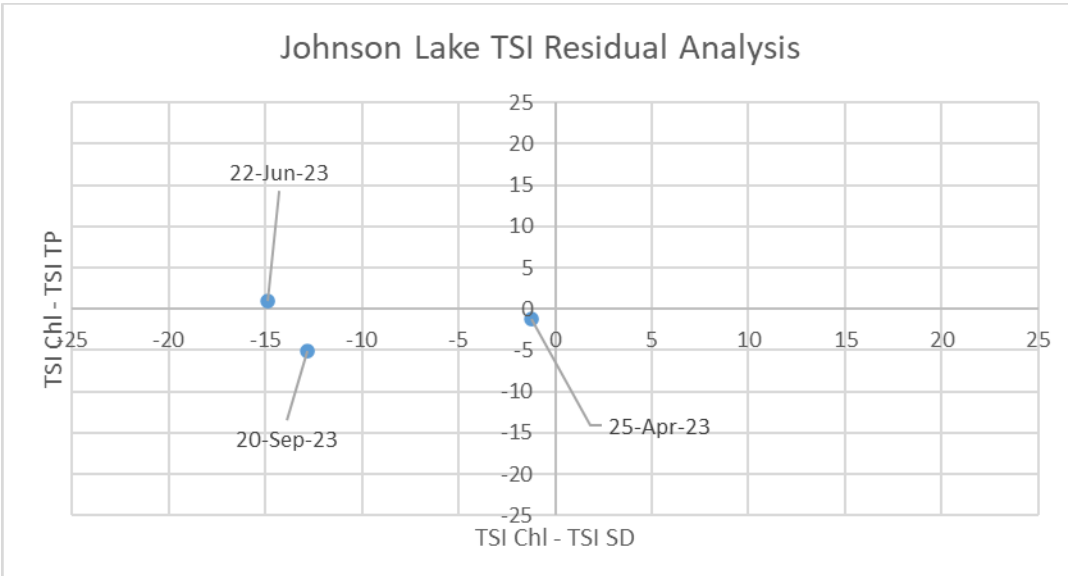


Figure 7.6. Residuals from TSI values obtained over the course of the 2022 growing season in Johnson Lake

When assessed with Kirchner and Dillon's phosphorus retention model, Johnson Lake was calculated to have a retention value of approximately 0.61, suggesting that the waterbody retains slightly less than two-thirds of all incoming phosphorus in a year. When this value is used in the Dillon-Rigler predicted phosphorus model, Johnson Lake was estimated to have a Springtime phosphorus concentration of approximately 0.01 mg/L, or 0.02 mg/L if internal loading is considered. These largely align with the concentration of 0.02 mg/L obtained in the field during the April sampling event. Walker's Springtime predictive phosphorus model yielded similar concentrations of approximately 0.01 mg/L or 0.02 mg/L if internal loads are considered. Walker's trophic state assessment predicted that the pond has 100% likelihood of being oligotrophic. This result suggests that the lake is oligotrophic to a slightly larger degree than Carlson's TSI does. Carlson's predicted chlorophyll *a* model predicted a summertime chlorophyll *a* concentration of approximately 2.21 µg/L or 4.36 µg/L when internal loads are included in the calculation. These are similar to the Summer concentration obtained in the field of 2.20 µg/L. Vollenweider's predicted phosphorus model predicted a concentration of approximately 0.01 mg/L of phosphorus (0.02 mg/L when internal loads are used), while Reckhow's model yielded a prediction of approximately 0.02 mg/L, or 0.03 mg/L when internal loads are considered.

FOREST LAKE

The June sampling event conducted at Forest Lake yielded a relatively low phosphorus concentration, yielding a phosphorus-based TSI value of approximately 37.35, characteristic of an oligotrophic lake. It should be noted that the surface phosphorus concentration obtained during the September event produced a higher phosphorus-based TSI value of 53.20, which is suggestive of eutrophic conditions. Forest Lake's June surface chlorophyll *a* concentration was relatively high and yielded a Chlorophyll *a*-based TSI value of 61.36 mg/L, suggesting eutrophic conditions. The summer event yielded the highest Secchi depth of the year, which produced a Secchi-based TSI value of approximately 46.23, suggesting Mesotrophic conditions.

Residuals from Forest Lake's 2023 TSI values are plotted below in Figure 7.7. The points representing the April and September sampling event are both located close to the graph's origin, suggesting that algae growth was generally the result of phosphorus concentrations and that Secchi depths could be explained as a product of algae growth. The point representing the June sampling event is located in the upper-right quadrant, suugesting that algae growth was notably limited by phosphorus availability and that Secchi depths were higher than expected based on chlorophyll *a* concentrations, possibly due to the presence of larger algae cells, such as those produced by some cyanobacteria.

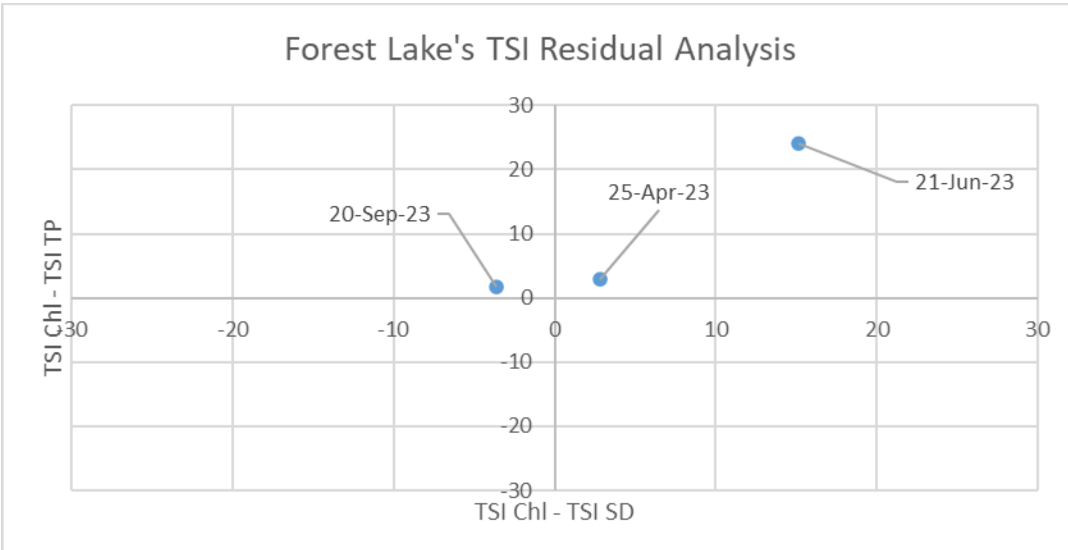


Figure 7.7. Residuals from TSI values obtained over the course of the 2022 growing season in Forest Lake.

Analysis using the Kirchner-Dillon phosphorus retention model yielded a retention value of approximately 0.79, suggesting that Forest Lake retains over three-quarters of the phosphorus that enters over the course of an average year. When this coefficient is used as part of the Dillon-Rigler predictive phosphorus model, Forest Lake is estimated to have a Springtime phosphorus concentration of approximately 0.01 mg/L, or 0.04 mg/L if the internal phosphorus load is accounted for. The value obtained using only external loading is only slight underestimation when compared to the surface concentration of 0.02 mg/L that was obtained in the field during the April event. Analysis with Walker's predicted phosphorus model yields an estimated Springtime phosphorus concentration of approximately 0.03 mg/L when only considering the external phosphorus load and yields an estimate of approximately 0.11 mg/L if internal loading is included in the calculation. When only the external load is used in the calculation, the Walker trophic state model estimated that Forest Lake has an approximately 90% likelihood of being oligotrophic and a 10% likelihood of being mesotrophic. When the internal load is included, this model predicts that the lake has an 85% probability of being mesotrophic, a 10% probability of being oligotrophic, and a 5% probability of being eutrophic. Carlson's predicted summer chlorophyll model yielded a concentration of approximately 3.75 µg/L when using the results of the Dillon-Rigler model for external loads only and 19.7 µg/L when using the same model for both external and internal loads. The model output that includes both sources of phosphorus more closely aligns with the 23.0 µg/L obtained from the surface sample collected during the June event. Vollenweider's predicted phosphorus concentration yielded an estimated phosphorus concentration of approximately 0.01 mg/L when only the external load is used and 0.04 mg/L when both external and internal loading are accounted for. The Reckhow predicted phosphorus model yielded an estimated concentration of approximately 0.03 mg/L when only the external load is used in the calculation and 0.05 mg/L mg/L when the internal load is included.

PANTHER LAKE

Panther Lake's surface samples collected during the summer event yielded relatively low phosphorus concentrations, resulting in a phosphorus-based TSI value of 47.35, suggesting mesotrophic conditions. Of note was a higher phosphorus-based TSI value of 53.20 derived from spring surface phosphorus concentrations. This concentration is characteristic of eutrophic lake systems. Surface chlorophyll *a* concentrations were also relatively low during the June event, resulting in a chlorophyll *a*-based TSI of 42.31, characteristic of mesotrophic systems. The Secchi depths obtained during the June event yielded a Secchi-based TSI value of 52.35, characteristic of eutrophic systems. It should be noted that the fall event yielded a higher Secchi depth, resulting in a Secchi-based TSI value of 46.23, characteristic of mesotrophic systems.

TSI residual values for data collected from Panther Lake are plotted below in Figure 7.8. Points representing the April and September events are relatively close to the origin of the figure, suggesting that chlorophyll *a* concentrations and algae growth during these dates is largely controlled by phosphorus concentrations, while water clarity during these dates was largely a product of algae growth. The June event is located near the x-axis but to the left of the y-axis. This suggests that algae was largely a product of phosphorus concentrations, but water clarity was not solely a product of algae growth, and may have been effected by another factor such as suspended particulates. The somewhat increased TSS concentration obtained from the surface during this event lends further evidence for this hypothesis.

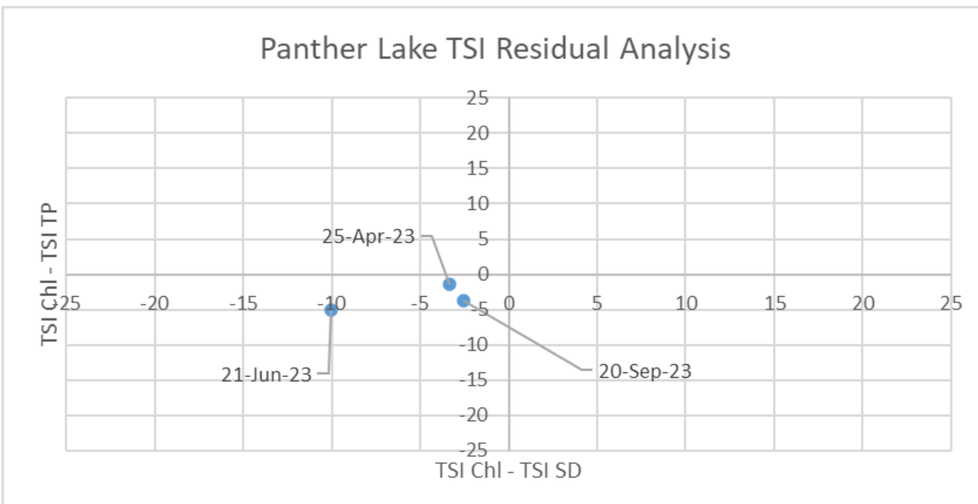


Figure 7.8. Residuals from TSI values obtained over the course of the 2023 growing season in Panther Lake

When assessed with Kirchner and Dillon's phosphorus retention model, Panther Lake received a retention coefficient of approximately 0.72, suggesting that the lake retains approximately three-quarters of the phosphorus it receives over the course of an average year. When this coefficient is used in the Dillon-Rigler predictive phosphorus model, the lake is estimated to feature a Springtime phosphorus concentration of approximately 0.02 mg/L, or 0.05 mg/L when internal loads are also accounted for. This aligns with the concentration of 0.02 mg/L obtained during the April field event at the surface of the lake. The Walker model predicted a Springtime phosphorus load of approximately 0.04 mg/L or approximately 0.10 mg/L when internal loads are included in the calculation. When assessed with Walker's trophic state model, Panther Lake is estimated to have a 100% likelihood of being oligotrophic. When internal loads are also included in this analysis, the lake is estimated to have a 90% probability of being oligotrophic and a 10% probability of being mesotrophic. The Carlson predictive summer chlorophyll model yields an estimated summer chlorophyll concentration of approximately 6.22 µg/L, or 25.33 µg/L if the internal load is included. The result obtains by using only the external phosphorus load more closely aligns with the surface chlorophyll *a* concentration of 3.3 µg/L obtained during the summer field sampling event. When assessed with the Vollenweider model, Panther Lake was estimated to feature a phosphorus concentration of 0.02 mg/L (0.05 mg/L if internal loads are included), while the Reckhow model yielded an estimate of approximately 0.03 mg/L (0.07 mg/L if internal loads are included). As mentioned above, these models typically are based on external loading, and even when internal loading is included, they may not fully accurately represent the trophic condition of the lake. Panther Lake is estimated to have a large internal phosphorus load than that which enters from its watershed, as mentioned in a previous report section, and this may lead to a less accurate representation of the lake's trophic state when using these models. Furthermore, the lake features a notable aquatic macrophyte population, which may sequester phosphorus from the water column, leading to lower concentrations of phosphorus and chlorophyll in the water itself. The models used here do not usually account for this sequestered phosphorus and may misrepresent the total amount present within the lake.

JEFFERSON LAKE

Surface phosphorus concentrations obtained during the Summer sampling event at Jefferson Lake were relatively low, resulting in a phosphorus-based TSI of 47.35, characteristic of mesotrophic systems. Chlorophyll *a* concentrations were similarly somewhat low, yielding a chl. *a*-based TSI of approximately 46.77, also characteristic of a mesotrophic system. The Secchi depth obtained during the summer event was somewhat moderate, yielding a Secchi-based TSI of approximately 51.53, suggestive of eutrophic conditions.

TSI residuals for Jefferson Lake are plotted in Figure 7.9. The point representing the April event is located in the upper-left quadrant, suggesting that algae growth was limited by phosphorus availability and that Secchi depths may have been in part either an effect of smaller algae particles or non-algal turbidity. The June event is represented by a point located along the x-axis to the left of the y-axis. This suggests that algae growth was likely explained by phosphorus availability, while Secchi depths may have been in part a product of either smaller algae particulates or non-algal turbidity. The point representing the September event is located in the upper-right quadrant, suggesting a large degree of phosphorus limitation. This also indicates that Secchi depths were somewhat high given the surface concentration of chlorophyll *a*, suggesting that algae may have been mostly present as larger cells/colonies, such as those produced by cyanobacteria.

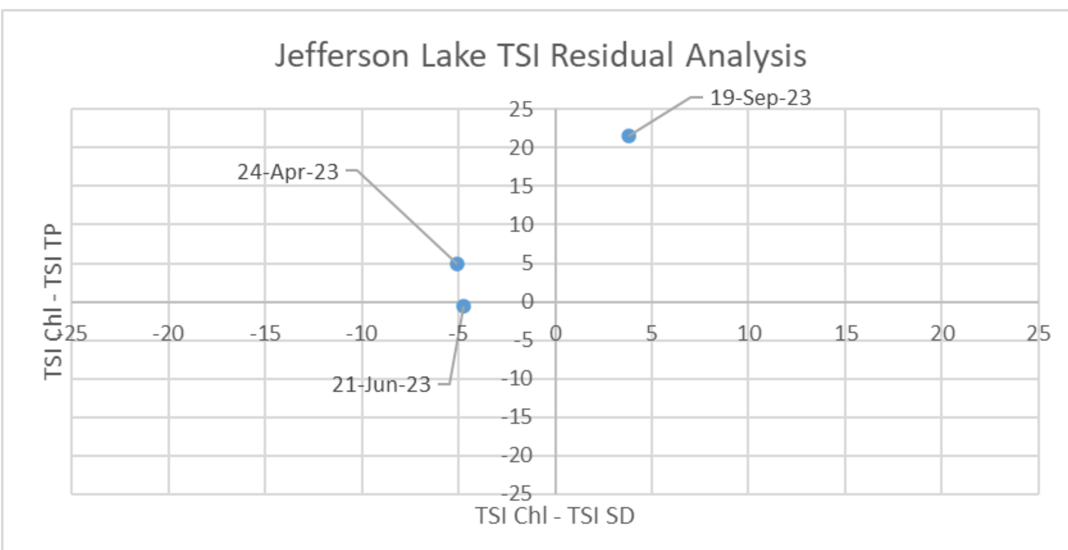


Figure 7.9. Residuals from TSI values obtained over the course of the 2023 growing season in Jefferson Lake.

When assessed using the Kirchner-Dillon phosphorus retention model, Jefferson Lake received a phosphorus retention coefficient of approximately 0.39, suggesting that the lake retains over a third of the phosphorus that enters over the course of an average year. When this result is entered into the Dillon-Rigler predicted phosphorus model, the lake is estimated to feature a Springtime phosphorus concentration of 0.03 mg/L. This is an overestimation when compared to the phosphorus concentration of 0.01 mg/L obtained during the Spring sampling event. The Walker predictive phosphorus model yielded more accurate estimated Springtime phosphorus concentrations of approximately 0.02 mg/L. The results of Walker's trophic state analysis suggest that Jefferson Lake has a 100% likelihood of being oligotrophic. This model suggests that Jefferson Lake trends towards oligotrophy more than the summer Carlson's TSI results do. Carlson's predicted summer chlorophyll model estimated a concentration of approximately 10.3 µg/L (11.16 µg/L when internal loads are included in the calculation). This is an overestimation when compared to the surface concentration of 5.2 µg/L obtained during the summer event. The Vollenweider predicted phosphorus model yielded a predicted springtime phosphorus concentration of approximately 0.04 mg/L, while the Reckhow model yielded a predicted concentration of 0.03 µg/L. When comparing the results with surface concentrations obtained in the field, many of the above models overestimate Spring phosphorus. As with many other lakes in this study, Jefferson Lake features notable macrophyte growth during portions of the growing season; these may sequester phosphorus and result in less algal biomass than the models suggest.

STAG POND

Surface total phosphorous concentrations in Stag Pond were slightly lower during the summer event than during the two other sampling events. The Summer concentration yielded a phosphorus-based TSI of 37.35, suggestive of oligotrophic conditions, while the Spring and Autumn sampling events both yielded phosphorus-based TSI values of 47.35, suggestive of mesotrophic conditions. Similar to its surface phosphorus concentrations, Stag Pond's surface chlorophyll *a* concentrations were at their lowest during the Summer event, yielding a Chlorophyll-based TSI value of 35.81, a value indicative of oligotrophic conditions. It should be noted that the surface chlorophyll *a* concentration was much higher during the Autumn event, yielding a chlorophyll-based TSI value of 58.96, a value consistent with eutrophic conditions. The June sampling event yielded the highest Secchi depth for Stag Pond in 2023, yielding a Secchi-based TSI value of 44.17, suggesting mesotrophic conditions.

Figure 7.10 below displays the plotted TSI residuals from Stag Pond. The point representing the April event is located close to the graph's origin, suggesting that algae growth was largely explained by the availability of phosphorus and that Secchi depths were largely tied to algae growth. The point representing the June event is located to the left of the y-axis along the x-axis, suggesting that algae growth was largely tied to phosphorus availability, but Secchi depth was not limited solely by algae growth. The point representing the September sampling event is located in the upper-right quadrant, suggesting that algae growth was largely limited by phosphorus growth. This also indicates that Secchi depths were somewhat high given the surface concentration of chlorophyll a, suggesting that algae may have been mostly present as larger cells/colonies, such as those produced by cyanobacteria.

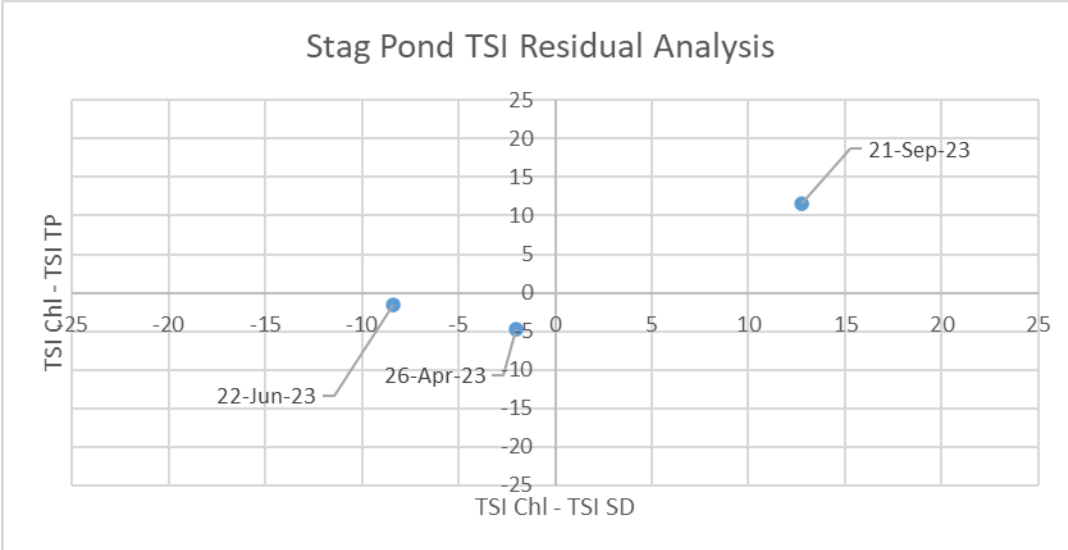


Figure 7.10. Residuals from TSI values obtained over the course of the 2023 growing season in Stag Pond.

When assessed with the Kirchner-Dillon model, Johns Lake yielded a phosphorus retention coefficient of approximately 0.68, suggesting that the waterbody retains approximately two-thirds of incoming phosphorus over the course of a year. When this is used for the Dillon-Rigler model for springtime phosphorus prediction, a phosphorus concentration of approximately 0.004 mg/L is estimated if only accounting for external loads, while a concentration of 0.02 mg/L is estimated if internal loading is included in the calculation. The latter estimate aligns with the surface phosphorus concentration of 0.02 mg/L obtained in the field during the April event. Walker's spring phosphorus prediction model yielded higher estimates of approximately 0.01 mg/L if external loads are used only and 0.03 mg/L if both loading sources are accounted for. Walker's trophic state model estimates that Stag Pond has a 100% likelihood of being oligotrophic. Carlson's summertime chlorophyll *a* predictive model estimates that Stag Pond will have a summer chlorophyll *a* concentration of approximately 0.71 µg/L when using external loads only, and a concentration of approximately 6.53 µg/L when internal loads are included. The former is a slight underestimate of the concentration obtained at the surface of Stag Pond during the Summer event of 1.7 µg/L. Vollenweider's predictive phosphorus model estimated a springtime phosphorus concentration of approximately 0.004 mg/L (0.02 mg/L when internal loading is included in the calculations), Reckhow's model estimated approximately 0.001 mg/L (0.03 mg/L when internal loading is included). Given Stag Pond's relatively high internal load and notable macrophyte growth, much of the phosphorus estimated to enter the water column over the course of the year is likely not captured in surface water quality samples. As such, the above models may underestimate the trophic state of Stag Pond.

KOFFERLS POND

Surface concentrations of phosphorus in Kofferls Pond were at their lowest during the summer sampling event, yielding a phosphorus-based TSI of 27.36, a value indicative of oligotrophic conditions. The highest phosphorus-based TSI in Kofferls Pond occurred during the spring event with a value of 47.35, a value indicative of mesotrophic conditions. The Summer event's surface chlorophyll *a* concentration was similarly lower than those obtained during the other two sampling events, yielding a chlorophyll *a*-based TSI of 36.90, indicative of oligotrophic conditions. The highest chlorophyll *a* concentrations was collected during the spring event, yielding a chlorophyll-based TSI of 41.04, indicative of mesotrophic conditions. Secchi-based TSI values ranged from 45.16 during the Spring event, indicative of mesotrophic conditions, to 50.01 during both the Summer and Autumn events, suggesting early Eutrophic conditions.

Figure 7.11 below displays the TSI residuals for all three events at Kofferls Pond. All points are located to the left of the y-axis, suggesting that Secchi depths were not entirely the product of algae growth. While this would usually suggest that non-algal turbidity is limiting Secchi depths, in Kofferls Pond it may more so be the product of relatively shallow water depths and dense plant growth. The point representing the April event is located below the x-axis, suggesting that algae growth may have not been only caused by phosphorus availability at this time. The point representing the June event is located above the x-axis, suggesting that algae growth was notably limited by phosphorus availability at this time. The September event's point is located close to the x-axis, suggesting that algae growth is relatively proportional to phosphorus availability.

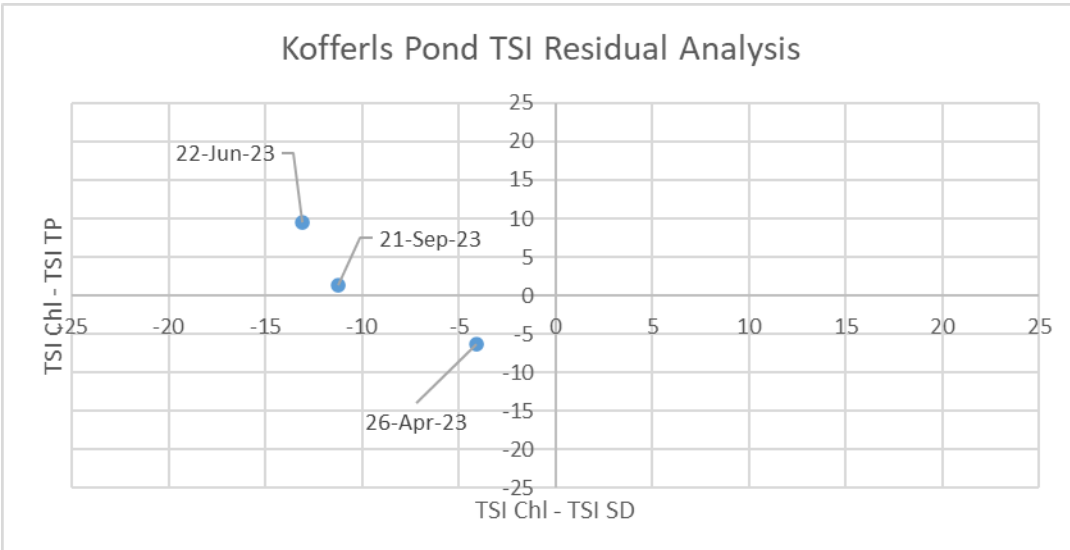


Figure 7.11. Residuals from TSI values obtained over the course of the 2023 growing season in Kofferls Pond.

When assessed with the Kirchner-Dillon phosphorus retention model, Kofferls Pond received a retention coefficient of approximately 0.49, suggesting that the pond retains approximately half of the phosphorus that enters over the course of an average year. When used in the Dillon-Rigler predictive phosphorus model, Kofferls Pond was estimated to feature a Springtime phosphorus concentration of 0.01 mg/L or 0.02 mg/L if the internal load is accounted for. These are slight overestimations of the phosphorus concentration obtained during the summer event, which was below the detectable concentration. The Walker predictive phosphorus model yielded similar predictions of 0.01 mg/L or 0.02 mg/L if the internal load is included in the analysis. The results of Walker's trophic state analysis suggest that Kofferls Pond has a 100% likelihood of being an oligotrophic system. Carlson's predicted Summer chlorophyll *a* model yielded a concentration of 3.99 µg/L or 5.13 µg/L if the internal load is included in the analysis. Both of these results are overestimations when compared with the surface chlorophyll *a* concentration of 1.9 µg/L obtained in the field during the Summer event. The Vollenweider predictive phosphorus model and the Reckhow model both yielded a springtime phosphorus estimate of approximately 0.02 mg/L. Kofferl's Pond is largely a macrophyte-dominated system, and as such the phosphorus entering the waterbody is not translated to water-borne chlorophyll. This resulted in trophic models yielding results indicative of oligotrophic or mesotrophic conditions when the pond may actually be more eutrophic.

8.0 ANALYSIS OF THE POLLUTANT REMOVAL THROUGH THE IMPLEMENTATION OF WATERSHED BASED MANAGEMENT

8.1 INTRODUCTION

This analysis allowed for identification of those sub-watersheds having the greatest impact on the pond, as well as those sub-watersheds having the most manageable (correctable) loads. Using this data, a list of BMPs is provided below to the SCPF 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 capacity for the removal of nutrients. An examination and discussion of the water quality benefits of restoring and/or creating wetland buffers, riparian buffers, and pond front aquascape shorelines has also been performed. Where possible, based on inspections of the watershed or information contained in reports made available, we have also identified examples of site-specific locations where wetland buffers, riparian buffers, and pond front aquascaping could potentially be implemented as part of future watershed management efforts.

8.2 PROPOSED SITE RECOMMENDATIONS

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 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. Below please find a brief list of examples of such challenges:

    - **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, water 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's 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 cannot be 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.

CRANBERRY LAKE

SITE 1: TAMARACK PARK WESTERN PARKING LOT

Site 1, with an estimated drainage area of 15,500 square feet, is the parking area to the northwest of the soccer fields. The center island is a grass area that divides the western parking lot. There are a few light poles and trees in this area. Runoff from the parking lot western half of the parking lot flows into center island before flowing onto the soccer field.

Photo 8-1: The western parking lot at Tamarack Park (Recommendation 1A)

Recommendations

Recommendation 1A: Princeton Hydro recommends converting the ends of the island, approximately 2,550 square feet, into rain gardens and grading the center of the island to send runoff into the rain gardens. The rain gardens will increase stormwater infiltration and help remove pollutants from the parking lot runoff from migrating onto the soccer field.

Approximate Recommendation Costs

Cost Site 1A: The estimated cost for design, permitting and construction is anticipated to be between $130,000 and $160,000.

SITE 2: SWALE ALONG ROUTE 206

Site 2, with an estimated drainage area of 250,000 square feet, is an existing stormwater swale located on the northbound side of Route 206. This swale has an approximate length of 675 feet and runs, roughly, from N Shore Rd to Tamarack Rd. At the southern end of the swale, there is a storm drain that drains directly into Cranberry Lake via a culvert under Route 206.

Photo 8-2: Swale that runs alongside Route 206 N (Recommendation 2A)

Photo 8-3: The drainage from the swale across Route 206 (Recommendation 2B)

Recommendations

Recommendation 2A: Princeton Hydro recommends vegetating the swale with native plantings to both prevent erosion and enhance the filtration of stormwater. This would also provide additional ecological services for pollinators.

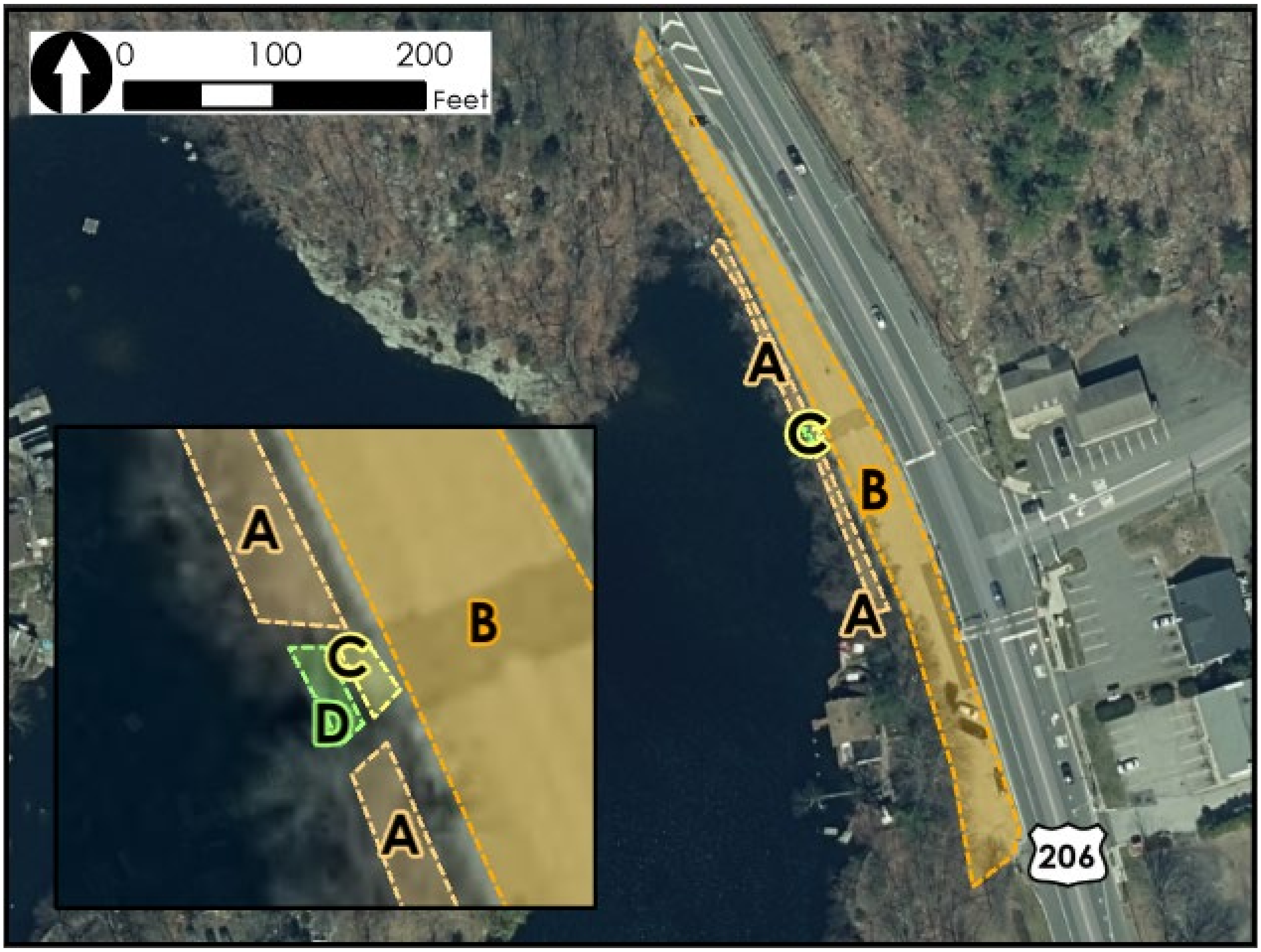
Recommendation 2B: Princeton Hydro recommends the installation of biochar bags at the outlet of the culvert to remove nutrients from the stormwater runoff.

Approximate Recommendation Costs

Cost Site 2A: The estimated cost for design, permitting and construction is anticipated to be between $180,000 and $220,000.

Cost Site 2B: The estimated cost for design, permitting and construction is anticipated to be between $2,000 and $4,000.

SITE 3: PARKING LOT ALONG ROUTE 206



Site 3, with an estimated drainage area of 30,000 square feet, is a large public parking lot on the southbound side of Route 206 located directly along the shoreline of Cranberry Lake. There are multiple drainage features, including catch basins and curbside storm drains located on Route 206. These drainage features receive stormwater from Route 206 and discharge directly into Cranberry Lake via a culvert. There were no stormwater inlets identified in the parking lot. There was sparse vegetation along the shoreline with stormwater ruts and areas of erosion were observed. There were also large amounts of gravel observed along the shoreline, indicating stormwater runoff.

Photo 8-5: An example of the rills created along the parking lot draining directly into the lake (Recommendation 3A)

Photo 8-4: A drainage pipe from a Route 206 storm drain into Cranberry Lake (Recommendation 3D)

Recommendations

Recommendation 3A: Princeton Hydro recommends to enhance the shoreline buffer with native vegetation. This will improve shoreline stabilization as well as filtration of stormwater prior to entering the lake.

Recommendation 3B: Princeton Hydro recommends to convert the 17,000 square foot parking lot with pervious pavement. This will reduce the volume of stormwater runoff discharging directly into the lake, enhance infiltration and improve the water quality of the runoff discharging into the lake. It will also reduce erosion along the shoreline of Cranberry Lake that stormwater drainage is currently causing.

Recommendation 3C: If the pervious pavement is not feasible, Princeton Hydro recommends the installation of manufactured treatment device(s) (MTD) with filter media in line with the existing subsurface stormwater system that is currently draining into the lake from Route 206, allowing for sediment and nutrient removal.

Recommendation 3D: The drainage pipe from 206 becomes exposed when the lake is lowered. During this time the stormwater runoff is creating a plunge pool in the lake substrate. Princeton Hydro recommends lining this area with riprap to reduce future localized erosion.

Approximate Recommendation Costs

Cost Site 3A: The estimated cost for design, permitting and construction is anticipated to be between $250,000 and $300,000.

Cost Site 3B: The estimated cost for design, permitting and construction is anticipated to be between $1,000,000 and $1,500,000.

Cost Site 3C: The estimated cost for design, permitting and construction is anticipated to be between $500,000 and $1,000,000.

Cost Site 3D: The estimated cost for design, permitting and construction is anticipated to be between $4,000 and $6,000.

SITE 4: CRANBERRY LAKE BOAT RAMP

Site 4, with an estimated drainage area of 700 square feet, the boat ramp located on the northeast side of Cranberry Lake. There is a walking path and road that leads directly to the ramp. There is visible erosion on the sides of the ramp caused by stormwater runoff from the road. The ramp itself seems to be degrading and many of the cinder blocks are misplaced and are slumping into the lake.

Photo 8-6: North side of the Cranberry Lake boat ramp (Recommendation 4A)

Photo 8-7: Cranberry Lake boat ramp (Recommendation 4A)

Recommendations

Recommendation 4A: Princeton Hydro recommends stabilizing the boat ramp by adding footer rocks at the toe of the ramp to hold the ramp in place and resetting the paver blocks. This should help reduce the erosion that is occurring due to the shifting of the cinder blocks during use.

Approximate Recommendation Costs

Cost Site 4A: The estimated cost for design, permitting and construction is anticipated to be between $30,000 and $50,000.

LAKE LACKAWANNA

SITE 5: SENECA LAKE BEACH

The Seneca Lake parking area is approximately 15,000 square feet and is located at the intersection of Mountain Heights Dr and Seneca Lake Rd at the southern end of the lake. There is an impervious entrance road and parking lot located between Seneca Lake Rd and the beach. There is a grass area that varies between approximately 15 – 25 ft in width located between Seneca Rd and the parking lot; the grade is relatively steep and slopes down towards the parking lot. The playground area is blocked off by wooded beams with visible erosion of the ground along the sides of them.

Photo 8-8: Parking area for Seneca Lake (Recommendation 5A)

Photo 8-9: The grass area between Seneca Rd and the paved roadway to the parking lot (Recommendation 5B)

Photo 8-10: Erosion along the northwest side of the playground located in the beach area (Recommendation 5C)

Photo 8-11: Common Reed (Phragmites australis) growing in the wetland by the outlet structure (Recommendation 5D)

Recommendations

Recommendation 5A: Princeton Hydro recommends replacing the 4,000 square foot parking area with pervious pavement to reduce surface runoff from flowing towards the playground, beach, and lake.

Recommendation 5B: Princeton Hydro recommends installing a 1,200 square foot rain garden in the area between the paved roadway and Seneca Lake Rd. This will help with erosion of the area and stormwater control from road runoff. It will also provide habitat, and signs can help inform the public on how rain gardens can help the watershed.

Recommendation 5C: Princeton Hydro recommends addressing the erosion on the northwest side of the playground. The implementation of a vegetative conveyance would help with erosion and stormwater control. The native plants would provide additional pollinator habitat and help filter stormwater prior to entering the lake.

Recommendation 5D: Princeton Hydro recommends treating the invasive phragmites in the forested wetland on the east side of the property. This can be supplemented with native plantings to increase available habitat.

Approximate Recommendation Costs

Cost Site 5A: The estimated cost for design, permitting and construction is anticipated to be between $300,000 and $400,000.

Cost Site 5B: The estimated cost for design, permitting and construction is anticipated to be between $60,000 and $100,000.

Cost Site 5C: The estimated cost for design, permitting and construction is anticipated to be between $6,000 and $10,000.

Cost Site 5D: The estimated cost for design, permitting and construction is anticipated to be between $2,000 and $5,000.

SITE 6: AMITY & SPARTA ROAD INTERSECTION

Site 6, with an estimated drainage area of 300,000 square feet, is located near the Amity and Sparta Rd intersection where an un-named tributary crosses under Sparta Rd on its way to a confluence Lubbers Run. This crossing consists of two (concrete) culverts, one of which is perched with numerous places where the concrete has broken. There is an erosion channel created by stormwater run-off from Sparta Rd that has eroded down to the existing road deck. Further erosion of this area could begin to undermine the road.

Photo 8-12: Upstream view of culverts that cross under Sparta Rd (Recommendation 6A)

Photo 8-13: Upstream view of culverts that cross under Sparta Rd (Recommendation 6A)

Photo 8-14: Rill draining into the un-named tributary that is eroding along Sparta Rd (Recommendation 6A)

Recommendations

Recommendation 6A: Princeton Hydro recommends replacing the broken culverts and to stabilize the erosion coming off Sparta Rd by adding rock along the erosion channel. Addressing the roadside erosion and replacing the culverts with pipe inverts on the stream bottom would protect the roadway and reduce sediment load entering the tributary.

Approximate Recommendation Costs

Recommendation Cost 6A: The estimated cost for design, permitting and construction is anticipated to be between $75,000 and $100,000.

SITE 7: SPARTA ROAD NEAR ASCOT LANE

Site 7, with an estimated drainage area of 90,000 square feet, consist of three retention basins that handle stormwater runoff from the development on Ascot Ln. Two basins flank the Ascot Ln/Sparta Rd intersection and discharge on the other side of Sparta Rd enroute to Lubbers Run. The third basin is roughly 700 feet north along Sparta Rd. and consists of the drainage basin and the crossing of an un-named tributary that runs, generally, south towards Lubbers Run. The drainage basin crosses under the driveway of 520-522 Sparta Rd before draining into the neighboring un-named tributary prior to crossing under Sparta Rd. The upstream portion of the HDPE crossing is encased in a headwall while the downstream portion is not. The tributary alignment flows into the road bank in lieu of the culvert itself and erosion can be seen on the road bank opposing the discharge point. Further, an overflow channel deviates from the main channel about 35 feet from the culvert. This overflow channel works its way back down Sparta Rd, in doing so there is a significant amount of erosion around power pole (BT 544 BM) and down into the culvert area. Debris wrack was noted along the banks in the vicinity of the culvert which may indicate water backing up in this region during storm events.

Photo 8-15: Southern retention basin at intersection of Ascot Ln and Sparta Rd (Recommendation 7A)

Photo 8-16: Northern retention basin at intersection of Ascot Ln and Sparta Rd (Recommendation 7A)

Photo 8-137: Drainage basin at the Ascot/Sparta Rd intersection (Recommendation 7A)

Photo 8-148: Active erosion around utility pole from stormwater runoff (Recommendation 7B)

Photo 8-19: Downstream section of culvert showing exposed HDPE pipe and potential for erosion along edge of the road (Recommendation 7B)

Photo 8-20: Misaligned channel and bank erosion along culvert headwall (Recommendation 7B)

Recommendations

Recommendation 7A: Princeton Hydro recommends performing invasive species management, reduce mowing or naturalize the drainage basin with native wildflowers in all three basins. Remove the concrete low-flow channel and replace with a rock lined channel to facilitate low flow infiltration. This would help reduce the amount of stormwater entering the tributary and associated pollutants.

Recommendation 7B: Princeton Hydro recommends realigning the current flow channels and stabilize erosion with bank grading and native plants. Raise the area along the downstream side of the culvert to match the road deck and stabilize with native vegetation.

Approximate Recommendation Costs

Recommendation Cost 7A: The estimated cost for design, permitting and construction is anticipated to be between $240,000 and $450,000.

Recommendation 7B: The estimated cost for design, permitting and construction is anticipated to be between $125,000 and $250,000.

SITE 8: LACKAWANNA DRIVE NEAR CROWN VEHICLE SALVAGE

Site 8, with an estimated drainage area of 60,000 square feet, is a culvert located along Lackawanna Drive where and un-named tributary crosses under the road in a southerly direction towards Lubbers Run. The crossing occurs just to the east of the Crown Vehicle Salvage driveway. There is large rirap lining the road/driveway bank that surrounds the concrete culvert. Some riprap is in the channel creating a restriction just prior to reaching the culvert. Further, stone from the adjacent driveway is being plowed toward the culvert and can be seen migrating towards the culvert opening.

Photo 8-21: View of driveway material being plowed into the drainage swale (Recommendation 8A)

Photo 8-22: The culvert is being partially blocked by the riprap and is becoming clogged with driveway material and plant matter (Recommendation 8A)

Recommendations

Recommendation 8A: Princeton Hydro recommends installing a riprap apron at the discharge end of the culvert and removing the driveway stone from the riprapped area. Disturbed areas should be stabilized and seeded with a native seed mix to displace the existing patch of invasive species.

Approximate Recommendation Costs

Recommendation Cost 8A: The estimated cost for design, permitting and construction is anticipated to be between $20,000 and $50,000.

SITE 9: BYRAM FIREHOUSE

Site 9, with an estimated drainage area of 8,500 square feet, is the driveway of the Byram Fire Department. The firehouse is located at the intersection of Lackawanna Dr and Roseville Rd. There is a 5,000 square foot, paved lot that is sloped towards the intersection, and stormwater drains to a catch basin in the parking lot and a series of curbside catch basins in the road. The pavement in the parking lot is in poor condition, with multiple potholes and loose gravel observed. Water was also observed pooling at the Lackawanna Dr entrance due to existing potholes and lack of proper drainage. Freeze thaw cycles are likely causing the existing pavement to degrade in this area.

Figure 8-23: Byram Fire Department Parking lot as seen from Roseville Rd (Recommendation 9A)

Photo 8-24: Byram Fire Department Parking lot looking north on Lackawanna Dr (Recommendation 9A)

Recommendations

Recommendation 9A: Princeton Hydro recommends replacing the current pavement in the parking lot with pervious pavement. This will fix the degraded state of the parking lot and provide localized infiltration to help reduce surface runoff while reducing pollutants from entering the lake. Pervious pavement will also help address water pooling at the Lackawanna Dr entrance.

Approximate Recommendation Costs

Cost Site 9A: The estimated cost for design, permitting and construction is anticipated to be between $320,000 and $450,000.

JOHNSON LAKE

SITE 10: SHORELINE ALONG TAMARACK ROAD

Site 10, with an estimated drainage area of 7,000 square feet, is located along the roadside of Johnson Lake along Tamarack Road just northeast of Old Indian Spring Road has sparce vegetation and was visibly eroded during the site visit. There is little room between the lake and Tamarack Road, and runoff from the road drains directly to the lake.

Photo 8-25: The shoreline of Johnson Lake along Tamarack Rd (Recommendation 10A)

Recommendations

Recommendation 10A: Princeton Hydro recommends planting this area is to add salt tolerant native plants to the 2,000 square foot shoreline between the roadway and lake. This will help decrease erosion, increase filtration of roadway runoff, and provide ecological services for pollinators.

Approximate Recommendation Costs

Recommendation Cost 10A: The estimated cost for design, permitting and construction is anticipated to be between $50,000 and $80,000.

WOLF LAKE

SITE 11: ROSEVILLE ROAD CROSSING

Site 11, with an estimated drainage area of 7,800 square feet, is an approximately 260-foot stretch of Roseville Rd that is lined with guide rails with a 20-foot-wide bridge crossing. Wolf lake spans Roseville Rd before being confined to a channel to the southeast that then drains into Lake Lackawanna. Active road deck erosion along the road margins is evidenced along both sides of the road. Scour erosion around guardrail supports was also observed. It was also noted the bridge has four (4) drain holes that allow stormwater to drain directly to the lake.

Photo 8-26: Erosion forming along the Roseville road base (Recommendation 11A)

Photo 8-27: Shows edge of road degrading from surface runoff and gravel washout (Recommendation 11A)

Photo 8-28: Scour hole is being formed along the guardrail support from stormwater runoff (Recommendation 11A)

Photo 8-29: Holes to drain road runoff directly into Wolf Lake
(Recommendation 11B)

Recommendations

Recommendation 11A: Princeton Hydro recommends raising the banks along roadside so they are set flush with the current road deck and stabilize the banks with native wildflowers. This vegetated filter strip, with an estimated total area of 1,600 square feet would help protect the road from being undermined and provide additional stormwater filtration.

Recommendation 11B: Princeton Hydro recommends plugging the four (4) drainage holes in the bridge. This would direct flow from the bridge and down the vegetated banks instead of draining directly into the lake.

Approximate Recommendation Costs

Recommendation Cost 11A: The estimated cost for design, permitting and construction is anticipated to be between $80,000 and $150,000.

Recommendation 11B: The estimated cost for design, permitting and construction is anticipated to be between $5,000 and $20,000.

LAKE LACKAWANNA

SITE 12: THE ALIBI BAR & GRILL

Site 12, with an estimated drainage area of 2,000 square feet, is the large parking lot outside of the Alibi Bar and Grill located on the south side of Lackawanna Dr. There are areas where water was visibly pooling in unpaved areas on the south side of the parking lot during the site visit. This area has a lot of uneven surfaces and road gravel build-up. Currently, the stormwater runoff flows over the parking lot and down a vegetated bank into the lake.

Photo 8-30: Southern parking lot of Alibi Bar & Grill (Recommendation 12A)

Photo 8-3115: The south end of the parking lot with excess road gravel and pooled water (Recommendation 12B)

Recommendations

Recommendation 12A: Princeton Hydro recommends converting the 16,000 square foot parking lot to pervious pavement. This will reduce runoff directly into the lake from the parking lot by increasing infiltration and reducing the amount of impervious service in the area.

Recommendation 12B: Princeton Hydro recommends installing a 1,000 square foot rain garden in the southern, gravel area of the parking lot. This area would filter stormwater, increase infiltration, and reduce the amount of pollutants flowing from the parking area toward the lake.

Approximate Recommendation Costs

Cost Site 12A: The estimated cost for design, permitting and construction is anticipated to be between $1,000,000 and $1,500,000.

Cost Site 12B: The estimated cost for design, permitting and construction is anticipated to be between $60,000 and $100,000.

SITE 13: LAKE LACKAWANNA DAM AREA

Site 13, with an estimated drainage area of 5,000 square feet, is a large mowed grass recreational area to the west of the dam. A rope fence has been installed on the shoreline of the lake to deter geese from the area. This area has been cleared of vegetation and mulched with wood chips.

Photo 8-32: The mulched shoreline of the recreational area near the Lackawanna dam (Recommendation 13A)

Recommendations

Recommendation 13A: Princeton Hydro recommends planting the 800 square feet mulched area along the shoreline with native meadow vegetation and shrubs with designated access paths as necessary. The plantings will help stabilize the shoreline, reducing erosion and allowing for the filtration of stormwater. Establishing a shoreline buffer should also deter geese from landing in the grass area.

Approximate Recommendation Costs

Cost Site 13A: The estimated cost for design, permitting and construction is anticipated to be between $10,000 and $20,000.

SITE 14: LAKE LACKAWANNA BOAT RAMP

Site 14, with an estimated drainage area of 7,000 square feet, is the boat launch area of Lake Lackawanna located on Richman Rd. In the winter this area is used to store boats and docks that are taken out of the lake. The gravel roadway is eroding, creating potholes and gravel wash into the lake.

Photo 8-33: The boat launch and associated grass area of Lake Lackawanna (Recommendation 14A-14B)

Recommendations

Recommendation 14A: Princeton Hydro recommends converting the 1,300 square foot boat ramp to pervious pavement. This will stop the gravel wash into the lake and help with filtration of stormwater prior to entering the lake.

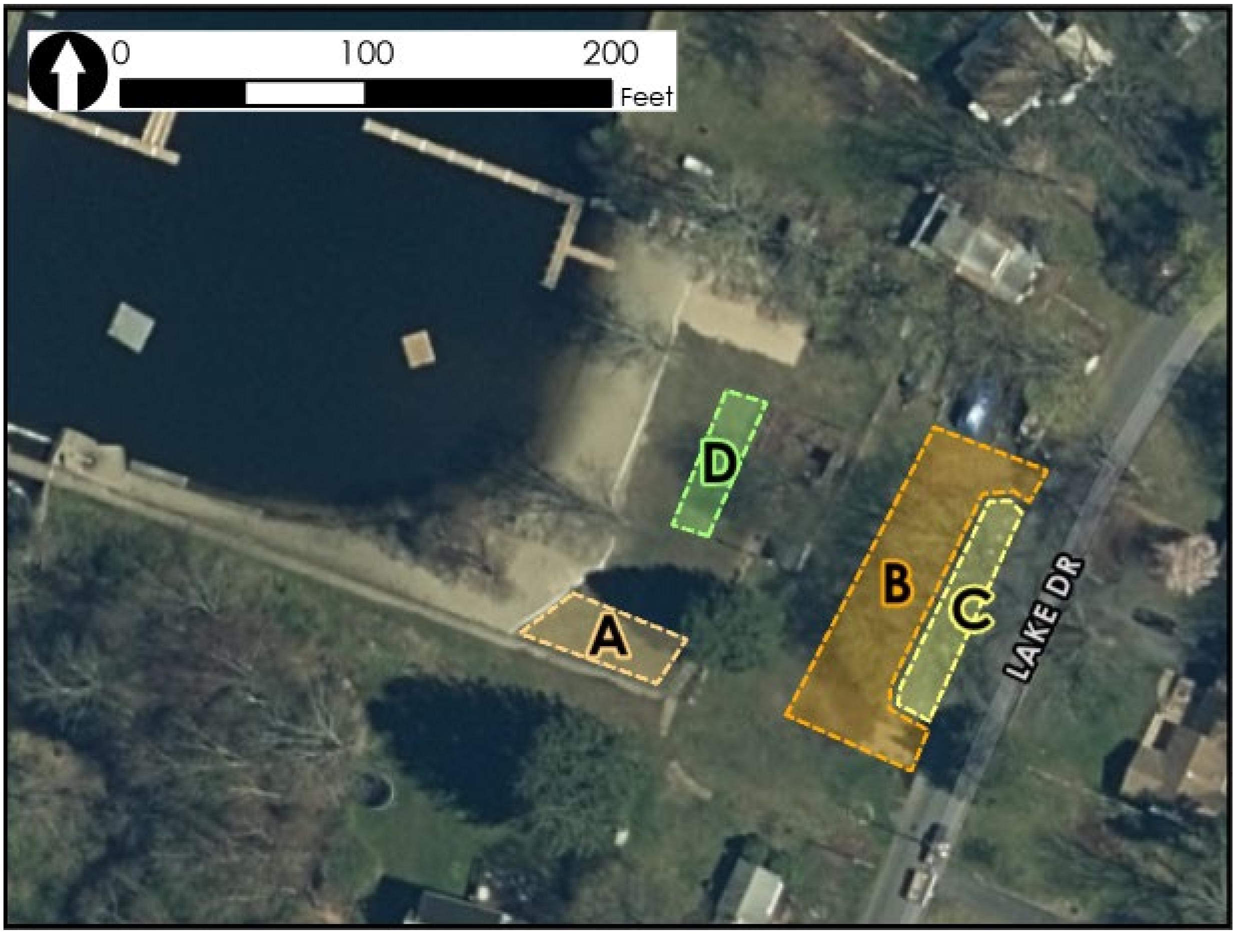
Recommendation 14B: Princeton Hydro recommends a 1,000 square foot no-mow zone on the west side of the boat ramp. Native plantings should also be put into place to provide filtration and habitat creation.

Approximate Recommendation Costs

Cost Site 14A: The estimated cost for design, permitting and construction is anticipated to be between $90,000 and $140,000.

Cost Site 14B: The estimated cost for design, permitting and construction is anticipated to be between $15,000 and $30,000.

SITE 15: LAKE LACKAWANNA BEACH



Site 15, with an estimated drainage area of 30,000 square feet, consists of the Lake Lackawanna beach and the associated parking lot are located just to the north of the intersection of Heminover St and Lake Dr. On the southeast side of the property, there is a poorly drained gravel parking lot with trees and large rocks lining the roadway. The gravel portion on the parking lot lacks sufficient stone, resulting in soil compaction. The paved portions have settled, causing pooling to occur. There is a small strip of grass and a chain link fence separating the parking area from a playground which is on the beach. The recreation area extends the width of the property and extends to the beach area which is approximately 6,800 square feet.

Photo 8-34: The beach from the dam of Lake (Recommendation 15A)

Photo 8-35: The parking lot outside of the Lackawanna beach (Recommendation 15B)

Photo 8-36: The area where the parking lot meets Lake Dr (Recommendation 15C)

Recommendations

Recommendation 15A: Princeton Hydro recommends reducing the amount of mowed grass in the areas leading to the beach and replace them with, approximately 1,000 square feet of vegetated buffers. The native vegetation will stabilize the soil, reduce erosion of the soil and the sand, and aid in filtration of the stormwater.

Recommendation 15B: Princeton Hydro recommends removing the paved area and replace the 6,500 square foot parking lot with pervious pavement. Doing so would address the pooling that is currently occurring in the lot and allow stormwater and pollutants to infiltrate into the substrate.

Recommendation 15C: Princeton Hydro recommends a 1,000 square foot bioretention system be added to the area dividing the road and gravel parking area. This would allow water coming off of the road to be directed and filtered causing less runoff into the parking lot.

Recommendation 15D: Princeton Hydro recommends installing a 1,000 square foot educational rain garden between the parking lot and beach area. This will improve drainage in the parking lot and provide an opportunity to inform the public about the importance of watershed management.

Approximate Recommendation Costs

Cost Site 15A: The estimated cost for design, permitting and construction is anticipated to be between $20,000 and $35,000.

Cost Site 15B: The estimated cost for design, permitting and construction is anticipated to be between $1,200,000 and $1,500,000.

Cost Site 15C: The estimated cost for design, permitting and construction is anticipated to be between $55,000 and $85,000.

Cost Site 15D: The estimated cost for design, permitting and construction is anticipated to be between $60,000 and $90,000.

SITE 16: LAKE LACKAWANNA GOLF COURSE

Site 16, with an estimated drainage area of 170,000 square feet, Is along the first hole of the Lake Lackawanna Golf course and is located along the fairway and behind the green. Along the fairway, there is water pooling on the fairway and in an adjacent drainage swale that runs along Reis Ave. Behind the 1st green, water is pooling instead of draining into a small pond to the west.

Photo 8-37: Standing water behind the 1st green on the Lackawanna golf course along Reis Ave (Recommendation 16A)

Photo 8-38: Standing water on the 1st fairway along Reis Ave(Recommendation 16B)

Recommendations

Recommendation 16A: Princeton Hydro recommends creating a 100 linear foot bioswale to drain water towards the south end of the site. This will help with course drainage as well as keep heavy nutrient loads flowing over more surface area before into the watershed.

Recommendation 16B: Princeton Hydro recommends converting the drainage swale along Reis Ave to a bioswale and rain garden. A 3,000 square foot rain garden in the low area with 200 linear feet of native vegetated swales to direct water into to the rain garden would allow the water coming from the golf course to infiltrate instead of pooling in this area.

Approximate Recommendation Costs

Cost Site 16A: The estimated cost for design, permitting and construction is anticipated to be between $7,000 and $12,000.

Cost Site 16B: The estimated cost for design, permitting and construction is anticipated to be between $175,000 and $240,000.

SITE 17: POND ALONG LAKE DR BY THE 3RD TEE

Site 17, with an estimated drainage area of 150,000 square feet, consists of two ponds on the southwest corner of the Lake Lackawanna golf course. The ponds collect runoff from the golf course before draining into Lake Lackawanna. Nutrient loading in these ponds is likely due to fertilizer inputs typically used on golf courses.

Photo 8-39: Pond near the 3rd tee that drains into Lake Lackawanna (Recommendation 17A)

Recommendation 17A: Princeton Hydro recommends installing biochar to help reduce nutrients from the golf course from entering the lake.

Approximate Recommendation Costs

Cost Site 17A: The estimated cost for design, permitting and construction is anticipated to be between $15,000 and $25,000.\

JEFFERSON LAKE

SITE 18: ROUTE 206 & S SHORE ROAD CONFLUENCE DEPRESSION

Site 18, with an estimated drainage area of 210,000 square feet, is comprised of a depression between Route 206 and S Shore Rd. Within this depression is the confluence of Ghost Pony Brook and two un-named tributaries that drain nearby wetland areas. Ghost Pony enters the depression via an adequately sized bridge crossing under 206 while the two un-named tributaries enter via concrete or steel culverts. The flow leaves the depression by way of a bridge crossing along S Shore Rd. This bridge crossing on S Shore Rd is showing signs of deterioration to its railing and support beams. There is also evidence of erosion occurring at abutments from flooding events.

Photo 8-40: Lawn area between S Shore Rd and Rt 206

Photo 8-41: 206 crossing of Ghost Pony Brook [Site Inlet] (Recommendation 18A)

Photo 8-42: Gravel bank by guardrail along 206 (Recommendation 18B)

Photo 8-43: S Shore Rd bridge crossing [Site Outlet] (Recommendation 18C)

Recommendations

Recommendation 18A: Princeton Hydro recommends the approximately 280 square foot area along 206 be converted into a vegetated filter strip. This area receives water directly from 206. A vegetated filter strip will help filter out trash and pollutants from the runoff before entering the tributary.

Recommendation 18B: Princeton Hydro recommends converting the area, roughly 2,300 square feet, of site 18 that is currently lawn into a no-now area or to native wildflower area while maintaining billboard access and roadway line of sight/sight triangle requirements. This would reduce maintenance costs, reduce and filter runoff from the road and provide ecological services for pollinators.

Recommendation 18C: Princeton Hydro recommends widening the opening while replacing the bridge. This would reduce backwater in this area during high flow events helping with localized flooding and will protect the roadway from overbank erosion.

Approximate Recommendation Costs

Recommendation Cost 18A: The estimated cost for design, permitting and construction is anticipated to be between $60,000 and $90,000 for the conversion to native wildflowers. It would also reduce the amount of maintenance required in at this site.

Recommendation Cost 18B: The estimated cost for design, permitting and construction is anticipated to be between $10,000 and $20,000.

Recommendation 18C: The estimated cost for design, permitting and construction is anticipated to be between $350,000 and $1,000,000.

SITE 19: CRANBERRY LAKE OUTFALL

Site 19, with an estimated drainage area of12,750,000 square feet, is the outfall of the Cranberry Lake dam. Cranberry Lake, and the associated wetland complex, ultimately, drains into Jefferson Lake. Downstream of the outlet structure, there is a small settling pond which filters sediment prior to discharging to the stream. There is a roadway on the east, downstream side of the impoundment with a small bridge that appeared to be in good condition. There is sparce vegetation along the outside of the pond, and the north end of the pond is lined with rock.

Photo 8-44: Cranberry Lake pond (Recommendation 19A)

Recommendations

Recommendation 19A: Princeton Hydro recommends converting the 16,000 square feet grassed area around the shoreline of the pond to native wildflowers to reduce maintenance, help with the filtration of stormwater, and increase the population of native flora.

Recommendation 19B: Princeton Hydro recommends adding biochar to the pond to remove nutrients before flowing downstream.

Approximate Recommendation Costs

Cost Site 19A: The estimated cost for design, permitting and construction is anticipated to be between $380,000 and $420,000.

Cost Site 19B: The estimated cost for design, permitting and construction is anticipated to be between $10,000 and $15,000.

SITE 20: ROUTE 206 (40.9465, -74.7307)

Site 20, with an estimated drainage area of 15,000 square feet, is located along Route 206 between Pierson Dr. and Sutton Ln. and involves the western side of Rt. 206 that runs along wetland complex that ultimately drains into Jefferson Lake. Looking south, the wetland complex side of the guide rail is lined with gravel and has two sections of riprap placed as erosion control.

Photo 8-45: Gravel bank along Route 206 south towards Sutton Ln (Recommendation 20A)

Photo 8-46: Storm run-off runs along the shoulder of Rt. 206 (Recommendation 20A)

Photo 8-47: Gravel bank along Route 206 south towards Sutton Ln (Recommendation 20A)

Photo 8-48: Storm runoff rills in front of guardrail toward wetland complex (Recommendation 20B)

Recommendations

Recommendation 20A: Princeton Hydro recommends the 150 linear foot length that runs from the riling seen in the above figures and extends up to a yellow diamond road ahead sign be converted into a bioswale to convey the storm run-off currently running along the shoulder. This would help reduce trash, runoff, and road pollutants from roughly 5,500 square feet drainage area from directly entering the wetland complex.

Recommendation 20B: Princeton Hydro recommends a 380 linear foot vegetated filter strip north of the guardrail along 206 S. This would help prevent localized erosion, filter road runoff, and provide ecological services for pollinators.

Approximate Recommendation Costs

Recommendation Cost 20A: The estimated cost for design, permitting and construction is anticipated to be between $75,000 and $120,000.

Recommendation Cost 20B: The estimated cost for design, permitting and construction is anticipated to be between $75,000 and $105,000.

SITE 21: ROUTE 206 (40.9470, -74.7310)

Site 21, with an estimated drainage area of 10,000 square feet, is just up the road from Site 20 and runs along the northbound side of Route 206. The northern extent of this site is at mile marker RT 206 N MILE 100.5. Rock armoring along the grassed area and a road patch that was likely necessary due to the concentrated flow that is seen between the shoulder and the lawn. The runoff then enters a storm grate and is sent under the road to the west toward the wetland complex.

Photo 8-49: Stormwater Runoff along Rt 206 North in front of Metro Self Storage (Recommendation 21A)

Photo 8-50: Stormwater Runoff along Rt 206 North in front of Metro Self Storage (Recommendation 21A)

Recommendations

Recommendation 21A: Princeton Hydro recommends shifting the flow path from along the road deck to a drainage swale that drains into the existing stormwater drain. It is further recommended that the swale be stabilized rock and/or native plants depending on the design constraints associated with slope and estimated flows during major storm events. Doing so will help filter out trash and roadway pollutants from the runoff before entering the storm grate.

Approximate Recommendation Costs
Recommendation Cost 21A: The estimated cost for design, permitting and construction is anticipated to be between $50,000 and $100,000.

SITE 22: JEFFERSON LAKE ROAD

Site 22, with an estimated drainage area of 6,500 square feet, occurs along Jefferson Lake Rd. from the outflow culverts, North, till the road turns to the Northwest. Along the upper extents of this reach there is a grass strip on the lake side of the guide rail and a swath of cattail (*Typha sp.*) that acts as a good buffer for road runoff. Traveling south along Jefferson Lake Rd. these buffers reduce to the point where there is erosion up to the road deck. A pair of concrete culverts act an overflow, that direct water from Jefferson Lake to Lubbers Run.

Photo 8-51: Area along Jefferson Lake Rd where a no-mow zone is recommended (Recommendation 22A)

Photo 8-52: Shore erosion around rusting guardrail posts (Recommendation 22B)

Photo 8-53: View of the overflow culverts looking toward Jefferson Lake. The inset is an overhead view of the hole in the road deck that drains into the culvert on the left (Recommendation 22C)

Recommendations

Recommendation 22A: Princeton Hydro recommends converting the grass area before the guardrail to native plant community. In addition to reduced maintenance costs, vegetation that is allowed to grow increases runoff infiltration and trash filtration from the road. A less intensive option would be to treat the grassed area as no-mow zone

Recommendation 22B: Princeton Hydro recommends building up the shore along Jefferson Lake Rd along a, roughly, 350-foot section. This section runs from the parking lot to the south and where the road bends to the left towards the camp. Lake erosion along this stretch is beginning to erode around the guardrail posts, which themselves, are oxidizing and rusting through in some places. The shore expansion should attempt to retain the existing native woody species present and be stabilized with an appropriate native seed mix.

Recommendation 22C: A hole has formed in the road deck that leads directly into one of the overflow culverts as well as the top of the culvert itself. The holes should be patched, and the culverts secured as part of the shore expansion in recommendation 1B.

Approximate Recommendation Costs

Recommendation Cost 22A: The estimated cost for design, permitting and construction is anticipated to be between $10,000 and $20,000. Adopting a no-mow only approach for this area would result in savings on the costs associated with maintaining this area.

Recommendation Cost 22B: The estimated cost for design, permitting and construction is anticipated to be between $100,000 and $200,000 depending on the extents of regrading and shore stabilization needed.

Recommendation Cost 22C: The estimated cost for patching the road and culvert is anticipated to be between $1,000 and $3,000.

SITE 23: JEFFERSON LAKE BOAT LAUNCH

Site 23, with an estimated drainage area of 13,000 square feet, is a roughly 6,500 square foot paved parking lot at the Jefferson Lake boat launch located along Jefferson Lake Road on the eastern side of the lake. There is a paved boat ramp that connects to the parking lot and leads directly to the lake; the boat launch is in poor condition and is eroding into the lake. There are forested areas on either side of the parking lot with a few dead trees located near the lake. There is erosion along the shoreline on both sides of the boat ramp.

Photo 8-54: Jefferson Lake Boat Launce (Recommendation 23A)

Photo 16: Existing snag and erosion along the Jefferson Lake boat launch (Recommendation 23A

Recommendations

Recommendation 23A: Princeton Hydro recommends repaving the parking lot and boat ramp wither pervious pavement to reduce the erosion that is occurring and increase infiltration of parking lot runoff before entering the lake. This should be supplemented with shoreline buffer enhancement to allow proper shoreline stabilization and filtration.

Approximate Recommendation Costs

Cost Site 23A: The estimated cost for design, permitting and construction is anticipated to be between $460,000 and $560,000.

KOFFERLS POND

SITE 24: KOFFERLS POND CROSSING AMITY ROAD

Site 24, with an estimated drainage area of 50,000 square feet, is an un-named tributary of Kofferls Pond that crosses under Amity Rd near the 330 Amity Rd driveway. The area on the south side of Amity Rd, the residential side, is lined with riprap that is good condition while the north, pond side, has an abundance or reedy and woody vegetation. The culvert itself, however, is nearly clogged with gravel.

Photo 8-17: Downstream side of culvert (Recommendation 24A)

Photo 8-18: Upstream side of culvert (Recommendation 24A)

Photo 8-19: Downstream side of culvert (Recommendation 24A)

Recommendations

Recommendation 24A: Princeton Hydro recommends cleaning out the culvert and surrounding area. If disturbance is created re-seed with native seed or plants. This will reduce standing water, which provides habitat for mosquito larvae and allow for aquatic organisms to migrate downstream. Adding native plants will benefit pollinators and enhance the native seed bank.

Approximate Recommendation Costs

Recommendation Cost 24A: The estimated cost for is anticipated to be between $2,000 and $10,000.

8.3 REGULATORY EVALUATION

The recommendations above are varied in type and location. Some of them, depending on the proposed activities will require permits and approvals from the State of New Jersey or the county. Below is a discussion of the expected site studies (e.g., Wetland Delineations, Flood Hazard Verifications), permits (e.g., Freshwater Wetlands), and approvals that may be required for some of the proposed projects. Following the descriptions is a table that summarizes the anticipated requirements for each of the project categories recommended above. Please note that the permits and approvals are only required when a proposed activity would disturb or impact the regulated resource (e.g., replacing an inlet or stabilizing a stream bank). Therefore, the requirement to obtain a permit (or approval) is heavily dependent on the existing site conditions and how the proposed activity is installed or constructed. Without site-specific investigation and conceptual designs, at minimum, this evaluation can only be generic in nature.

WETLAND DELINEATION

The proposed projects may require a delineation of the Project Areas' freshwater wetlands and State open waters in accordance with the Federal Manual for Identifying and Delineating Jurisdictional Wetlands of 1989 and the Regional Supplement to the Corps of Engineers Wetland Delineation Manual: Northcentral and Northeast Region (Version 2.0). Wetland delineations are based on an examination of the vegetation, soils, and hydrology found on the site. State open Waters are delineated by the ordinary highwater mark. The wetlands and State open waters would be identified by sequentially numbered, colored survey flagging. Subsequent to the delineation, a professional land surveyor licensed in New Jersey would need to survey the boundary flags in support of a wetland delineation plan (described below). In support of a Letter of Interpretation – Line Verification (see below), all requisite data related to the required soil borings, plant inventory, and site hydrology would be collected during this effort and incorporated into the Letter of Interpretation – Line Verification application submitted to the New Jersey Department of Environmental Protection (NJDEP) Division of Land Resource Protection (DLRP) to request its concurrence on the boundaries delineated herein.

NJDEP LETTER OF INTERPRETATION – LINE VERIFICATION APPLICATION

A Letter of Interpretation (LOI)- Line Verification in compliance with N.J.A.C. 7:7A-4.5 may be required for the proposed projects. The LOI is a process through which an applicant requests that the NJDEP DLRP review a wetland delineation and concur with the delineated boundaries of freshwater wetlands and State open waters on the site. The submittal includes an application, site mapping (e.g., USGS, Aerial, Soils, mapped wetlands), a database search for threatened and endangered species, a wetland delineation report, a photograph log and map, and a wetland delineation map signed by a professional land surveyor licensed in New Jersey. While never required, an LOI may be a good option if the project proponent does not intend to complete a project immediately because an approved LOI is valid for up to five years and can be renewed.

Fee: $1,000 plus $100 per acre or fraction thereof associated with the block(s), lot(s), or project area that are the subject of the LOI application.

RECORDING VERIFICATION WITH THE COUNTY CLERK AND NJDEP

Subsequent to receipt of the LOI, the NJDEP DLRP requires that all LOIs be recorded with the county in which the LOI was issued. The recording must include the approval and expiration date of the LOI; a metes and bounds description of the wetland boundary approved under the LOI (prepared by the surveyor); the width and location of any transition area approved under the LOI; and the following statement: "The State of New Jersey has determined that all or a portion of this lot lies in a freshwater wetland and/or transition area. Certain activities in wetlands and transition areas are regulated by the New Jersey Department of Environmental Protection and some activities may be prohibited on this Site or may first require a freshwater wetland permit. Contact the DLRP at (609) 777-0454 or http://www.nj.gov/dep/landuse for more information prior to any construction onsite."

Recording Fee: $45 first sheet, $10 each additional sheet.

FLOOD HAZARD AREA VERIFICATION

A Flood Hazard Area (FHA) Verification, in compliance with N.J.A.C 7:13-5, may be required for the proposed projects, dependent on existing FEMA and state flood studies. The verification provides the NJDEP DLRP official determination of the extent of the flood hazard areas (i.e., floodway and flood fringe) and design flood elevation, and riparian zone limits. The submittal includes an application form, site mapping (e.g., USGS, Aerial, Soils), an engineering report, a photographic log and map, a database search for threatened and endangered species, and a Flood Hazard Area Verification Plan that represents the extent of the proposed flood hazard area (floodway, flood fringe,) and riparian zone. This plan would also include a metes and bounds description of the proposed flood hazard area and is required to be signed by a professional engineer licensed in the state of New Jersey. An approved FHA verification is valid for up to five years.

Fee: Dependent on FEMA and state flood studies.

RECORDING VERIFICATION WITH THE COUNTY CLERK AND NJDEP

After receipt of an approved flood hazard verification, the NJDEP-DLRP requires that all verifications be recorded with the County in which the verification was issued. The recording must include the following information : (1) the NJDEP file number for the verification; (2) the approval and expiration dates of the verification; (3) a metes and bounds description of any flood hazard area limit and/or floodway limit approved under the verification; (4) the flood hazard area design flood elevation approved under the verification; (5) the width and location of any riparian zone approved under the verification; and (6) the statement described at N.J.A.C. 7:13-5.6(a)6.

Fee: $45 first sheet, and $10 for each additional sheet.

PRE-APPLICATION MEETING

Before the submission of the required applications (described below) pre-application meeting(s) with the NJDEP-DLRP is recommended. The purpose of the meeting would be to introduce the proposed project to the agencies along with the anticipated permitting pathway to seek (1) their initial comments on the proposed project, and (2) get agency buy-in on the proposed permitting pathway. This offers the presiding agencies and design team the opportunity to clarify potential design conflicts as they relate to the required permit approvals and to identify any potential concerns related to the issuance of the requisite permits to implement the proposed project. It is also an opportunity for the agencies to provide recommendations related to streamlining the review process based on the proposed design.

Fee: No fee

HIGHLANDS WATER PROTECTION AND PLANNING ACT

The Highlands Water Protection and Planning Act and its implementing rules found at N.J.A.C. 7:38, identify the Highlands as an essential source of drinking water for half of the residents of New Jersey. Byram Township is primarily located within the Highlands Preservation, with a small portion near Byram Center, located within the Planning Area. If any of the proposed projects are a major Highlands development in the preservation area, it must first obtain a Highlands Preservation Area Approval (HPAA) or a Highlands Applicability Determination (HAD) for an exemption determination. Major Highlands Developments are defined in N.J.A.C. 7:38-1.4 and include, but are not limited to, the disturbance of one acre or more of land or a cumulative increase in impervious surface by one-quarter acre or more; any activity in the preservation area, that results in the disturbance of one-quarter acre or more of forested areas; any capital or other project of a State or local government unit, in the preservation area, that requires an environmental land use or water permit or that results in the disturbance or one acre or more of land or a cumulative increase in impervious surface by one-quarter acre or more.

FRESHWATER WETLANDS PROTECTION ACT

Freshwater wetlands, their associated transition areas, and State open waters are regulated under the Freshwater Wetlands Protection Act and its implementing rules in N.J.A.C. 7:7A. Further, all waterbodies and wetlands within the Highlands Preservation and Planning Area are considered "Highlands open waters" as defined in N.J.A.C. 7:38-1.4. The distinguishing factor is that all wetlands, springs, streams (perennial and intermittent), and bodies of surface water (natural or artificial) have a 300-foot buffer adjacent to their upland boundaries per N.J.A.C. 7:38-3.6. Any project that would disturb Highlands open waters or the 300-foot buffer would require review and authorization under the Freshwater Wetlands Protection Act or one of the two Highlands General Permits; General Permit 1 – Habitat Creation and Enhancement Activities or General Permit 2 – Bank Stabilization.

RECORDING VERIFICATION WITH THE COUNTY CLERK AND NJDEP

After receipt of an approved freshwater wetlands permit, the NJDEP-DLRP requires that all permits be recorded with the County in which the verification was issued. The recording must include the following information : (1) the NJDEP file number for the permit; (2) the approval and expiration dates of the permit; (3) a metes and bounds description of any flood hazard area limit and/or floodway limit approved under the verification; (4) the flood hazard area design flood elevation approved under the verification; (5) the width and location of any riparian zone approved under the verification; and (6) the statement described at N.J.A.C. 7:13-5.6(a)6.

Fee: $45 for the first sheet and $10 for each additional sheet.

RARE, THREATENED, AND ENDANGERED SPECIES & HABITAT (NHP)

Some of the proposed projects would require an evaluation of the potential effects on rare, threatened, and endangered species and their habitats. The first step is a data request sent to the NJDEP Natural Heritage Program (NHP). The request is a single-page form and requires a site map (USGS topographic map). The review time is 30 days, and the fee is $70. In return, the NHP will provide a list of species observed on-Site and in the vicinity. It is then the responsibility of the applicant to determine the effects of the project on the identified species and their habitats. NJDEP biologists in the Threatened and Endangered Species unit then review the assessment and either accept the determinations or provide comments and recommendations on the proposed activities.

CLEAN WATER ACT SECTION 401 WATER QUALITY CERTIFICATION

Under the CWA, states have the authority to grant, deny, or waive certification of proposed federal licenses or permits that may discharge into or fill waters of the United States and/or navigable waters. As such, during the federal permitting process listed above, the state of New Jersey will also review the project and determine if it is consistent with Section 401 of the Federal Clean Water Act in accordance with N.J.A.C. 7:7A and the Surface Water Quality Standards provided in N.J.A.C. 7:9B. The NJDEP DLRP would conduct this review during the Freshwater Wetlands Protection Ac Permit process described above.

Fee: No fee.

FLOOD HAZARD AREA CONTROL ACT PERMIT

The New Jersey Flood Hazard Area Control Act, N.J.S.A. 58:16A-50 et seq. are implemented via the Flood Hazard Area (FHA) Control Act Rules at N.J.A.C 7:13. The proposed projects may require approval(s) under these rules for proposed disturbance to the floodway, flood fringe and riparian zone of regulated waters, as define in N.J.A.C 7:13-1.2.

The NJDEP DLRP has several permit pathways, including permits-by-rule, permits-by-certification, general permits, and individual permits. It is recommended that the specific permitting pathway be discussed and agreed upon with DLRP, via a pre-application meeting, before the preparation and submission of any permit application.

Fee: The permit fees are dependent on the activities proposed and the subsequent permit pathways.

SOIL EROSION AND SEDIMENT CONTROL PLAN CERTIFICATION

The New Jersey Soil Erosion and Sediment Control Act (N.J.S.A. 4:24-39 et seq.) stipulates that any project that proposes 5,000 square feet of land disturbance or greater requires certification from the presiding Soil Conservation District. This certification includes a review of the proposed earth disturbance activities and proposed Erosion and Sediment Control Best Management Practice (ESC-BMP) measures to be implemented to minimize erosion and the associated potential for pollution to water resources to the maximum extent practicable. The implementation and maintenance of ESC-BMPs are required to minimize the potential for accelerated erosion and sedimentation. Some of the proposed projects may exceed 5,000 square feet of earth disturbance and are proximate to waterbodies. Therefore, approval from the Somerset Union Soil Conservation District (SUSCD) may be required.

The required submission would include a completed SUSCD application form and checklist, a completed requisite plan set, and a project drainage report supporting stability and erosion control calculations.

Fee: Fees are dependent on disturbance. Please refer to the fee schedule here: https://www.co.somerset.nj.us/home/showpublisheddocument/50576/638222650773330000

NEW JERSEY POLLUTION DISCHARGE ELIMINATION SYSTEM (NJPDES) PERMITS

5G3-CONSTRUCTION ACTIVITY

Certain construction activities that disturb greater than one acre of land within New Jersey require a 5G3-Construction Activity Stormwater approval from NJDEP. Examples of earth disturbance activities include but are not limited to, commercial and residential development, timber harvesting, utility line installation, and road maintenance and drainage improvements. If any of the projects exceed the one-acre of earth disturbance threshold, it would trigger the requirement to procure this approval.

Fee: Projects with an area of disturbance of less than five (5) acres require a $450 dollar fee. Projects with an area of disturbance greater than or equal to five (5) acres require a $650 fee.

LOCAL AND OTHER PERMITS

Discussed above, are permits and approvals that are required under state laws. However, some additional permits and approvals may be required on a case-by-case basis for the proposed projects. We recommend that an assessment of other required permits and approvals be conducted before commencing design on any of these projects. For instance, the township, Somerset County, and the New Jersey Department of Transportation have ownership and rights for the roads and rights-of-way they maintain. Activities that will obstruct or require "opening" the roadway would require a road opening or encroachment permit from the roadway owner.

Activity	Wetland Delineation	Letter of Interpretation	Flood Hazard Area Verification	Pre-Application Meeting	Highlands Preservation Area Approval/Highlands Applicability Determination	Freshwater Wetlands Protection Act Permit	Rare, Threatened, and Endangered Species & Habitat Evaluation	CWA Section 401 Certification	Flood Hazard Area Control Act Permit	Soil Erosion and Sediment Control Plan Certification	NJDPES 5G-3 Permit	Other Permits and Approvals
Watershed Based Activities												
Native Vegetation Plantings (Stream Bank/Riparian Zone or Lake Shorelines)	Recommended	Not Needed	Site-Dependent	Not Needed	Not Needed	Project/Site Dependent	Site Dependent	Project/Site Dependent	Site Dependent	Not Needed	Not Needed	Site-Dependent
Rain Gardens, vegetated swales & Bio-retention Systems	Site-Dependent	As needed	Site-Dependent	Case-by-Case	HAD minimum	Site Dependent	Site Dependent	Site Dependent	Site Dependent	Site Dependent	Site Dependent	Not Needed
Gradient creation (minor grading)	Site-Dependent	As needed	Site-Dependent	Case-by-Case	HAD minimum	Site Dependent	Site Dependent	Site Dependent	Site Dependent	Site Dependent	Site Dependent	Not Needed
Porous Pavement	Site-Dependent	Not Needed	Site-Dependent	Not needed	Not Needed	Site Dependent1	Site Dependent	Site Dependent	Not Needed[2]	Site Dependent	Site Dependent	Site-Dependent
Terrestrial Invasive Species Management	Site-Dependent (but recommended)	Not Needed	Site-Dependent (but unlikely)	Not needed	HAD recommended	Site Dependent[3]	Site Dependent	Site Dependent	Site Dependent[4]	Site Dependent (but unlikely)	Site Dependent (but unlikely)	Site-Dependent (but unlikely)
No mow zones	Not Needed	Not Needed	Not Needed	Not needed	Not Needed	Not Needed	Not Needed	Not Needed	Not Needed	Not Needed	Not Needed	Not Needed
Installation of Manufactured Treatment Device or catch basin inserts	Site-Dependent (but recommended)	Not Needed	Site-Dependent	Case-by-Case	HAD recommended	Site Dependent	Site Dependent	Site Dependent	Site Dependent	Site Dependent (but unlikely)	Site Dependent (but unlikely)	Site-Dependent
Beaver lodge management	Recommended	Not Needed	Site-Dependent	Recommended	HAD recommended	Required	Required	Required	Site Dependent	Site Dependent (but unlikely)	Site Dependent (but unlikely)	Site-Dependent
Boat ramp repairs	Required	Recommended	Not Needed	Recommended	HAD minimum	Required	Required	Required	Required[5]	Site Dependent	Site Dependent (but unlikely)	Site Dependent
Biochar	Not Needed	Not Needed	Not Needed	Recommended	HAD recommended	Site Dependent	Site Dependent	Site Dependent	Site Dependent	Not needed	Not needed	Site-Dependent (but unlikely)

[1] A Freshwater wetlands Permit is required if repaving is located within a transition area. General permit 26 (NJAC 7:7A-7.26) maybe applicable if the conditions are met.

[2] A Flood Hazard Area permit is required if the work is located within the Flood Hazard Aras. Permits by rule 1-3 (NJAC 7:13-7.1-7.3) may apply if the conditions are met.

[3] A Freshwater Wetlands Permit is required if pesticide is applied in wetlands or transition areas. General Permit 27 (NJAC 7:7A-7.27) maybe applicable if the conditions are met.

[4] A Flood Hazard Area permit is required if the treatment is located within a riparian zone. Permit-by-rule 14 (NJAC 7:13-9.14) may apply if the conditions can be met.

[5] A Flood Hazard Area permit is required, but Permit-by-Rule 18 can be used provided the conditions at NJAC 7:13-6.7 are met.

9.0 CONCLUSIONS AND RECOMMENDATIONS

9.1 GENERAL IN-LAKE 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.

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.

DREDGING

Dredging is an effective, but expensive, lake management technique. Dredging involves the removal of accumulated unconsolidated sediments from the bottom of a pond. 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 now include, at a minimum, an updated bathymetric assessment and NJDEP required sediment sampling.

Dredging has multiple benefits, including water deepening, nutrient control (removal), potential toxic substance removal, and rooted macrophyte control. Sediment removal directly results in the deepening of a pond and provides nutrient control through the removal of phosphorus-rich sediment, which can otherwise cause internal phosphorus loading in ponds 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.

However, until the sources of a lake's sediment infilling are corrected, removing the currently accumulated sediments will have a general short-lived positive impact. From a regulatory perspective, at best it may be possible to accomplish the removal of any deltas that have formed in the vicinity of the tributary and storm water outfalls under a Freshwater Wetlands (NJAC 7:7A) General Permit #10 and one of the Flood Hazard Area (NJAC 7:13) General Permits. More than likely though the dredging will require the issuance of a Freshwater Wetland GP#13 along with the appropriate Flood Hazard Area General Permit. In addition, any maintenance dredging within 200 feet of a dam will require a letter of approval by the NJDEP Department of Dam Safety. Local permitting will include a Soil Conservation District approved Erosion and Sediment Plan. It will be necessary to collect a specific sediment sample from the areas in which dredging is anticipated and test these sediments in accordance with NJDEP sediment sampling and analysis plan requirements. This typically entails the measurement of the contaminants analyzed by means of the NJDEP-Site Remediation Standards list testing (which includes among other contaminants heavy metals, pesticides, and petroleum hydrocarbons). The physical composition of the sediments must also be analyzed. This constitutes the measurement of grain size, organic content and moisture content. Overall, the permit application process (which encompasses engineering data and the aforementioned chemical testing) may cost much as $50,000-$75,000. As noted above, if the specific dredged material are free of contaminants and of the proper consistency it is possible that they could be disposed of nearby. However, in planning for any dredging a lake community should assume the material will need to be hauled offsite. As such, the per cubic yard cost to dredge, remove and dispose of a lake's sediment will be in the range of $200 to $250.

In conclusion, it should be emphasized that the dredging of lakes are not an "all or none" scenario. Although expensive, the projects typically measurably improve the condition of the portions of the lake dredged. However, until the overall watershed based sources of sediment loading are managed and controlled we do not recommend that portions of the lakes be dredged. It should also be noted that based upon the public status of some of the lakes, the possibility of obtaining public funding for dredging, be it the form of a grant or a loan, is now possible given NJDEP funding that became available starting in 2022.

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 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.

ANNUAL WATER QUALITY MONITORING

Princeton Hydro strongly recommends the establishment of an annual water quality monitoring program for each lake. This not only allows for the establishment of long-term trends but allows lake managers to assess the progress and effectiveness 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 2023, with at least three events occurring over the course of a year, more if possible, 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.

9.2 SPECIFIC IN-LAKE RECOMMENDATIONS

CRANBERRY LAKE

Vegetation Management – Cranberry Lake 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, Cranberry Lake may wish to manage this vegetation in the areas most frequently used by those for recreation. 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 size of the lake 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, and a subsequent Management Plan, may also be desirable in order to develop long-term management goals and strategies.

Chemical Control of Aquatic Vegetation - Moderate-to-dense amounts of the native aquatic vegetation species yellow pond lilies, watershield, and white water lilies are present in the southern basin of Cranberry Lake. The invasive species Eurasian watermilfoil and curlyleaf pondweed were also observed in some areas of the waterbody; these have a potential to create dense, problematic beds during some years. The native bigleaf pondweed also has this potential. A number of aquatic plant control management techniques can be utilized as part of a lake management plan. The most frequently implemented technique involves the application of contact herbicides. The contact herbicides impact plant growth by destroying the plant's cell structure upon contact; essentially "burning" the plant tissue.

Contact aquatic herbicides provide immediate, short-term relief or control of excessive densities of a nuisance plant(s). Thus, the primary advantages of contact herbicides include their fairly immediate (days to weeks) reduction in nuisance plant densities and their relatively lower product costs. The disadvantages of using contact herbicides include potential impacts on non-target organisms, a depletion of DO concentrations as a result of bacterial decomposition of the dead plant material and the recycling of nutrients back into the water column that would otherwise be bound in plant biomass. For example, algal blooms frequently occur immediately after the application of contact herbicides (due to increased nutrient recycling).

Other potentially negative impacts associated with contact herbicides include the non-discriminate impacts on both nuisance and favorable (i.e. native) aquatic plants and the possible destruction of fish habitat. In addition, more than one treatment of the contact herbicides may be required to achieve the desirable level of control through the entire growing season. Depending on local climatic conditions and the nuisance species targeted for control, between two to four treatments may be required through the course of one growing season. However, given the difficulty in controlling yellow pond lilies and white water lilies, as well as the extensive root systems they possess, we do not recommend a contact herbicide treatment program at this time for these species. The only effective means of controlling these species is through the dredging of the pond and/or the selective removal of the plant and root systems through other mechanical techniques which will be discussed below. Furthermore, while these plants may be a nuisance when growing in front of lakeshore owners' properties, they appear to largely be occurring in the farther southern areas of the lake where they should not pose a large nuisance to boaters.

Treatment of the invasive species Eurasian watermilfoil and curlyleaf pondweed in Cranberry Lake may be warranted in some years if these species grow to nuisance levels, particularly if they begin out-competing native species. Eurasian watermilfoil may be treated with the SePRO® product ProcellaCOR®, a selective herbicide that provides selective, long-term control of milfoil species at low doses. SePRO's® product Sonar® (Fluoridone) can also be used to treat both species. Both of these products are systemic herbicides, meaning that the herbicide works by remaining in the water column and/or bottom sediments over a period of time and is incorporated by the targeted plant species, disrupting growth. While these are potential solutions for both of these invasive species, it is recommended that Cranberry Lake receives an updated aquatic plant survey in order to better assess the current densities and distributions of these species and to ascertain the potential presence of state-listed rare or endangered species that would need to be considered when treating. It is also recommended at this time that any chemical treatment of nuisance vegetation in Cranberry Lake be limited to spot-treatments of smaller prioritized areas.

Hydroraking - As described above, Cranberry Lake features moderate-to-dense populations of floating vegetation species in the southern basin. Given the recreational usage of the lake and the benefit of allowing some of these native species to continue growing, limited mechanical hydroraking may be an ecologically sound method of controlling nuisance plant densities. One consistent advantage mechanical hydroraking has over other management techniques, such as the application of herbicides, is that phosphorus is removed from the pond along with the plant biomass. It may also selectively be used in prioritized areas of high boat traffic.

A program at the lake, while presenting some challenges, is feasible. The boat launch near the lake's dam provides adequate access to trailer-mounted vehicles such as hydrorakes, however this is at least 3,000 ft from the area of dense floating vegetation growth, adding to the time required for the operation. A strategic disposal location along a nearby shoreline would need to be established; given the private nature of much of the surrounding shorelines, this may present a challenge.

Based on aerial imagery, the area of potentially problematic floating vegetation growth in the southern portion of cranberry lake is over 45 acres. Given that a hydrorake will remove aquatic vegetation from a waterbody at the rate of approximately 0.1 - 0.2 acres per day, complete removal would be expensive and not feasible. A more cost-effective option would likely be to limit hydroraking to smaller prioritized areas such as areas of boat traffic or swimming areas.

An element that makes hydroraking particularly effective is that the hydrorake removes submerged aquatic vegetation from the roots, allowing for total removal and more effective control. Removed aquatic vegetation is then placed onto the shoreline for disposal. It is interesting to note that removed aquatic vegetation can be placed with compost piles, and therefore may be attractive to any local agricultural or nursery operations, thereby reducing disposal costs. Hydroraking operations can typically cost up to $3,000.00 per day hydroraked. Another factor to consider in these costs is the required NJDEP permits and the disposal of the hydroraked material, which are NOT included in the $3,000.00/day estimate.

The costs of mechanical hydroraking are significantly higher than any chemical control. Given the size of the area of floating vegetation, it is anticipated that the costs of such a program may be notably large when compared to chemical treatment program costs. In addition, the necessary NJDEP permits and disposal costs of the harvested plants would need to be added. The benefit, as stated previously, with the mechanical hydroraking of these plants is a reduction in total phosphorus loading. Although it will never be possible to remove all of this phosphorus from the lake via hydroraking, chemical treatments only put this phosphorus back into the water column, making the released phosphorus once again available for assimilation by other plants and algae. It is recommended that consideration be given to the use of hydroraking should an alternative to herbicide treatments be desired. Hydroraking operations could be conducted in different targeted select locations annually, either as a means of removing rooted floating aquatic plants such as the waterlily or removing the accumulated organic material that supports both filamentous algae and aquatic plant growth.

There are a number of logistic issues that need to be taken into consideration before implementing any hydroraking operation in Cranberry Lake. These issues include the necessary NJDEP permits, disposal of the hydroraking spoils, annual budgeting, program expectations and contractor selection via bid.

Expanded Sampling in Southern Basin – As mentioned in the general recommendations section, Cranberry Lake would likely benefit from a continued water quality management program. Based on observations and measurements collected during the 2023 season, it appears that the northern basin (from which surface and deep samples were collected) and the southern basin may behave somewhat differently from one another. In particular, the southern basin, while being the shallower of the two, appears to have the larger proclivity for featuring anoxic conditions at the bottom of the water column. As such, it is recommended that future water quality programs collect additional discrete water quality samples at the surface and bottom of the water column in this area. These should at the least be analyzed for total phosphorus in order to assess the potential for internal phosphorus loading in the southern portion of the waterbody.

Septic System Assessment – As mentioned in the general recommendations section, septic systems in a waterbody's watershed can yield a disproportionally high amount of nutrients, especially when many houses are immediately near the water's edge. This is particularly applicable to Cranberry Lake, as watershed-based nutrient modeling suggests that septic systems yield the highest annual load, likely as a product of the many septic systems in the watershed and immediately near the water's edge. It is recommended that a "Septic-Snooper" or other assessment of septic influence on Cranberry Lake be conducted and that homeowners be encouraged to maintain their septic tanks in working order, as described in the previous section.

LAKE LACKAWANNA

Invasive Vegetation Management – Observations made during the 2023 growing season suggest that Lake Lackawanna is regularly dominated by vascular plants rather than by algae. In many cases, the plant community appears to be dominated by the invasive species Eurasian water milfoil or curlyleaf pondweed. The lake is already managed via the use of a mechanical harvester at points in the summer. These efforts should continue; as discussed previously in this section in regard to Cranberry Lake, the removal of vegetation results in the direct removal of phosphorus and other nutrients to the waterbody as long as proper disposal away from the lake occurs. While treatment with herbicides may be desired in certain scenarios, this should occur in limited prioritized areas. As discussed previously, the decomposition of a large quantity of plants following a treatment may cause reductions in dissolved oxygen or the release of nutrients and a subsequent algae bloom.

Dredging – As discussed in general recommendations, dredging, while expensive, can be a particularly effective lake management technique due to the direct removal of sediment and nutrients from the waterbody. Lake Lackawanna's overall shallow depth and subsequent problems with excessive aquatic vegetation growth make this form of management a particularly viable option, although the expense for such a project may be high. For further details regarding the management of a waterbody via dredging, please refer to the general recommendations section above.

Floating Wetland Islands - A potential solution for nutrient removal within Lake Lackawanna is the installation of floating wetland islands (FWIs) in the northern portion of the waterbody. FWIs consist of a floating matrix that is planted with wetland plant species and anchored in a strategic location in a waterbody. Over the course of a few years, as the wetland plants grow on the island, their roots and the matrix develop a beneficial biofilm that uptakes nutrients that would be otherwise used by undesirable plants and algae. Additionally, these structures have the added benefit of providing habitat for fish, turtles, and other animals, and are often planted with aesthetically pleasing flowering wetland plants. FWIs are often an option recommended for the control of smaller concentrations of phosphorus after other management methods have been enacted, and, as such, this is likely a project the Lake Lackawanna community may want to pursue in the future, after other solutions have been implemented.

Biochar - Biochar is a processed wood material that has a high affinity to absorb 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.

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-waterbody phosphorus. Biochar strategically placed in ponds offers the opportunity to remove internally released phosphorus from the system, further complimenting the watershed management measures that reduce 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 9.1: Examples of biochar being used in ponds (left) and streams (right).

Watershed-based nutrient modeling suggests that the golf course along Lake Lackawanna's southern shoreline yields the highest annual amount of phosphorus per acre. As such, biochar bags in the lake directly around areas of drainage from the golf course into the lake may serve to intercept some of this phosphorus before it proliferates into the rest of the lake.

JOHNSON LAKE

Vegetation management – Johnson Lake is a shallow waterbody that us dominated by vascular plants, with floating plants such as waterlilies and watershield covering a large portion of the lake surface. In many lakes utilized for boating or swimming, this would likely be considered a nuisance. However, Johnson Lake appears to largely be managed for fishing, paddling, and ecological benefits. While fishing and paddling may be somewhat impeded by a dense macrophyte population, removal of many of these macrophytes is generally not necessary, especially since most of them are native. The only exception to this would be the selective removal of some floating vegetation to allow for better atmospheric mixing of oxygen into the water column. Johnson Lake was measured to be overall low during the autumn event; this is likely due to the waterbody's high coverage with floating vegetation, which may reduce the ability of oxygen to mix into the water column from the atmosphere. Paired with a large amount of organic matter that may be decomposing as water temperatures cool, this may result in overall low dissolved oxygen concentrations in the water column, negatively affecting the lake's fish populations. Should this be a concern, selective removal of floating vegetation may be warranted. Please refer to the discussion of vegetation management in Cranberry Lake above for further details on floating vegetation management.

Dam Removal – A potential option for the management of Johnson Lake and waterbodies and streams downstream is the removal of the lake's dam and the restoration of the lake area into a stream corridor with surrounding wetlands. These wetlands would likely serve to sequester incoming nutrients prior to their further travel downstream. While a large project with a significant initial expense, this is becoming a popular option for some impoundments that are no longer serving their original use. The removal of the dam may allow for increased habitat for stream fish living downstream of it and depending on post-removal conditions and the current condition of the areas downstream, may be manageable as a trout stream. Furthermore, the proper removal of a dam eliminates the liability, safety concerns, and resulting costs associated with maintaining a functioning dam. An obvious issue with removing the Johnson Lake Dam would be the loss of the recreational and potential ecological value of the lake itself. Additionally, given the shallow and vegetated nature of Johnson Pond, it likely already sequesters a large amount of nutrients prior to their downstream travel.

FOREST LAKE

Aeration System Feasibility Study – During the 2023 growing season, Forest Lake was observed to consistently feature reduced bottom dissolved oxygen. Furthermore, the lake was estimated to receive a large internal phosphorus load as a result of this bottom anoxia and relatively high concentrations of deep-water phosphorus. This may be remedied with the installation of an aeration system. Such systems contain onshore compressors connected to diffusers installed at the lake bottom in deeper areas. This results in a constant stream of dissolved oxygen, with proliferates through the water column. Prior to the installation of such a system, however, an aeration feasibility study must be conducted. This involves a bathymetric study of the lake and estimations of the amount of power required, the size of the compressor required to effectively deliver air to the diffusers, the number of diffuser heads needed, and other details. It is also recommended that at least one further year of water quality monitoring occur to further assess the potential extent of external loading.

Nutrient Inactivation and/or Sequestration – Another solution that may assist in controlling phosphorus concentrations in Forest Lake is the application of Aluminum Sulfate (Alum) or the lanthanum clay-based product PhosLock®. Both products, when applied, bind to phosphorus in the water column and cause it to sink to the bottom, making it less available for use by algae and cyanobacteria. Forest Lake may benefit from applying alum or PhosLock® during instances of increased algae growth during the summer. Due to the tendency of alum to lower the pH of water, prior to application, an alum bench test must first be performed. The purpose of this test is to assess the approximate amount of alum that can be applied to the waterbody before the waterbody's pH drops to a level dangerous to fish and other aquatic life. Because of this, the pH level of the lake should also be monitored during the application process.

Septic System Assessment – As mentioned in the general recommendations section, septic systems in a waterbody's watershed can yield a disproportionally high amount of nutrients, especially when many houses are immediately near the water's edge. This is particularly applicable to Forest Lake, as watershed-based nutrient modeling suggests that septic systems yield a significant annual load, likely as a product of the many septic systems in the watershed. It is recommended that a "Septic-Snooper" or other assessment of septic influence on Forest Lake be conducted and that homeowners be encouraged to maintain their septic tanks in working order, as described in the previous section.

PANTHER LAKE

Aeration System Feasibility Study – During the 2023 growing season, the southern portion of Panther Lake was observed to consistently feature reduced bottom dissolved oxygen. Furthermore, the lake was estimated to receive a large internal phosphorus load as a result of this bottom anoxia and relatively high concentrations of deep-water phosphorus. This may be remedied with the installation of an aeration system. Such systems contain onshore compressors connected to diffusers installed at the lake bottom in deeper areas. This results in a constant stream of dissolved oxygen, with proliferates through the water column. Prior to the installation of such a system, however, an aeration feasibility study must be conducted. This involves an updated bathymetric study of the lake and estimations of the amount of power required, the size of the compressor required to effectively deliver air to the diffusers, the number of diffuser heads needed, and other details. It is also recommended that at least one further year of water quality monitoring occur to further assess the potential extent of external loading.

Additionally, depending on management goals, it may be preferred to maintain a thermocline in Panther Lake. This would allow for the habitat of some fish and zooplankton to remain intact. If this is desired, an alternative aeration system type may be necessary.

Nutrient Inactivation and/or Sequestration – Another solution that may assist in controlling phosphorus concentrations in Panther Lake is the application of Aluminum Sulfate (Alum) or the lanthanum clay-based product PhosLock®. Both products, when applied, bind to phosphorus in the water column and cause it to sink to the bottom, making it less available for use by algae and cyanobacteria. Panther Lake may benefit from applying alum or PhosLock® during instances of increased algae growth during the summer. Due to the tendency of alum to lower the pH of water, prior to application, an alum bench test must first be performed. The purpose of this test is to assess the approximate amount of alum that can be applied to the waterbody before the waterbody's pH drops to a level dangerous to fish and other aquatic life. Because of this, the pH level of the lake should also be monitored during the application process.

It should be noted that cyanobacteria were rarely detected in plankton samples collected in 2023. As such, the use of nutrient inactivation products may not be necessary if this trend continues in future years.

EutroSORB F® Bags – A notable amount of nutrients is modeled to enter Panther Lake from its southeast tributary. This may be mitigated with the use of the SePro product EutroSORB F®, a compound designed to remove SRP from flowing water. These products can be installed in streams to remove phosphorus prior to entry into a lake. It should be noted however that EutroSORB F® bags need to be periodically changed to achieve continued proper removal rates. Additionally, installation of bags into the stream may require permits through the NJDEP.

Aquatic Vegetation Management – Early-season growth of curlyleaf pondweed in Panther Lake was observed to reach nuisance densities in the Spring of 2023. Herbicide treatment may be used to control this plant in limited areas; however, due to the presence of the state-endangered Illinois Pondweed, this should be performed with extreme care. More information regarding the control of nuisance aquatic vegetation is provided above under recommendations for Cranberry Lake.

Floating Wetland Islands - A potential solution for nutrient removal within Panther Lake is the installation of floating wetland islands (FWIs) in the southeast cove adjacent to the lake's inlet. FWIs consist of a floating matrix that is planted with wetland plant species and anchored in a strategic location in a waterbody. Over the course of a few years, as the wetland plants grow on the island, their roots and the matrix develop a beneficial biofilm that uptakes nutrients that would be otherwise used by undesirable plants and algae. Additionally, these structures have the added benefit of providing habitat for fish, turtles, and other animals, and are often planted with aesthetically pleasing flowering wetland plants. FWIs are often an option recommended for the control of smaller concentrations of phosphorus after other management methods have been enacted, and, as such, this is likely a project the Panther Lake campground may want to pursue in the future, after other solutions have been implemented.

JEFFERSON LAKE

EutroSORB F® Bags – A large portion of Jefferson Lake's total annual nutrient load is modeled to enter the Lake from its main inlet stream, Ghost Pony Brook. This may be mitigated with the use of the SePro product EutroSORB F®, a compound designed to remove SRP from flowing water. These products can be installed in streams to remove phosphorus prior to entry into a lake. It should be noted however that EutroSORB F® bags need to be periodically changed to achieve continued proper removal rates. Additionally, installation of bags into the stream may require permits through the NJDEP.

Floating Wetland Islands - A potential solution for nutrient removal within Jefferson Lake is the installation of floating wetland islands (FWIs) in the inlet cove in the northwestern corner of the lake. FWIs consist of a floating matrix that is planted with wetland plant species and anchored in a strategic location in a waterbody. Over the course of a few years, as the wetland plants grow on the island, their roots and the matrix develop a beneficial biofilm that uptakes nutrients that would be otherwise used by undesirable plants and algae. Additionally, these structures have the added benefit of providing habitat for fish, turtles, and other animals, and are often planted with aesthetically pleasing flowering wetland plants. In a setting such as the Jeff Lake Day Camp, FWIs have the added benefit of serving as a potential educational installment and can be accompanied with nearby onshore signage to explain the purpose of the islands to camp attendees. FWIs are often an option recommended for the control of smaller concentrations of phosphorus after other management methods have been enacted, and, as such, this is likely a project the Panther Lake campground may want to pursue in the future, after other solutions have been implemented.

Nutrient Inactivation and/or Sequestration – Another solution that may assist in controlling phosphorus concentrations in Jefferson Lake is the application of Aluminum Sulfate (Alum) or the lanthanum clay-based product PhosLock®. Both products, when applied, bind to phosphorus in the water column and cause it to sink to the bottom, making it less available for use by algae and cyanobacteria. Jefferson Lake may benefit from applying alum or PhosLock® during instances of increased algae growth during the summer. Due to the tendency of alum to lower the pH of water, prior to application, an alum bench test must first be performed. The purpose of this test is to assess the approximate amount of alum that can be applied to the waterbody before the waterbody's pH drops to a level dangerous to fish and other aquatic life. Because of this, the pH level of the lake should also be monitored during the application process.

Aquatic Vegetation Management – Jefferson Lake was observed in 2023 to feature moderate amounts of aquatic vegetation in the shallower western portion of the lake. This may be a nuisance to boaters in this portion of the lake. Should removal be desired, this can be accomplished by spot treatment with herbicides or potentially via hydroraking. For further information detailing aquatic plant control, please refer to the recommendations for Cranberry Lake.

STAG POND

Aeration System Feasibility Study – During the 2023 growing season, the deeper central portion of Stag Pond was observed to feature reduced bottom dissolved oxygen. Furthermore, the lake was estimated to receive a large internal phosphorus load as a result of this bottom anoxia and relatively high concentrations of deep-water phosphorus. This may be remedied with the installation of an aeration system. Such systems contain onshore compressors connected to diffusers installed at the lake bottom in deeper areas. This results in a constant stream of dissolved oxygen, with proliferates through the water column. Prior to the installation of such a system, however, an aeration feasibility study must be conducted. This involves an updated bathymetric study of the lake and estimations of the amount of power required, the size of the compressor required to effectively deliver air to the diffusers, the number of diffuser heads needed, and other details. It is also recommended that at least one further year of water quality monitoring occur to further assess the potential extent of external loading.

Nutrient Inactivation and/or Sequestration – Another solution that may assist in controlling phosphorus concentrations in Stag Pond is the application of Aluminum Sulfate (Alum) or the lanthanum clay-based product PhosLock®. Both products, when applied, bind to phosphorus in the water column and cause it to sink to the bottom, making it less available for use by algae and cyanobacteria. Stag Pond may benefit from applying alum or PhosLock® during instances of increased algae growth during the summer. Due to the tendency of alum to lower the pH of water, prior to application, an alum bench test must first be performed. The purpose of this test is to assess the approximate amount of alum that can be applied to the waterbody before the waterbody's pH drops to a level dangerous to fish and other aquatic life. Because of this, the pH level of the pond should also be monitored during the application process.

Invasive Species Management – Stag Pond features a diverse aquatic macrophyte community which includes the state-listed rare flat-leaved bladderwort. Management of the invasive species Eurasian watermilfoil involves lowering the water level during the winter months so as to freeze the plant's overwintering propagules. This was observed in 2023 to generally keep growth of this invasive plant relatively minimal in Stag Pond. In fall of 2023, however, the invasive plant brittle naiad (*Najas minor*) was observed in the waterbody in moderate-to-dense beds. Brittle naiad is a plant that spreads via seeds and may grow more prevalently following the lowering of a waterbody (Wagner, 2020). This plant is typically managed in other northern NJ waterbodies by the use of herbicides. Physical removal is another potential solution; however, the plant has a tendency to fragment, potentially spreading seeds into other areas of the waterbody. For more information regarding general aquatic macrophyte management, please refer to the recommendations for Cranberry Lake.

KOFFERLS POND

Invasive Species Management – Kofferls Pond was observed in 2023 to be dominated largely by vascular plants rather than algae, with the invasive species Eurasian watermilfoil occurring in dense beds throughout the pond. As mentioned in the Cranberry Lake recommendations section, this species can be effectively treated with the systemic herbicide ProcellaCOR®, however this should be done slowly over the course of a few seasons to as not to introduce a large amount of available nutrients to the water column at one time or cause a sudden drop in dissolved oxygen. Alternatively, mechanical removal of milfoil can be conducted, however the lack of access for larger vessels may complicate this process. Furthermore, mechanical removal occurs at a relatively slow rate and would likely be more expensive than chemical treatment.

Biochar - Biochar is a processed wood material that has a high affinity to absorb 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.

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-waterbody phosphorus. Biochar strategically placed in ponds offers the opportunity to remove internally released phosphorus from the system, further complimenting the watershed management measures that reduce 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.

Watershed-based nutrient modeling suggests that the pond's main inlet, which enters at the northeastern end, produces a notable annual phosphorus load. As such, biochar bags in the pond directly around the inlet area may intercept some of this phosphorus before it proliferates into the rest of the lake.

EutroSORB F® Bags – Alternatively to or in addition to the installation of biochar, the nutrient load entering Kofferls Pond from its northeastern inlet may be mitigated with the use of the SePro product EutroSORB F®, a compound designed to remove SRP from flowing water. These products can be installed in streams to remove phosphorus prior to entry into a lake. It should be noted however that EutroSORB F® bags need to be periodically changed to achieve continued proper removal rates. Additionally, installation of bags into the stream may require permits through the NJDEP.

9.3 WATERSHED GENERAL RECOMMENDATIONS

In addition to the specific site recommendations within the lakes individual watersheds listed above in Section 8.0, Princeton Hydro also provides the following general recommendations for implementation throughout the watersheds. These include bank stabilization, riparian zone enhancement, as well as in-pond measures for all applicable locations in the project areas. Additionally, given both ponds are located on County park facilities, there is excellent opportunity to use this platform to educate residents about lake and watershed management general.

STREAMBANK STABILIZATION AND RIPARIAN BUFFER ENHANCEMENTS

Streambank Stabilization

Another important set of watershed management measures throughout Byram Township involves streambank stabilization and riparian buffer enhancements. While some stream reaches throughout the township were assessed as part of the watershed investigations, there are likely hundreds of miles of streams throughout the township. As such, focus was given to stream reaches near the receiving lake and streams that receive major stormwater inflow. Any specific stream reaches that were deemed to be in poor condition during the watershed assessments were included above with a specific site location and recommended management measure. Given the moderate to high grade throughout many of the watersheds, there are likely additional stream sites that could be restored or enhanced through streambank and streambed stabilization as well as riparian buffer enhancements. As such, this section will provide a brief overview of these general stream restoration measures and how they can reduce pollutant loading to the Byram Township Lakes.

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

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

Riparian Buffer Enhancements

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

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

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

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

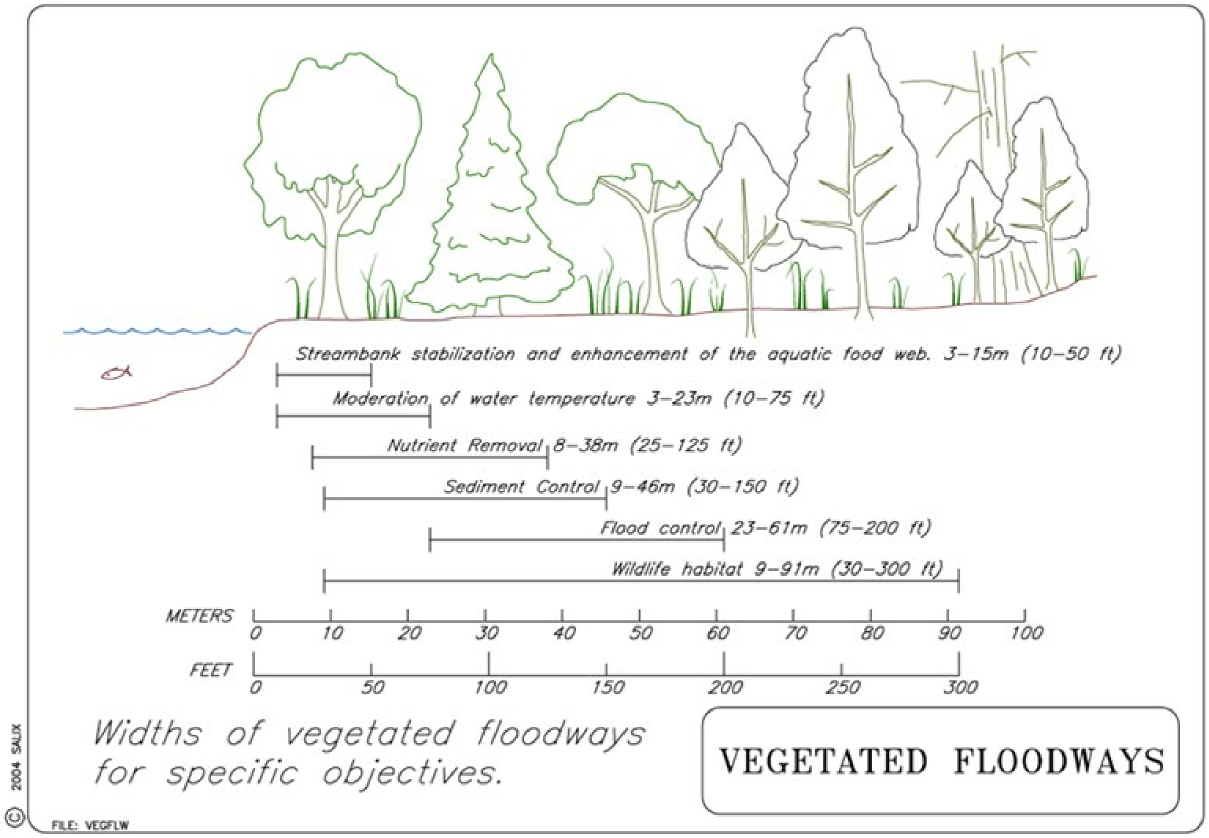


Figure 9.1: Riparian buffer zones and functional value widths

Bank Stabilization

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

Grade Control

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

SEPTIC SYSTEM MANAGEMENT

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

Septic System Failure

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

Hydraulic – Excessive hydraulic loading to undersized systems, low soil permeability, ponding, poor maintenance, or increasing water use over the design capacity.
Organic – Excessive organic loading from unpumped, sludge-filled tanks results in biomat loss of permeability (a stratum of anaerobic bacteria lining the trenches in the drain field).
Depth to Limiting Zone – Insufficient soil depths, high water tables, and impermeable layers can all diminish pathogen removal and hydraulic performance. Sand mound systems correct for depth to limiting zones by mounding appropriate soil for treatment.
System Age – Systems more than 25 to 30 years old on average. Failure rates in older systems triple. Regular maintenance, e.g., tank pumping and alternating leach fields, can substantially prolong system life.
Design Failure – Inappropriate system design for site characteristics including hydraulic load or restrictions.
System Density – Cumulative effluent load from all systems in watershed or groundwater recharge area exceeds the capacity of the area to accept or properly treat effluent.

Signs of Septic System Failure

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

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

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

- Inspection
- Maintenance
- Repair
- Replacement

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

Inspection

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

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

Maintenance and Best Management Practices

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

- Septic tanks should be pumped out and inspected every 3 years for full-time residents and every 5 years for part-time residents. For systems that may be undersized, experience heavy use, have exhibited performance problems, are subject to non-flushable wipes, or are nearing the end of their life cycle, pumping frequency may need to be increased. Please refer to Pennsylvania Department of Environmental Protection (PADEP) Title 25, Chapter 73 regulations for septic sizing criteria and use relative to bedrooms, occupancy, and treatment volume.
- Maintain inspection records and know the location of the access manhole, inspection ports, and drainfield.
- Practice water conservation and limit, where possible, excessive wastewater generation
- Do not drive and park on the septic as this has the potential to damage septic components and compact soils.
- Divert runoff from impervious areas including roofs and driveways away from the system.
- Limit vegetation on the systems to grass; woody vegetation can damage pipes and tanks.
- Use low-phosphorus or no-phosphorus detergents.
- Septic system additives are not effective and may compound problems or leach organic solvents.
- Do not dispose of non-degradable material such as grease, cigarette butts, or personal hygiene items, do not use garbage disposals as these can overload the system with organic materials, and do not dispose of medicines, solvents, paints, poisons, or excessive household cleaning chemicals.

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

Repairs, Replacements, and New Construction

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

STORMWATER MANAGEMENT

Downspout Disconnection

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

Photo 9.2: Downspout Disconnection, Source: USEPA

Rainwater Harvesting

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

For a small roof such as a house, a rain barrel is the ideal container for rainwater harvesting. Rain barrels are typically 55-gallon drums but can be purchased or built to accommodate larger volumes. Additionally, multiple rain barrels can be connected with hoses for increased storage capacity. There are countless resources on how to build and install a rain barrel at home and can cost from around $30 - $300 or more, depending on availability of the materials. Rutgers has a number of websites dedicated to rain barrels, including on how to build one (E329: Rain Barrels Part I: How to Build a Rain Barrel (Rutgers NJAES)).

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

Photo 9.3: Rain barrel (left) and cistern (right), Sources: CT DEEP (left) and USEPA (right)

Downspout Planters

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

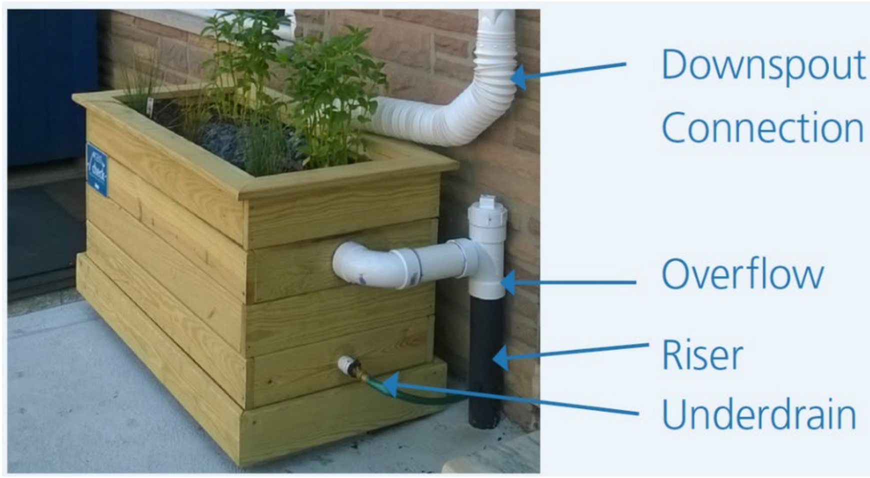


Photo 9.4: Downspout planter, Source: Phillywatersheds.org

Green Roof

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


Photo 9.5: Green Roof, Source: New Jersey Future

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

Curb Bumpout

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

Photo 9.6: Curb bumpout, Source: Phillywatersheds.org

Stormwater Planter

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

Photo 9.7: Stormwater Planter, Source: Philadelphia Water Department

Tree Boxes

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

Photo 9.8: Tree Box, Source: Contech

Pervious Pavers/Pavement

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

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

PET WASTE MANAGEMENT

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

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

NATURAL LANDSCAPING

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

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

FERTILIZER MANAGMENT

It should be noted that the New Jersey legislature has passed 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).

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 pond(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.

9.4 GENERAL RECOMMENDATIONS OVERALL

A primary reason for conducting this study was to identify what can be done in the watersheds of the lakes of Byram Township to minimize the annual pollutant load of each. A list of best management practices (BMPs) has been 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 has also been performed. Based on inspections of the watershed or information contained in reports made available, we have identified 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. 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. Some portions of these projects may alsi be eligible for funding from the New Jersey Highlands Council.

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 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.
- NJDEP in-lake restoration grants (provided on a year to year basis)
- 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.