AN ASSESSMENT OF THE LAKES AND WATERSHEDS OF RINGWOOD BOROUGH

BOROUGH OF RINGWOOD, PASSAIC COUNTY, NEW JERSEY

MARCH 2021

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1. INTRODUCTION

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

Ringwood Borough in Passaic County is located entirely within the Preservation Area of the Highlands Region (18,230 acres). The municipality's Petition for Plan Conformance was approved by the Highlands Council on October 13, 2011. Providing drinking water to millions of New Jersey residents, the Borough of Ringwood is situated in the heart of the New Jersey Highlands and is home to several public and private lakes that sit within the Ramapo Mountains.

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

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

However, Lakes greater than 10-acres in size which are permanently preserved, including state-owned lakes, were eliminated from the study, as were other heavily studied lakes such as the Wanaque and Monksville Reservoirs, which are owned by private water utilities and were not included in the study. Finally, lakes less than 10 acres that may possess a swimming beach WERE included due to the potential impacts of harmful algal blooms on the contact recreational use of these lakes.

The Borough of Ringwood contains four (4) sets of private lakes and associated lake communities, totaling six (6) waterbodies. These lakes are as follows: Cupsaw Lake, Upper and Lower Erskine Lakes, Upper and Lower Skyline Lakes and Rickonda Lake. Despite the private status of these lakes, the Borough has expressed interest in taking an active role in managing the associated waterbody of each lake in order to limit the amount of sediment and nutrients entering each lake. In 2019, several lakes in northern NJ suffered from long-lasting harmful algae blooms (HABs), a phenomenon caused by an overpopulation of cyanobacteria ("blue-green algae") in a waterbody. In addition to impacting the aesthetic condition of a lake, cyanobacteria produce toxins that can cause a host of health issues in humans and animals that come in contact with the water. The Borough has therefore expressed interest in implementing watershed management measures in order to reduce the impact of watershed nutrient loading, which can influence cyanobacteria growth. The balance of this report details the results of Princeton Hydro's mapping, modeling and monitoring efforts in each waterbody and its respective watershed, along with recommendations for management implementations that may serve to curb the effects of nutrient and sediment loading, both within the lakes and their respective watersheds.

2. HISTORICAL DATA REVIEW

According to the New Jersey Department of Environmental Protection (NJDEP) all the above refenced lakes are classified as freshwater non-trout (FW2-NT), the most common surface water status in New Jersey, however many of the inlet and outlet streams of these water bodies are classified as Category 1 (C1) waters. C1 waters are afforded the highest-level protection by the NJDEP. As per the NJDEP "Category One (C1) is a type of antidegradation designation that provides additional protection to specific waterbodies. C1 waters are protected from any measurable change in existing water quality because of their exceptional ecological significance, exceptional recreational significance, exceptional water supply significance, or exceptional fisheries resources." As a result, the Borough of Ringwood wishes to afford these C1 category waters which feed the lakes of the Borough should be afforded the highest levels of protection that can be offered.

Also, historical water quality data for Lower Erskine, Upper Skyline, and Cupsaw Lakes are available online through the NJDEP's Bureau of Freshwater and Biological Monitoring Program's Water Quality Data Exchange program. Water quality data collected from a southern station on Cupsaw Lake in June, 2016 indicates that the lake featured bottom anoxia during this date and approximately 0.05 mg/L of Phosphorus near the surface of the water column. Chlorophyll *a* at the same depth was approximately 46.9 µg/L. Data collection at Lower Erskine Lake occurred at a mid-Lake station during May, August, and October 2008, as well as April and August 2013. During the August 2008 sampling data, the water column was recorded to feature anoxia within the bottom-most 0.5 m, although differences between bottom and surface phosphorus concentrations were not large. Bottom dissolve oxygen depletion was also recorded during the August 2013 date, however deep phosphorus data is not available for this date. Lastly, water quality data for Upper Skyline Lake exists for May, August, and October of 2008, as well as July and November 2013. The southern sampling station was not measured to feature a large occurrence of bottom dissolved oxygen depletion during any of the events, and phosphorus concentrations near the surface were at their highest at approximately 0.05 mg/L during the August 2008 and November 2013 events.

Additionally, as part of this project, Princeton Hydro also reviewed any and all historic data available. As part of this review, the data has been provided to Princeton Hydro by the individual lake associations has been reviewed. This data is discussed briefly below.

The Cupsaw Lake Environmental Committee has provided Princeton Hydro with a database of growing season Secchi Depth, water temperature and DO profiles, weather data, and other observations collected on Cupsaw Lake. Secchi depth and weather observation data was collected beginning in 2014, while Temperature data was collected starting in 2015 and DO data was collected starting in 2018. Profile data suggests a light thermocline forming in the water column during most summers, as well as periods of deep-water oxygen depletion at times during the summer of 2018. Late-July Secchi measurements each year have consistently yielded clarities of about 2-3'.

Additionally, the Cupsaw Lake Environmental Committee has provided Princeton Hydro with data from 2016, 2017, and 2018 studies of the tributaries of Cupsaw Brook that flow into the lake. In these studies, the South Brook and Hickory Brook yielded the highest concentrations of Phosphorus for the months of June and July, respectively. In 2017, the Kendal Drain, which drains roads in the northwest development adjacent to the lake, yielded a concentration of 0.36 mg/L of Phosphorus. Lastly, all tributaries yielded concentrations of phosphorus of 0.18 mg/L or higher in September of 2018. Another previous study of the hydrology of Cupsaw Lake's watershed estimated a mean annual streamflow of 7.2 cfs and a mean annual runoff of 7.31 cfs, with March and April yielding the highest monthly runoffs.

3. HYDROLOGIC AND POLLUTANT LOADING ANALYSIS

3.1 METHODS

Watersheds and sub-watersheds were delineated for each lake using USGS's Streamstats tool and the Stroud Research Center's Model My Watershed tool. Sub-watersheds were edited in ESRI's ArcMAP 10.2.2. Sub-watersheds that were too small for proper analysis with GWLF-E were combined with neighboring sub-watersheds. Maps displaying watersheds and sub-watersheds for each Lake are provided in Appendix I.

GIS shapefiles for each sub-watershed and total watershed were imported into Model My Watershed, which produced a .gms file containing hydrologic and nutrient data for a 30-year period. This file was subsequently entered into Penn State's Generalized Watershed Loading Functions-Enhanced (GWLF-E) tool. Septic-based phosphorus and nitrogen loads were calculated using Universal Areal Loading (UAL) modeling. For this methodology, houses within 100 meters (330') of the edges of each lake, as well as its tributaries, were counted and multiplied by the US census bureau's estimated number of person's per residence for Ringwood (2.9, rounded up to 3 persons per household (Census Reporter.Org, 2019)). This number was again multiplied by a coefficient used for the approximate amount of phosphorus produced by each resident of a watershed each year. The coefficient for total nitrogen (TN) provided by the EPA (Onsite Wastewater Treatment Systems Manual, 2002) is 4.4 kg TN/capita/year. While the EPA's loading coefficient has been 0.115 kg of phosphorus/capita/year, studies by Princeton Hydro in the past in West Milford and Jefferson Boroughs suggest that septic loading is higher than originally anticipated, yielding a coefficient of 0.165 kg of phosphorus/capita/year. This higher coefficient was used for UAL modeling for septic-based phosphorus in the Ringwood study.

Monthly Point Source Loads were also added for basins featuring known surface discharges using data provided through the NJDEP's New Jersey Pollutant Discharge Elimination System (NJPDES). GWLF-E was run for a 30-year period following all necessary data edits.

3.2 RESULTS

CUPSAW LAKE

The full watershed of Cupsaw Lake covers an area of 2,657.6 acres, with its northern edge extending into the state of New York (Table 1). The areas immediately surrounding the lake contains a mix of forested area and low-density open space, while larger expanses to the northern and eastern portions of the watershed are largely forested. Descriptions of the lake's sub-watersheds are as follows:

- **Beach –** This small 17.8-acre sub-watershed on the northeast end of Cupsaw Lake encompasses portions of Windbeam Avenue and Cupsaw Drive, as well as the Lake's Beach and main swimming access points. This sub-watershed is dominated by forested land and low-density open space.
- **Development –** This 47.6-acre sub-watershed in the northwest portion of the total watershed encompasses the development made up of Dolores Drive, Jayne Terrace, and Marcia Road, as well as portions of Kraft Pl. and Kendall Drive. This largely developed sub-watershed is dominated by low-density open space.
- **East Slope –** This sub-watershed encompasses a 25.9-acre area on the eastern side of the lake, and contains large portions of Stetson and Hillside Roads, as well as a small length of Cupsaw Drive downhill of these. This sub-watershed is dominated by forested land, while a little over a quarter of the basin is classified as low-density open space.
- **Northeast –** This 337-acre basin contains a portion of the developed land immediately adjacent to Cupsaw Lake, as well as a larger expanse of forested land to the east. This sub-watershed includes a portion of the Skyland Association Botanical Gardens, as well as Swan Pond and a tributary to Cupsaw brook. The basin is dominated by forested land.
- **Northwest –** This 104.6-acre sub-watershed contains the northwestern portion of the developed areas directly adjacent to Cupsaw lake, as well as largely forested land to the north.
- **Old Road –** This 70.2-acre watershed drains forested areas to the east of Cupsaw Lake and contains stretches of Honeysuckle Lane, Windbeam Ave, Old Road, and Skylands Road. The basin is dominated by forested land.
- **Shepherd Pond –** This is the largest sub-watershed of Cupsaw lake at 1008.5 acres. The northern boundary of this basin exists near Sterlington Road in New York State. The sub-watershed drains Sheperd Pond and the northern-most tributary to Cupsaw Brook and is dominated by forested land.
- **Skylands –** This largely-wooded sub-watershed encompasses a 746-acre area in the southeast portion of the full Cupsaw Lake watershed. It contains Glasmere Ponds, Weyble Pond, Gatun Pond, and a tributary to Cupsaw Brook. It is dominated by forested land.
- **Southeast –** This 126.9-acre basin encompasses the developed areas along Woodland, Skylands, Bear Mountain, and Valley Roads, as well as part of the Martin J Ryerson Middle school and a tributary to the Cupsaw Brook. This basin is dominated by forested land, with a relatively large proportion of low-density open space also present.
- **West Slope –** This 50.0-acre sub-watershed encompasses most of a developed areas adjacent to the lake known as The Loop, as well as the southern portion of West Cir. and Windbeam Loop. This sub-watershed is dominated by low-density open space.

Table 1. Land-use by sub-watershed in the Cupsaw Lake watershed.

Source	Full Watershed	Beach	Development	East Slope	Northeast	Northwest Area (Acres)	Old Road	Shepherds Pond	Skylands	Southeast	West Slope
Open Water	128.5	0.4	2.0	0.0	0.0	0.0	0.0	71.7	2.5	3.8	1.1
Hay/Pasture	2.0	0.0	0.0	0.0	0.0	0.0	0.0	2.0	0.0	0.0	0.0
Cropland	17.5	0.0	0.0	0.0	17.5	0.0	0.0	0.0	0.0	0.0	0.0
Forest	2035.4	10.6	2.0	17.8	274.0	68.7	60.0	848.1	670.4	66.5	15.8
Wetland	187.8	0.2	7.7	1.0	15.3	18.3	3.5	91.9	42.7	2.2	2.0
Open Land	16.6	0.0	0.0	0.0	0.0	0.0	0.0	16.6	0.0	0.0	0.0
Barren Land	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Low-Density Mixed	21.0	0.5	4.0	0.2	4.0	0.5	0.0	6.7	1.0	3.5	0.7
Medium-Density Mixed	6.4	0.2	0.0	0.0	1.0	0.0	0.0	3.7	0.5	1.0	0.0
High-Density Mixed	0.7	0.0	0.0	0.0	0.0	0.0	0.0	0.2	0.2	0.2	0.0
Low-Density Open Space	241.7	5.9	31.9	6.9	25.2	17.1	6.7	39.3	28.7	49.7	30.4
Total	2657.6	17.8	47.6	25.9	337.0	104.6	70.2	1080.2	746.0	126.9	50.0

Source	Full Watershed	Beach	Development	East Slope	Northeast	Northwest Area (%)	Old Road	Shepherds Pond	Skylands	Southeast	West Slope
Open Water	4.8	2.5	4.2	0.0	0.0	0.0	0.0	6.6	0.3	3.0	2.2
Hay/Pasture	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.2	0.0	0.0	0.0
Cropland	0.7	0.0	0.0	0.0	5.2	0.0	0.0	0.0	0.0	0.0	0.0
Forest	76.6	59.4	4.2	68.7	81.3	65.7	85.5	78.5	89.9	52.4	31.6
Wetland	7.1	1.1	16.2	3.9	4.5	17.5	5.0	8.5	5.7	1.7	4.0
Open Land	0.6	0.0	0.0	0.0	0.0	0.0	0.0	1.5	0.0	0.0	0.0
Barren Land	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Low-Density Mixed	0.8	2.8	8.4	0.8	1.2	0.5	0.0	0.6	0.1	2.8	1.4
Medium-Density Mixed	0.2	1.1	0.0	0.0	0.3	0.0	0.0	0.3	0.1	0.8	0.0
High-Density Mixed	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.2	0.0
Low-Density Open Space	9.1	33.1	67.0	26.6	7.5	16.3	9.5	3.6	3.8	39.2	60.8
Total	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0

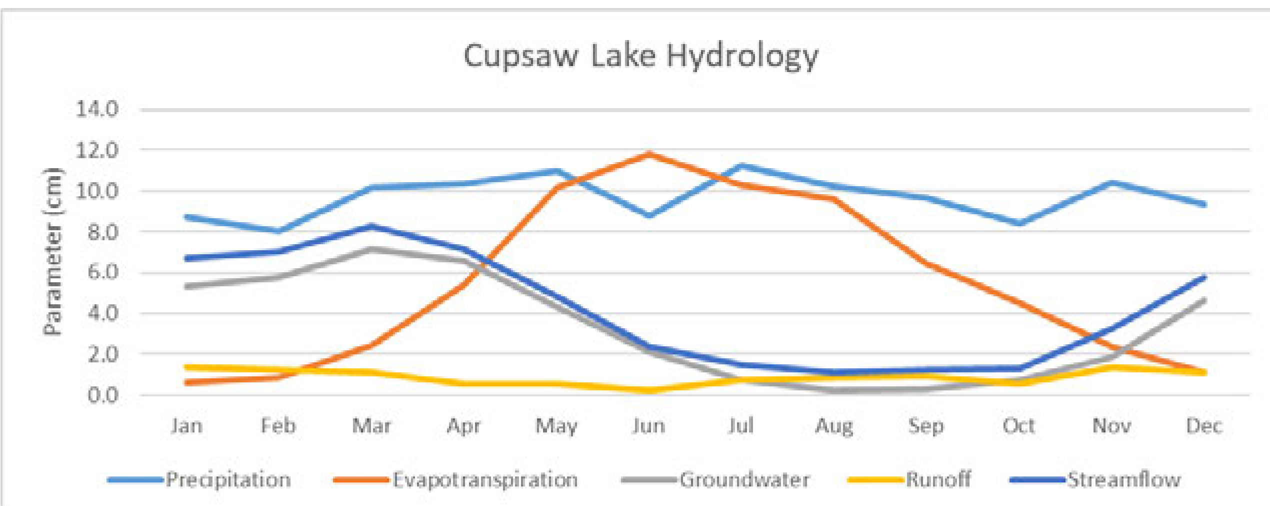

Figure 1. Estimated seasonal changes in hydrology in the Cupsaw Lake watershed

Table 2. Total hydrological parameters in the Cupsaw Lake watershed

Month	Precipitation	Evapotranspiration	Groundwater	Runoff	Streamflow	
	cm	cm	cm	cm	cm	cfs
Jan	8.8	0.6	5.4	1.4	6.7	9.6
Feb	8.0	0.9	5.8	1.2	7.0	10.9
Mar	10.2	2.4	7.2	1.1	8.3	11.7
Apr	10.4	5.4	6.6	0.6	7.2	10.5
May	11.0	10.2	4.3	0.5	4.9	6.9
Jun	8.8	11.8	2.1	0.3	2.4	3.5
Jul	11.2	10.3	0.8	0.7	1.5	2.1
Aug	10.2	9.6	0.2	0.9	1.1	1.5
Sep	9.7	6.5	0.3	0.9	1.2	1.8
Oct	8.4	4.5	0.7	0.6	1.3	1.8
Nov	10.4	2.4	1.9	1.4	3.3	4.8
Dec	9.3	1.1	4.7	1.1	5.8	8.2
Total	116.36	65.62	39.9	10.6	50.6	6.1

Among most of the Cupsaw Lake sub-watersheds, runoff only varies by approximately 0.3-0.4 cm (Figure 2). The Development sub-watershed, however, consistently features the highest runoff throughout most of the year. This is likely due to this sub-watershed's high proportion of developed land, which features relatively high amounts of impervious landcover, allowing for greater runoff. Note that, while this sub-watershed features the highest percentage of developed land, the Sheperds Pond and Southeast sub-watersheds contain greater total areas of developed land. The majority of the developed land, and, thus, impervious landcover, occur relatively close to Cupsaw Lake's shoreline. When direct precipitation and evapotranspiration to and from the Lake itself are factored in, Cupsaw Lake is estimated to receive approximately 5,559,284 m³ or 1,468.6 million gallons of water a year.

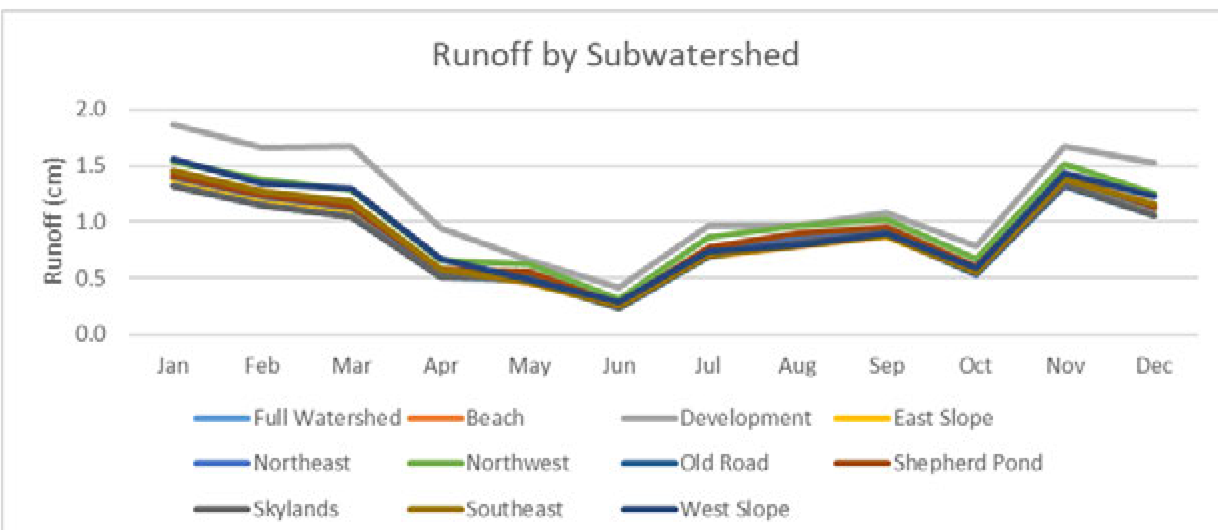

Figure 2. Average monthly runoff occurring by sub-watershed in the Cupsaw Lake watershed

Table 3: Estimated annual loads of nitrogen in the total Cupsaw Lake Watershed

Category	Description	Total Nitrogen kg	Total Nitrogen %
Runoff	Hay/Pasture	0.9	0.0
	Cropland	59.4	0.8
	Forest	152.8	2.1
	Wetland	35.8	0.5
	Open Land	9.6	0.1
	Barren Land	0.0	0.0
	Low-Density Mixed	2.3	0.0
	Medium-Density Mixed	3.6	0.1
	High-Density Mixed	0.4	0.0
	Low-Density Open Space	26.2	0.4
Other Sources	Farm Animals	0.0	0.0
	Stream Bank	53.0	0.7
	Groundwater	2491.4	34.6
	Septic Systems	4369.2	60.6
	Total	7204.6	100.0

Table 4: Estimated annual loads of nitrogen by sub-watershed in the Cupsaw Lake Watershed

Category	Description	Full Watershed kg	Beach kg	Development kg	East Slope kg	Northeast kg	Northwest kg	Old Road kg	Shepherd Pond kg	Skylands kg	Southeast kg	West Slope kg
Runoff	Hay/Pasture	0.9	0.0	0.0	0.0	0.0	0.0	0.0	0.9	0.0	0.0	0.0
	Cropland	59.4	0.0	0.0	0.0	53.5	0.0	0.0	0.0	0.0	0.0	0.0
	Forest	152.8	0.8	0.1	1.3	19.8	5.1	4.6	66.7	52.0	5.1	1.2
	Wetland	35.8	0.1	1.5	0.2	3.7	3.5	0.7	17.5	8.2	0.4	0.4
	Open Land	9.6	0.0	0.0	0.0	0.0	0.0	0.0	9.6	0.0	0.0	0.0
	Barren Land	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	Low-Density Mixed	2.3	0.1	0.4	0.0	0.5	0.1	0.0	0.8	0.1	0.4	0.1
	Medium-Density Mixed	3.6	0.1	0.0	0.0	0.6	0.0	0.0	1.7	0.3	0.6	0.0
	High-Density Mixed	0.4	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.2	0.2	0.0
	Low-Density Open Space	26.2	0.8	3.5	0.7	2.9	1.8	0.6	4.5	3.0	5.5	3.2
Other Sources	Farm Animals	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	Stream Bank	53.0	0.0	0.0	0.0	2.0	0.0	0.0	5.0	5.0	0.0	0.0
	Groundwater	2491.4	24.7	61.3	43.0	181.6	128.9	99.5	554.5	681.9	308.1	65.0
	Septic Systems	4369.2	184.8	237.6	369.6	422.4	343.2	171.6	448.8	554.4	752.4	884.4
	Total (kg)	7204.6	211.4	304.4	414.8	686.8	482.5	277.0	1110.1	1305.0	1072.7	954.3

In many of the Cupsaw Lake sub-watersheds, the total nitrogen load was dominated by septic tank effluent (Tables 3, 4). The Old Road, Shepherd Pond, and Skylands sub-watersheds yielded a larger load from groundwater than from septic, however this is likely due to the relatively larger expanses of non-urbanized lands in these watersheds. 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. Forested lands also yielded a higher percentage of nitrogen runoff than the other land-uses, however this is likely a product of the largely forested nature of this watershed; per unit area, forests are not a particularly large contributor of nitrogen.

Table 5: Estimated annual loads of phosphorus from various sources in the Cupsaw Lake Watershed

Category	Description	Total Phosphorus kg	Total Phosphorus %
Runoff	Hay/Pasture	0.4	0.1
	Cropland	16.5	5.4
	Forest	12.3	4.0
	Wetland	2.2	0.7
	Open Land	0.9	0.3
	Barren Land	0.0	0.0
	Low-Density Mixed	0.3	0.1
	Medium-Density Mixed	0.4	0.1
	High-Density Mixed	0.0	0.0
	Low-Density Open Space	2.9	0.9
Other Sources	Farm Animals	0.0	0.0
	Stream Bank	25.0	8.2
	Groundwater	81.7	26.7
	Septic Systems	163.8	53.5
	Total	306.2	100.0

Table 6: Estimated annual loads of phosphorus by sub-watershed in the Cupsaw Lake Watershed

Category	Description	Full Watershed kg	Beach kg	Development kg	East Slope kg	Northeast kg	Northwest kg	Old Road kg	Shepherd Pond kg	Skylands kg	Southeast kg	West Slope kg
Runoff	Hay/Pasture	0.4	0.0	0.0	0.0	0.0	0.0	0.0	0.4	0.0	0.0	0.0
	Cropland	16.5	0.0	0.0	0.0	4.6	0.0	0.0	0.0	0.0	0.0	0.0
	Forest	12.3	0.0	0.0	0.1	1.0	0.4	0.5	6.4	4.9	0.5	0.1
	Wetland	2.2	0.0	0.1	0.0	0.2	0.2	0.0	1.1	0.5	0.0	0.0
	Open Land	0.9	0.0	0.0	0.0	0.0	0.0	0.0	0.8	0.0	0.0	0.0
	Barren Land	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	Low-Density Mixed	0.3	0.0	0.1	0.0	0.0	0.0	0.0	0.1	0.0	0.0	0.0
	Medium-Density Mixed	0.4	0.0	0.0	0.0	0.0	0.0	0.0	0.2	0.0	0.1	0.0
	High-Density Mixed	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	Low-Density Open Space	2.9	0.0	0.4	0.1	0.1	0.2	0.1	0.5	0.3	0.6	0.4
Other Sources	Farm Animals	0.0	0.0	0.0	0.0	0.0	0.0	0.0	6.2	4.5	0.0	0.0
	Stream Bank	25.0	0.0	0.0	0.0	0.0	0.0	0.0	2.0	2.0	0.0	0.0
	Groundwater	81.7	0.7	1.5	1.0	5.3	3.0	2.2	16.3	24.4	3.7	1.4
	Septic Systems	163.8	6.9	8.9	13.9	12.9	12.9	6.4	16.8	20.8	28.2	33.2
	Total (kg)	306.2	7.7	10.9	15.0	24.2	16.7	9.2	50.8	57.4	33.2	35.1

Influence from septic systems was estimated to contribute to over half of the watershed's total phosphorus load (Tables 5, 6). While this pattern held true for many of the sub-watersheds, the Shepherd Pond and Skylands watersheds' individual phosphorus loads were contributed to equally or more by groundwater, although it should be noted that septic leachate will influence groundwater quality. It should be noted that septic loading yielded over 90% of the annual estimated phosphorus load in the Beach and East Slope sub-watershedsub-watershed. The development sub-watershed was estimated to yield the highest amount of phosphorus from urbanized areas, with the southeast sub-watershed also featuring a relatively high percentage when compared with the other sub-watersheds.

Table 7: Estimated annual loads of sediment from various sources in the total Cupsaw Lake Watershed

Category	Description	Sediment kgx1000	Sediment %
Runoff	Hay/Pasture	0.0	0.0
	Cropland	10.6	10.0
	Forest	4.3	4.0
	Wetland	0.3	0.3
	Open Land	0.6	0.6
	Barren Land	0.0	0.0
	Low-Density Mixed	0.1	0.1
	Medium-Density Mixed	0.2	0.2
	High-Density Mixed	0.0	0.0
	Low-Density Open Space	1.3	1.2
Other Sources	Farm Animals	0.0	0.0
	Stream Bank	88.5	83.6
	Groundwater	0.0	0.0
	Septic Systems	0.0	0.0
	Total	105.9	100.0

Table 8: Estimated annual loads of sediment by sub-watershed in the Cupsaw Lake Watershed

Description	Full Watershed kg x 1000	Beach kg x 1000	Development kg x 1000	East Slope kg x 1000	Northeast kg x 1000	Northwest kg x 1000	Old Road kg x 1000	Shepherd Pond kg x 1000	Skylands kg x 1000	Southeast kg x 1000	West Slope kg x 1000
Hay/Pasture	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Cropland	10.6	0.0	0.0	0.0	10.1	0.0	0.0	0.0	0.0	0.0	0.0
Forest	4.3	0.0	0.0	0.0	0.3	0.2	0.2	2.9	2.2	0.2	0.1
Wetland	0.3	0.0	0.0	0.0	0.0	0.0	0.0	0.2	0.1	0.0	0.0
Open Land	0.6	0.0	0.0	0.0	0.0	0.0	0.0	0.6	0.0	0.0	0.0
Barren Land	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Low-Density Mixed	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Medium-Density Mixed	0.2	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.0	0.0	0.0
High-Density Mixed	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Low-Density Open Space	1.3	0.0	0.2	0.0	0.1	0.1	0.0	0.2	0.2	0.3	0.2
Farm Animals	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Stream Bank	88.5	0.0	0.0	0.0	4.1	0.0	0.0	8.8	8.9	0.0	0.0
Groundwater	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Septic Systems	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Total (kgx1000)	105.9	0.1	0.2	0.1	14.7	0.3	0.3	10.2	11.3	0.6	0.3

A majority of sediment entering Cupsaw Lake was estimated to come from the erosion of streambanks (Tables 7, 8). Another relatively large contributor of sediment in the watershed is runoff from areas of cultivated crops, which only occurred in the northeast sub-watershed. While this basin only contains 17.5 acres of cropland (5.2% of the total area of the sub-watershed), this relatively small area produces an average of 10,600 kg a year of sediment, 68.4% of the sub-watershed's sediment load and 10.02% of that of the full Cupsaw watershed.

UPPER ERSKINE LAKE

Upper Erskine Lake's watershed covers an area of 235.2 acres (Table 9). The area immediately surrounding the lake largely consists of low-density open space, with higher elevation areas consisting of forested land in areas farther from the lake. Descriptions of the lake's sub-watersheds are as follows:

- **West –** This 34-acre sub-watershed encompasses the intersection of Upper Lakeview Avenue and Valley Road. This basin consists largely of low-density open space and forested land.
- **North –** This 56.1-acre sub-watershed encompasses parts of Upper Lakeview Avenue and Valley Road, as well as several acres of forested higher-elevation land.
- **East –** This is the largest sub-watershed that drains into Upper Erskine Lake at 95.2-acres. This basin encompasses a length of Upper Lakeview Avenue but is largely forested. Catnest swamp is located in the basin's northeast corner and drains into the lake via a small ephemeral stream.
- **South –** This 50.4-acre sub-watershed drains the residential areas along Bellot Road, Pequot Road, Laurel Place, and Spruce Place, as well as portions of Upper Lakeview Avenue and Lakeview Avenue. The remainder of the sub-watershed is largely forested.

Table 9. Land-use by sub-watershed in the Upper Erskine Lake watershed.

Source	Full Watershed	East	North	South	West
			Area (acres)		
Open Water	29.9	0.7	0.7	15.3	13.3
Hay/Pasture	0.0	0.0	0.0	0.0	0.0
Cropland	0.0	0.0	0.0	0.0	0.0
Forest	154.9	84.8	41.8	21.3	7.2
Wetland	12.4	7.2	3.5	0.0	1.7
Open Land	0.0	0.0	0.0	0.0	0.0
Barren Land	0.0	0.0	0.0	0.0	0.0
Low-Density Mixed	1.0	0.5	0.0	0.7	0.0
Medium-Density Mixed	0.7	0.0	0.0	0.0	0.7
High-Density Mixed	0.0	0.0	0.0	0.0	0.0
Low-Density Open Space	36.3	2.0	10.1	13.1	11.1
Total	235.2	95.2	56.1	50.4	34.0

Table 9 (cont'd). Land-use by sub-watershed in the Upper Erskine Lake watershed.

Source	Full Watershed	East	North	South	West
			Area (%)		
Open Water	12.7	0.7	1.2	30.4	39.1
Hay/Pasture	0.0	0.0	0.0	0.0	0.0
Cropland	0.0	0.0	0.0	0.0	0.0
Forest	65.9	89.1	74.5	42.3	21.2
Wetland	5.3	7.6	6.2	0.0	5.0
Open Land	0.0	0.0	0.0	0.0	0.0
Barren Land	0.0	0.0	0.0	0.0	0.0
Low-Density Mixed	0.4	0.5	0.0	1.4	0.0
Medium-Density Mixed	0.3	0.0	0.0	0.0	2.1
High-Density Mixed	0.0	0.0	0.0	0.0	0.0
Low-Density Open Space	15.4	2.1	18.0	26.0	32.6
Total	100	100	100	100	100

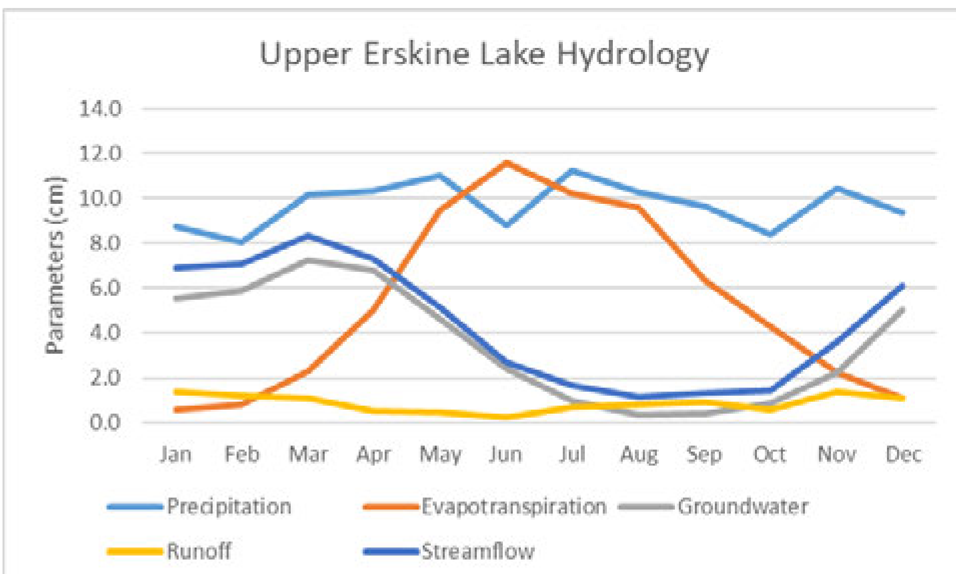

Figure 3. Estimated seasonal changes in hydrology in the Upper Erskine Lake watershed

Table 10: Total hydrological parameters in the full Upper Erskine Lake watershed over the course of a simulated year

Month	Precipitation	Evapotranspiration	Groundwater	Runoff	Streamflow	
	cm	cm	cm	cm	cm	cfs
Jan	8.8	0.6	5.5	1.4	6.9	0.9
Feb	8.0	0.8	5.9	1.2	7.1	1.0
Mar	10.2	2.3	7.2	1.1	8.3	1.0
Apr	10.4	5.0	6.8	0.5	7.3	0.9
May	11.0	9.5	4.7	0.5	5.1	0.6
Jun	8.8	11.6	2.4	0.3	2.7	0.3
Jul	11.2	10.2	1.0	0.7	1.7	0.2
Aug	10.2	9.6	0.3	0.8	1.2	0.1
Sep	9.7	6.4	0.4	0.9	1.3	0.2
Oct	8.4	4.3	0.9	0.6	1.4	0.2
Nov	10.4	2.2	2.2	1.4	3.6	0.5
Dec	9.3	1.1	5.0	1.1	6.1	0.8
Total	116.4	63.5	42.3	10.4	52.7	0.6

The West sub-watershed was estimated to yield a notably higher amount of runoff than the other sub-watersheds draining into Upper Erskine Lake, likely due to the relatively high percentage of low-density open space (Figure 4). It is also the only sub-watershed to contain land classified as medium-density mixed urban. The other three watersheds contain higher percentages of forested land, which contain more permeable landcover and likely serve to mitigate some total stormwater runoff. After factoring in direct precipitation and evaporation to the lake itself, Upper Erskine lake is estimated to receive approximately 569,999.6 m³ or 150.6 million gallons of water a year.

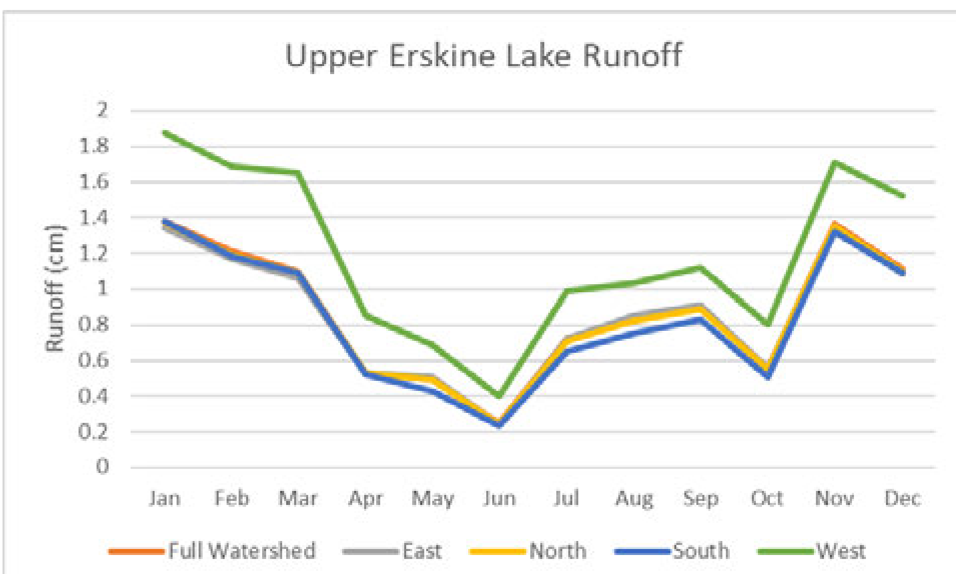

Figure 4. Average monthly runoff within sub-watersheds of the Upper Erskine Lake watershed

Table 11: Estimated annual loads of nitrogen in the total Upper Erskine Lake Watershed

Category	Description	Total Nitrogen kg	%
Runoff	Hay/Pasture	0.0	0.0
	Cropland	0.0	0.0
	Forest	15.2	0.9
	Wetland	2.4	0.1
	Open Land	0.0	0.0
	Barren Land	0.0	0.0
	Low-Density Mixed	0.1	0.0
	Medium-Density Mixed	0.4	0.0
	High-Density Mixed	0.0	0.0
	Low-Density Open Space	3.7	0.2
Other Sources	Farm Animals	0.0	0.0
	Stream Bank	0.0	0.0
	Groundwater	597.6	35.1
	Septic Systems	1082.4	63.6
	Total	1701.8	100.0

Table 12: Estimated annual loads of nitrogen by sub-watershed in the Upper Erskine Lake Watershed

Category	Description	Full Watershed kg	East kg	North kg	South kg	West kg
Runoff	Hay/Pasture	0.0	0.0	0.0	0.0	0.0
	Cropland	0.0	0.0	0.0	0.0	0.0
	Forest	15.2	7.8	3.4	1.6	0.8
	Wetland	2.4	1.4	0.7	0.0	0.3
	Open Land	0.0	0.0	0.0	0.0	0.0
	Barren Land	0.0	0.0	0.0	0.0	0.0
	Low-Density Mixed	0.1	0.1	0.0	0.1	0.0
	Medium-Density Mixed	0.4	0.0	0.0	0.0	0.4
	High-Density Mixed	0.0	0.0	0.0	0.0	0.0
	Low-Density Open Space	3.7	0.3	1.0	1.6	1.0
Other Sources	Farm Animals	0.0	0.0	0.0	0.0	0.0
	Stream Bank	0.0	0.0	0.0	0.0	0.0
	Groundwater	597.6	50.4	146.8	122.8	97.8
	Septic Systems	1082.4	382.8	198.0	343.2	158.4
	Total (kg)	1701.8	442.7	349.9	469.2	258.8

As with the previous lakes discussed, a majority of Upper Erskine Lake's nitrogen load originates from septic systems (Tables 11, 12). In addition, small amounts of nitrogen are also contributed by forested land-use types, particularly in the eastern sub-watershed.

Table 13: Estimated annual loads of phosphorus in the total Upper Erskine Lake Watershed

Category	Description	Total Phosphorus kg	Total Phosphorus %
Runoff	Hay/Pasture	0.0	0.0
	Cropland	0.0	0.0
	Forest	2.5	5.0
	Wetland	0.1	0.3
	Open Land	0.0	0.0
	Barren Land	0.0	0.0
	Low-Density Mixed	0.0	0.0
	Medium-Density Mixed	0.0	0.1
	High-Density Mixed	0.0	0.0
	Low-Density Open Space	0.4	0.8
Other Sources	Farm Animals	0.0	0.0
	Stream Bank	0.0	0.0
	Groundwater	7.0	13.9
	Septic Systems	40.6	80.0
	Total	50.7	100.0

Table 14: Estimated annual loads of phosphorus by sub-watershed for Upper Erskine Lake Watershed

Category	Description	Full Watershed kg	East kg	North kg	South kg	West kg
Runoff	Hay/Pasture	0.0	0.0	0.0	0.0	0.0
	Cropland	0.0	0.0	0.0	0.0	0.0
	Forest	2.5	1.2	0.4	0.1	0.1
	Wetland	0.1	0.1	0.0	0.0	0.0
	Open Land	0.0	0.0	0.0	0.0	0.0
	Barren Land	0.0	0.0	0.0	0.0	0.0
	Low-Density Mixed	0.0	0.0	0.0	0.0	0.0
	Medium-Density Mixed	0.0	0.0	0.0	0.0	0.0
	High-Density Mixed	0.0	0.0	0.0	0.0	0.0
	Low-Density Open Space	0.4	0.0	0.1	0.2	0.1
Other Sources	Farm Animals	0.0	0.0	0.0	0.0	0.0
	Stream Bank	0.0	0.0	0.0	0.0	0.0
	Groundwater	7.0	1.5	1.7	1.4	1.2
	Septic Systems	40.6	14.4	7.4	12.9	5.9
	Total (kg)	50.7	17.2	9.7	14.6	7.3

Septic systems were also the overall largest source of phosphorus in the Upper Erskine Lake watershed, contributing to 80% of the total annual load (Tables 13, 14). Groundwater influence was also estimated to contribute to a notable amount of the annual phosphorus. The West and East sub-watersheds were estimated to produce relatively low concentrations of phosphorus compared to the other two sub-watersheds, with the eastern sub-watershed featuring the highest estimated annual load.

Table 15: Estimated annual loads of sediment in the Upper Erskine Lake Watershed

Category	Description	Sediment kgx1000	Sediment %
Runoff	Hay/Pasture	0.0	0.0
	Cropland	0.0	0.0
	Forest	1.8	86.9
	Wetland	0.0	1.0
	Open Land	0.0	0.0
	Barren Land	0.0	0.0
	Low-Density Mixed	0.0	0.5
	Medium-Density Mixed	0.0	1.0
	High-Density Mixed	0.0	0.0
	Low-Density Open Space	0.2	9.3
Other Sources	Farm Animals	0.0	0.0
	Stream Bank	0.0	1.3
	Groundwater	0.0	0.0
	Septic Systems	0.0	0.0
	Total	2.0	100.0

Table 16: Estimated annual loads of sediment by sub-watershed in the Upper Erskine Lake Watershed

Category	Description	Full Watershed kg x 1000	East kg x 1000	North kg x 1000	South kg x 1000	West kg x 1000
Runoff	Hay/Pasture	0.0	0.0	0.0	0.0	0.0
	Cropland	0.0	0.0	0.0	0.0	0.0
	Forest	1.8	0.8	0.3	0.0	0.0
	Wetland	0.0	0.0	0.0	0.0	0.0
	Open Land	0.0	0.0	0.0	0.0	0.0
	Barren Land	0.0	0.0	0.0	0.0	0.0
	Low-Density Mixed	0.0	0.0	0.0	0.0	0.0
	Medium-Density Mixed	0.0	0.0	0.0	0.0	0.0
	High-Density Mixed	0.0	0.0	0.0	0.0	0.0
	Low-Density Open Space	0.2	0.0	0.1	0.1	0.1
Other Sources	Farm Animals	0.0	0.0	0.0	0.0	0.0
	Stream Bank	0.0	0.0	0.0	0.0	0.0
	Groundwater	0.0	0.0	0.0	0.0	0.0
	Septic Systems	0.0	0.0	0.0	0.0	0.0
	Total (kgx1000)	2.0	0.8	0.3	0.1	0.1

Most of the Upper Erskine Lake sub-watersheds' sediment loads are a product of runoff from forested and low-density open space land-use types, as well as from the erosion of stream banks (Tables 15, 16). The West sub-watershed is also estimated to yield a considerable sediment load from water running off of medium-density mixed urban land. In total, the full watershed is estimated to yield a relatively small amount of sediment, with the eastern sub-watershed contributing the most. Most of this sub-watershed's sediment load originates in forested land, however.

LOWER ERSKINE LAKE

Lower Erskine Lake's watershed covers an area of 488.9 acres and contains a larger percentage of urbanized land than that of Upper Erskine Lake (Table 17). A smaller portion of each sub-watershed (aside from that of Upper Erskine Lake) consists of forested land use. The lake drains west to Wanaque Reservoir. Descriptions of the lake's sub-watersheds are as follows:

- **Northwest –** This 65.6-acre sub-watershed contains the areas around the lake's dam, including the intersection of Lakeview Avenue and Mohawk Trail and a length of Oliver Place. This basin is dominated by low-density open space.
- **Southwest –** This 51.1-acre sub-watershed contains the intersection of Oliver Place and Tice Place, as well as the intersection of Short Place and Lakeview Avenue. The southern portion of this sub-watershed also contains about 15-acres of forested land, however the sub-watershed is dominated by low-density open space.
- **Beach –** This relatively small, 27.4-acre sub-watershed contains the lake's southern beach area, as well as some of the immediately adjacent developed and forested areas.
- **Southeast –** This 30.3-acre basin contains the intersections of Lakeview avenue with Laurel Place and Bellot Road. This basin is dominated by low-density open space.
- **Upper Erskine Lake –** This 314.8-acre sub-watershed contains the entire Upper Erskine Lake watershed (described above), as well as portions of northeast lower Erskine Lake. This sub-watershed is dominated by forested land.

Table 17. Land-use by sub-watershed in the Lower Erskine Lake watershed.

Source	Full Watershed	Beach	Northwest	Southeast	Southwest	Upper Erskine
	Area (acres)					
Open Water	98.2	15.96	13.52	11.75	7.09	49.88
Hay/Pasture	0	0	0	0	0	0
Cropland	0	0	0	0	0	0
Forest	199.2	4.2	9.4	3.7	7.7	174.2
Wetland	23	0	4	0	1.2	17.8
Open Land	0	0	0	0	0	0
Barren Land	0	0	0	0	0	0
Low-Density Mixed	9.4	1	2.7	0.7	2.2	2.7
Medium-Density Mixed	1.7	0	0.2	0	0.5	1
High-Density Mixed	0.2	0	0.2	0	0	0
Low-Density Open Space	157.2	6.2	35.6	14.1	32.4	69.2
Total	488.9	27.36	65.62	30.25	51.09	314.78

Source	Full Watershed	Beach	Northwest	Southeast	Southwest	Upper Erskine
	Area (%)					
Open Water	20.1	58.3	20.6	38.8	13.9	15.8
Hay/Pasture	0.0	0.0	0.0	0.0	0.0	0.0
Cropland	0.0	0.0	0.0	0.0	0.0	0.0
Forest	40.7	15.4	14.3	12.2	15.1	55.3
Wetland	4.7	0.0	6.1	0.0	2.3	5.7
Open Land	0.0	0.0	0.0	0.0	0.0	0.0
Barren Land	0.0	0.0	0.0	0.0	0.0	0.0
Low-Density Mixed	1.9	3.7	4.1	2.3	4.3	0.9
Medium-Density Mixed	0.3	0.0	0.3	0.0	1.0	0.3
High-Density Mixed	0.0	0.0	0.3	0.0	0.0	0.0
Low-Density Open Space	32.2	22.7	54.3	46.6	63.4	22.0
Total	100	100	100	100	100	100

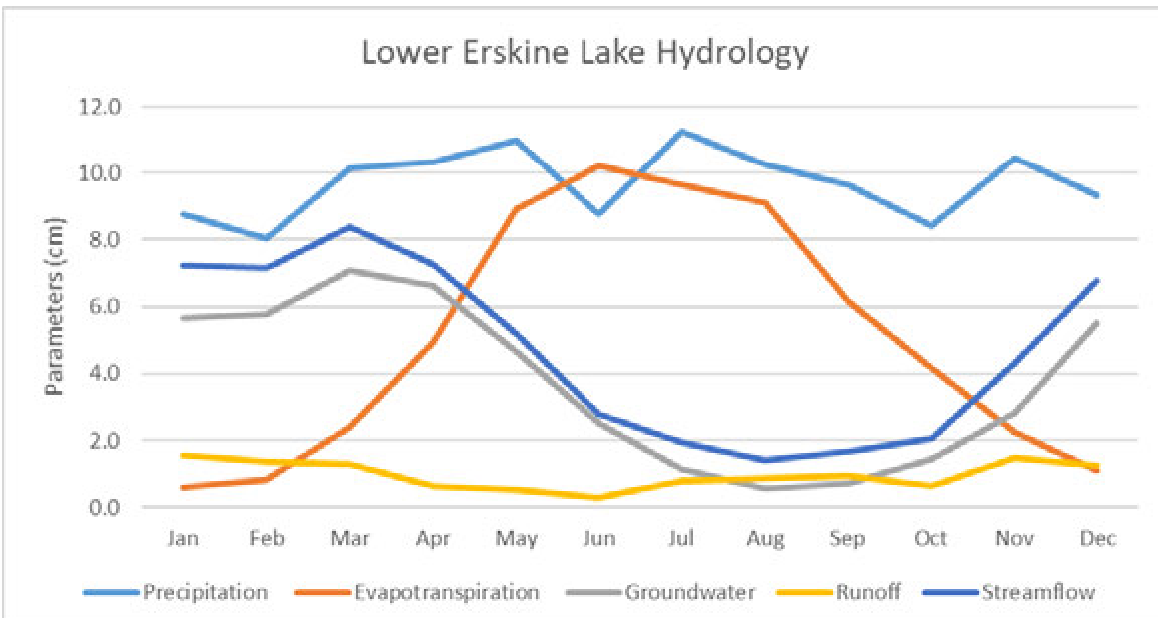

Figure 5. Estimated seasonal changes in hydrology in the Lower Erskine Lake watershed

Table 18: Total hydrological parameters in the full Lower Erskine Lake watershed

Month	Precipitation	Evapotranspiration	Groundwater	Runoff	Streamflow	
	cm	cm	cm	cm	cm	cfs
Jan	8.8	0.6	5.7	1.6	7.2	1.9
Feb	8.0	0.8	5.8	1.4	7.2	2.0
Mar	10.2	2.4	7.1	1.3	8.4	2.2
Apr	10.4	4.9	6.6	0.6	7.3	2.0
May	11.0	8.9	4.7	0.5	5.2	1.4
Jun	8.8	10.2	2.5	0.3	2.8	0.8
Jul	11.2	9.6	1.1	0.8	1.9	0.5
Aug	10.2	9.1	0.6	0.9	1.4	0.4
Sep	9.7	6.2	0.7	1.0	1.7	0.5
Oct	8.4	4.2	1.4	0.6	2.1	0.5
Nov	10.4	2.2	2.8	1.5	4.3	1.2
Dec	9.3	1.1	5.5	1.3	6.8	1.8
Total	116.4	60.3	44.5	11.7	56.2	1.2

Runoff into Lower Lake Erskine was generally similar between the different sub-watersheds, although the northwest and southwest basins feature slightly higher rates of runoff earlier in the year, likely due to the increased amount of impervious landcover in these sub-watersheds (Figure 6). When direct precipitation and evapotranspiration in the Lake itself is factored in, Lower Erskine Lake is estimated to receive an annual hydrologic load of approximately 1,514,078 m³ or 400 million gallons of water.

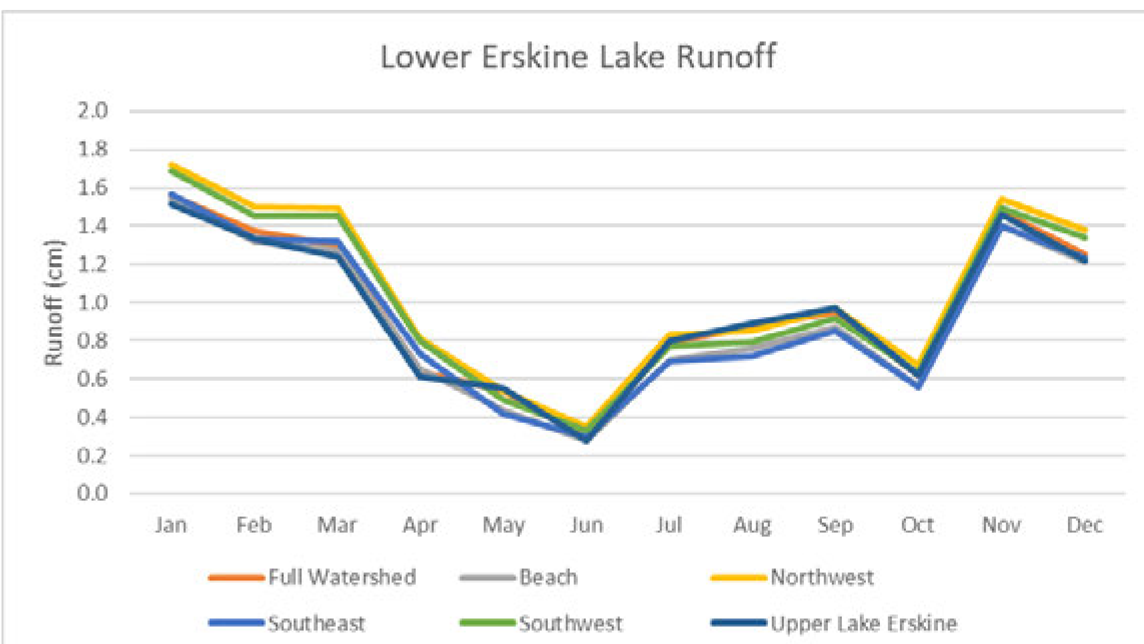

Figure 6. Average monthly runoff within each sub-watershed in the Lower Erskine Lake watershed

Table 19: Estimated annual loads of nitrogen in the total Lower Erskine Lake Watershed

Category	Description	Total Nitrogen kg	Total Nitrogen %
Runoff	Hay/Pasture	0.0	0.00
	Cropland	0.0	0.00
	Forest	19.4	0.34
	Wetland	4.4	0.08
	Open Land	0.0	0.00
	Barren Land	0.0	0.00
	Low-Density Mixed	1.0	0.02
	Medium-Density Mixed	0.8	0.01
	High-Density Mixed	0.1	0.00
	Low-Density Open Space	16.5	0.29
Other Sources	Farm Animals	0.0	0.00
	Stream Bank	4.0	0.07
	Groundwater	1169.0	20.64
	Septic Systems	4448.4	78.54
	Total	5663.6	100

Table 20: Estimated annual loads of nitrogen by sub-watershed in the Lower Erskine Lake Watershed

Category	Description	Full Watershed kg	Beach kg	Northwest kg	Southeast kg	Southwest kg	Upper kg
Runoff	Hay/Pasture	0.00	0.00	0.00	0.00	0.00	0.00
	Cropland	0.00	0.00	0.00	0.00	0.00	0.00
	Forest	19.42	0.31	0.69	0.22	0.57	18.46
	Wetland	4.36	0.00	0.74	0.00	0.23	3.38
	Open Land	0.00	0.00	0.00	0.00	0.00	0.00
	Barren Land	0.00	0.00	0.00	0.00	0.00	0.00
	Low-Density Mixed	0.99	0.11	0.30	0.08	0.24	0.28
	Medium-Density Mixed	0.80	0.00	0.14	0.00	0.27	0.54
	High-Density Mixed	0.11	0.00	0.19	0.00	0.00	0.00
	Low-Density Open Space	16.51	0.70	3.97	1.48	3.46	7.19
Other Sources	Farm Animals	0.00	0.00	0.00	0.00	0.00	0.00
	Stream Bank	4.00	0.00	1.00	0.00	0.00	0.00
	Groundwater	1168.98	10.70	179.66	14.22	25.55	764.00
	Septic Systems	4448.40	211.20	844.80	501.60	897.60	1993.20
	Total (kg)	5663.57	223.02	1031.49	517.60	927.92	2787.05

Nitrogen loads in the Lower Erskine watershed were mainly contributed by septic system influence, which, as stated above, can result in a considerable amount also being contributed by groundwater flows (Tables 19, 20). While not a high percentage of the watershed's overall nitrogen load, forested land and urban areas contributed the majority of the runoff-based nitrogen load.

Table 21: Estimated annual loads of phosphorus in the total Lower Erskine Lake Watershed

Category	Description	Total Phosphorus	
		kg	%
Runoff	Hay/Pasture	0.0	0.0
	Cropland	0.0	0.0
	Forest	2.5	1.3
	Wetland	0.3	0.1
	Open Land	0.0	0.0
	Barren Land	0.0	0.0
	Low-Density Mixed	0.1	0.1
	Medium-Density Mixed	0.1	0.0
	High-Density Mixed	0.0	0.0
	Low-Density Open Space	1.8	1.0
Other Sources	Farm Animals	0.0	0.0
	Stream Bank	2.0	1.1
	Groundwater	14.1	7.5
	Septic Systems	166.8	88.9
	Total	187.7	100.0

Table 22: Estimated annual load of phosphorus/sub-watershed in the Lower Erskine Lake Watershed

Category	Description	Full Watershed	Beach	Northwest	Southeast	Southwest	Upper
		kg	kg	kg	kg	kg	kg
Runoff	Hay/Pasture	0.0	0.0	0.0	0.0	0.0	0.0
	Cropland	0.0	0.0	0.0	0.0	0.0	0.0
	Forest	2.5	0.0	0.1	0.0	0.0	3.0
	Wetland	0.3	0.0	0.0	0.0	0.0	0.2
	Open Land	0.0	0.0	0.0	0.0	0.0	0.0
	Barren Land	0.0	0.0	0.0	0.0	0.0	0.0
	Low-Density Mixed	0.1	0.0	0.0	0.0	0.0	0.0
	Medium-Density Mixed	0.1	0.0	0.0	0.0	0.0	0.1
	High-Density Mixed	0.0	0.0	0.0	0.0	0.0	0.0
	Low-Density Open Space	1.8	0.1	0.4	0.1	0.4	0.8
Other Sources	Farm Animals	0.0	0.0	0.0	0.0		0.0
	Stream Bank	2.0	0.0	0.0	0.0	0.0	0.0
	Groundwater	14.1	0.3	2.3	0.4	0.8	9.0
	Septic Systems	166.8	7.9	31.7	18.8	33.7	74.7
	Total (kg)	187.7	8.3	34.6	19.3	34.9	87.8

As with nitrogen loads, phosphorus loads in the Lower Erskine Lake watershed are estimated to originate largely (over 90% in most cases) from septic systems, as well as, to a lesser extent, groundwater flows (Tables 21, 22). Runoff from low-density open space also contributes noticeably to phosphorus loading, particularly in the northwest and southwest sub-watersheds, as does forested land in the Upper Erskine Lake watershed.

Table 23: Estimated annual loads of sediment in the total Lower Erskine Lake Watershed

Category	Description	Sediment kgx1000	Sediment %
Runoff	Hay/Pasture	0.0	0.0
	Cropland	0.0	0.0
	Forest	1.5	16.7
	Wetland	0.0	0.3
	Open Land	0.0	0.0
	Barren Land	0.0	0.0
	Low-Density Mixed	0.1	0.6
	Medium-Density Mixed	0.0	0.4
	High-Density Mixed	0.0	0.1
	Low-Density Open Space	0.8	9.1
Other Sources	Farm Animals	0.0	0.0
	Stream Bank	6.5	72.8
	Groundwater	0.0	0.0
	Septic Systems	0.0	0.0
	Total	8.9	100.0

Table 24: Estimated annual loads of sediment by sub-watershed in the Lower Erskine Lake Watershed

Category	Description	Full Watershed kg x 1000	Beach kg x 1000	Northwest kg x 1000	Southeast kg x 1000	Southwest kg x 1000	Upper kg x 1000
Runoff	Hay/Pasture	0.0	0.0	0.0	0.0	0.0	0.0
	Cropland	0.0	0.0	0.0	0.0	0.0	0.0
	Forest	1.5	0.0	0.0	0.0	0.0	2.0
	Wetland	0.0	0.0	0.0	0.0	0.0	0.0
	Open Land	0.0	0.0	0.0	0.0	0.0	0.0
	Barren Land	0.0	0.0	0.0	0.0	0.0	0.0
	Low-Density Mixed	0.1	0.0	0.0	0.0	0.0	0.0
	Medium-Density Mixed	0.0	0.0	0.0	0.0	0.0	0.0
	High-Density Mixed	0.0	0.0	0.0	0.0	0.0	0.0
	Low-Density Open Space	0.8	0.0	0.2	0.1	0.2	0.4
Other Sources	Farm Animals	0.0	0.0	0.0	0.0	0.0	0.0
	Stream Bank	6.5	0.7	1.3	0.5	0.1	0.0
	Groundwater	0.0	0.0	0.0	0.0	0.0	0.0
	Septic Systems	0.0	0.0	0.0	0.0	0.0	0.0
	Total (kgx1000)	8.9	0.7	1.5	0.5	0.3	2.5

Most of the sediment entering Lower Erskine lake is contributed by stream bank erosion; this is particularly prevalent in the beach sub-watershed (Tables 23, 24). The southwest sub-watershed is estimated to contribute a relatively large proportion of sediment via runoff from urbanized areas.

UPPER SKYLINE LAKE

Upper Skyline Lake's watershed covers an area of 1,734.3 acres (Table 25). While this watershed contains relatively large amounts of urban land, it also contains many acres of high-elevation forested land. Of particular note is that the two Skyline lakes are the only Lakes in this study whose watersheds contain known point-source surface water discharges. These occur near the eastern end of Alta Vista Drive and just north of the Route 692 bridge over High Mountain Brook. Descriptions of Upper Skyline Lake's sub-watersheds are as follows:

- **Upper High Mountain –** This 570.3-acre sub-watershed consists almost entirely of higher-elevation forested land in the Ramapo Mountains, including High Mountain Brook's headwaters at Brushwood Pond.
- **Lower High Mountain –** This 835.5-acre sub-watershed is dominated by forested land, with considerable amounts of urbanized land closer to the lake. It also contains a point-source discharge into High Mountain Brook, as mentioned above.
- **Plaza –** This 185.2-acre sub-watershed is split between forested land and developed area, with commercial parking lots and buildings in the northern portion. The point-source discharge located near Alta Vista Drive is located in this sub-watershed.
- **West –** This 92.1-acre sub-watershed is dominated low-density open space, containing a length of Skyline Lake Drive, as well as Smokey Ridge Road, Hilltop Road, and Buena Vista Drive.
- **East –** This 49.2-acre sub-watershed is split between forested and urbanized land, containing a length of Skyline Lake Drive, as well as Lakeview Road, High Mountain Road, and Finch Road.

Table 25: Land-use by sub-watershed in the Upper Skyline Lake watershed

Source	Full Watershed	East	Lower High Mt.	Upper High Mt.	Plaza	West
			Area (acres)			
Open Water	19.8	9.1	0.0	2.5	0.0	7.1
Hay/Pasture	0.0	0.0	0.0	0.0	0.0	0.0
Cropland	0.0	0.0	0.0	0.0	0.0	0.0
Forest	1154.5	21.3	506.1	520.4	82.5	24.5
Wetland	106.5	0.0	34.8	43.7	20.5	7.2
Open Land	2.5	0.0	0.0	2.5	0.0	0.0
Barren Land	0.0	0.0	0.0	0.0	0.0	0.0
Low-Density Mixed	58.1	3.5	38.1	0.0	11.1	4.9
Medium-Density Mixed	12.8	0.7	1.5	0.0	10.6	0.0
High-Density Mixed	4.7	0.0	0.0	0.0	4.7	0.0
Low-Density Open Space	375.4	14.6	255.0	1.2	55.8	48.4
Total	1734.3	49.2	835.5	570.3	185.2	92.1

Source	Full Watershed	East	Lower High Mt. Area (%)	Upper High Mt.	Plaza	West
Open Water	1.1	18.5	0.0	0.4	0.0	7.7
Hay/Pasture	0.0	0.0	0.0	0.0	0.0	0.0
Cropland	0.0	0.0	0.0	0.0	0.0	0.0
Forest	66.6	43.3	60.6	91.3	44.5	26.6
Wetland	6.1	0.0	4.2	7.7	11.1	7.8
Open Land	0.1	0.0	0.0	0.4	0.0	0.0
Barren Land	0.0	0.0	0.0	0.0	0.0	0.0
Low-Density Mixed	3.4	7.1	4.6	0.0	6.0	5.3
Medium-Density Mixed	0.7	1.4	0.2	0.0	5.7	0.0
High-Density Mixed	0.3	0.0	0.0	0.0	2.5	0.0
Low-Density Open Space	21.6	29.7	30.5	0.2	30.1	52.6
Total	100.0	100.0	100.0	100.0	100.0	100.0

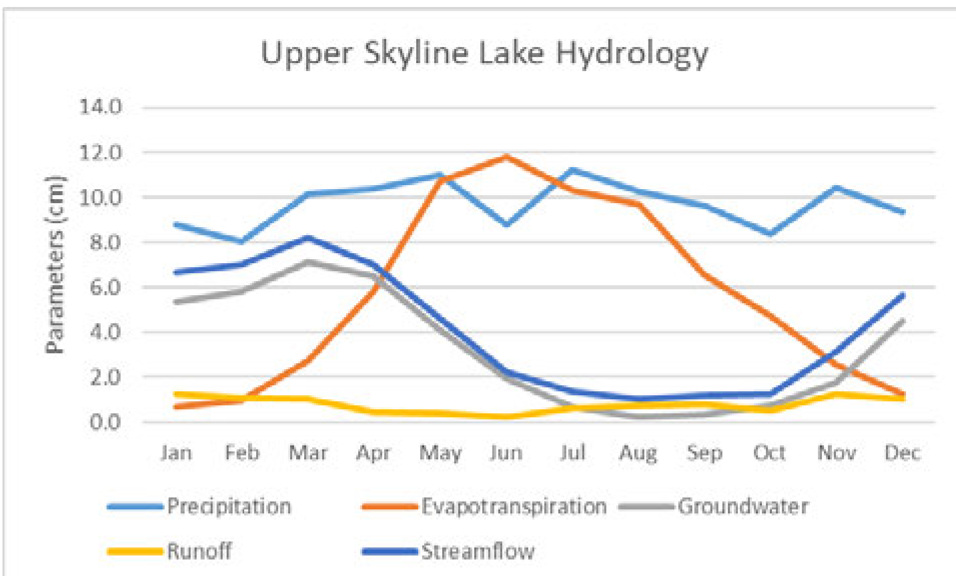

Figure 7. Estimated seasonal changes in hydrology in the Upper Skyline Lake watershed

Table 26: Total hydrological parameters in the full Upper Skyline Lake watershed

Month	Precipitation	Evapotranspiration	Groundwater	Runoff	Streamflow	
	cm	cm	cm	cm	cm	cfs
Jan	8.8	0.7	5.3	1.3	6.7	6.2
Feb	8.0	1.0	5.8	1.1	7.0	7.1
Mar	10.2	2.7	7.1	1.0	8.2	7.6
Apr	10.4	5.8	6.5	0.5	7.0	6.7
May	11.0	10.7	4.1	0.4	4.6	4.2
Jun	8.8	11.8	1.9	0.2	2.2	2.1
Jul	11.2	10.3	0.7	0.6	1.4	1.3
Aug	10.2	9.7	0.2	0.7	1.0	0.9
Sep	9.7	6.6	0.4	0.8	1.2	1.2
Oct	8.4	4.7	0.7	0.5	1.3	1.2
Nov	10.4	2.6	1.8	1.3	3.1	3.0
Dec	9.3	1.3	4.5	1.0	5.7	5.2
Total	116.4	67.8	39.1	9.4	49.4	3.9

Relatively high rates of runoff are estimated to occur in the East, West, and Plaza watersheds, likely due to the high proportion of urbanized land-use in these areas (Figure 8). The Lower High Mountain sub-watershed features a markedly lower estimated runoff compared to the other sub-watersheds; while this sub-watershed contains large amounts of urbanized land, it likely is estimated to contain enough forested and wetland land-cover to offset some of the runoff occurring over the urbanized areas. When direct precipitation and evaporation to and from the lake itself are factored in, Upper Skyline Lake is estimated to receive approximately 3,444,125 m³ or 909.8 million gallons of water a year.

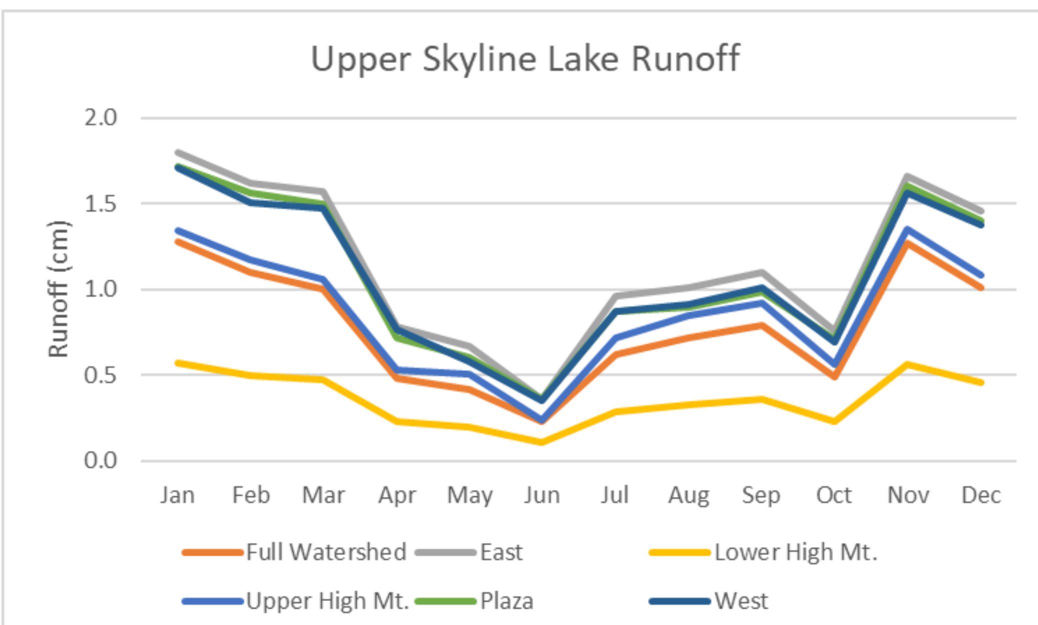

Figure 8. Average monthly runoff occurring within the Upper Skyline Lake watershed

Table 27: Estimated annual loads of nitrogen in the total Upper Skyline Lake Watershed

Category	Description	Total Nitrogen	
		kg	%
Runoff	Hay/Pasture	0.0	0.0
	Cropland	0.0	0.0
	Forest	79.7	1.2
	Wetland	20.4	0.3
	Open Land	1.6	0.0
	Barren Land	0.0	0.0
	Low-Density Mixed	6.7	0.1
	Medium-Density Mixed	8.1	0.1
	High-Density Mixed	3.0	0.0
	Low-Density Open Space	43.5	0.7
Other Sources	Farm Animals	0.0	0.0
	Stream Bank	65.0	1.0
	Groundwater	2006.4	30.7
	Point Source Discharges	654.4	10.0
	Septic Systems	3643.2	55.8
	Total	6532.1	100.0

Table 28: Estimated annual loads of nitrogen by sub-watershed in the Skyline Lake Watershed

Category	Description	Full Watershed	East	Lower High Mt.	Upper High Mt.	Plaza	West
		kg	kg	kg	kg	kg	kg
Runoff	Hay/Pasture	0.0	0.0	0.0	0.0	0.0	0.0
	Cropland	0.0	0.0	0.0	0.0	0.0	0.0
	Forest	79.7	2.6	40.6	41.7	5.6	2.3
	Wetland	20.4	0.0	8.6	8.3	3.9	1.3
	Open Land	1.6	0.0	0.0	1.7	0.0	0.0
	Barren Land	0.0	0.0	0.0	0.0	0.0	0.0
	Low-Density Mixed	6.7	0.5	4.4	0.0	1.3	0.5
	Medium-Density Mixed	8.1	0.4	0.5	0.0	7.0	0.0
	High-Density Mixed	3.0	0.0	0.0	0.0	3.1	0.0
	Low-Density Open Space	43.5	1.9	29.6	0.1	6.5	5.3
Other Sources	Farm Animals	0.0	0.0	0.0	0.0	0.0	0.0
	Stream Bank	65.0	0.0	28.0	1.0	0.0	4.0
	Groundwater	2006.4	62.5	1081.1	311.2	85.9	110.0
	Point Source discharges	654.4	0.0	21.4	0.0	4.8	0.0
	Septic Systems	3643.2	633.6	1597.2	0.0	369.6	1042.8
	Total (kg)	6532.1	701.5	2811.4	364.0	487.6	1166.2

Most of the Upper Skyline Lake external nitrogen load originates from septic systems and, as a result, groundwater flows (Tables 27, 28). It should be noted that, although not a large source of nitrogen relative to septic systems or groundwater, point source discharges are estimated to yield approximately 654.4 kg of nitrogen a year.

Table 29: Estimated annual loads of phosphorus in the total Upper Skyline Lake Watershed

Category	Description	Total Phosphorus kg	%
Runoff	Hay/Pasture	0.0	0.0
	Cropland	0.0	0.0
	Forest	10.0	3.9
	Wetland	1.2	0.5
	Open Land	0.2	0.1
	Barren Land	0.0	0.0
	Low-Density Mixed	0.7	0.3
	Medium-Density Mixed	0.8	0.3
	High-Density Mixed	0.3	0.1
	Low-Density Open Space	4.8	1.8
Other Sources	Farm Animals	0.0	0.0
	Stream Bank	24.0	9.3
	Groundwater	54.2	20.9
	Point Source Discharges	26.2	10.1
	Septic Systems	136.6	52.7
	Total	259.1	100.0

Table 30: Estimated annual loads of phosphorus/sub-watershed in the Upper Skyline Lake Watershed

Category	Description	Full Watershed kg	East kg	Lower High Mt. kg	Upper High Mt. kg	Plaza kg	West kg
Runoff	Hay/Pasture	0.0	0.0	0.0	0.0	0.0	0.0
	Cropland	0.0	0.0	0.0	0.0	0.0	0.0
	Forest	10.0	0.2	3.6	4.0	0.8	0.2
	Wetland	1.2	0.0	0.5	0.5	0.2	0.1
	Open Land	0.2	0.0	0.0	0.2	0.0	0.0
	Barren Land	0.0	0.0	0.0	0.0	0.0	0.0
	Low-Density Mixed	0.7	0.1	0.5	0.0	0.1	0.1
	Medium-Density Mixed	0.8	0.0	0.1	0.0	0.7	0.0
	High-Density Mixed	0.3	0.0	0.0	0.0	0.3	0.0
	Low-Density Open Space	4.8	0.2	3.3	0.0	0.7	0.6
Other Sources	Farm Animals	0.0	0.0	0.0	0.0	0.0	0.0
	Stream Bank	24.0	0.0	10.0	0.0	0.0	2.0
	Groundwater	54.2	1.4	24.6	8.0	2.5	2.4
	Point Source Discharges	26.2	0.0	23.1	0.0	3.0	0.0
	Septic Systems	136.6	23.8	59.9	0.0	13.9	39.1
	Total (kg)	259.1	25.7	125.5	12.7	22.3	44.4

As with nitrogen concentrations, phosphorus in the Upper Skyline Lake watershed is estimated to largely originate from groundwater and septic systems, with a notable concentration also originating from point source discharges (Tables 29, 30). The Lower High Mountain sub-watershed was estimated to yield the largest yearly phosphorus load, with most of this load originating from septic systems, while groundwater and point source discharges also notably contribute. This sub-watershed's relatively high annual phosphorus load is likely a product of the relatively high amount of development that occurs on both sides of Skyline Drive. The plaza watershed also yields a considerable amount of estimated yearly phosphorus from point source discharges; however, this is largely surpassed by loading from septic systems. Additionally, forested Land and low-density open space contribute significantly to phosphorus entering the lake from runoff.

Table 31: Estimated annual loads of sediment in the total Upper Skyline Lake Watershed

Category	Description	Sediment	
		kgx1000	%
Runoff	Hay/Pasture	0.0	0.0
	Cropland	0.0	0.0
	Forest	6.2	6.5
	Wetland	0.2	0.2
	Open Land	0.1	0.1
	Barren Land	0.0	0.0
	Low-Density Mixed	0.3	0.3
	Medium-Density Mixed	0.4	0.4
	High-Density Mixed	0.1	0.1
	Low-Density Open Space	2.0	2.1
Other Sources	Farm Animals	0.0	0.0
	Stream Bank	86.0	90.2
	Groundwater	0.0	0.0
	Septic Systems	0.0	0.0
	Total	95.4	100.0

Table 32: Estimated annual loads of sediment by sub-watershed in the Upper Skyline Lake Watershed

Category	Description	Full Watershed kg x 1000	East kg x 1000	Lower High Mt. kg x 1000	Upper High Mt. kg x 1000	Plaza kg x 1000	West kg x 1000
Runoff	Hay/Pasture	0.0	0.0	0.0	0.0	0.0	0.0
	Cropland	0.0	0.0	0.0	0.0	0.0	0.0
	Forest	6.2	0.1	1.6	1.8	0.5	0.1
	Wetland	0.2	0.0	0.1	0.1	0.0	0.0
	Open Land	0.1	0.0	0.0	0.1	0.0	0.0
	Barren Land	0.0	0.0	0.0	0.0	0.0	0.0
	Low-Density Mixed	0.3	0.0	0.2	0.0	0.1	0.0
	Medium-Density Mixed	0.4	0.0	0.0	0.0	0.3	0.0
	High-Density Mixed	0.1	0.0	0.0	0.0	0.1	0.0
	Low-Density Open Space	2.0	0.1	1.4	0.0	0.3	0.3
Other Sources	Farm Animals	0.0	0.0	0.0	0.0	0.0	0.0
	Stream Bank	86.0	0.1	35.1	1.5	0.1	5.7
	Groundwater	0.0	0.0	0.0	0.0	0.0	0.0
	Septic Systems	0.0	0.0	0.0	0.0	0.0	0.0
	Total (kgx1000)	95.4	0.3	38.5	3.5	1.4	6.1

As with nitrogen and phosphorus, the Lower High Mountain watershed is estimated to yield the highest yearly sediment load, over 90% of which is contributed to by stream bank erosion (Tables 31, 32). Forested land and low-density open space also contribute significantly to the portion of sediment entering the lake from runoff.

LOWER SKYLINE LAKE

Lower Skyline Lake's watershed covers an area of 1,892.32 acres (Table 33). While this area is largely dominated by forested land, a considerable amount of urbanized landcover is also present, particularly in the East and Northwest sub-watersheds. Descriptions of Lower Skyline Lake's subwaterlands are as follows:

- **Hidden Valley Lake –** This 107.7-acre sub-watershed is dominated by forested land, with a considerable amount of urbanized land also present. This watershed contains the entire watershed of Hidden Valley Lake, which flows into the Western portion of Lower Skyline Lake.
- **Southwest –** This small, 6.7-acre sub-watershed is dominated by urbanized land. It contains a small portion of skyline lakes drive and the southwestern beach.
- **Northwest –** This 14.8-acre sub-watershed is also dominated by urbanized land, encompassing the intersection of Skyline Lakes Drive and Mountain Glen Road.
- **East –** This 31.2-acre sub-watershed is dominated by urbanized land, with a considerable amount of forested land also present. It contains the eastern portion of Skyline Lakes Drive and part of Finch Road.

Table 33. Land-use by sub-watershed in the Lower Skyline Lake watershed.

Source	Full Watershed	East	Hidden Valley Lake	Northwest	Southwest	Upper Skyline
	Area (acres)					
Open Water	32.1	5.8	2.7	2.9	2.7	19.8
Hay/Pasture	0.0	0.0	0.0	0.0	0.0	0
Cropland	0.0	0.0	0.0	0.0	0.0	0
Forest	1221.7	11.1	52.1	3.7	0.0	1154.5
Wetland	124.5	0.7	16.3	0.0	1.0	106.5
Open Land	2.5	0.0	0.0	0.0	0.0	2.5
Barren Land	0.0	0.0	0.0	0.0	0.0	0
Low-Density Mixed	79.6	4.0	14.3	2.5	1.2	58.1
Medium-Density Mixed	19.5	0.2	6.2	0.0	0.2	12.8
High-Density Mixed	5.4	0.0	0.5	0.0	0.2	4.7
Low-Density Open Space	407.0	9.4	15.6	5.7	1.0	375.4
Total	1892.3	31.2	107.7	14.8	6.3	1734.3

Source	Full Watershed	East	Hidden Valley Lake	Northwest	Southwest	Upper Skyline
	Area (%)					
Open Water	1.7	18.5	2.5	19.5	42.5	1.1
Hay/Pasture	0.0	0.0	0.0	0.0	0.0	0.0
Cropland	0.0	0.0	0.0	0.0	0.0	0.0
Forest	64.6	35.6	48.4	25.0	0.0	66.6
Wetland	6.6	2.2	15.1	0.0	16.0	6.1
Open Land	0.1	0.0	0.0	0.0	0.0	0.1
Barren Land	0.0	0.0	0.0	0.0	0.0	0.0
Low-Density Mixed	4.2	12.8	13.3	16.9	19.2	3.4
Medium-Density Mixed	1.0	0.6	5.8	0.0	3.2	0.7
High-Density Mixed	0.3	0.0	0.5	0.0	3.2	0.3
Low-Density Open Space	21.5	30.2	14.5	38.6	16.0	21.6
Total	100	100	100	100	100	100.0

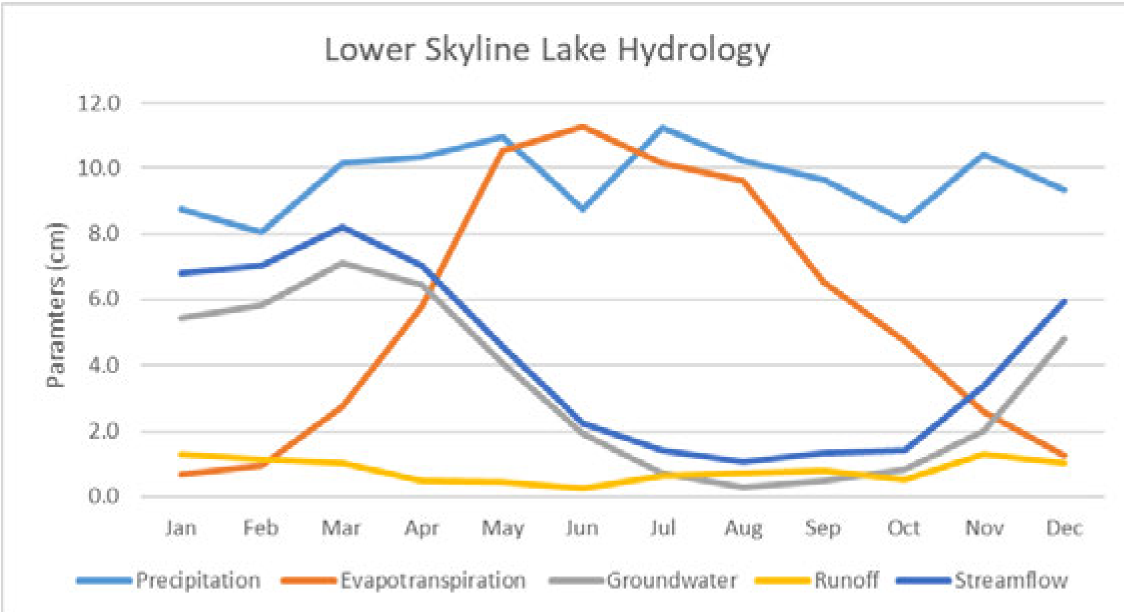

Figure 9. Estimated seasonal changes in hydrology in the Lower Skyline Lake watershed

Table 34: Total hydrological parameters in the full Lower Skyline Lake watershed

Month	Precipitation	Evapotranspiration	Groundwater	Runoff	Streamflow	
	cm	cm	cm	cm	cm	cfs
Jan	8.8	0.7	5.4	1.3	6.8	6.9
Feb	8.0	1.0	5.8	1.1	7.0	7.8
Mar	10.2	2.7	7.1	1.0	8.2	8.3
Apr	10.4	5.8	6.5	0.5	7.0	7.3
May	11.0	10.5	4.1	0.4	4.6	4.6
Jun	8.8	11.3	1.9	0.2	2.2	2.3
Jul	11.2	10.1	0.7	0.6	1.4	1.4
Aug	10.2	9.6	0.3	0.7	1.1	1.1
Sep	9.7	6.5	0.5	0.8	1.3	1.4
Oct	8.4	4.7	0.8	0.5	1.4	1.4
Nov	10.4	2.6	2.0	1.3	3.4	3.5
Dec	9.3	1.3	4.8	1.0	5.9	6.0
Total	116.4	66.8	39.9	9.6	50.4	4.3

The Southwest watershed is estimated to produce a markedly higher rate of runoff per unit area than the other watersheds (Figure 10). This likely is a product of the watershed's relatively high prevalence of impervious landcover. Once precipitation and evapotranspiration to and from the lake directly are factored in, lower Skyline Lake is estimate to receive approximately 3,822,315 m³ or 1,009.8 million gallons of water a year.

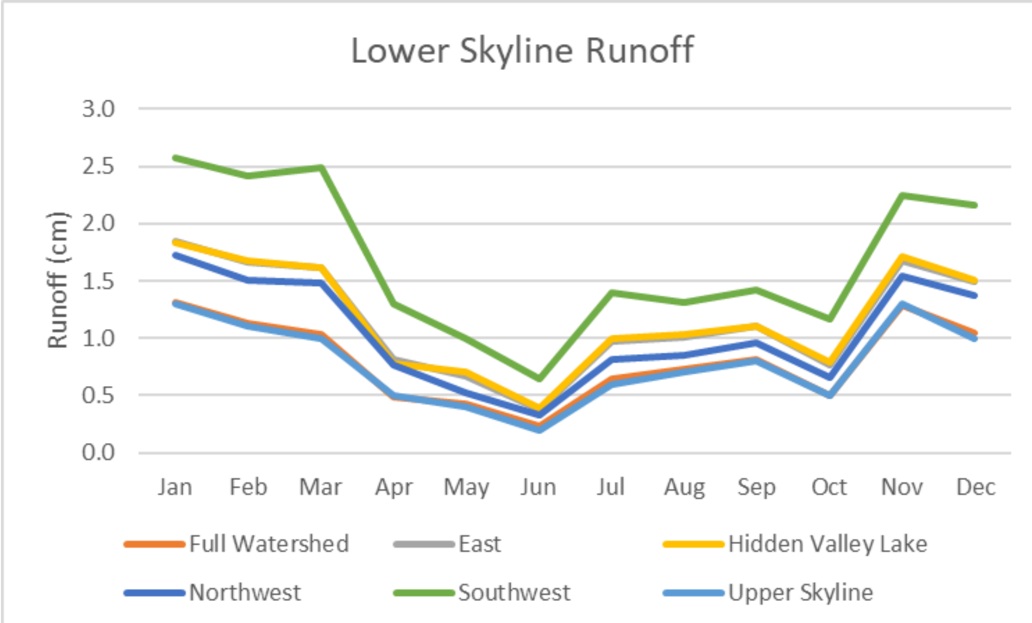

Figure 10. Average monthly runoff within each sub-watershed in the Lower Skyline Lake watershed

Table 35: Estimated annual loads of nitrogen in the total Lower Skyline Lake Watershed

Category	Description	Total Nitrogen kg	%
Runoff	Hay/Pasture	0.0	0.0
	Cropland	0.0	0.0
	Forest	75.9	0.9
	Wetland	21.6	0.3
	Open Land	1.5	0.0
	Barren Land	0.0	0.0
	Low-Density Mixed	8.6	0.1
	Medium-Density Mixed	10.9	0.1
	High-Density Mixed	3.0	0.0
	Low-Density Open Space	44.2	0.6
Other Sources	Farm Animals	0.0	0.0
	Stream Bank	69.0	0.9
	Groundwater	2064.2	25.8
	Point source discharges	591.7	7.4
	Septic Systems	5108.4	63.9
	Total	7999.0	100.0

Table 36: Estimated annual loads of nitrogen by sub-watershed in the Lower Skyline Lake Watershed

Category	Description	Full Watershed	East	Hidden Valley Lake	Northwest	Southwest	Upper Skyline
		kg	kg	kg	kg	kg	kg
Runoff	Hay/Pasture	0.0	0.0	0.0	0.0	0.0	0.0
	Cropland	0.0	0.0	0.0	0.0	0.0	0.0
	Forest	75.9	1.4	4.0	0.3	0.0	79.7
	Wetland	21.6	0.1	3.0	0.0	0.2	20.4
	Open Land	1.5	0.0	0.0	0.0	0.0	1.6
	Barren Land	0.0	0.0	0.0	0.0	0.0	0.0
	Low-Density Mixed	8.6	0.5	2.3	0.4	0.2	6.7
	Medium-Density Mixed	10.9	0.1	3.1	0.0	0.1	8.1
	High-Density Mixed	3.0	0.0	0.3	0.0	0.2	3.0
	Low-Density Open Space	44.2	1.2	2.4	0.9	0.2	43.5
Other Sources	Farm Animals	0.0	0.0	0.0	0.0	0.0	0.0
	Stream Bank	69.0	0.0	0.0	2.0	0.0	65.0
	Groundwater	2064.2	38.5	129.8	21.1	8.6	2006.4
	Point Source	591.7	0.0	0.0	0.0	0.0	654.4
	Septic Systems	5108.4	620.4	567.6	211.2	66.0	3643.2
	Total (kg)	7999.0	662.2	712.4	235.9	75.4	6532.0

The Hidden Valley Lake sub-watershed is estimated to yield the largest nitrogen load other than that coming from Upper Skyline Lake (Tables 35, 36). A large majority of this nitrogen is estimated to originate in septic systems and groundwater flows, with a significant amount of the runoff-based component of the nitrogen load originating in areas with urban land use, wetlands, and forested areas.

Table 37: Estimated annual loads of phosphorus in the total Lower Skyline Lake Watershed

Category	Description	Total Phosphorus kg	Total Phosphorus %
Runoff	Hay/Pasture	0.0	0.0
	Cropland	0.0	0.0
	Forest	8.2	2.8
	Wetland	1.1	0.4
	Open Land	0.1	0.0
	Barren Land	0.0	0.0
	Low-Density Mixed	0.8	0.3
	Medium-Density Mixed	1.0	0.3
	High-Density Mixed	0.3	0.1
	Low-Density Open Space	4.1	1.4
Other Sources	Farm Animals	0.0	0.0
	Stream Bank	22.0	7.5
	Groundwater	46.2	15.6
	point source	20.0	6.8
	Septic Systems	191.6	64.9
	Total	295.3	100.0

Table 38: Estimated annual loads of phosphorus/sub-watershed in the Lower Skyline Lake Watershed

Category	Description	Full Watershed kg	East kg	Hidden Valley Lake kg	Northwest kg	Southwest kg	Upper Skyline kg
Runoff	Hay/Pasture	0.0	0.0	0.0	0.0	0.0	0.0
	Cropland	0.0	0.0	0.0	0.0	0.0	0.0
	Forest	8.2	0.1	0.4	0.0	0.0	10.0
	Wetland	1.1	0.0	0.2	0.0	0.0	1.2
	Open Land	0.1	0.0	0.0	0.0	0.0	0.2
	Barren Land	0.0	0.0	0.0	0.0	0.0	0.0
	Low-Density Mixed	0.8	0.1	0.2	0.0	0.0	0.7
	Medium-Density Mixed	1.0	0.0	0.3	0.0	0.0	0.8
	High-Density Mixed	0.3	0.0	0.0	0.0	0.0	0.3
	Low-Density Open Space	4.1	0.1	0.3	0.1	0.0	4.8
Other Sources	Farm Animals	0.0	0.0	0.0	0.0	0.0	0.0
	Stream Bank	22.0	0.0	0.0	1.0	0.0	24.0
	Groundwater	46.2	0.9	2.7	0.5	0.2	54.2
	Point Source	20.0	0.0	0.0	0.0	0.0	26.2
	Septic Systems	191.6	23.3	21.3	7.9	2.5	136.6
	Total (kg)	295.3	24.4	25.4	9.5	2.7	259.0

As with the other watersheds covered thus far, most of Lower Skyline Lake's annual phosphorus load is estimated to originated from septic systems, with groundwater and point source discharges also contributing a notable load (Tables 37, 38). An overwhelming majority of phosphorus is estimated to occur in the Upper Skyline Lake watershed, which is much larger than the others from Lower Skyline. The East and Hidden Valley Lake Watersheds are estimated to yield the largest yearly phosphorus loads aside from that coming from Upper Skyline lake. In both of these watersheds, the majority of the yearly phosphorus load is estimated to originate from septic systems and groundwater.

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

Category	Description	Sediment kgx1000	Sediment %
Runoff	Hay/Pasture	0.0	0.0
	Cropland	0.0	0.0
	Forest	2.2	5.8
	Wetland	0.1	0.2
	Open Land	0.0	0.1
	Barren Land	0.0	0.0
	Low-Density Mixed	0.1	0.4
	Medium-Density Mixed	0.2	0.5
	High-Density Mixed	0.1	0.1
	Low-Density Open Space	0.7	2.0
Other Sources	Farm Animals	0.0	0.0
	Stream Bank	33.7	90.9
	Groundwater	0.0	0.0
	Septic Systems	0.0	0.0
	Total	37.1	100.0

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

Category	Description	Full Watershed kg x 1000	East kg x 1000	Hidden Valley Lake kg x 1000	Northwest kg x 1000	Southwest kg x 1000	Upper Skyline kg x 1000
Runoff	Hay/Pasture	0.0	0.0	0.0	0.0	0.0	0.0
	Cropland	0.0	0.0	0.0	0.0	0.0	0.0
	Forest	2.2	0.0	0.1	0.0	0.0	6.2
	Wetland	0.1	0.0	0.0	0.0	0.0	0.2
	Open Land	0.0	0.0	0.0	0.0	0.0	0.1
	Barren Land	0.0	0.0	0.0	0.0	0.0	0.0
	Low-Density Mixed	0.1	0.0	0.1	0.0	0.0	0.3
	Medium-Density Mixed	0.2	0.0	0.1	0.0	0.0	0.4
	High-Density Mixed	0.1	0.0	0.0	0.0	0.0	0.1
	Low-Density Open Space	0.7	0.1	0.1	0.0	0.0	2.0
Other Sources	Farm Animals	0.0	0.0	0.0	0.0	0.0	0.0
	Stream Bank	33.7	0.0	0.0	2.2	0.3	86.0
	Groundwater	0.0	0.0	0.0	0.0	0.0	0.0
	Septic Systems	0.0	0.0	0.0	0.0	0.0	0.0
	Total (kgx1000)	37.1	0.1	0.5	2.3	0.3	95.3

The Northwest sub-watershed is estimated to yield the largest yearly load of sediment, with a majority being contributed by streambank erosion (Tables 39, 40). While the East and Hidden Valley Lake sub-watersheds are estimated to yield relatively low yearly sediment loads, it should be noted that a significant amount of this sediment is contributed by runoff from urbanized land.

LAKE RICKONDA

Lake Rickonda's full watershed covers a relatively small area of 31.7 acres (Table 41). The full watershed is mostly split between low-density open space and forested land. No true perennial inlets drain into the lake, which is largely spring fed, although a small spring fed water input was observed on the southern end of the Lake. The Lake drains north to Monksville Reservoir. Descriptions of the Lake's three sub-watersheds are as follows:

- **Northeast –** This 15.1-acre sub-watershed encompasses low-density open space adjacent to the lake, as well as higher-elevation forested land.
- **Southeast –** This 10.8-acre sub-watershed also encompasses urbanized land close to the lake and uphill forested land, as well as the area near the lake's short southern "inlet".
- **West –** This 5.6-acre sub-watershed features a narrow area immediately near the lake's shoreline, as well as the lake's beach and "inlet".

Table 41. Land-use by sub-watershed in the Lake Rickonda watershed.

Source	Full Watershed	Northeast	Southeast	West
	Area (acres)			
Open Water	3.6	2.2	0.7	0.7
Hay/Pasture	0.0	0.0	0.0	0.0
Cropland	0.0	0.0	0.0	0.0
Forest	11.6	7.2	4.2	0.0
Wetland	5.2	0.5	0.0	4.7
Open Land	0.0	0.0	0.0	0.0
Barren Land	0.0	0.0	0.0	0.0
Low-Density Mixed	0.2	0.0	0.2	0.0
Medium-Density Mixed	0.0	0.0	0.0	0.0
High-Density Mixed	0.0	0.0	0.0	0.0
Low-Density Open Space	11.1	5.2	5.7	0.2
Total	31.7	15.1	10.8	5.6

Source	Full Watershed	Northeast	Southeast	West
	Area (%)			
Open Water	11.2	14.7	6.2	12.0
Hay/Pasture	0.0	0.0	0.0	0.0
Cropland	0.0	0.0	0.0	0.0
Forest	36.7	47.6	39.0	0.0
Wetland	16.4	3.3	0.0	84.4
Open Land	0.0	0.0	0.0	0.0
Barren Land	0.0	0.0	0.0	0.0
Low-Density Mixed	0.6	0.0	1.9	0.0
Medium-Density Mixed	0.0	0.0	0.0	0.0
High-Density Mixed	0.0	0.0	0.0	0.0
Low-Density Open Space	35.1	34.4	52.9	3.6
Total	100.0	100.0	100.0	100.0

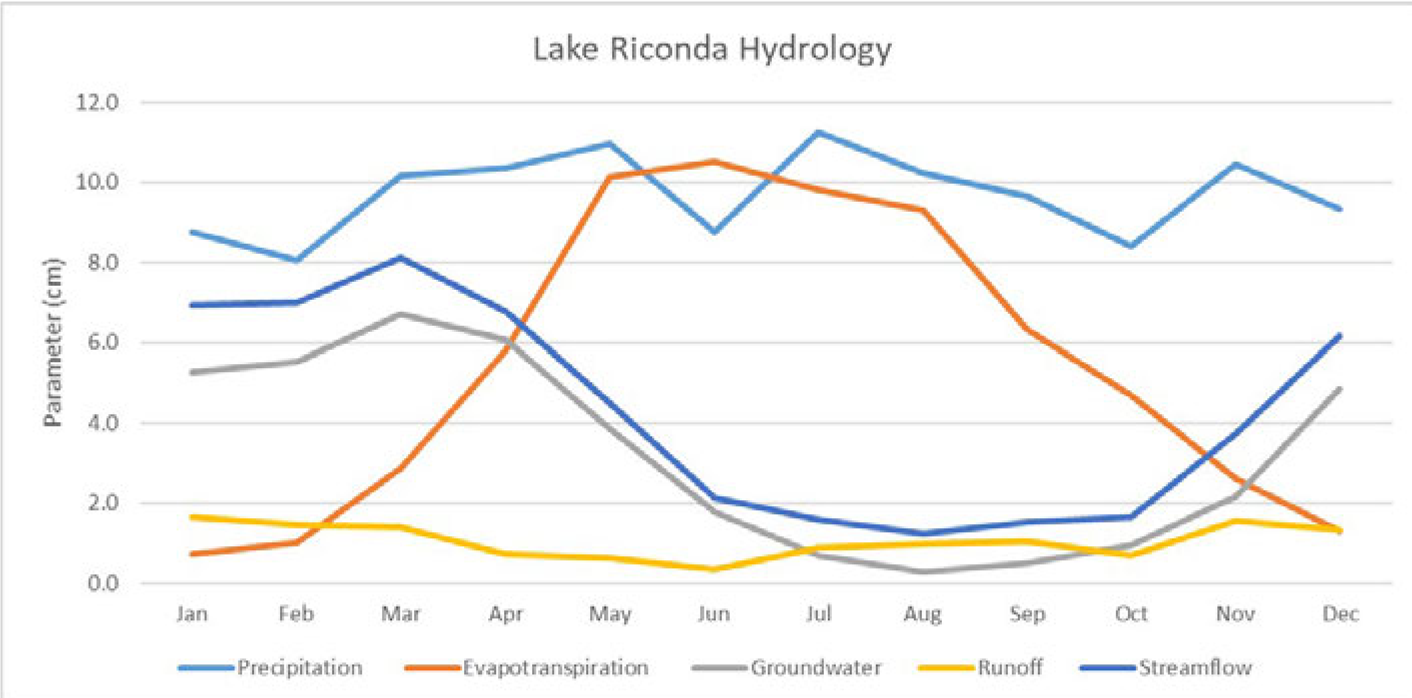

Figure 11. Estimated seasonal changes in hydrology in the Rickonda Lake watershed

Table 42. Total hydrological parameters in the full Lake Rickonda watershed

Month	Precipitation	Evapotranspiration	Groundwater	Runoff	Streamflow	
	cm	cm	cm	cm	cm	cfs
Jan	8.8	0.7	5.3	1.6	6.9	0.1
Feb	8.0	1.0	5.5	1.5	7.0	0.1
Mar	10.2	2.9	6.7	1.4	8.1	0.1
Apr	10.4	5.8	6.1	0.7	6.8	0.1
May	11.0	10.1	3.9	0.6	4.5	0.1
Jun	8.8	10.5	1.8	0.3	2.1	0.0
Jul	11.2	9.8	0.7	0.9	1.6	0.0
Aug	10.2	9.3	0.3	1.0	1.3	0.0
Sep	9.7	6.3	0.5	1.0	1.5	0.0
Oct	8.4	4.7	1.0	0.7	1.7	0.0
Nov	10.4	2.6	2.2	1.6	3.7	0.1
Dec	9.3	1.3	4.8	1.3	6.2	0.1
Total	116.4	65.1	38.6	12.7	51.4	0.1

While the Northeast and Southeast sub-watersheds are very similar to each other in regards to runoff, the West sub-watershed features considerably higher runoff, often a full centimeter higher than the other two basins (Figure 12). When direct precipitation and evaporation to and from the Lake itself is factored in, Lake Rickonda is estimated to receive approximately 80,345.3 m³ or 21.2 million gallons of water a year.

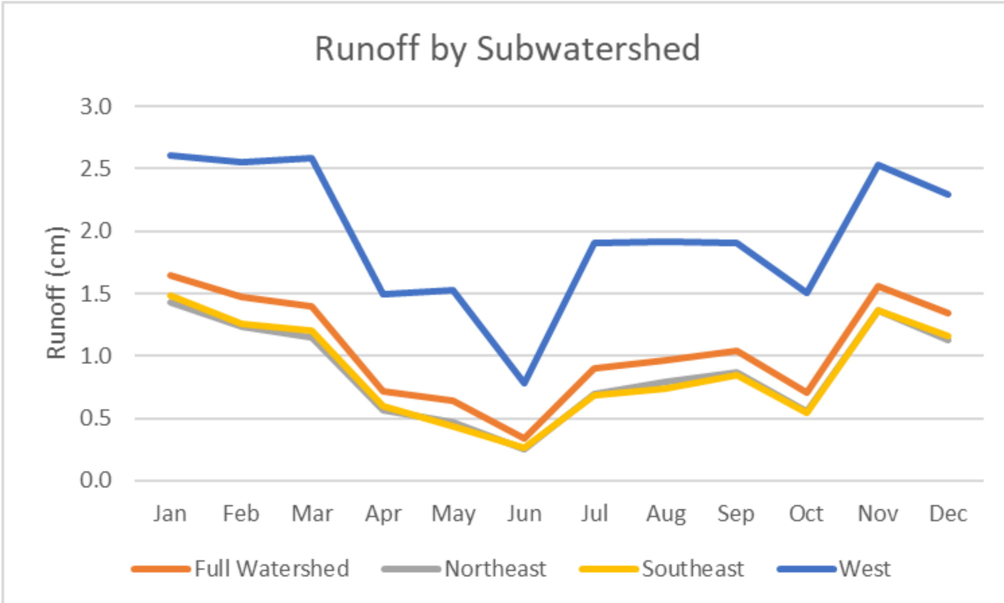

Figure 12. Average monthly runoff occurring in each sub-watershed in the Lake Rickonda watershed

Table 43: Estimated annual loads of nitrogen in the total Lake Rickonda Watershed

Category	Description	Total Nitrogen kg	%
Runoff	Hay/Pasture	0.0	0.0
	Cropland	0.0	0.0
	Forest	0.9	0.3
	Wetland	1.0	0.3
	Open Land	0.0	0.0
	Barren Land	0.0	0.0
	Low-Density Mixed	0.0	0.0
	Medium-Density Mixed	0.0	0.0
	High-Density Mixed	0.0	0.0
	Low-Density Open Space	1.0	0.4
Other Sources	Farm Animals	0.0	0.0
	Stream Bank	0.0	0.0
	Groundwater	15.0	5.3
	Septic Systems	264.0	93.7
	Total	281.9	100.0

Table 44: Estimated annual loads of nitrogen by sub-watershed in the Rickonda Lake Watershed

Category	Description	Full Watershed kg	Northeast kg	Southeast kg	West kg
Runoff	Hay/Pasture	0.0	0.0	0.0	0.0
	Cropland	0.0	0.0	0.0	0.0
	Forest	0.9	0.5	0.3	0.0
	Wetland	1.0	0.1	0.0	0.9
	Open Land	0.0	0.0	0.0	0.0
	Barren Land	0.0	0.0	0.0	0.0
	Low-Density Mixed	0.0	0.0	0.0	0.0
	Medium-Density Mixed	0.0	0.0	0.0	0.0
	High-Density Mixed	0.0	0.0	0.0	0.0
	Low-Density Open Space	1.0	0.5	0.2	0.0
Other Sources	Farm Animals	0.0	0.0	0.0	0.0
	Stream Bank	0.0	0.0	0.0	0.0
	Groundwater	15.0	7.6	5.4	1.9
	Septic Systems	264.0	105.6	105.6	52.8
	Total (kg)	281.9	114.4	111.6	55.6

In each of the three sub-watersheds, a large majority of the nitrogen estimated to enter Rickonda Lake originates from Septic Systems, likely due to the relatively large percentage of the total watershed that contains residential housing (Tables 43, 44). Very little nitrogen is estimated to enter the lake via runoff in any of the three watersheds.

Table 45: Estimated annual loads of phosphorus in the total Lake Rickonda Watershed

Category	Description	Total Phosphorus kg	%
Runoff	Hay/Pasture	0.0	0.0
	Cropland	0.0	0.0
	Forest	0.1	0.7
	Wetland	0.1	0.6
	Open Land	0.0	0.0
	Barren Land	0.0	0.0
	Low-Density Mixed	0.0	0.0
	Medium-Density Mixed	0.0	0.0
	High-Density Mixed	0.0	0.0
	Low-Density Open Space	0.1	1.0
Other Sources	Farm Animals	0.0	0.0
	Stream Bank	0.0	0.0
	Groundwater	0.4	4.2
	Septic Systems	9.9	93.6
	Total	10.6	100.0

Table 46: Estimated annual loads of phosphorus by sub-watershed in the Rickonda Lake Watershed

Category	Description	Full Watershed kg	Northeast kg	Southeast kg	West kg
Runoff	Hay/Pasture	0.0	0.0	0.0	0.0
	Cropland	0.0	0.0	0.0	0.0
	Forest	0.1	0.0	0.0	0.0
	Wetland	0.1	0.0	0.0	0.1
	Open Land	0.0	0.0	0.0	0.0
	Barren Land	0.0	0.0	0.0	0.0
	Low-Density Mixed	0.0	0.0	0.0	0.0
	Medium-Density Mixed	0.0	0.0	0.0	0.0
	High-Density Mixed	0.0	0.0	0.0	0.0
	Low-Density Open Space	0.1	0.1	0.1	0.0
Other Sources	Farm Animals	0.0	0.0	0.0	0.0
	Stream Bank	0.0	0.0	0.0	0.0
	Groundwater	0.4	0.2	0.2	0.1
	Septic Systems	9.9	4.0	4.0	2.0
	Total (kg)	10.6	4.3	4.2	2.1

Very little phosphorus (10.6 kg/yr) was estimated to enter Rickonda Lake from the watershed when compared to the loads estimated for the other lakes in this study, and a large percentage of this phosphorus is estimated to originate from septic tank influence (Tables 45, 46). The West sub-watershed is also estimated to yield a small amount of phosphorus via runoff from wetlands. The Northeast and Southeast sub-watersheds also are estimated to contribute small amounts of phosphorus to their total annual loads via runoff from low-density open space.

Table 47: Estimated annual loads of sediment by in the total Rickonda Lake Watershed

Category	Description	Sediment kgx1000	Sediment %
Runoff	Hay/Pasture	0.00	0.00
	Cropland	0.00	0.00
	Forest	0.02	3.70
	Wetland	0.00	0.00
	Open Land	0.00	0.00
	Barren Land	0.00	0.00
	Low-Density Mixed	0.00	0.00
	Medium-Density Mixed	0.00	0.00
	High-Density Mixed	0.00	0.00
	Low-Density Open Space	0.05	9.24
Other Sources	Farm Animals	0.00	0.00
	Stream Bank	0.47	87.06
	Groundwater	0.00	0.00
	Septic Systems	0.00	0.00
	Total	0.54	100.00

Table 48: Estimated annual loads of sediment by sub-watershed in the Rickonda Lake Watershed

Category	Description	Full Watershed kg x 1000	Northeast kg x 1000	Southeast kg x 1000	West kg x 1000
Runoff	Hay/Pasture	0.00	0.00	0.00	0.00
	Cropland	0.00	0.00	0.00	0.00
	Forest	0.02	0.01	0.01	0.00
	Wetland	0.00	0.00	0.00	0.00
	Open Land	0.00	0.00	0.00	0.00
	Barren Land	0.00	0.00	0.00	0.00
	Low-Density Mixed	0.00	0.00	0.00	0.00
	Medium-Density Mixed	0.00	0.00	0.00	0.00
	High-Density Mixed	0.00	0.00	0.00	0.00
	Low-Density Open Space	0.05	0.03	0.04	0.00
Other Sources	Farm Animals	0.00	0.00	0.00	0.00
	Stream Bank	0.47	0.13	0.19	0.00
	Groundwater	0.00	0.00	0.00	0.00
	Septic Systems	0.00	0.00	0.00	0.00
	Total (kgx1000)	0.54	0.17	0.24	0.00

As with phosphorus, very little (540 kg/yr) sediment is estimated to enter Rickonda Lake from the watershed (Tables 47, 48). Most sediment entering the Lake is estimates to originate from streambank or erosion. In the West sub-watershed, this is the only estimated source of sediment, while in the Northeast and Southeast sub-watersheds, runoff from low-density open space is also estimated to contribute significantly to the lake's sediment load.

4. LAKE-BASED WATER QUALITY DATA

4.1 METHODS

Sampling events were conducted at each of the six lakes three different times over the course of 2020 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 the analysis of *In-situ* water quality data (Certification #10006). This data was collected throughout the water column in half-meter to one-meter increments in order to generate full profiles of the entirety of the water column. The parameters sampled as part of *In-situ* water quality sampling are water temperature (°C), dissolved oxygen (mg/L), specific conductivity (mS/cm), and pH (standard units). Additionally, water clarity was measured using a Secchi disk.

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

- Total Phosphorus (TP)
- Soluble Reactive Phosphorus (SRP)
- Chlorophyll *a* (Chl. *a*)
- Nitrate Nitrogen (NO_3-N)
- Nitrite Nitrogen (NO_2-N)
- Ammonia Nitrogen (NH_3-N)
- Total Suspended Solids (TSS)

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

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

4.2 RESULTS

CUPSAW LAKE

In-situ water quality

Despite early-season cold surface water temperatures, Cupsaw Lake was thermally stratified between 3 and 4 meters in depth at the beginning of May (Figure 13). Thermal stratification is a common phenomenon that occurs in lakes typically towards the middle of the summer season. As surface water temperatures rise, this water becomes less dense and rises above a layer of colder water situated in the bottom of the water column. As the difference in temperature between these two layers increases, they become less able to mix. The sharpest change in water temperature between two adjacent depths under these conditions is typically referred to as the thermocline. *In-situ* water quality data for all lakes studied is provided in Appendix III.

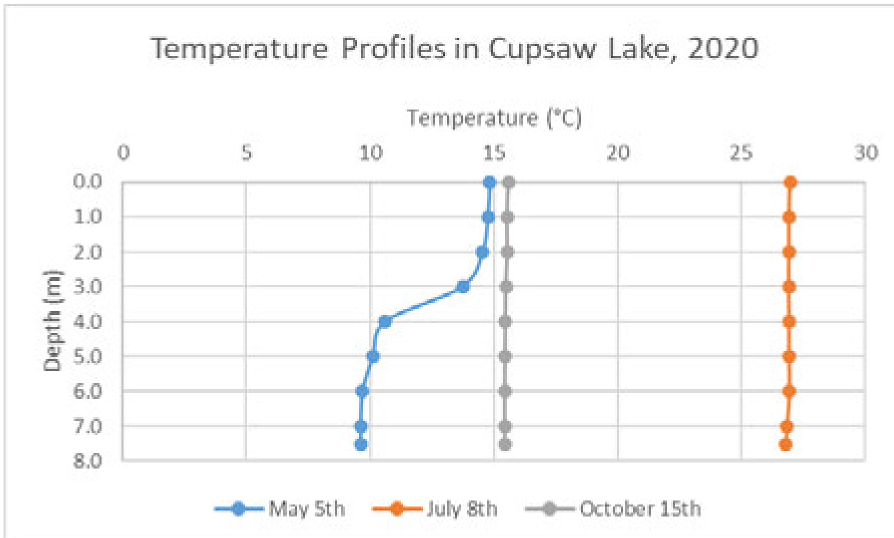

Figure 13. Temperature profiles collected during dates in 2020 at the dam station at Cupsaw Lake

Dissolved oxygen concentrations during the May sampling event were sufficient through 6 meters in depth, before approaching hypoxic concentrations towards the bottom of the water column (Figure 14). The reduction of dissolved oxygen at the bottom of the lake is a common occurrence associated with thermal stratification. As the warm, upper layer of the water column separates from the cooler, deeper layer, atmospheric oxygen that normally mixes into the water column at the surface is less able to mix to the lower reaches of the water column. As a result, dissolved oxygen concentrations at the bottom of a stratified lake will typically become reduced through respiration of bacteria and other organisms. This both reduces available habitat for fish and other organisms and can potentially lead to the loading of phosphorus into the water column from the bottom sediments, which will be described in greater detail below.

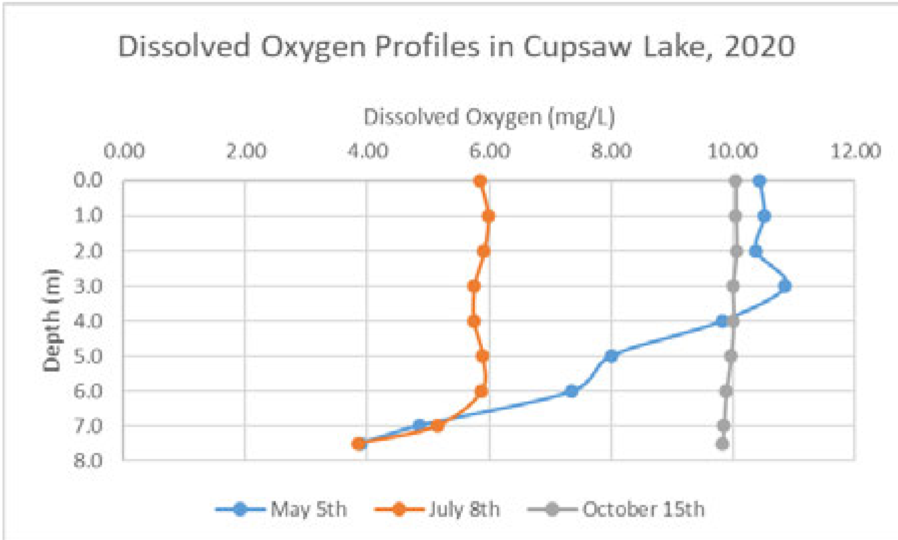

Figure 14. Dissolved oxygen profiles collected 2020 at the dam station at Cupsaw Lake

By the beginning of July, Cupsaw Lake's water column had become thermally well-mixed, likely as a product of the lake's aeration system. Accordingly, dissolved oxygen concentrations were mostly sufficient near the bottom of water column; however, the full water column displayed overall depressed dissolved oxygen concentrations. This may be a product of a recent increase in organic matter and an accompanying increase in biological oxygen demand as this matter began decomposing. By the mid-October sampling event, the water column had cooled to approximately 15.5°C throughout, and dissolved oxygen concentrations were measured between 98.5-101.0% saturation throughout. Water clarity at Cupsaw Lake as measured by Secchi depth began relatively high in Spring at 2.1 m. This dropped to 0.8 m in July, and was observed to have increased to 0.9 m in October.

Discrete water quality

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

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

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

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

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

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

Surface and deep phosphorus were both measured at 0.03 mg/L during the Spring event, while SRP was not present in measurable quantities at the surface and only present in the deep sample at 0.002 mg/L (Figure 15). Surface concentrations of TP increased to 0.05 mg/L in July, while deep concentrations were measured at 0.06 mg/L. Concentrations were similar in October, with 0.06 mg/L at the surface and 0.06 mg/L measured in the deep sample. It should be noted that these are above the NJ surface water quality standard of 0.05 mg/L. SRP, however, was not present in measurable concentrations in any of the July and October events.

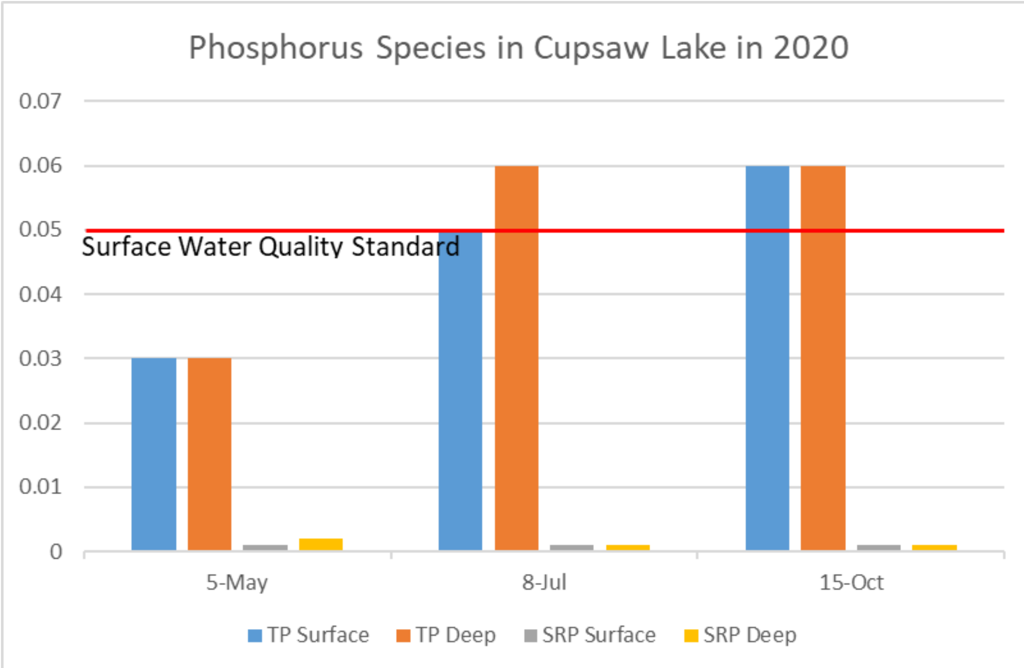

Figure 14. Concentrations of total phosphorus (TP) and soluble reactive phosphorus (SRP) measured from surface and deep samples in 2020 from the dam station at Cupsaw Lake

Nitrate-N concentrations in the spring were relatively high, at both 0.18 mg/L for surface and deep concentrations. These had decreased by July to 0.07 mg/L at the surface and 0.09 mg/L at depth, and in October were measured at 0.07 mg/L for both depths. Ammonia-nitrogen was only measured at relatively low concentrations at both depths throughout the year when it was at measurable concentrations at all.

TSS concentrations were relatively low during the May and October events, however the July event saw concentrations of 11 and 12 mg/L for the surface and deep samples, respectively.

Chlorophyll *a* concentrations in May were measured in the surface sample at 5.7 µg/L and in the deep sample at 11 µg/L. Concentrations in July and October were relatively high, with July featuring surface and deep concentrations of 28 and 32 µg/L, respectively (Figure 16). October concentrations were similar, with concentrations of 27 and 31 µg/L for surface and deep samples, respectively. During all dates, deep samples were slightly higher than surface samples, suggesting the presence of deep-water algae populations.

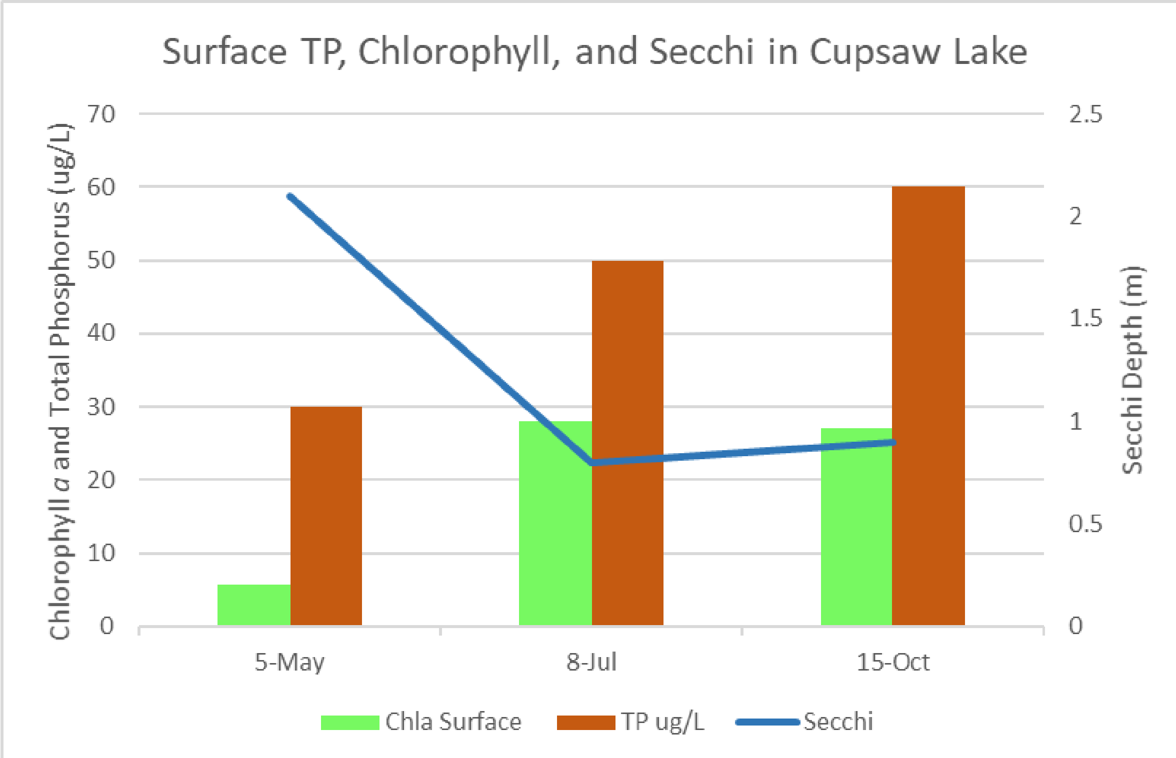

Figure 15. Concentrations of chlorophyll a (Chlorophyll a) and total phosphorus (TP), as well as Secchi depths, measured from the surface of the dam station at Cupsaw lake on three dates in 2020.

Plankton and macrophytes

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

Cupsaw Lake saw a relatively high abundance of phytoplankton during the May event, with the sample yielding abundant densities of the diatoms *Asternionella* and *Fragilaria,* the golden algae genus *Dinobryon,* and the green algae genus *Mougeotia*. In the zooplankton community, the large-bodied herbivorous cladoceran *Daphnia* was observed in common densities in the sample, as were the copepod *Microcyclops* and the rotifer *Keratella*. The cyanobacteria genus *Aphanocapsa* was present in the sample during this date, but not at problematic densities. Phytoplankton densities remained high in July, with the lake experiencing a bloom of the filamentous diatom *Melosira*. Abundant densities of *Fragilaria,* the green algae genus *Pediastrum,* and *Aphanocapsa* were also observed in the sample. The zooplankton community during this event featured common densities of many taxa, with no one genus dominating the sample. These include the cladoceran *Bosmina, Microcyclops* and copepod nauplii, and the rotifers *Keratella, Polyarthra,* and *Tricocerca*. In October, the phytoplankton assemblage was dominated by the diatom *Tabellaria* and the green algae genus *Pediastrum*. Cyanobacteria were still present in the sample, with *Aphanocapsa* and *Aphanizomenon* observed at common densities. The zooplankton assemblage during October was somewhat similar to that observed in July, with the exception of a dominance by *Bosmina*.

The macrophyte community in May was observed to consist mostly of the invasive plant curlyleaf pondweed (*Potamogeton crispus*), which grows relatively early in the season when water temperatures are still cool. By July, populations of this plant had completely senesced, and only a small amount of the plant-like algae *Chara* was observed at the boat launch, while patches of white waterlily were observed to the north. Waterlily (*Nymphaea* or *Nuphar*), spikerush (*Eleocharis sp.*), and pickerel weed (*Pontederia* cordta) were observed at the upper end of the lake during the October event.

UPPER ERSKINE LAKE

In-situ Water Quality

Upper Erskine Lake featured a minor degree of thermal stratification during the May event; however, dissolved oxygen concentrations were oversaturated (>100% DO saturation) throughout most of the water column (Figures 17, 18). This, combined with the relatively high pH levels found at both sites (over 9 at the Lake's dam), suggests that a high rate of photosynthesis from plants and/or algae was occurring. The water column was stratified between 2 and 3 meters in depth in July and featured anoxia within the bottom-most 0.2 m. This is not a large problem, especially for this time of the year, given that most of the water column was still useable as fish habitat and only a relatively small area was likely anoxic. By October, the water column was well mixed and well oxygenated throughout.

Water clarity in May was relatively high, with the mid-Lake station featuring clarity almost to the bottom (3.4 meters of clarity). This dropped to 1.6 m in July before increasing slightly again to 2.1 in October.

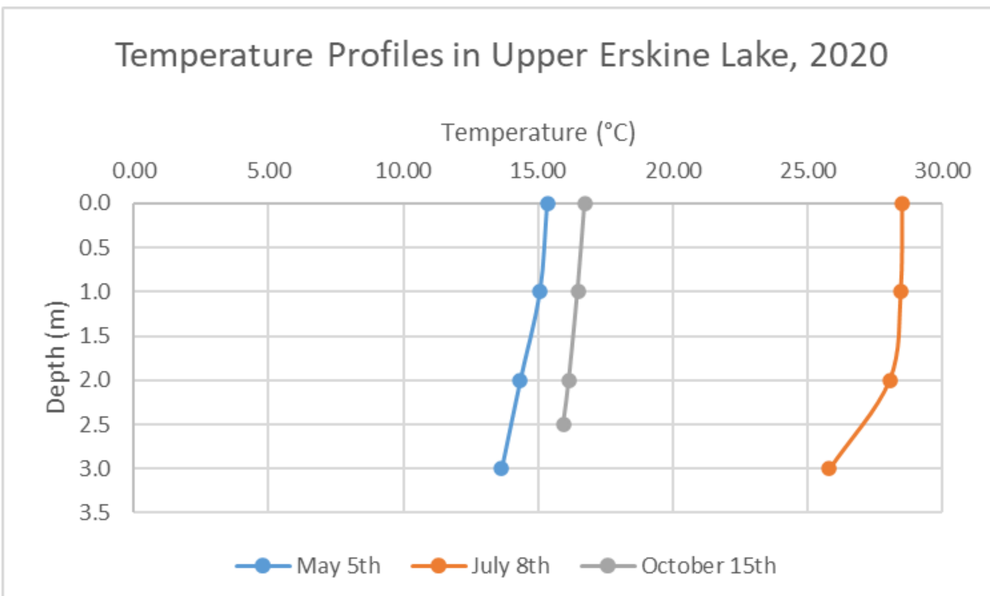

Figure 16. Temperature profiles collected during 2020 at the mid-lake station at Upper Erskine Lake

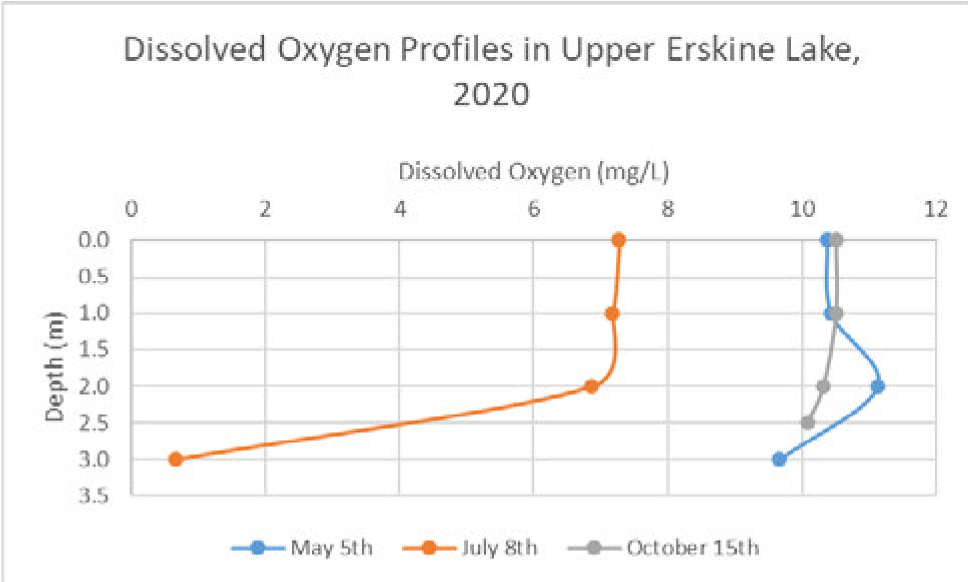

Figure 17. Dissolved oxygen profiles collected during 2020 at the mid-Lake station/Upper Erskine Lake

Discrete Water Quality

Total phosphorus concentrations were relatively low in May, with both the surface and deep sample yielding 0.02 mg/L (Figure 19). SRP for both surface and deep samples during this date were both measured at 0.002 mg/L. For both the July and October events, both surface and deep samples yielded 0.04 mg/L of TP, while SRP was not present in measurable concentrations for either surface or deep samples during these dates. Nitrate-N concentrations were relatively high during the Spring event, with samples yielding 0.24 and 0.19 mg/L for surface and deep samples, respectively. These concentrations dropped in July to 0.03 mg/L for both depths and increased slightly in October to 0.05 and 0.06 for the surface and deep samples, respectively. Ammonia-N was not detected in measurable concentrations during the May or October events, and only increased to 0.03 mg/L during the July event.

TSS were never detected at high concentrations in Upper Erskine Lake in 2020, with the highest detected concentration being 5 mg/L in the deep sample in May. Chlorophyll *a* concentrations were relatively low in May, but increased to 21 µg/L (surface) and 20 µg/L (deep) in July, before dropping slightly to 12 (surface) and 11 µg/L (deep) in October (Figure 20).

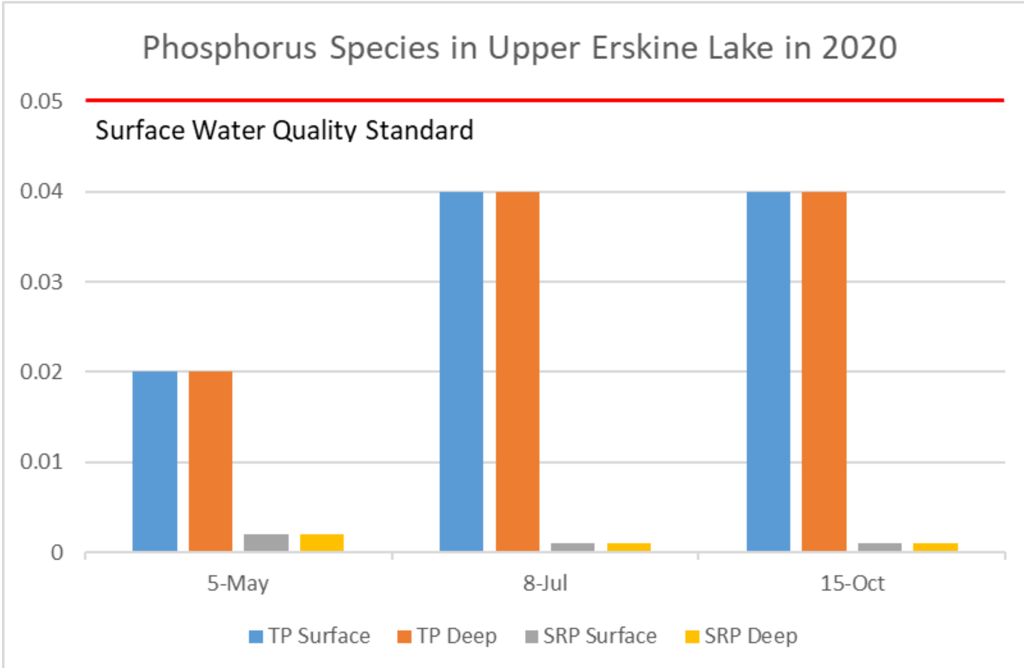

Figure 18. Concentrations of total phosphorus (TP) and soluble reactive phosphorus (SRP) measured from surface and deep samples collected in 2020 from the mid-lake station at Upper Erskine Lake

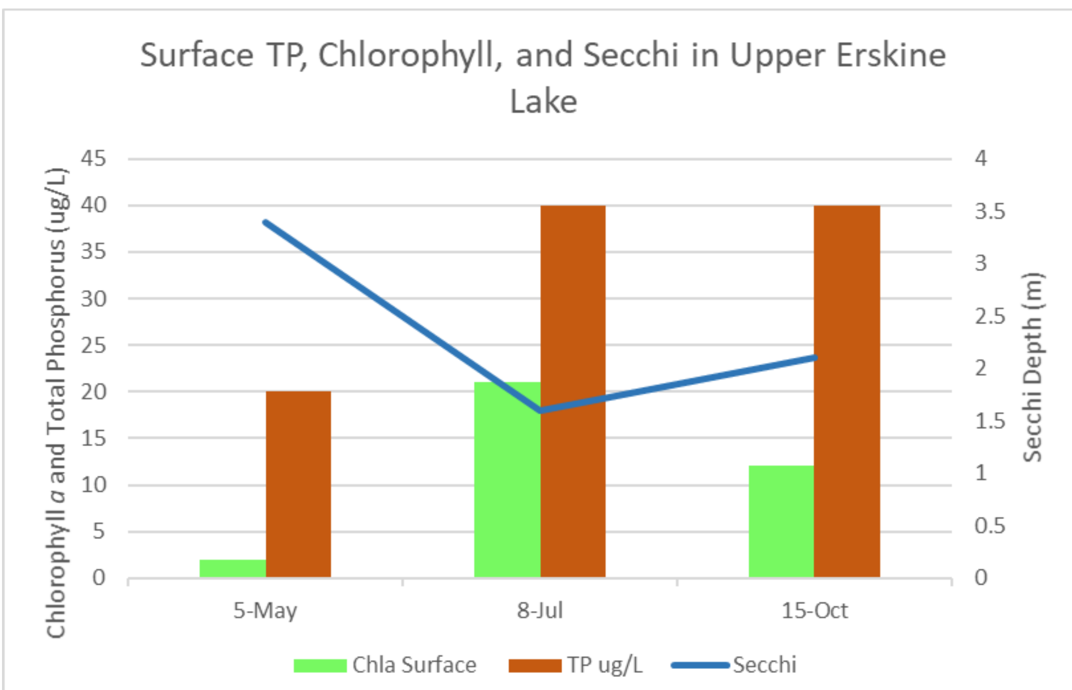

Figure 19. Concentrations of chlorophyll a (Chlorophyll a) and total phosphorus (TP), as well as Secchi depths, measured from the surface of the mid-lake station at Upper Erskine lake in 2020.

Plankton and Macrophytes

Upper Erskine Lake's phytoplankton community during the May event was dominated by common densities of the diatom *Fragilaria* and the green algae genera *Mougeotia* and *Pediastrum*. The cyanobacteria genus *Microcystis* was detected in the sample for this event as well; however, this was at rare densities. The Lake's zooplankton community at this time was dominated by abundant densities of large-bodied herbivorous taxa, particularly the cladoceran *Daphnia* and the copepod *Skistodiaptomus.* Copepod nauplii were also abundant in the sample. By the July event, the phytoplankton community had become dominated by abundant populations of the green algae genera *Pandorina* and the desmid *Staurastrum.* The cyanobacteria genera *Lyngbya* and *Dolichospermum* (formerly known as *Anabaena*) were also detected in common densities during this date. The zooplankton community had shifted to a largely rotifer-dominated community at this time, with the predator *Asplanchna* being observed at abundant densities. The October event's phytoplankton community saw continued dominance by *Staurastrum,* as well as abundant densities of the dinoflagellate *Ceratium.* The cyanobacteria genus *Aphanizomenon* was also common in the sample at this time. Overall zooplankton densities dropped slightly in October, however common densities of *Daphnia* and *Keratella* were observed in the sample.

The May event saw a dense patch of curlyleaf pondweed adjacent to the boat launch in the southwest corner of the Lake. This plant was observed in occasional patches scattered around the shoreline, as well as in a moderate population near the Lake's Dam. Another pondweed species, likely water-thread pondweed (*Potamogeton diversifolius*) was also observed at the launch in smaller densities. This plant was also observed near the launch during the July event, along with leafy pondweed (*Potamogeton foliosus*) and waterwort (*Elatine sp.*). Pickerelweed (*Pontederia cordata*) and leafy pondweed were also observed at the launch in October.

LOWER ERSKINE LAKE

In-situ *Water Quality*

During the May event, Lower Erskine lake was thermally stratified at the mid-Lake station between 5 and 6 meters in depth (Figure 21). The water column was sufficiently oxygenated throughout, however (Figure 22). Water clarity as measured by a Secchi disk was relatively high in May, with a clarity of 4 meters at the Mid-lake station. By early July, a sharper thermocline was detected between 4 and 6 meters. The bottom-most 2.5 meters were also detected to be largely anoxic; however, while 5 meters in depth featured anoxia, 6 meters in depth featured a slight increase (up to approximately 2.0 mg/L) before becoming anoxic again at subsequent depths. This may be explained as the result of a small population of deep-water algae occurring at this depth. Water clarity had decrease slightly to 3 meters at this point. By October, the water column was thermally mixed and featured sufficient dissolved oxygen throughout. Water clarity was measured to be 2 meters at this time.

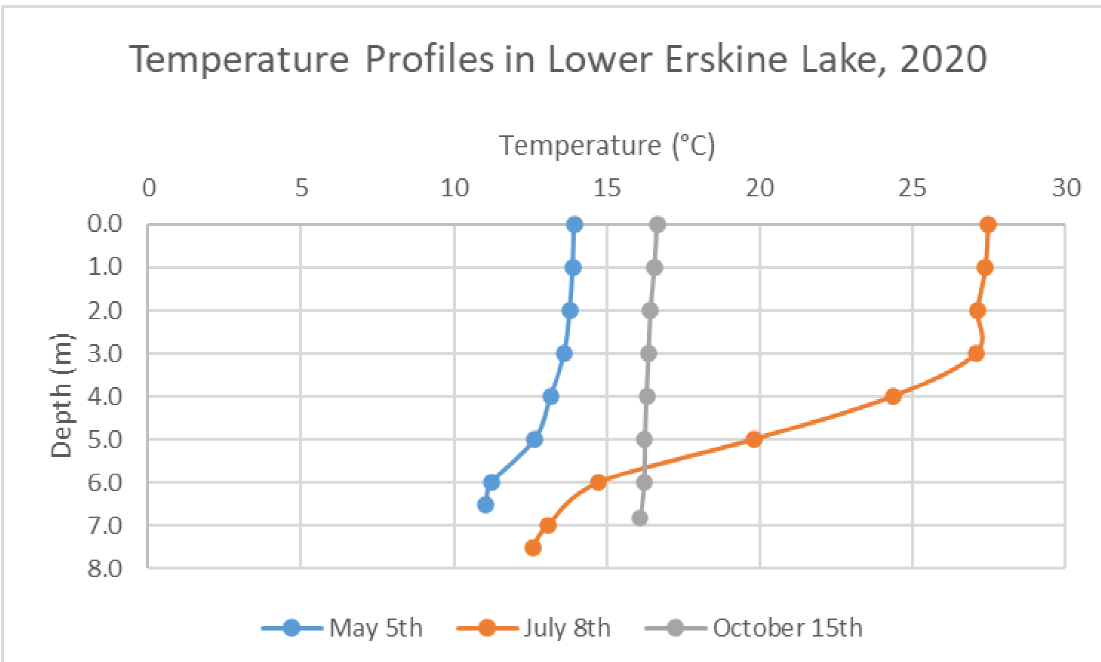

Figure 20. Temperature profiles collected during 2020 at the mid-lake station at Lower Erskine Lake

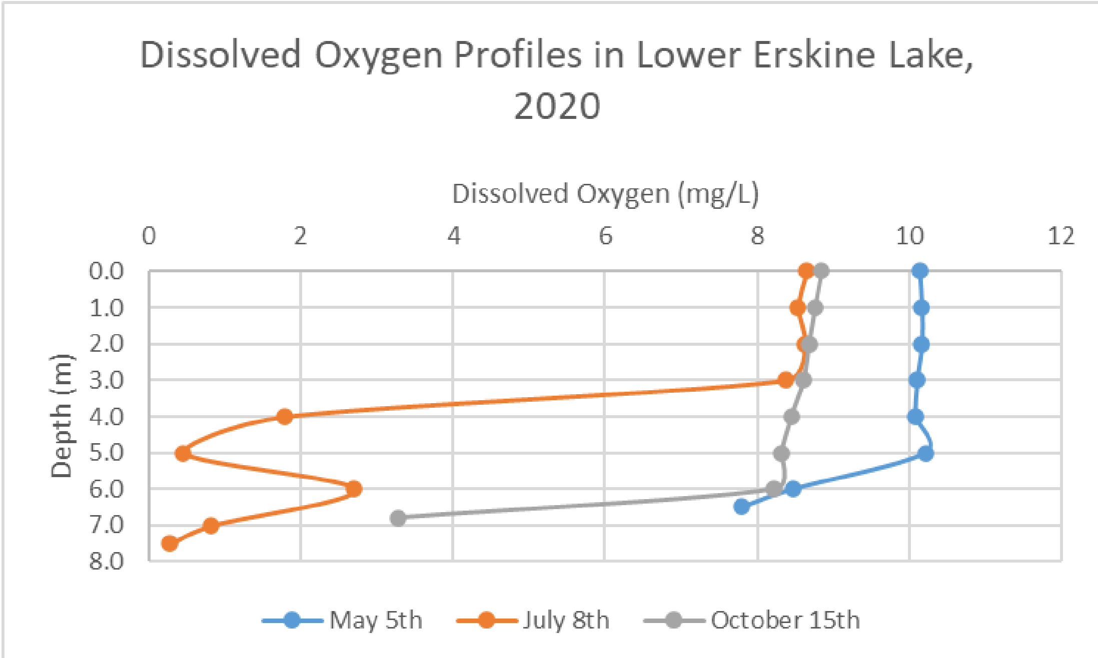

Figure 21. Dissolved oxygen profiles collected during 2020 at Lower Erskine Lake

Discrete Water Quality

Surface phosphorus concentrations were relatively low, only reaching 0.03 mg/L in October after the Lake had thermally mixed (Figure 23). Deep TP concentrations, however, were measured at 0.06 mg/L in the sample taken during the July event, exceeding the NJ surface water quality standard. SRP concentrations, however, were only present in detectable concentrations in the surface sample collected in May.

Surface concentrations of nitrate-N were initially relatively high in May, with a concentration of 0.34 mg/L. These dropped, however, for the remainder of the year in subsequent events. Ammonia-N was relatively low throughout the year, with a seasonal high of 0.05 mg/L in the deep sample in July.

Total suspended solids were also relatively low throughout the year, with the seasonal highs being 6 mg/L at the surface in May and 8 mg/L in the deep sample in July. Lastly, while surface chlorophyll *a* concentrations only reached a seasonal high of 10 µg/L in October, a deep concentration of 41 µg/L was measured in July (Figure 24). This further suggests that Lower Erskine Lake may experience increased deep-water algae or cyanobacteria populations during certain times of the year.

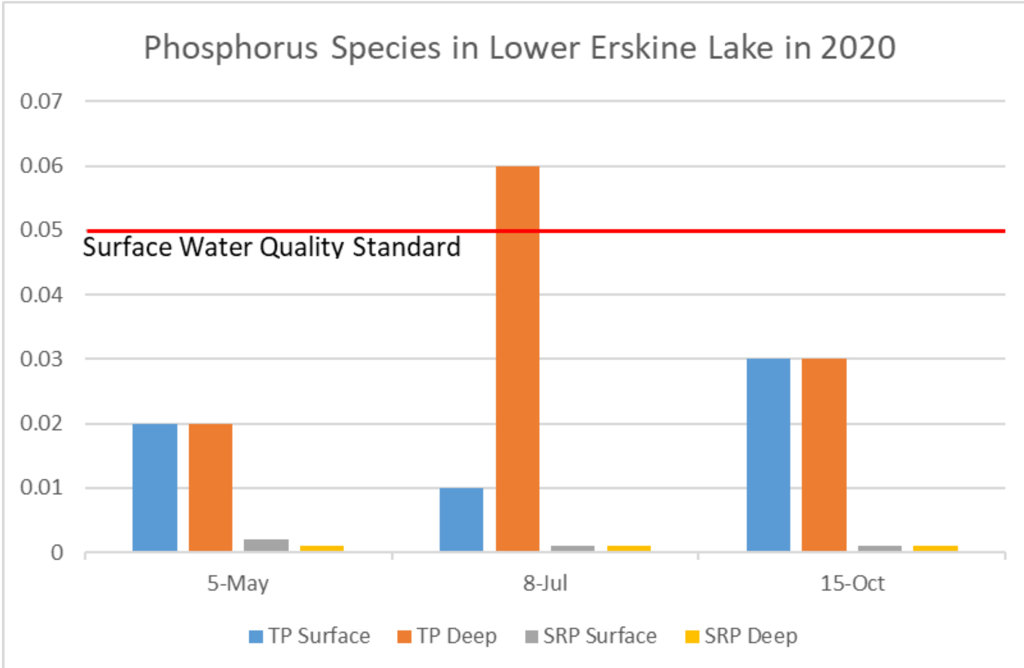

Figure 22. Concentrations of total phosphorus (TP) and soluble reactive phosphorus (SRP) measured from surface and deep samples collected in 2020 from the mid-lake station at Lower Erskine Lake

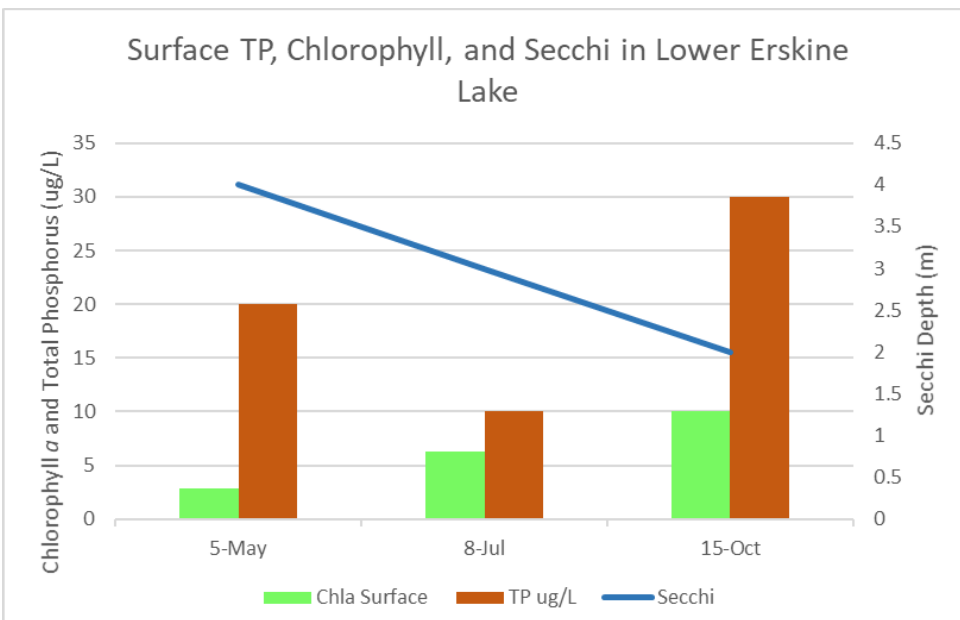

Figure 23. Concentrations of chlorophyll a (Chlorophyll a) and total phosphorus (TP), as well as Secchi depths, measured from the surface of the mid-Lake station at Lower Erskine Lake in 2020.

Plankton and Macrophytes

The plankton sample collected in May was somewhat low in density, with only the green algae genus *Gloeocystis* occurring in common densities. Similarly, the zooplankton community featured common densities of copepod nauplii and smaller numbers of seven other genera. The phytoplankton community increased in density by July, with the sample being dominated by the cyanobacteria genus *Oscillatoria.* This genus in particular often forms dense populations at depth. The zooplankton community had also grown in density at this point, with the sample yielding abundant densities of the cladoceran *Daphnia,* the copepod genus *Microcyclops,* and copepod nauplii. By October, the phytoplankton community was dominated by the green algae genus *Mougeotia* and the dinoflagellate *Ceratium*. Cyanobacteria populations were presented by common densities of *Dolichospermum, Aphanizomenon,* and *Microcystis*. Zooplankton densities had decreased slightly, with the sample yielding common densities of *Daphnia* and the rotifer *Keratella.*

Small amounts of benthic algae (likely *Spirogyra*) were observed near the boat launch in May. This algae was also observed in the southwest cove, along with some thin-leaved pondweed (likely leafy pondweed) and a small stand of the invasive plant curlyleaf pondweed. This thin-leaved pondweed was also observed near the boat launch in October, along with curlyleaf pondweed.

UPPER SKYLINE LAKE

In-situ *Water Quality*

Upper Skyline Lake was observed experiencing minor thermal stratification in May between 2 and 3 meters, particularly at the mid-Lake station (Figure 25). Dissolved oxygen was sufficient throughout the water column, with super-saturated concentrations occurring closer to the surface (Figure 26). This is likely a product of the diatom bloom that was occurring during this event, which also resulted in relatively high pH levels towards the top of the water column. The maximum water clarity for the event was 1.4 meters, obtained at the north station. The Lake featured a sharper thermocline in July, with an approximate 6°C temperature difference between 3 and 4 meters. Anoxia was occurring in the bottom-most 4 meters during this event as well. This event saw the yearly high for water clarity, with a Secchi depth of 2.3 at the mid-Lake station. By October, the water column was well-mixed thermally. The water column was observed to be mostly well-oxygenated, although some hypoxic conditions were observed towards the bottom at the mid-lake site. The maximum Secchi depth obtained during this date was 1.3 m in the northern end of the waterbody.

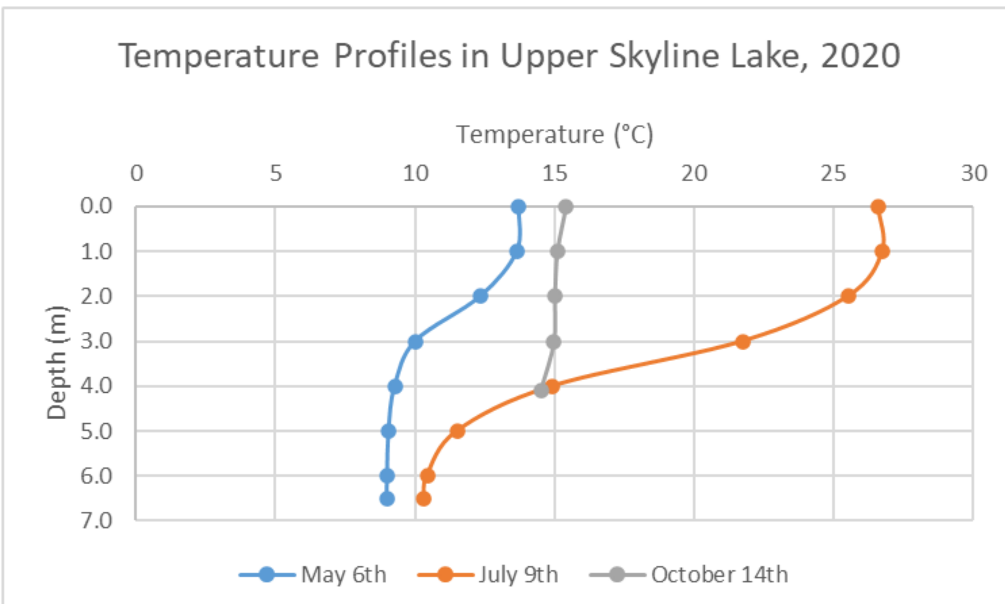

Figure 24. Temperature profiles collected during 2020 at the mid-Lake station at Upper Skyline Lake.

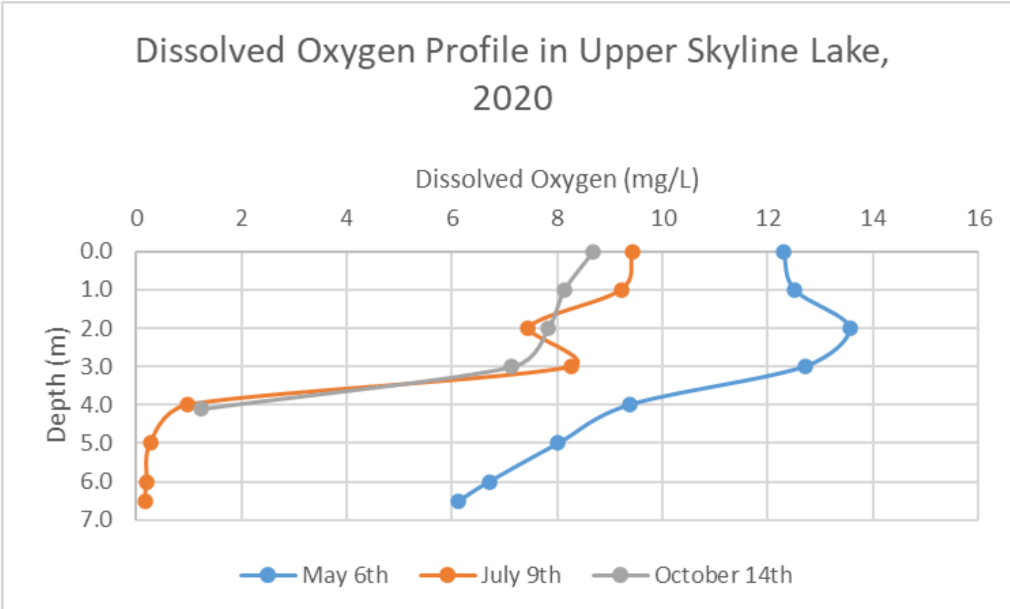

Figure 25. Dissolved oxygen profiles collected during 2020 at Upper Skyline Lake

Discrete Water Quality

Both the surface and deep samples collected during the May event yielded TP concentrations of 0.04 mg/L, while SRP occurred at a concentration below the minimum detectable concentration at both depths (Figure 27). In July, while surface concentrations of TP and SRP were low, the deep sample yielded a TP concentration of 0.83 mg/L and an SRP concentration of 0.190 mg/L. As these were collected during a period of significant bottom anoxia, this suggests that the lake experiences a relatively high rate of internal phosphorus loading. By October, the surface sample yielded 0.08 mg/L of TP and 0.002 mg/L of SRP, while the deep sample yielded 0.56 mg/L of TP and 0.090 mg/L of SRP. It should be noted that these concentrations of phosphorus put the Lake at high risk for algae and cyanobacteria blooms.

Nitrate-N concentrations were relatively high throughout the season, particularly during May, with surface and deep concentrations of 1.2 mg/L and 1.3 mg/L, respectively. These dropped in July, with a surface concentration of 0.73 mg/L and a deep concentration of 0.26 mg/L. By October, surface and deep concentrations were measured at 0.36 mg/L and 0.35 mg/L, respectively. While surface concentrations of ammonia were not problematic throughout the season, the deep sample in July yielded a concentration of 0.49 mg/L. As this occurred during a period of bottom anoxia, this area of the lake bottom likely lacked the microorganisms that would have normally fixed the ammonia into other forms of nitrogen.

Surface concentrations of TSS were relatively low throughout the season, with a seasonal high of 9 mg/L in May, while deep concentrations averaged moderate, with a seasonal high of 13 mg/L in July. Chlorophyll *a* concentrations were consistently high, with surface concentrations ranging from 28 μg/L in the Spring to 31 μg/L in October (Figure 28). The July event yielded a concentration of 45 μg/L in the Lake's deep sample, suggesting a high density of deep algae or cyanobacteria, although low dissolved oxygen concentrations at this depth suggests significant rates of photosynthesis were not occurring.

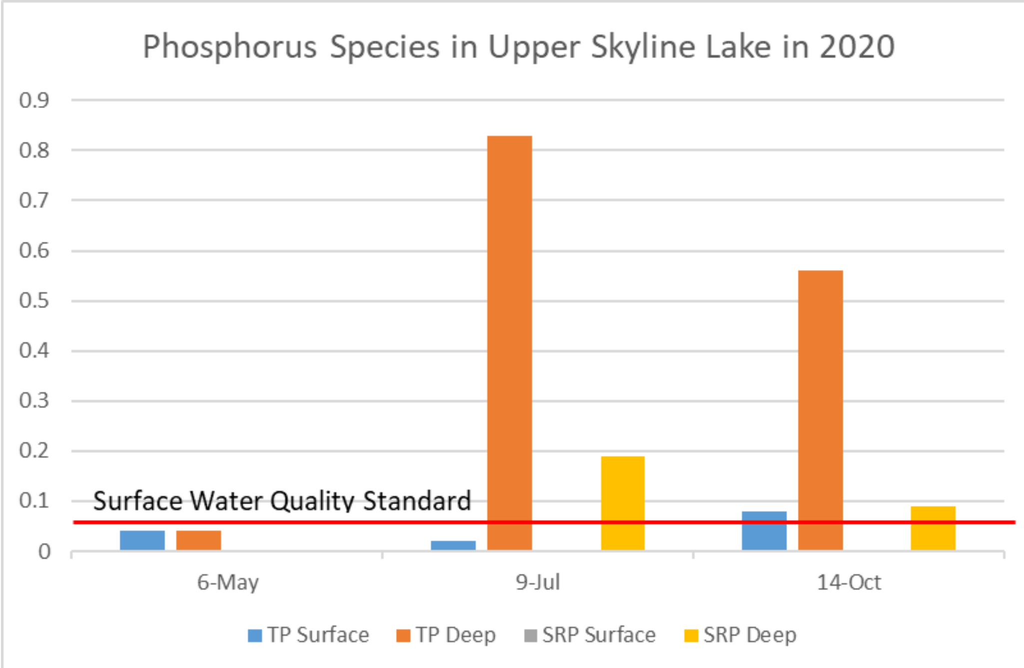

Figure 26. Concentrations of total phosphorus (TP) and soluble reactive phosphorus (SRP) measured from surface and deep samples collected in 2020 from the mid-lake station at Upper Skyline Lake

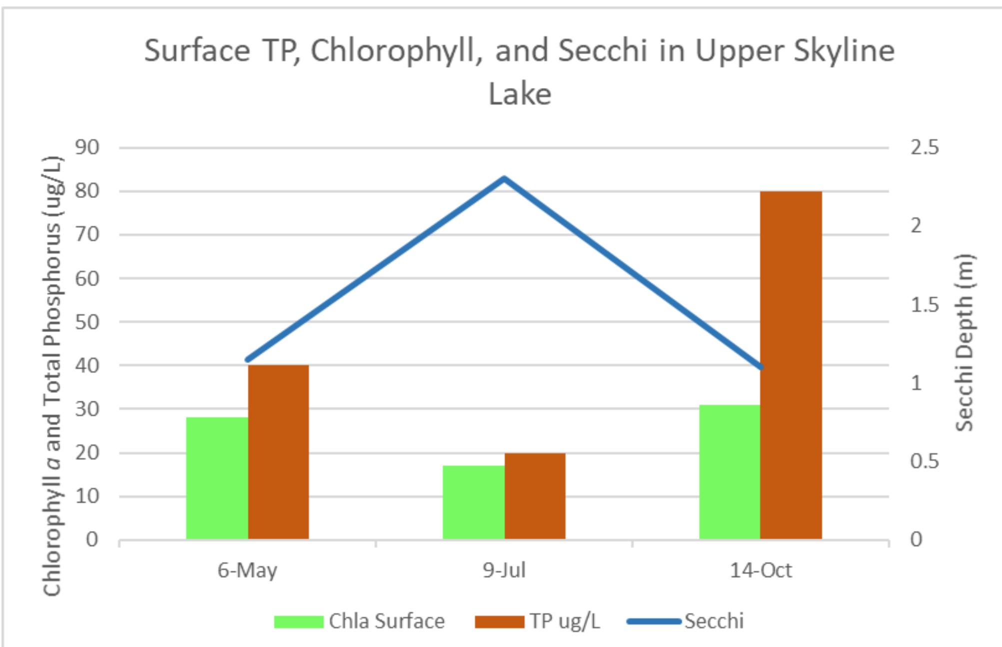

Figure 27. Concentrations of chlorophyll a (Chlorophyll a) and total phosphorus (TP), as well as Secchi depths, measured from the surface of the mid-lake station at Upper Skyline Lake on three dates in 2020.

Plankton and Macrophytes

Both of the Skyline Lakes experienced a bloom of the diatom *Asterionella* during the May event. This organism is not harmful to humans and presents no large problems in recreational Lakes, however it will result in a turbid, brown water color. Common densities of the cryptomonad *Chroomonas* were also present. The zooplankton community was largely dominated by rotifers during this event, with the genus *Asplanchna* dominating. In July, Upper Skyline Lake featured a bloom of the cyanobacteria *Dolichospermum* and the dinoflagellate *Ceratium*. Also present in the sample were abundant densities of the diatom *Melosira,* the green algae genus *Eudorina,* and the cyanobacteria genus *Aphanizomenon.* While the zooplankton community was dominated by the rotifer *Branchionus* at this time, the sample also contained common densities of the large herbivores *Diaptomus* (a copepod) and *Daphnia* (a cladoceran). By October, the phytoplankton community had shifted away from cyanobacteria in favor of diatoms and golden algae, with common densities of *Melosira, Tabellaria,* and *Dinobryon* all being detected in the sample. The green algae genus *Pediastrum* was also common in the sample. The zooplankton community featured common densities of copepod nauplii and the rotifers *Keratella* and *Asplanchna.*

Princeton Hydro staff did not observe any macrophyte growth in Upper Skyline Lake during the 2020 season. This may be a product of relatively turbid water and possibly lake lowering (the Lake was observed to have been lowered several feet in the later months of 2020).

LOWER SKYLINE LAKE

In-situ *Water Quality*

In May, Lower Skyline Lake featured a thermally well-mixed water column (Figure 29). Dissolved oxygen concentrations were super-saturated and pH levels were relatively high, likely as a product of the diatom bloom that was occurring (Figure 30). Water clarity on this date was low, at 0.65 meters. Conditions in July remained similar to those in the spring. October saw some slight thermal stratification, small increases in water clarity, and super-saturated dissolved oxygen, although pH levels were generally lower than those observed earlier in the year. The overall lack of significant thermal stratification may be a product of the Lake's relatively low depth resulting in a high flushing rate; however, a bathymetry would be need to be performed in order to acquire an estimate of the Lake's volume before this can be confirmed.

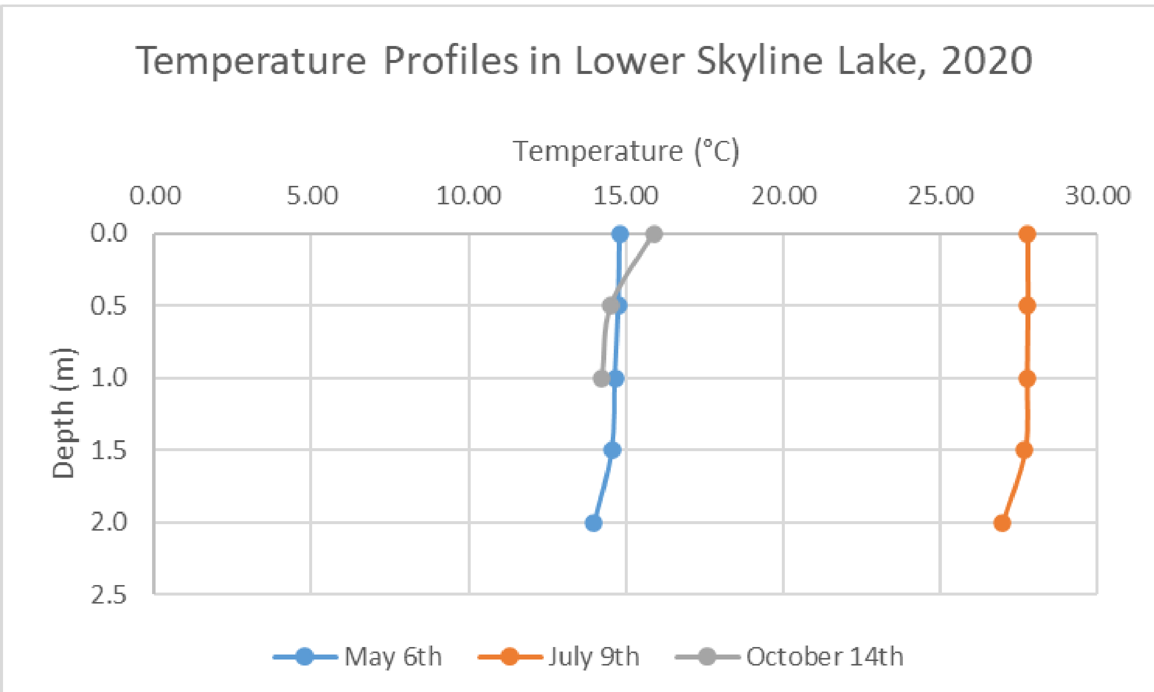

Figure 28. Temperature profiles collected during 2020 at the dam station at Lower Skyline Lake

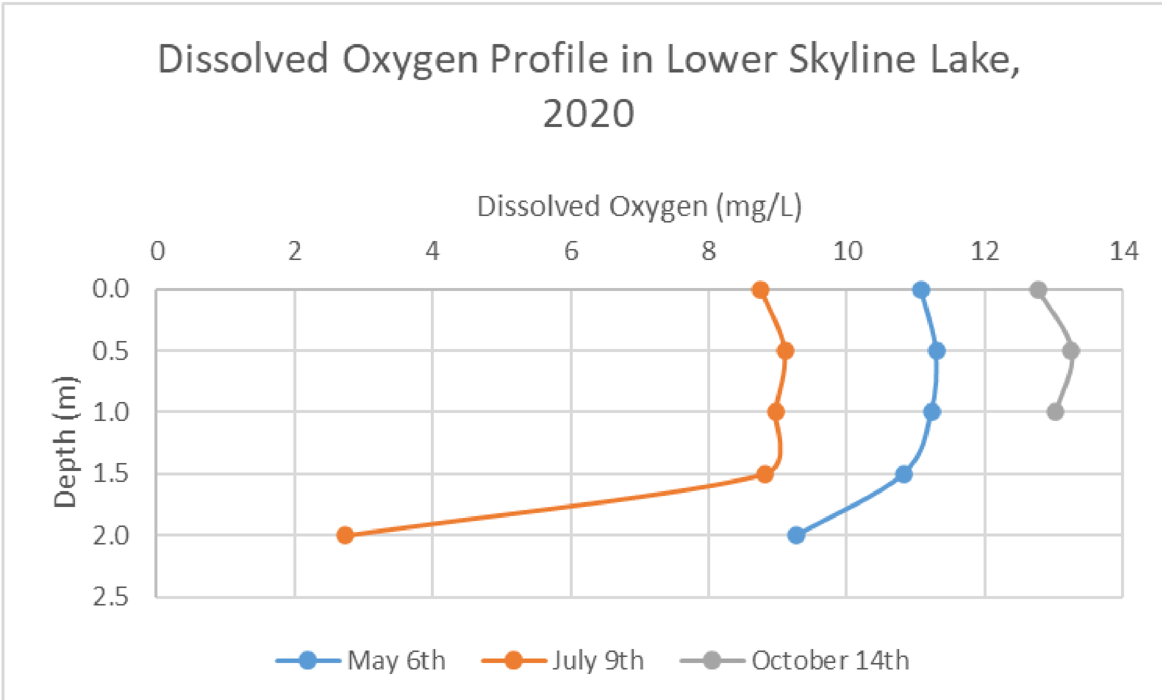

Figure 29. Dissolved oxygen profiles collected during 2020 at the dam station at Lower Skyline Lake

Discrete Water Quality

Lower Skyline Lake's total phosphorus concentrations where relatively high throughout the season, with every sample exceeding the NJ surface water quality standards for phosphorus (Figure 31). Concentrations in July were particularly high, with a surface sample of 0.1 mg/L and a deep sample of 0.11 mg/L. SRP concentrations, however, were all below the minimum detectable limit throughout the season. Nitrate-N concentrations were relatively high in the Spring, with a surface concentration of 0.75 mg/L and a deep concentration of 0.84 mg/L. These dropped to 0.05 mg/L for both depths as ammonia concentrations increased to 0.22 mg/L and 0.25 mg/L for the surface and deep samples respectively during the July event. Ammonia concentrations were otherwise very low throughout the rest of the season.

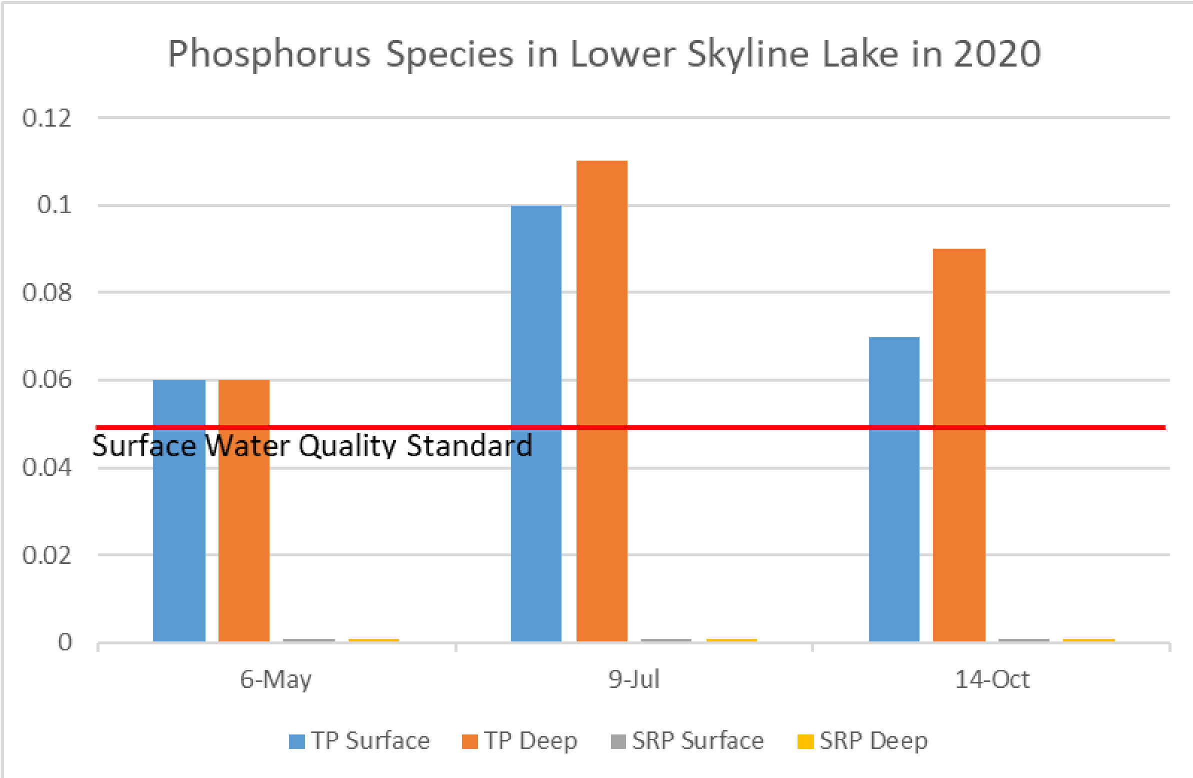

Figure 30. Concentrations of total phosphorus (TP) and soluble reactive phosphorus (SRP) measured from surface and deep samples collected in 2020 from the dam station at Lower Skyline Lake

Lower Skyline Lake featured moderate TSS concentrations during the Spring and Summer events, with the July event featuring surface and deep concentrations of 21 mg/L and 16 mg/L, respectively. Concentrations dropped to 7 mg/L for both depths by October. As with Upper Skyline Lake, Lower Skyline Lake featured overall high chlorophyll *a* concentrations throughout the year, with concentrations peaking during the July event, which yielded a surface concentration of 76 mg/L and a deep sample of 53 mg/L (Figure 32).

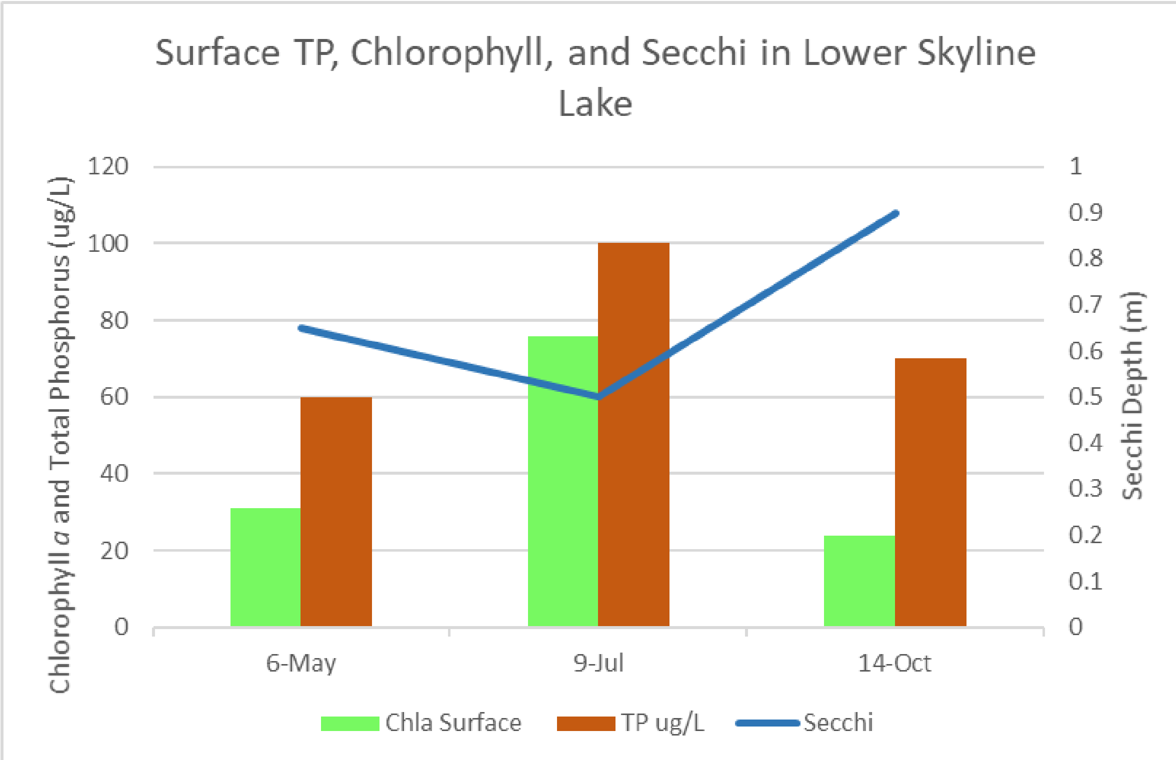

Figure 31. Concentrations of chlorophyll a (Chlorophyll a) and total phosphorus (TP), as well as Secchi depths, measured from the surface of the dam station at Lower Skyline Lake in 2020.

Plankton and Macrophytes

As mentioned above, both of the Skyline Lakes were experiencing a bloom of the diatom *Asterionella* during the May event. Lower Skyline also featured abundant densities of the diatom *Melosira* during this time. The zooplankton samples collected from this event yielded common densities of the large-bodied copepod *Leptodiaptomus* and the rotifer *Keratella*. During the July event, Princeton Hydro staff observed a surface bloom of cyanobacteria throughout most of the lake; the sample from this event contained an abundance of *Dolichospermum* and *Aphanizomenon,* as well as abundant densities of *Melosira*. The zooplankton assemblage had shifted in favor of cladocerans, with the smaller-bodied genus *Chydorus* dominating the sample. While the cyanobacteria genus *Aphanizomenon* was still abundant in the October sample and visible as floating colonies in the lake, the diatom *Asterionella* had also risen to abundant densities at this time, with multiple other taxa outside of Cyanophyta also being common in the sample. The zooplankton in the sample had shifted to a rotifer-dominated assemblage, with common densities of *Keratella* and *Polyarthra* observed.

As with Upper Skyline Lake, Lower Skyline Lake was not observed to contain significant populations of submerged aquatic vegetation. In addition to the reasons listed for Upper Skyline, Lower Skyline was observed in the field to contain populations of common carp (*Cyprinus carpio*), which can cause reductions in plant populations through bioturbation. This can also lead to algae problems as phosphorus is moved from the sediment to the surface.

LAKE RICKONDA

In-situ *Water Quality*

During the May event, Rickonda Lake featured light thermal stratification near the bottom of the water column (Figure 33). Dissolved oxygen concentrations were super-saturated throughout and pH levels were high, suggesting a high rate of photosynthesis occurring in the water column (Figure 34). The Secchi depth at the Lake's dam during this event was 1.8 m. During the July event, the Lake featured a sharper thermocline, again towards the bottom of the water column. Of particular concern were the low DO concentrations observed by the Dam; this area featured only 3.91 mg/L at the surface, and the water column was measured to become half a meter from the bottom. Additionally, the Secchi depth at the dam had dropped to 1.1 m during this event. By October, the water column had become well-mixed and well-oxygenated throughout, and the water clarity had risen to a seasonal high of 2.6 m, to the bottom of the water column.

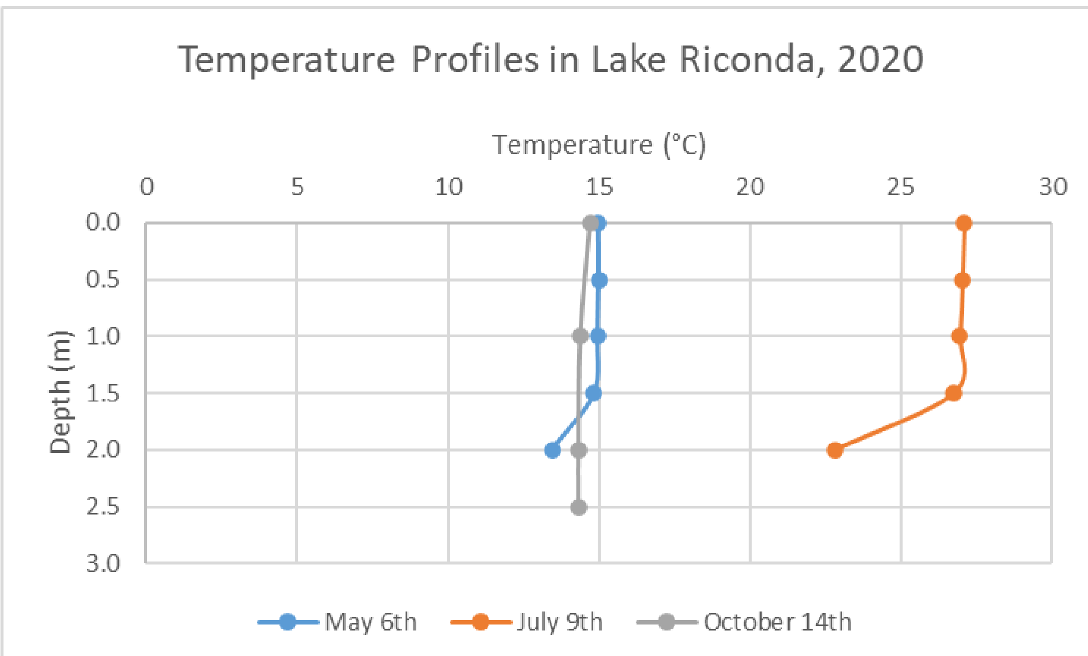

Figure 32. Temperature profiles collected during 2020 at the dam station at Lake Rickonda

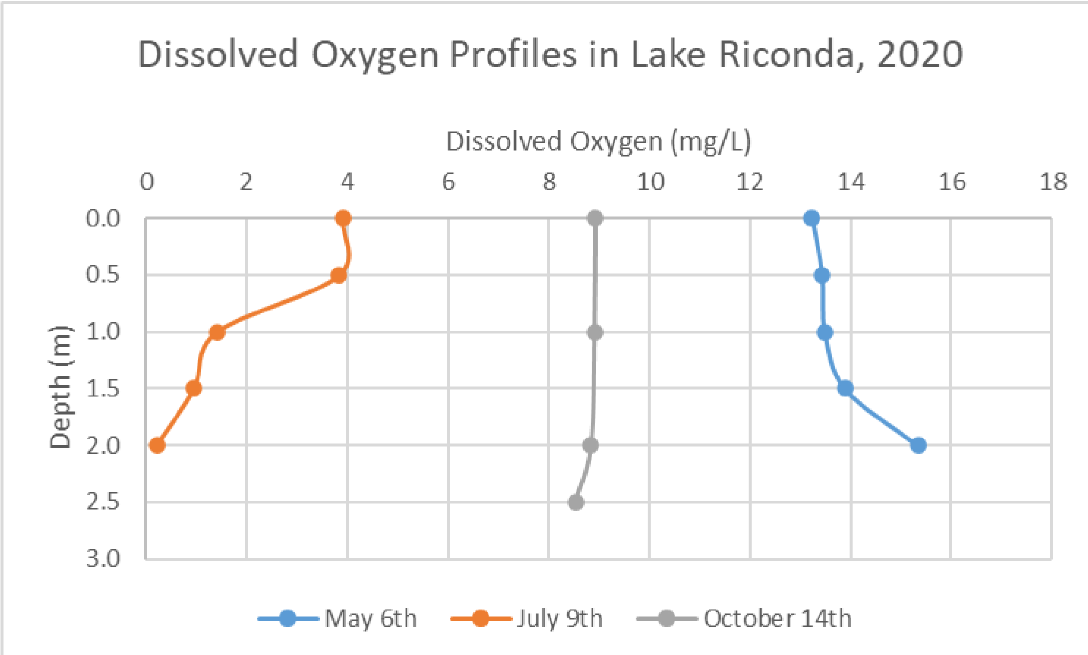

Figure 33. Dissolved oxygen profiles collected during 2020 at the dam station at Lake Rickonda

Discrete Water Quality

Rickonda Lake featured relatively low surface TP concentrations throughout the season; however, the bottom sample yielded a concentration of 0.08 mg/L, suggesting a degree of internal loading was occurring while the bottom was anoxic (Figure 35). The deep SRP concentration, while not detected at the surface or earlier in the year, was detected at 0.005 mg/L during this date. In October, SRP was not detected at the surface and was detected at a low concentration at the bottom of the water column. Nitrate-N concentrations where relatively low throughout the season in Rickonda Lake, with the seasonal high of 0.08 mg/L at both depths occurring in October. Ammonia-N was similarly relatively low throughout the season, with the highest concentration of 0.04 mg/L occurring in the deep sample in July.

TSS concentrations were relatively low throughout the year, with the only somewhat moderate concentration of 10 mg/L being measured at the bottom of the water column during the July event. Chlorophyll *a* concentrations followed a similar trend, being detected at relatively low concentrations throughout most of the season but with the deep sample in July yielding a higher concentration of 9.5 µg/L (Figure 36). This high concentration is generally still relatively low compared to concentrations seen in other NJ lakes during periods of increase algae or cyanobacteria growth.

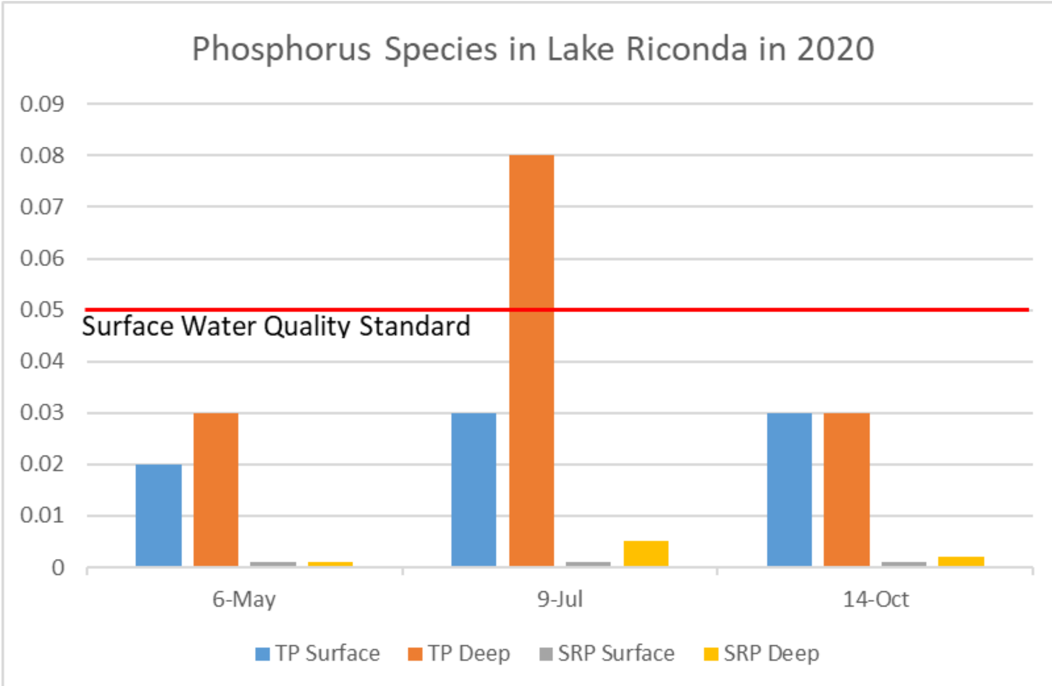

Figure 34. Concentrations of total phosphorus (TP) and soluble reactive phosphorus (SRP) measured from surface and deep samples collected in 2020 from the dam station at Lake Rickonda

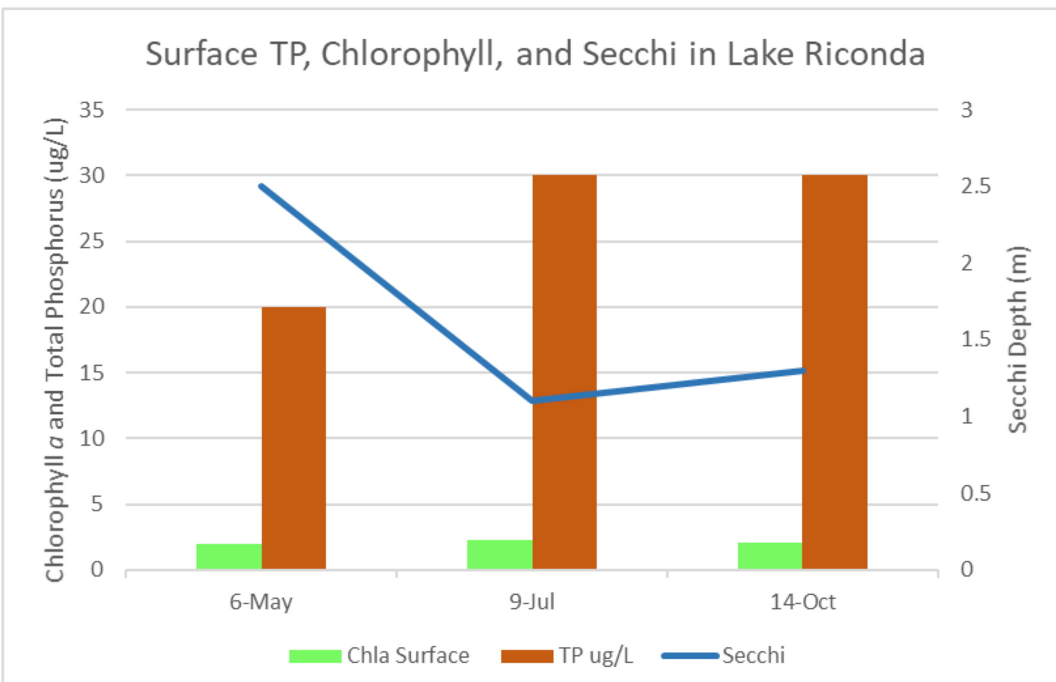

Figure 35. Concentrations of chlorophyll a (Chlorophyll a) and total phosphorus (TP), as well as Secchi depths, measured from the surface of the dam station at Lake Rickonda in 2020.

Plankton and Macrophytes

Despite high dissolved oxygen concentrations and pH levels observed in May, chlorophyll *a* concentrations and phytoplankton densities in Rickonda were very low on this date. The sample was dominated moreso with zooplankton than with phytoplankton, and only the diatom *Fragilaria* and the green algae genera *Spirogyra* and *Mougeotia* were present in the sample in low densities. The zooplankton assemblage during the May event was dominated by copepod nauplii and also featured common densities of the cladoceran *Daphnia* and the copepod *Microcyclops.* The phytoplankton sample in July was dominated by diatoms, with the genus *Melosira* being the most abundant. The zooplankton community at this time contained abundant densities of the copepod *Diaptomus*, the rotifer *Branchionus,* and genus *Ostracoda,* or seed shrimp. By October, the phytoplankton community was dominated by the dinoflagellate *Ceratium,* while *Keratella* dominated the zooplankton assemblage. Of particular note was the apparent almost complete absence of cyanobacteria throughout the season, with only *Microcystis* being observed in rare densities in October.

The thin-leaved species leafy pondweed (*Potamogeton foliosus*) was observed carpeting the bottom of the water column near the dock at the Lake's beach. Otherwise, no significant population of aquatic macrophytes were observed in Lake Rickonda, likely owing in part to treatments with blue dye, which limits the amount of sunlight that can reach the lake bottom.

5. BASELINE WATERSHED WATER QUALITY DATA

5.1 METHODS

Water samples were collected in streams entering each Lake (when present) during base-flows in order to assess the nutrient load contributed by these streams during periods when no additional runoff is occurring. Base flows typically reflect groundwater influence as well. These sampling events occurred three times a year on days where no significant rainfall had occurred in the previous 48 hours. Each stream was sampled once per season between Spring and Fall of 2020. In areas where the streams were not directly accessible to sample by hand (storm grates, tall bridges, etc.), tools such as a pump, a Van Dorn sampler, and an extendable rod with a bottle attached were used to aid in sample collection. Following collection, all samples were delivered to the laboratory Environmental Compliance Monitoring in Hillsborough, NJ for analysis. Samples were analyzed for the following parameters:

- Total Phosphorus (TP)
- Total Nitrogen (TN)
- Total Suspended Solids (TSS)

It should be noted that not all streams produced sufficient flow for sampling during all events. Additionally, Lake Rickonda does not feature any true inlets that flow during baseflow, and was not sampled for this portion of the study. Maps displaying sampling locations for the baseline sampling are provided in Appendix VI.

5.2 RESULTS

CUPSAW LAKE

In samples collected during the May 15th event, total phosphorus was low in all samples, with Cupsaw Brook's concentrations below the minimum detectable concentration. Total suspended solids were similarly low, with only Glen Brook yielding detectable concentrations. Total nitrogen concentrations, however, were higher, with Cascade Brook yielding a monthly high of 0.31 mg/L. This may be expected with many streams in the region, including those entering the other Lakes being studied. Most of these streams are likely partially fed by groundwater seepages, which naturally contain relatively high concentrations of nitrate.

TP concentrations greatly increased in the Summer, ranging from 0.05 mg/L to 0.07 mg/L, with Glen Brook yielding the highest concentration. TSS, while having slightly increased in Glen Brook, otherwise remained low and was again not detected in the other two streams. TN, however, increased in all sampled streams, with Cascade Brook yielding the seasonal high concentration of 0.64 mg/L. Cascade Brook's higher concentration may be a product of runoff from the Skyland Association's fields, which is located in the northeast portion of this sub-watershed.

In the December baseline event, total phosphorus was only detected in a very low concentration of 0.01 mg/L in Glen Brook, while the other two streams did not yield detectable concentrations. Similarly, TSS was detected to be low in Glen and Cascade Brooks, while Cupsaw Brook did not yield detectable concentrations. Total nitrogen concentrations decreased slightly, with Cascade Brook once again yielding the seasonal high at 0.43 mg/L.

UPPER ERSKINE LAKE

Both of the Lake's inlet streams yielded no detectable concentrations of TP or TSS during the spring event, while nitrogen concentrations in both streams were measured at 0.24 mg/L. The relatively low nutrient load may be because of the largely forested makeup of the sub-watersheds these streams originate from. During the Summer event, the North Inlet was not flowing and therefore not contributing nutrients to the lake; however, the East inlet yielded an elevated total nitrogen load of 2.7 mg/L, as well as a TP concentration of 0.08 mg/L. No TSS was detected at this site during this time. In December, the northern inlet was again flowing and yielded an elevated nitrogen concentration of 1.3 mg/L. TP concentrations however were detected to be very low at this site and were not detectable at the east inlet, while both sites yielded a low TSS concentration of 2 mg/L.

LOWER ERSKINE LAKE

The only inlet that flows into Lower Erskine Lake during base-flows is the outlet stream flowing from Upper Erskine Lake's Dam. During the Spring baseline sampling event, this location yielded minimal TP and TSS, as well as a nitrogen concentration of 0.38 mg/L. In July, nitrogen concentrations increased at this location to 0.52 mg/L, while TP was detected at 0.05 mg/L and TSS was detected at 4 mg/L. While most of this water is only traveling a short distance to the sampling point after leaving Upper Erskine Lake, it is not known what amount of groundwater influence (if any) is present between the Upper Erskine Dam and the sampling point.

UPPER SKYLINE LAKE

Upper Skyline Lake's two inlets that flow during dry-weather periods are High Mountain Brook and a smaller tributary that flows through the Plaza sub-watershed. Unlike the streams mentioned above, the small Plaza tributary featured a relatively high TP concentration during the spring event, yielding a concentration of 0.08 mg/L. Both streams also yielded relatively high TN concentrations at this time of over 1 mg/L. The Plaza tributary yielded a small concentration (3 mg/L) of TSS during this event, while High Mountain Brook's sample did not feature measurable concentrations. It should be noted that both of these streams are the only locations in the study that feature point-source inputs farther upstream; these may be contributing factors leading to increased nutrient concentrations. Both tributaries also pass through or near significant urban areas may receive nutrient runoff from these areas.

During the Summer event, the Plaza tributary yielded a seasonal high TP concentration of 0.10 mg/L, while High Mountain Brook yielded a seasonal high TN concentration of 3.9 mg/L. High Mountain Brook also yielded 0.07 mg/L of total phosphorus, and both streams exceeded the NJ surface water quality standard for this parameter, likely due to relatively high rates of septic influence, especially in High Mountain Brook. Both streams yielded no detectable concentrations of TSS, however. During the December sampling event, both streams yielded a TN concentration of 2.31 mg/L. The Plaza tributary also yielded 0.03 mg/L of TP and 2 mg/L of TSS, while High Mountain Brook's sample did not yield detectable concentrations of either of these.

LOWER SKYLINE LAKE

During the Spring event, the Hidden Valley Lake outlet stream yielded a TN concentration of 0.58 mg/L, as well as 0.02 mg/L of TP and 3 mg/L of TSS. The water flowing out of Upper Skyline Lake yielded a higher nitrogen concentration of 0.94 mg/L and a higher TSS concentration of 4 mg/L, but a lower TP concentration of 0.01 mg/L. As with many of the other streams surveyed, TP increased during the summer, with the Upper Skyline Lake outlet yielding a concentration of 0.04 mg/L and the Hidden Valley Lake outlet stream yielding 0.09 mg/L. Nitrogen concentrations were lower than those measured in the Spring, with the Upper Skyline Lake outlet yielding 0.33 mg/L and the Hidden Valley Lake outlet stream yielding 0.25 mg/L. Both streams featured a TSS concentration of 2 mg/L at this time. During the December sampling event, Upper Skyline Lake had been drawn down several feet, and water was not flowing over the dam between it and Lower Skyline Lake. The Hidden Valley Lake outlet stream, however, yielded a seasonal high nitrogen concentration of 0.96 mg/L, while TP concentrations were measured at a low 0.02 mg/L and TSS concentrations were measured at 4 mg/L.

6. STORM EVENT WATER QUALITY DATA

6.1 METHODS

Water samples were collected both in streams and storm water flows entering each Lake during storm events in order to assess the nutrient load contributed by these streams during periods of increased runoff. These sampling events occurred three times a year on days where significant rainfall had occurred. Each location was sampled once per season between Spring and Fall of 2020. In areas where locations were not directly accessible to sample by hand (storm grates, tall bridges, etc.), tools such as a pump, a Van Dorn sampler, and an extendable rod with a bottle attached were used to aid in sample collection. Following collection, all samples were delivered to the laboratory Environmental Compliance Monitoring in Hillsborough, NJ for analysis. Samples were analyzed for the following parameters:

- Total Phosphorus (TP)
- Total Nitrogen (TN)
- Total Suspended Solids (TSS)

Maps displaying sampling locations for the baseline sampling are provided in Appendix VII.

6.2 RESULTS

CUPSAW LAKE

During the April event, Glen Brook saw a seasonal high of TSS, yielding a concentration of 290 mg/L. This stream also featured a relatively high nitrogen concentration of 1.12 mg/L during this event, while the other two streams were considerably lower. Glen Brook also saw the highest TP concentration of this event among the Cupsaw Lake streams, with a concentration of 0.42 mg/L, while Cascade Brook featured a concentration of 0.24 mg/L and Cupsaw Brook featured a concentration of 0.16 mg/L. These all exceed the surface water quality standard for streams (0.1 mg/L). In July, concentrations of TP and TSS dropped at all sites, while TN concentrations dropped in Glen Brook but increased in the other two sites. Cascade Brook featured the highest TP concentration of the three streams during this event, with a concentration of 0.22 mg/L. By October, TP and TSS concentrations had dropped considerably in all sites. TN concentrations had dropped in Glen Brook and Cupsaw Brook but had increased in Cascade Brook.

UPPER ERSKINE LAKE

During the April storm event, the North Inlet featured the greatest concentration of TN, at 1.69 mg/L, and the greatest concentration of TSS, at 33 mg/L. The Beach storm drain, however, featured the highest concentration of TP during this event, likely due to the higher amount of urbanization and impervious land cover in this location's sub-watershed. During the July storm event, however, the North Inlet featured the highest TP concentrations of the three locations, with a concentration of 0.42 mg/L, exceed the surface water quality standard for streams. This stream again featured the highest TN concentration also, with a concentration of 1.22 mg/L, while the East Inlet featured the highest TSS concentration, at 110 mg/L. During the October event, both the north inlet and the beach drain did not receive enough flow to be sampled. The East inlet, however, featured a TN concentration of 1.01 mg/L, a TP concentration of 0.09 mg/L, and a TSS concentration of 2 mg/L.

LOWER ERSKINE LAKE

During the April Storm event, the north pipe location yielded the highest TN and TSS concentrations, at 1.93 mg/L and 29 mg/L, respectively. The southwest pipe yielded the highest TP concentration during this event at 0.10 mg/L. While the outlet stream from Upper Erskine Lake generally yielded comparatively low nutrient concentrations during the April event, in July it yielded the highest TN concentration at 2.43 mg/L. During this event the north pipe location yielded the highest TP concentration at 0.27 mg/L, while the southwest pipe yielded the highest TSS concentration at 27 mg/L. During the October event, the southwest pipe did not yield enough flow to sample; however, the northern pipe yielded the highest TN concentration (2.31 mg/L) and the highest TP concentration (0.45 mg/L) of the other two sites. TSS was generally low in both of the two flowing sites during this event.

UPPER SKYLINE LAKE

During the Spring storm event, high concentrations of TN were measured in the sample collected from the Smoky Run drain, however this location yielded low concentrations of the other nutrients relative to the other two sites. The Plaza tributary station yielded the highest concentrations of TP (0.69 mg/L, exceeding the NJ surface water quality standard threshold) and TSS (220 mg/L) for this event, likely due to its sub-watershed containing a large, urbanized area and a point-source discharge to the north, as noted above. In July, this station once again featured the highest TSS concentration (18 mg/L), while High Mountain Brook featured the highest TN concentration (2.60 mg/L) of the three streams, and all three sites yielded a TP concentration of 0.18 mg/L. High concentrations of TP may be explained as an effect of septic influence from nearby upstream urbanized areas, as described above. During the October event, High Mountain Brook yielded a very high TN concentration of 4 mg/L, as well as the only detectable concentration of TSS (3 mg/L). The Smoky Run drain yielded the highest TP concentration for this event at 0.30 mg/L.

LOWER SKYLINE LAKE

During the spring storm event, the Hidden Valley Outlet Stream yielded the highest TN concentration (0.48 mg/L) and the highest TP concentration (0.24 mg/L, exceeding the surface water quality standard threshold) of the three sites, while the Mountain Glen Drain yielded the highest TSS concentration at 80 mg/L. During the July event, the Mountain Glen drain yielded the highest concentrations of TN (1.52 mg/L) and TP (0.46 mg/L), while the Beach drain yielded the highest concentration of TSS (80 mg/L). It should be noted that the beach drain box was consistently observed to contain large amounts of leaves; these should be cleared periodically to aid with drainage and prevent additional nutrients from entering the lake. In October, both the beach drain and the Mountain Glen drain were not flowing sufficiently enough for sample collection, however the Hidden Valley Lake outlet stream yielded 0.53 mg/L of TN, 0.20 mg/L of TP, and a low 3 mg/L of TSS.

LAKE RICKONDA

The Spring storm event saw Willow Lane yield the highest concentrations of all nutrients between the two sampling locations, with a TN concentration of 1.65 mg/L, a TP concentration of 0.21 mg/L, and a TSS concentration of 270 mg/L. During the July event, this site yielded the highest TN concentration (1.08 mg/L) and the highest TP concentration (0.81 mg/L), however the south drain yielded a very high TSS concentration during this event of 430 mg/L. In October, Willow Lane once again yielded the highest concentrations of each pollutant, with a TP concentration of 0.45 mg/L, and TN concentration of 0.80 mg/L, and a TSS concentration of 73 mg/L.

7. IN-LAKE CONCLUSIONS AND RECOMMENDATIONS

As expected, the results of the modeling and field studies suggest that both stormwater and baseflows contribute watershed-based nutrients and sediment to each lake. However, data collected in some of the Lakes surveyed also suggests that there are also significant in-lake processes that are likely contributing to nutrient loading and, therefore, algae and cyanobacteria blooms. Princeton Hydro therefore will provide recommendations in the balance of this report for management measures that can be taken in each Lake and its watershed. A more detailed and comprehensive description of some of the watershed-based recommendations are provided in Section 8. Because the Borough of Ringwood is focused on watershed-based solutions, recommendations will be broken into watershed-based and In-lake solutions. In-lake recommendations are provided for the benefit of each Lake's community; however, should a Lake community wish to move forward with any of the in-lake recommendations, the Lake community must do so without contribution from the Borough. Additionally, general recommendations that can apply to all of the Lakes studied are provided at the end of the section.

7.1 CUPSAW LAKE

Cupsaw Lake's watershed, while largely forested to the north and east, contains many acres of residential land in the areas directly adjacent to the Lake. As is the case with many similar lakes in North Jersey, this can lead to negative impacts from septic tank influence. In addition, the increased amount of impervious landcover can exacerbate runoff and allow for more nutrients and sediment to move towards the waterbody. Sampling results suggest that Glenn Brook is overall one of the largest watershed-based conveyors of nutrients to Cupsaw Lake. In addition, Cascade Brook contributes a relatively large amount of nitrogen to the lake compared to the other two streams studied, particularly during baseflow periods. This may indicate a large groundwater influence. Despite issues with bottom anoxia detected in Cupsaw Lake by Princeton Hydro in 2019, the lake was not detected to have this problem in 2020. Elevated total phosphorus concentrations however were observed to occur regardless, along with a notable presence of cyanobacteria in plankton samples.

Based on these findings, Princeton Hydro recommends the following:

WATERSHED-BASED RECOMMENDATIONS

As will be described in great detail in the following section, Princeton Hydro recommends several measures, many of which will involve treating runoff in several larger parking lots throughout the watershed. This will involve such best management practices as the installation of rain gardens and the use of alternative (semipervious) pavement. Also recommended is the conversion of formerly dammed portions of Cupsaw Brook and a smaller unnamed tributary to sediment forebays. A manufactured treatment device (MTD) for the stormwater outfall in the northwestern portion of the lake is also recommended, as is the daylighting and vegetation of Cascade Brook near its confluence with the lake. All of these practices would serve to intercept flows and remove sediment and nutrients prior to the water entering the lake.

IN-LAKE RECOMMENDATIONS

Aeration System – Cupsaw Lake utilizes an aeration system to keep the water column from stratifying. If used and maintained properly, this system should allow the bottom to remain relatively well-oxygenated and prevent excess loading of phosphorus occurring at the lake bottom. While the lake was observed to be stratified in early May, prior to the activation of the aeration system, the activation of the system appears to have precluded further stratification and observable bottom dissolved oxygen problems in the Summer and Autumn events. Princeton Hydro recommends that the system is activated as early as possible in the season so as to reduce phosphorus loading due to anoxia. Should stratification and anoxia be found to still occur despite proper use of the aeration system, upgrades may need to be made to the system to either increase the airflow to the diffusers currently in use or to add additional diffusers to other areas of the lake.

Floating Wetland Islands – A potential method for controlling phosphorus concentrations in Cupsaw Lake is the installation of floating wetland islands (FWIs). 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 Cupsaw Lake, FWIs would likely be best placed in the shallower northern portion of the Lake, where they can treat water entering the system from the numerous inlets in this area.

7.2 UPPER ERSKINE LAKE

Similar to Cupsaw Lake, Upper Erskine Lake features a largely forested watershed with low-density residential land occupying the areas immediately adjacent to the lake. Areas to the south and west, however, feature increased urban land cover; however, the eastern sub-watersheds were estimated via modeling to yield the largest annual load of total phosphorus. While the Lake experienced a small degree of thermal stratification and bottom dissolved oxygen reduction during the summer event, there was no difference between surface and deep TP concentrations, suggesting that internal loading was not a large source of phosphorus during the 2020 season. The lake experienced a notable presence of cyanobacteria in plankton samples during the July and October events, however these were not observed to cause visibly problematic conditions in the lake during sampling events.

Based on these findings, Princeton Hydro recommends the following:

WATERSHED-BASED RECOMMENDATIONS

As noted above, the southern sub-watershed contributes the highest annual estimated load of total phosphorus to Upper Erskine Lake. An area of concern in this sub-watershed is the boat launch/beach parking area. As will be explained in greater detail in the next section, Princeton Hydro recommends the installation of permeable pavement or pavers in parts of this area in order to intercept stormwater and allow it to filter into the groundwater rather than directly enter the lake. Additionally, restabilization and vegetation of the northeastern bank of the beach peninsula is also recommended.

While not mentioned as part of the management measures in the following section, another watershed-based implementation that Princeton Hydro has been exploring recently is the use of Biochar. Biochar is charcoal biomass material made from trees, shrubs, and other vegetation. It has a high affinity for removing nutrients, particularly phosphorus. Removal rates from this agricultural waste have been documented as being greater than 90% for various forms of phosphorus and between 60 and 80% for various forms of nitrogen. However, the manufacturer did note that these high removal rates are based on a longer duration of contact time between the water and the Biochar. In addition, the material tends to be lower in cost than other filter media and can be used as mulch and/or used as a media for plant growth after used to remove nutrients in a waterbody. Thus, the Biochar can be disposed of in a very "green" fashion and is very sustainable. In the Upper Erskine Lake Watershed, sleeves of biochar can be utilized in the storm drain box located at the entrance to the boat-launch/beach parking lot in order to treat stormwater entering the lake from areas further uphill in the southern sub-watershed. Biochar Sleeves can also be placed along the eastern and northern inlet streams to treat flows entering the lake from these sub-watersheds. Depending on the portion of the stream targeted, however, Ringwood Borough would either need to acquire permission from landowners or from the New Jersey Division of Parks and Forestry if working in Ramapo Mountain State Forest.

IN-LAKE RECOMMENDATIONS

Floating Wetland Islands – As mentioned above for Cupsaw Lake, Upper Erskine Lake may benefit from the installation of floating wetland islands. In particular, areas of the lake that may benefit from FWIs are the southeastern side of the beach peninsula, near the boat storage area and outflow of the parking lot storm-drain, and near where the north and east inlets enter the lake.

Aeration System – While Upper Erskine Lake was not observed to experience advanced internal loading of phosphorus during the 2020 season as a product of bottom anoxia, it is not known if this is the case every year, as different annual weather patterns may lead to the lake to thermally stratify at slightly different points in time each year. Should bottom anoxia prove to be a problem in future years, Upper Erskine Lake may benefit from an aeration system similar to that used in Cupsaw Lake. Additional years of water quality sampling should be conducted before this decision is made, however.

7.3 LOWER ERSKINE LAKE

Lower Erskine Lake's watershed features a relatively urbanized watershed, and septic system leaching is estimated to dominate contributions to the Lake's total phosphorus and nitrogen load. The northwest and southwest sub-watersheds were estimated to yield the highest annual load of phosphorus, and results of stormwater sampling events indicate that a stormwater pipe outfall into the Lake in the northwest sub-watershed yielded the highest TP concentrations during the summer and fall. The Lake was observed to be experiencing bottom anoxia during the July in-Lake sampling event, and the difference in surface and bottom TP concentrations during this date suggests that the lake was experiencing a degree of advanced internal phosphorus loading during this time. The Lake featured notable concentrations of cyanobacteria, with some taxa likely forming deep-water populations. Zooplankton populations, however, featured a healthy population of large-bodied herbivorous taxa, which likely aid in keeping numbers of some algae species in control.

Based on these findings, Princeton Hydro recommends the following:

WATERSHED-BASED RECOMMENDATIONS

As will be described in greater detail below, Princeton Hydro recommends the installation of manufactured treatment devices (MTDs) in numerous stormwater systems around the lake, including that contributing to the southwest and northern pipe locations sampled during stormwater sampling. Additionally, the installation of permeable pavement and vegetated pavers are recommended for the beach parking lot on the southern edge of the lake and the boat launch along lakeside avenue respectively.

While not mentioned as part of the management measures in the following section, the concrete between Upper Erskine Lake and Lower Erskine Lake upstream of Lakeview Avenue is a potential location for the implementation of a planted wetland and/or biochar bags. While management efforts made in Upper Erskine Lake's watershed should serve to reduce nutrient and sediment concentrations in the lake water flowing through this channel, this area can be used to further treat water moving between the two lakes. Because of the location of this site on Upper Erskine Lake's dam, however, any implementation(s) will need to be designed so as to preserve the structural integrity of the dam.

IN-LAKE RECOMMENDATIONS

Aeration System – During in-lake sampling conducted in July of 2020, Lower Erskine Lake was observed to strongly stratify, with bottom anoxia being observed. Given the difference of surface and deep total phosphorus concentrations, advanced internal phosphorus loading is likely contributing to the Lake's total phosphorus load at some point in time during the growing during most years. This may be remedied by the installation of an aeration system similar to that utilized in Cupsaw Lake, which serves to keep the lake in a destratified state, reducing dissolved oxygen reduction in deeper waters. Before a system is installed, a bathymetric survey (mapping of water and sediment depths), as well as a more thorough modeling of in-lake phosphorus loading should be conducted in order to assess the reductions in phosphorus that could be attained by the installation of such a system. This should also be paired with annual water quality surveys in order to assess the effectivity of the system; other potential benefits of further water quality surveys will be described at the end of this section.

Floating Wetland Islands – As mentioned above for Cupsaw Lake and Upper Erskine Lake, Lower Erskine Lake may benefit from the installation of floating wetland islands after in-lake aeration has been implemented. In particular, areas of the lake that may benefit from FWIs are the areas where stormwater flows enter, such as near the northeast boat launch, southwest cove near the stormwater outfall, and in the cove near the northwestern outfall pipe, as well as near the inlet from Upper Erskine Lake.

Nutrient Sequestration – Another potential solution to internal phosphorus loading is the application of the sequestration agent, SePRO's Phoslock®. This product serves to blanket the bottom sediment and bind to phosphorus, preventing it from precipitating into the water column if the bottom of the water column experiences anoxia. Phoslock® is usually best applied in the Spring, before stratification occurs.

7.4 UPPER SKYLINE LAKE

While Upper Skyline Lake's watershed features large expanses of forested land to the northeast, it also contains relatively large acreages of urbanized areas, particularly in areas immediately around the lake and to the north, where a shopping plaza is located. The Lake's two main tributaries, High Mountain Brook and the Plaza tributary (also known as Meadow Brook) are estimated to convey nutrients and sediment to the Lake, as does the western sub-watershed, likely due to septic system influence. Results of water quality samples collected in the watershed during the 2020 season further confirmed this, particularly during stormwater events. During the July in-lake sampling event, the water column was thermally stratified and featured 4 meters of anoxia. This event, as well as the October event, saw very large differences in surface and deep TP and SRP concentrations, suggesting that an advanced state of internal loading was contributing to the Lake's phosphorus load. The Lake also featured very high densities of cyanobacteria during the July event; however, the lake also featured common densities of two large-bodied herbivorous zooplankton as this time, which may have served to control other algae species to some degree.

Based on these findings, Princeton Hydro recommends the following:

WATERSHED-BASED RECOMMENDATIONS

As will be discussed in greater detail in the following section, Princeton Hydro recommends several practices that aim to treat stormwater moving into the Plaza tributary from the shopping center in the northern portion of this sub-watershed. These include a retention basin on the eastern side of Skyline Dr., adjacent to the intersection with fieldstone drive, along with an MTD along the outflowing stormwater pipe, and a vegetated buffer strip on the western edge of the parking lot west of Skyline Dr. Additionally, Princeton Hydro recommends using either porous or vegetate pavers in the parking lot near the western side of the Lake's dam in order to allow stormwater flows to percolate into groundwater, rather then runoff into the lake.

While not mentioned as part of the management measures in the following section, Upper Skyline Lake may benefit from the addition of Biochar sleeves into some of the stormwater drains and inlets entering the waterbody, as described above for some of the previous lakes. In particular, the storm-drain box where Smoky Run stormwater samples were collected, along the western side of the lake on Skyline Dr., may be a good candidate for either this measure or an MTD, or order to remove stormwater based nutrients prior to its entering into the lake. The Plaza tributary and High Mountain Brook may also be good candidates for a Biochar installation; however, permission may need to be secured from landowners, depending on the selected location on either stream.

IN-LAKE RECOMMENDATIONS

Aeration System – During in-lake sampling conducted in July of 2020, Upper Skyline Lake was observed to strongly stratify, with bottom anoxia being observed in the bottom-most 4 meters. Given the large difference of surface and deep total phosphorus and soluble reactive phosphorus concentrations, advanced internal phosphorus loading is likely contributing to the Lake's total phosphorus load. As with Lower Erskine Lake, this may be remedied by the installation of an aeration system, which would serve to keep the lake in a destratified state, reducing dissolved oxygen reduction in deeper waters. Before a system is installed, however, a bathymetric survey (mapping of water and sediment depths), as well as a more thorough modeling of in-lake phosphorus loading should be conducted in order to assess the reductions in phosphorus that could be attained by the installation of such a system. This should also be paired with annual water quality surveys in order to assess the effectivity of the system; other potential benefits of further water quality surveys will be described at the end of this section.

Nutrient Sequestration – As with Lower Erskine Lake, another potential solution to internal phosphorus loading is the application of the sequestration agent, SePRO's Phoslock®. This product serves to blanket the bottom sediment and bind to phosphorus, preventing it from precipitating into the water column if the bottom of the water column experiences anoxia. Phoslock® is usually best applied in the Spring, before stratification occurs.

7.5 LOWER SKYLINE LAKE

As with the other Lakes in this study, Lower Skyline Lake features a largely forested watershed with urbanized areas in the immediate vicinity of the lake itself. A majority of the Lake's nutrient loads come from Upper Skyline Lake's watershed, however the Hidden Valley Lake and Eastern sub-watersheds also yield a fair percentage of the Lake's total phosphorus loads, largely due to septic system influence. The northwest sub-watershed yields a relatively high sediment load as well. Unlike some of the other lakes studied, the water column was not observed to significantly thermally stratify, and dissolved oxygen concentrations were generally sufficient throughout the water column, although it is not known if these conditions exist every year. Despite this, the lake featured elevated surface and deep phosphorus concentrations and low water clarities throughout the year, and a surface bloom of cyanobacteria was observed to occur in July.

Based on these results, Princeton Hydro recommends the following:

WATERSHED-BASED RECOMMENDATIONS

As will be discussed in greater detail in the section below, Princeton Hydro recommends the installation of porous or vegetated pavers in the parking lot to the beach on the western side of the lake. Vegetate pavers and shoreline stabilization are also recommended for the gravel boat launch that extends towards the lake off of this parking lot. The installation of alternative paving measures would aim to allow incoming stormwater to infiltrate into the groundwater rather than enter the lake directly.

IN-LAKE RECOMMENDATIONS

Fisheries Survey – Based on in-field observations by Princeton Hydro staff, the invasive bottom-feeding fish common carp are suspected to be present in Lower Skyline Lake. When present in large population densities, these fish can create turbidity problems, harm aquatic plant populations, and can move bottom nutrients to the top of the water column through bioturbation, making these nutrients available for assimilation by algae and cyanobacteria. Several methods are available for removing larger numbers of carp from a waterbody; however, Princeton Hydro recommends first conducting a survey of the lake's fishery to acquire an estimate of the carp population size, as well as to a general assessment of other fish populations in the lake. A high population of other fish species such as alewife or golden shiners may have a negative impact on the Lake's zooplankton community, which can lead to an abundance of green algae. A fish population conducted with the purpose of assessing carp populations can also detect these fish.

Vegetation replanting – While full, comprehensive surveys for aquatic macrophytes (plants and plant-like algae) were not conducted as part of this study, both of the Skyline lakes were not observed to feature significant macrophyte populations. While macrophytes can become a nuisance to lake users at high densities, a properly managed population of native macrophytes can provide benefits to a lake, such as sport fish habitat, nutrient uptake, and sediment stability. A high population density of common carp, if present, may preclude establishment of beneficial macrophyte beds; however, this may be an avenue worth perusing in Lower Skyline Lake once these fish populations have been reduced. Nearshore areas away from homeowner properties and designated swimming areas, are good candidates for riparian and submerged macrophyte planting.

7.6 LAKE RICKONDA

Lake Rickonda features a small watershed compared to the surface area of the waterbody itself; accordingly, the watershed is estimated to produce lower nutrient and sediment loads then those of other lakes in this study. As with the other lakes studied, septic system influence is estimated to yield a majority of the lake's nutrient load. Stormwater sampling; however, yielded results that suggest that notable nutrient loads still enter the lake via the watershed at times, particularly at the Willow Lane sampling site. The lake featured thermal stratification and overall low dissolved oxygen concentrations during the July sampling event. High deep phosphorus concentrations at this time relative to those found at the surface suggest that advanced internal loading may had been occurring. Chlorophyll concentrations stayed low, however, and no problematic cyanobacteria populations were observed in plankton samples. It is not known if these conditions are typical for this lake, however.

Based on these findings, Princeton Hydro recommends the following:

WATERSHED-BASED RECOMMENDATIONS

As will be further described below, Princeton Hydro recommends the conversion of the stormwater swale along the southern edge of the Lake's beach to a vegetated swale featuring small pools for the settling of sediment. This swale will serve to remove sediment and some nutrients from stormwater entering the lake from Lake Rickonda Drive. As with the other lakes in the study, the Lake may also benefit from further shoreline stability and re-vegetation efforts in multiple areas around the Lake's shoreline.

IN-LAKE RECOMMENDATIONS

Floating Wetland Islands - As mentioned above for some of the other lakes, Lake Rickonda may benefit from the installation of floating wetland islands. In particular, areas of the lake that may benefit from FWIs are the southern end near the stormwater outfall from the South Drain stormwater sampling location, as well as near the stormwater input from Willow Lane.

Aeration Systems – Given the low dissolved oxygen concentrations observed in July of 2020, Lake Rickonda may benefit from an aeration system, which, if properly used, should keep the water column from stratifying and allow for better atmospheric mixing of oxygen into the water column. However, Princeton Hydro recommends that further years of water quality data be collected before installing such a system in order to assess whether or not this drop in dissolved oxygen is a yearly occurrence.

Nutrient Sequestration – As with Lower Erskine Lake and upper Skyline Lake, the use of Phoslock® to bind phosphorus to bottom sediments in Lake Rickonda may be beneficial during times of reduced dissolved oxygen at the bottom of the water column. However, given the lack of cyanobacteria problems observed in 2020, Princeton Hydro recommends this only if a regular yearly pattern in cyanobacteria blooms begins to occur and can be traced to internally loaded phosphorus.

7.7 GENERAL RECOMMENDATIONS

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

WATERSHED-BASED RECOMMENDATIONS

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

IN-LAKE RECOMMENDATIONS

Annual Water Quality Monitoring – Princeton Hydro strongly recommends the establishment of an annual water quality monitoring program. This not only allows for the establishment of long-term trends, but allows lake managers to assess the progress and effectivity of established management implementations, detect problems as they arise, and set management goals. Ideally, a monitoring program should follow the timing and methodology utilized by Princeton Hydro in 2020, with at least three events occurring over the course of a year, and each event featuring the sampling of *In-situ* and discrete water quality data. Particulars and attention to other components can be tailored to suit an individual lake's needs, and indeed may change over the course of several years as a lake community's needs change.

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

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

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

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

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

8. WATERSHED-BASED CONCLUSIONS AND RECOMMENDATIONS

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

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

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

Specifically, the following list of potential funding sources is provided. Additional funding sources may be or become available in beyond those listed below.

Potential State Sources of Funding for Watershed Restoration Projects More details on the potential sources of funding through the programs listed below can be found at www.nj.gov/dep/grantandloanprograms.

- Non-Point Source Pollutant Control Grants (funds provided to NJDEP through Section 319 (h) of the federal Clean Water Act) to address watershed-based, non-point source pollution.

- Water Quality Management Planning Pass-Through Grants (funds provided to NJDEP through Section 604 (b) of the federal Clean Water Act), primarily to conduct wastewater management planning activities and develop management plans for on-site wastewater treatment systems.

- Dam Restoration & Inland Water Projects Loan Program (1992 Dam Restoration and Clean Water Trust Fund) can provide low-interest loans to assist in the funding of dam restoration, flood control projects, water pollution control projects, and water-related recreation and conservation projects.

- Green Acres Grants & Loans (funds provided through previous Green Acres bond issues and the 1998 Garden State Preservation Trust) can be used by municipalities or counties to acquire and/or develop municipal or county land for public recreation and conservation purposes.

- Green Acres Nonprofit Acquisition Grants (funds provided through previous Green Acres bond issues and the 1998 Garden State Preservation Trust) can be used by tax-exempted, non-profit organizations to acquire open space for recreation and conservation purposes statewide, and to develop outdoor recreational facilities in certain urban or densely populated municipalities and counties. All land funded under this program must be open to the public.

- Environmental Infrastructure Financing Program (funds provided by NJDEP and the New Jersey Environmental Infrastructure Trust) can provide low-interest loans for the construction of a variety of water quality protection measures and for open space acquisition.

8.1 MANAGEMENT MEASURES

This section consists of a description of the management measures necessary in the Ringwood community to achieve load reductions as well as a description of the areas where those measures will be implemented. This is one of the most important components of this document and consists of a list of projects that could be designed and implemented to reduce Total Suspended Solids (TSS), Total Phosphorus (TP), and other pollutant loads, such as nitrogen, from entering the lakes. Princeton Hydro reviewed desktop information including parcel boundaries, soils, topography, and land use/land cover as well as aerial imagery to identify potential sites. These sites were then field evaluated to determine recommendable best management practice(s), site constraints, and confirm feasibility to accommodate green infrastructure and provide efficient pollutant removal. Green infrastructure refers to natural and engineered ecological systems that treat stormwater in a way that mimics natural process; ex: bioretention systems or rain gardens that receive stormwater and sequester nutrients. In addition to green infrastructure, general recommendations for stormwater management and riparian zone improvements are also included in the report.

Princeton Hydro evaluated and identified sites within the watersheds of the six (6) lakes within the Borough. These lakes include: Cupsaw Lake, Upper & Lower Lake Erskine, Upper & Lower Skyline Lake, and Lake Rickonda. Figure 37 below depicts these water bodies, and the site locations described in more detail in the subsequent sections. Table 49 presents a list of the proposed Best Management Practice (BMP), the amount of TSS removed, and an estimated price.

Figure 37 – Management Measure Locations

Site[1]	Proposed BMP	Approximate Drainage Area (Acres)[2]	TSS Removal Rate (%)[3]	Potential Project Cost ($)[4]
1	Site 1: Cupsaw Lake – Parking Lot for the Sheppard Pond Recreation Area Pavement Conversion	10	80	300,000 - 750,000
2	Site 2: Cupsaw Lake – Thunder Mountain Trap and Skeet Pavement Conversion	2.5	80	50,000 - 100,000
3	Site 3: Cupsaw Lake – Morris Road Stream Crossing Sediment Forebay Creation	850	40 - 60	100,000 - 200,000
4	Site 4: Cupsaw Lake – Cupsaw Drive Stream Inlet Location Sediment Forebay Creation	100	40 - 60	250,000 - 750,000
5	Site 5: Cupsaw Lake – Cupsaw Lake House Daylighting Stream, Vegetated Filter Strip, Rain Garden	330	60 - 90	250,000 - 500,000
6	Site 6: Cupsaw Lake – Martin J Ryerson Middle School Vegetated Buffer, Pavement Conversion, Rain Garden	3	60 - 90	375,000 - 925,000
7	Site 7: Cupsaw Lake – Outlet at West Circle Manufactured Treatment Device	20	50 - 80	400,000 - 750,000
8	Site 8: Upper Erskine Lake – Upper Erskine Lake Beach Pavement Conversion	3	80	150,000 - 500,000
9	Site 9: Lower Erskine Lake – Upper Lakeview Avenue Boat Launch at Lower Erskine Lake Manufactured Treatment Device	3	50 - 80	400,000 - 750,000
10	Site 10: Lower Erskine Lake – Lakeview Avenue Boat Launch at Lower Erskine Lake Pavement Conversion	5	80	150,000 - 500,000
11	Site 11: Lower Erskine Lake – Laurel Drive Manufactured Treatment Device	10	50 - 80	400,000 - 750,000
12	Site 12: Lower Erskine Lake – Lower Erskine Lake Beach Pavement Conversion, Shoreline Stabilization	30	80	250,000 - 750,000
13	Site 13: Lower Erskine Lake – Ramapo Place Manufactured Treatment Device	3	50 - 80	400,000 - 750,000
14	Site 14: Lower Erskine Lake – Mohawk Trail Boat Launch Manufactured Treatment Device	12	50 - 80	400,000 - 750,000
15	Site 15: Upper Skyline Lake – Skyline Drive Shopping Center Retention Basin, Manufactured Treatment Device, Vegetated Buffer	37	50 - 80	575,000 - 1,100,000
16	Site 16: Upper Skyline Lake – Upper Skyline Lake Dam Pavement Conversion	10	80	150,000 - 500,000
17	Site 17: Lower Skyline Lake – Lower Skyline Lake Beach Pavement Conversion	10	80	150,000 - 500,000
18	Site 18: Lake Rickonda – Lake Rickonda Beach Vegetated Swale	1.5	60 - 80	75,000 - 200,000

Notes:

1. Site locations are located on Figure XX
2. Drainage areas were delineated basted on site visits, observations from aerial imagery, and available topography. Prior to any design the drainage arears to the Best Management Practice shall be delineated and verified.
3. Total Suspended Solids (TSS) removal efficiencies are based on the New Jersey Stormwater BMP Manual.
4. The costs presented are approximate and subject to variability over time and the sizing of the BMP.

Table 49. Best management practice site summary.

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

- **Site Investigations** – Part of the design process includes several different onsite investigation efforts including topographic survey, wetland delineation, and soils investigations. These investigations and the information gathered during them provide an understanding of the site conditions, any potential design challenges, and permitting pathways for the site.
    - **Depth to Bedrock** – The presence of shallow bedrock can result in implementation complications and a substantial increase in implementation costs.

  - **Depth to Water Table** – The presence of a shallow water table may indicate the presence of a wetland and/or recharge area for groundwater. Thus, this can result in complications as well as an increase in permitting and implementation costs.
  - **Utility Conflicts** – Location of sewer lines, gas lines, power lines, fiber optic lines all need to be located and mapped before any earth-moving or infrastructure work can be initiated. Without such information results could be extremely costly and even disastrous.
  - **Permit Requirements** – Depending on the site features and its location relative to the lake and associated waterways, regulatory permitting can vary from none to minimal to substantial. Thus, the potential required permitting must be determined to quantify the total costs associated with the design phase. While general permitting costs were estimated in the proposed cost for each project, the fees can vary based on access, size of the overall project and project type which have not been determined at this phase. The costs do not include permits specific to the Highlands Region. Due to the location of lakes and their watersheds being in the protected Highlands Region, additional permitting may be required.

- **Access and Ownership** – Issues such as rights-of-way and easements need to be identified and agreements in place prior to the progression of the design. Additionally, the source of the funding for implementation may limit where a project can be implemented. For example, typically if a project is being funded through an NPS 319-grant, the project site typically must be located on public / community lands. Private land can be not used for a project site for such grant funding; however, private easements or access approval can be allowed.

- **Maintenance Requirements** – The key to the long-term effectiveness of any watershed / stormwater project is for it to be well maintained. This will include routine activities such as clean-outs and media replacements as well as non-routine activities such as repairs or additional work after particularly large storms. The party responsible for the maintenance of the project needs to be well established and that party needs to be well informed on the maintenance requirements and costs. Any shared services agreements need to be well established prior to the initiation of a project.

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

8.2 WATERSHED RECOMMENDATIONS

GENERAL RECOMMENDATIONS

Along with the specific practices listed for the best management practices (BMP's) at all 18 sites, Princeton Hyrdo also provides the following general recommendations: bank stabilization, riparian zone enhancement, and defined stabilized access points for all applicable locations in the project area. The riparian zone is characterized as the buffer surrounding the border of a surface body of water, many times where hydrophilic vegetations resides. Sometimes, these locations can have vegetation enhancement to introduce more of this type of aquatic plantings to a specific area. Additionally, applying bank stabilizations measures of reducing bank slopes, and stabilizing areas of exposed soil near bodies of water will aide in this riparian zone enhancement process. To compliment these actions, defining stabilized access points for people or watercraft to enter bodies of water is recommended. This will help preserve said riparian areas, and limit bank erosion in areas with heavy watercraft traffic. While some areas are specifically defined within the following sites, this recommendation should be broadly applied to any area within these lake systems that would need it.

RIPARIAN ZONE ENHANCEMENT

During Princeton Hydro's sites visits it was noted that banks of the lakes, ponds, streams, swales, or other conveyances systems that have exposed soil containing little vegetation and/or invasive species. In aquatic settings, vegetation acts as a buffer between the pollutant-rich stormwater and the body of water it surrounds. Eroded and unvegetated banks can be a source of nutrients and sediment into the lake. Additionally, the vegetation on the banks will filter pollutants contained in the stormwater before it enters the water body. Vegetation within a riparian zone should consist of native species and include herbaceous groundcover and trees and shrubs for soil stability. This vegetation can manage sediment and nutrient loads discharging into the lake. Some areas where this can be implemented are listed specifically below however this can be implemented along any segment of bank.

DEFINED STABLIZED ACCESS POINTS

Throughout the watersheds there are multiple locations for storing and launching of boats including kayaks. Many of these locations do not have defined launch points and the banks are eroded and vertical which makes continued access difficult and can cause further sediment load to enter the lake. Some of these locations are specifically identified as a part of the sites listed below however there are other locations that are not specifically identified. Defining a location for boaters to access the water and buffering storage and foot traffic near the bank in all other areas will provide vegetate buffer and start to stabilize the banks. Vegetation can be planted in the non-access area to provide stabilization and to deter the use for access. Pending on the access location, stabilization methodology, and size permits may be required from regulatory agencies.

SEPTIC SYSTEM MANAGEMENT

Generally speaking, it can be assumed that homes within 300' of a lakes shoreline have groundwater-based influence on the lake or tributary. The homes within the Boroughs watersheds are most likely serviced by septic systems (on-lot wastewater treatment systems). Septic management should therefore be implemented to help minimize nutrient loading and protect against septic failures that could result in bacterial inputs. Successful septic management involves the integration of public education, product modification, septic system inspection and maintenance, and water conservation practices. In addition, it may rely on the use of advanced on-site wastewater renovation/treatment designs to correct failing systems or to dictate the construction of new systems in environmentally sensitive sections of the watersheds.

Product modification usually refers to the use of non-phosphorus or low phosphorus products that minimize septic-related phosphorus loading to the environment. However, it also applies to the use of septic tank chemical additives or the disposal of paint, solvents or left-over household chemicals and cleaning products in septic systems. Public education fliers and brochures advising against such practices are readily available through the NJDEP and regional watershed groups (e.g., Lake Hopatcong Commission). Additional related public information fact sheets of this nature can be obtained through the EPA's Small Flows Clearing House, which specializes in the dissemination of information pertaining to septic systems and other types of on-site waste water treatment systems. Such educational material would prove beneficial in this respect. All residents should be educated about the serious impacts to their septic systems of improperly disposed household chemicals and degreasing agents. These products can cause serious upsets to the biological treatment processes that occur in the septic tank itself and in the soils of the disposal field. Equally important, these products can result in serious groundwater pollution and the contamination of drinking water wells.

Also, the public should be educated concerning the lack of any benefit associated with enzymes, bacteria inoculants, or other products advertised as septic tank supplements. Such information should be made available through the Borough to residents. As demonstrated by the EPA (USEPA, 1997), these products do very little to enhance septic system operation. They also give a false sense of maintenance to the property owner and may actually dissuade them from regularly pumping or inspecting their system. Also, residents should be cautioned about the use of garbage disposal units/grinders. Excessive or improper use of these devices can increase organic loading and further stresses the system's operation by adding to both the sludge and grease layers. Furthermore, once ground up, the disposed solids can be converted into fine particulate material that resists settling. This can decrease the operational efficiency of a septic system and accelerate the clogging of the leach field.

Inspections and routine maintenance are usually the two controversial elements of most septic management programs. There is an innate resistance by homeowners to allow periodic inspections or to comply with a mandatory pump out schedules. Basically, the prevailing thought among most homeowners is "if it flushes, it's OK". However, as has been demonstrated in studies conducted as part of nationwide septic management studies, routine inspections help decrease the occurrence of large scale failures by identifying the more easily corrected, less costly problems early on (NYSDEC, 1994). Similarly, routine pump outs decrease the buildup of sludge and grease in the septic tank itself, both of which can be transported into the leach field and create clogging problems. In general, the inspections and pump outs should be viewed as an insurance policy for the long-term proper operation of the septic system and not an imposition of the property rights of a homeowner. It should be noted that for older tanks, there may be some liability associated with their pump out. For example old metal tanks that have become corroded or hand built cesspools can collapse once the liquid and sludge has been removed.

Water conservation measures are intended to reduce hydrologic loading to the leach field. Included in this category are the use of low flush toilets, flow reduction fixtures and other similar devices designed to reduce water usage. It can also encompass lifestyle habits such as spreading out laundry wash loads over a number of days, shorter showers, and other similar cooperative techniques.

PET WASTE MANAGEMENT

Another localized source of nutrients that can be easily controlled is that of pet waste. In addition to providing an ample source of phosphorus, these wastes are unsightly and may cause health concerns due to high fecal coliform bacteria concentrations in storm water runoff coming into contact with waste sources. Reduction of pet waste as a nutrient source can be obtained through the implementation of and the enforcement of an ordinance requiring the retrieval of pet wastes and through the pet owner's compliance. As stated previously, these ordinances can be difficult to police and enforce. However, this type of ordinance should be easily accomplished and enforced in the County and Borough owned parks located in the headwater areas of each watershed.

NATURAL LANDSCAPING

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

As part of the ongoing strategy to reduce the influx of lawn related pollutants into Chesapeake Bay, the National Park Service has started to use native ground covers to reduce the need for fertilization and irrigation (NPS News-Notes, 1996). Similar types of low maintenance vegetative cover have been promoted by NJDEP (NJDEP, 2004) and the Metropolitan Council of Governments (Schueler, 1987) as part of an overall strategy of reducing NPS loading.

Minimizing disturbance and utilizing natural landscaping are preventative pollutant load management techniques. When properly implemented these techniques can eliminate the need for the repeated fertilization of lawns, decrease the rate or frequency of pesticide applications and decrease irrigation requirements.

The pathway to implementation is through a successful public education program that demonstrates the advantages of implementing natural landscaping into the residential developments in the watershed. In the existing developments lawn areas can be easily retrofitted with natural landscaping features. Areas of the watershed located in the Borough's watershed consist of residential development which contains little to no storm water management measures. Such measures should especially be promoted at transition points and along riparian zone corridors, especially along the main tributaries.

Public education efforts should focus on the aesthetic, economic, and ecological advantages of maintaining portions of their property with natural landscaping techniques. This outreach could include brochures and newsletters which illustrate and describe the advantages of a natural landscape approach. The information should provide the public with resources where they can find native vegetation and mulch. The Hudson-Essex-Passaic County Soil Conservation District, possibly in conjunction with the local Borough's environmental commissions or other interested parties could also develop a backyard habitat program and provide hands on demonstration and other information on monthly basis during the growing season. Often the impediment for homeowner buy in is a lack of understanding of what natural landscaping techniques look like and how they function. The most effective mechanisms to overcome this obstacle are demonstration projects. The Borough should implement similar techniques on public property to demonstrate that these features are aesthetically pleasing, economically feasible, and have low maintenance requirements as compared with typical turf lawn cover. Funding for these types of projects may be available from the Natural Resource Conservation Service (NRCS) or the US Fish and Wildlife Service (USFWS). They also usually require a voluntary agreement or contract between the funding agency and the partner for long-term maintenance. Most of these projects also are cost-share and have a funding ratio of 75% grant and 25% match. For qualifying projects the NRCS and/or USFWS will provide expert technical assistance directly to both private and public landowners.

FERTILIZER MANAGEMENT

It should be noted that the New Jersey legislature has passed new rules regulating fertilizer composition and usage. More information of this law, which went into effect in January 2010, can be obtained by downloading copies of the bill (S-2554/A-2290). The most significant feature of the law is that it bans phosphorus from over the counter fertilizers (the types of products sold at most big box retail stores). The legislation also limits the amount of nitrogen (0.7 lbs/1,000 ft2) in the fertilizer and specifies that at least 20% of the nitrogen must be in a time release formula. The legislation also restricts the timing of fertilizer application (no fertilizer applications between November 15 and March 1). Although the passage of this legislation may have significantly reduced fertilizer related loading to lakes, the Borough should continue promote the voluntary measures discussed below.

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

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

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

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

Specific educational techniques that could be implemented by the Borough 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 Borough and any other pertinent stakeholders should conduct the public education campaign that informs all the residents of the benefits of fertilizer and pesticide management, stressing the low-cost alternatives and environmental benefits of such techniques. Residents should be educated about conducting soil pH and nutrient testing before applying any lawn care product to their lawn. They should also be informed about the benefits of liming, aeration, thatch control, and other non-chemical lawn care measures.

In summary, the pollutant loading analysis completed as a part of this characterization and assessment plan indicate that that the majority of the nutrient and sediment loading to a lake originates from the residential development that dominates a watershed. A public education program has the potential to drastically reduce the nutrient load associated with improper lawn care practices that are likely widespread among residents of the County/Borough and ultimately the watershed.

8.3 CUPSAW LAKE

SITE 1: CUPSAW LAKE – PARKING LOT FOR THE SHEPHERD POND RECREATION AREA

Cupsaw Brook conveys runoff from Shepherd Pond through Ringwood State Park to Cupsaw Lake. Cupsaw Brook discharges into the northeastern corner of Cupsaw Lake. Shepherd Pond serves as a forebay to

Cupsaw Brook and Lake thus the focus of the recommendation is the recreation area located downstream of the lake. The area is primarily connected pavement and other impervious surfaces which appear to be primarily utilized during the summer months. The drainage area of the existing stormwater system for Site 1 consists of paved roadway, turf lawn areas, commercial buildings, parking lots, and forest. The runoff from the Shepherd Pond Recreation Area parking lot is collected by an existing system of catch basins that directly discharges to Cupsaw Brook. Sediment and excess nutrients from the parking lot directly enter the Cupsaw Brook from the stormwater system on site. Photo 1 depicts the overall view of the parking lot and access. Note the connected impervious surfaces and the vegetated islands which receives limited runoff.

Photo 1: Parking Lot on Shepherd Pond Recreation Area

Recommendation Site 1: The recommended Best Management Practice (BMP) would be to disconnect the impervious surface via a pavement conversion of portions of the parking lot coupled with connecting the existing vegetated areas for potential conveyance, storage, and filtration of the runoff. The asphalt parking lot area could be partially converted to either a vegetated or a porous pavement system, which allows for filtration of the stormwater prior to discharging into Cupsaw Brook. The islands and potential parking lot spaces that could be converted into rain gardens would filter stormwater before discharging into Cupsaw Brook. These rain gardens would be landscaped with native plants that would reduce the volume of runoff leaving the site via evapotranspiration and would utilize nutrients in the water. Rain gardens and porous pavement may require underdrains and have outlet riser structures connected to the existing stormwater collection system via piping under the parking lot. The combination of rain gardens and a pavement conversion system in this location would reduce the total amount of sediment and excess nutrients discharged into Cupsaw Lake via Cupsaw Brook.

Estimated Costs Site 1: The approximate cost for design, permitting, and implementation of this BMP recommendation is anticipated to be between $300,000 and $750,000.

SITE 2: CUPSAW LAKE – THUNDER MOUNTAIN TRAP AND SKEET

Thunder Mountain Trap and Skeet is located on Mansion Road, on the top of a hill to the south of the Shepherd Pond Recreation Area. The drainage area for Thunder Mountain Trap and Skeet consists of an asphalt parking lot, a building, and a large field area with little to no vegetation. The site drains north to Cupsaw Brook which ultimately discharges into Cupsaw Lake. The site does not appear to have a stormwater collection system, with stormwater runoff from the parking lot draining into a ditch on the side of the entrance road, which makes its way into Cupsaw Brook. Photo 2 refers to the entrance of the Thunder Mountain Trap and Skeet Parking Lot, where the water is conveyed into a natural ditch on the side of the road.

Photo 2: Entrance Area to the Parking Lot for Thunder Mountain Trap and Skeet

Recommendation Site 2: The recommended BMP for this site is a conversion of the pavement on the western side of the parking lot of Thunder Mountain Trap and Skeet to a surface runoff filtration BMP and not a runoff generating impervious surface. The western side of the parking lot extends from the entrance area shown in Photo 2 to the southern end of the asphalt area on the site. Implementing a surface runoff BMP such as a vegetated or a porous pavement strip on the western border of this asphalt area would filter runoff from the site prior to discharging from the site. This BMP would capture and treat small storm events and the first flush of runoff in larger events, reducing the overall sediment and nutrient discharge from the site.

Estimated Costs Site 2: The approximate cost for design, permitting, and implementation of this BMP is anticipated to be between $50,000 and $100,000. The costs for this BMP is highly variable at this phase as it is dependent on property owner agreement and the selected approach.

SITE 3: CUPSAW LAKE – MORRIS ROAD STREAM CROSSING

Site 3 is the northern side of the Morris Road bridge over Cupsaw Brook within Ringwood State Park. Directly upstream of the bridge culvert is a concrete weir that the stream flows over prior to traveling through the rectangular stone masonry culvert as shown in Photo 3. This weir is impounding water, detritus, and sediment at this location, as seen in Photo 4. The drainage area of Site 3 is largely forested, but also contains paved/gravel roadways and parking lots, commercial buildings, and residential dwellings, as well as sites 1 and 2.

Photo 3: Site 3 Weir System

Photo 4: Site 3 Pond Caused by Weir, Proposed Forebay Location

Recommendation Site 3: The recommended BMP for Site 3 is to convert the impoundment into a vegetated forebay which may include a modification to the existing weir wall and excavate the area upstream so that the upstream area can act as a sediment forebay. The sediment forebay would enable sediment from in the stream to settle prior to traveling through the culvert, reducing the sediment and nutrient load entering Cupsaw Lake. Aquatic vegetation and native plants could be planted in areas surrounding forebay to aide in bank stability and nutrient uptake. An added benefit of this recommendation is that sediment could be routinely removed from the forebay prior to entering the lake, which would increase the periods of time between lake maintenance dredging. This area could also be used for ecological education.

Estimated Costs Site 3: The approximate cost for design, permitting, and implementation of this BMP is anticipated to be between $100,000 and $200,000.

SITE 4: CUPSAW LAKE – CUPSAW DRIVE STREAM INLET LOCATION

Site 4 is a small unnamed stream flowing from Ringwood State Park where it crosses Cupsaw Drive prior to discharging into the northwestern part Cupsaw Lake. Upstream of Cupsaw Drive, the stream channel is lined with concrete retaining walls and a concrete weir impounding flow in the pool shown in Photo 5. The water exits the impoundment via three (3) 12-inch diameter orifices or overtopping the weir. Downstream of the weir the stream flows under Cupsaw Drive via a culvert and into the Lake. The drainage area of the stream consists of paved roadway, lawn areas, residential dwellings, and the Ringwood State Park.

Recommendation Site 4: The recommended Best Management Practice (BMP) is to modify the existing weir wall and excavate the area upstream so that the upstream area can act as a sediment forebay. This would allow sediment from stormwater runoff travelling down the stream to settle prior to entering the lake. A sediment forebay would reduce the Total Suspended Solids (TSS) and nutrient load entering the lake from the stream. An added benefit would be that sediment could be routinely removed from the forebay prior to entering the lake, this would increase the periods of time between lake maintenance dredging. Another BMP option for this area would be to remove this weir wall and reconstruct the stream channel in the area shown in Photo 5. This newly constructed channel would be able to accommodate additional native vegetation which can have the same water quality benefits as the sediment forebay option above but would have less of an impact on the surrounding homeowner. All necessary permits and permissions from the private property owner must be in place before either BMP can be constructed.

Photo 5: Concrete Weir Wall at Site 4 Outlet Location

Estimated Costs Site 4: The approximate cost for design, permitting, and implementation of either alternative at this BMP location is anticipated to be between $250,000 and $750,000.

SITE 5: CUPSAW LAKE – CUPSAW LAKE HOUSE

The Cupsaw Lake House is located on the northeastern side of Cupsaw Lake. The site is bordered on the east by Cupsaw Drive. The site is comprised of a clubhouse, a parking area, several islands for kayak storage/recreation, a beach, and basketball court area. This area is used for recreation and small boat access during the summer months. An overview of the parking lot area can be shown in Photo 6. An existing stream flows west towards Site 5, along Windbeam Avenue. The stream is then piped from Cupsaw Drive, under the parking lot, and discharges into the lake. The stream conveys runoff into the lake from the paved roadways, buildings, and the lawns of residents in the surrounding area. The site includes a series of stormwater inlets to collect and control the runoff from the parking lot and parts of Cupsaw Drive, which connect to the underground pipe system conveying the stream as well. Refer to Figure 38 for an overview of the site and proposed BMP practice layout.

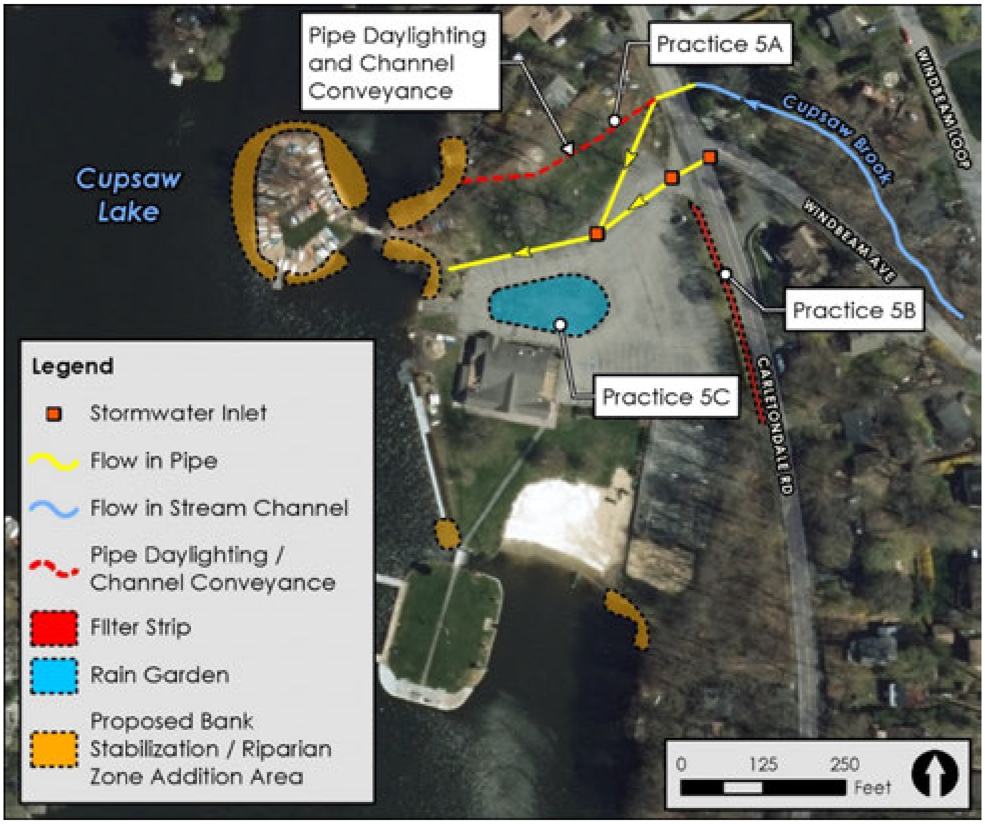

Figure 38: Site 5 Overview

Recommendation Practice 5A: One of the proposed practices for this site would be to convert the portion of the stream that is piped under the parking lot on site into a stream channel. As shown in Figure 38, the pipe conveying the stream into the lake would be removed, and the grassed area to the north of the parking lot would be excavated into a vegetated stream channel. A vegetated stream channel promotes filtration, enables evapotranspiration, and provides nutrient uptake by the vegetation planted in the area. The swale could also include a sediment forebay right after the bridge area that would collect sediment prior to it entering the lake. Both options of stream channel design will be included in the cost estimation.

Photo 6: Parking Lot Area Showing Potential Rain Garden Area (left) and Stream Channel Relocation Area (right)

Photo 7: Proposed Area for Practice 5B

Recommendation Practice 5B: Replacing the sparse vegetation on the shoulder of Cupsaw Drive (photo 7) on the eastern side of the site with a vegetated filter strip recommendation 5B. The native vegetation in the filter strip promotes filtration through the root structure of the plant, utilizes nutrients, and reduces runoff volumes through evapotransporation, improving lake water quality by reducing the amount of stormwater runoff that gets there.

Recommendation Practice 5C:

Practice 5C would be implemented to control the stormwater runoff in the parking lot area for the Cupsaw Lake House. As shown in Figure 38 above, any runoff that is not captured by practice's 5A or 5B will flow over the surface of the site to the impervious parking lot. The grassed island at this location could be converted into a rain garden to filter as much of that stormwater into the ground as possible. The possible system may need to include stormwater infrastructure such as an underdrain and outlet structure which will connect into the existing pipe system.

Estimated Costs Site 5: The approximate cost for design, permitting, and implementation of the three recommend BMPs assuming they are completed as a single project is anticipated to be between $500,000 and $1,000,000.

SITE 6: CUPSAW LAKE – MARTIN J. RYERSON MIDDLE SCHOOL

Martin J. Ryerson Middle School is located off Valley Road southeast of Cupsaw Lake. The school site contains an impervious entrance roadway from Valley Road, numerous parking lots, and recreational fields. The school's parking lots contain a drainage system that drains to a nearby stream, which eventually discharges into Cupsaw Lake. The many parking lots on the school site will contribute greatly to the amount of impervious runoff that discharges from the site itself. As shown in Figure 39, a proposed solution could contain several BMP practices working together to reduce the sediment and nutrient loads traveling into Cupsaw Lake from these impervious areas.

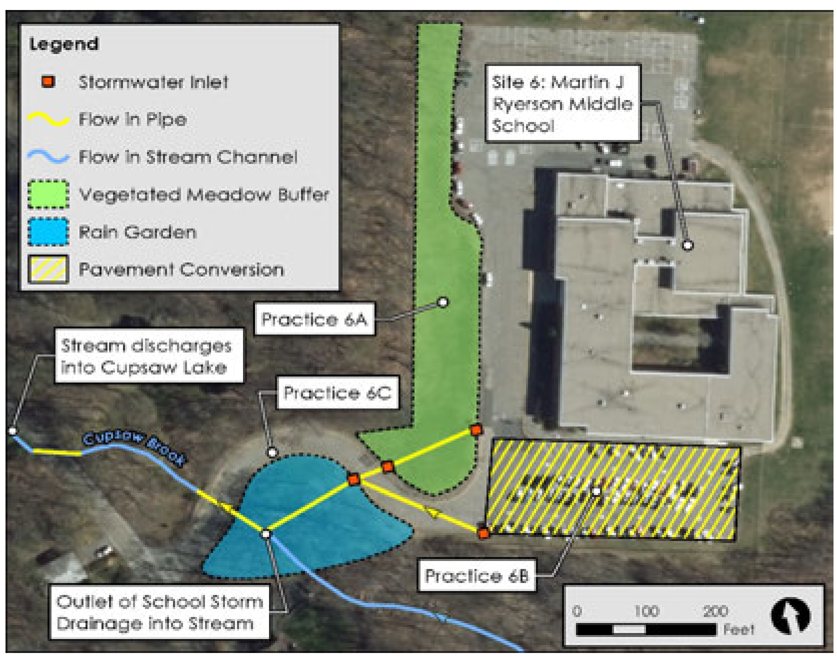

Figure 39: Site 4 Overall Outlet Location

Recommendation Practice 6A: The recommended Best Management Practice (BMP) for this location would be to construct a vegetated meadow buffer in the grassed area near the entrance of the school. This area would provide a vegetated buffer between the impervious area of the parking lot, and the stream draining into Cupsaw Lake. The surrounding parking lot area would be graded to drain into the vegetated meadow buffer, to ensure that as much impervious area as possible is managed with this practice. The majority of the impervious area managed by this practice will be from the northern school parking lot and the entrance of the school itself. A planting of native vegetation optimal for the hydrology within the area in this system would filter sediment and nutrients, as well as sequester nutrients before the stormwater runoff travels further down the drainage system and into the stream. Improvements would take place in the area shown on Figure 39.

Recommendation Practice 6B: While practice 6A manages the entranceway and the northern parking lot, practice 6B is intended to manage stormwater runoff from the southern parking lot of the site. This parking lot will have its pavement converted into either a vegetated or porous pavement system depending on site needs and project budget. These pavement conversion systems will reduce the amount of stormwater runoff, sediment/nutrient loading that travels further down the conveyance system by filtering the sediment and nutrients from the paved areas before the runoff conveys into the stream. Additionally, the intent is to disconnect the impervious surfaces and filter the runoff through vegetation or soil media to obtain nutrient removal. These improvements would take place in the area shown on Figure 39.

Recommendation Practice 6C: A third practice to be recommended for this site is practice 6C. This BMP will be a rain garden that intercepts the schools parking lot and entrance roadway drainage before it discharges into the stream. Refer to Figure 39for the approximate practice location. This rain garden would intercept runoff not treated by practices 6A or 6B, filter it removing sediment and nutrients before discharging via an underdrain to into the existing piping system. Planting of native vegetation optimal for the hydrology within the rain garden would aid in this filtration process and provide additional sediment and nutrient control.

Estimated Costs Practice 6A: The approximate cost for design, permitting, and implementation of this BMP recommendation is anticipated to be between $75,000 and $125,000.

Estimated Costs Practice 6B: The approximate cost for design, permitting, and implementation of this BMP recommendation is anticipated to be between $150,000 and $500,000.

Estimated Costs Practice 6C: The approximate cost for design, permitting, and implementation of this BMP recommendation is anticipated to be between $150,000 and $300,000.

SITE 7: CUPSAW LAKE – OUTLET AT WEST CIRCLE

West Circle is a street off Cupsaw Drive, on the western side of Cupsaw Lake. This site contains a paved portion of street area, which is used for parking and access to the lake, shown in Photo 8. The drainage area for this site consists of portions of West Circle, Cupsaw Drive, Kendall Drive, Winbeam Loop, Kraft Place, and bordering residences collects into a series of inlets and prior to discharging via a 36-inch diameter pipe into Cupsaw Lake. This discharge location and pipe are shown in Photo 9. This pipe conveys a large amount of unfiltered sediment and nutrients from these areas and before conveying them directly into Cupsaw Lake.

Photo 8: Site 7 End Pavement Area Draining to Cupsaw Lake

Recommendation Site 7: Due to the piped conveyance system, limited shoulder, and minimal open space, the installation of a Manufactured Treatment Device (MTD) along the stormwater pipe on the site of West Circle is recommended. By capturing and treating stormwater from the surrounding roadway drainage areas before it is discharged into the lake, this MTD reduces runoff into the lake from this location, which improves the lakes water quality.

Photo 9: Site 7 Discharge Location of 36 in. Concrete Pipe

Estimated Costs Site 7: The approximate cost for design, permitting, and implementation of this BMP recommendation is anticipated to be between \$200,000 and \$400,000.

8.4 UPPER ERSKINE LAKE

SITE 8: UPPER ERSKINE LAKE – UPPER ERSKINE LAKE BEACH

Upper Erskine Lake Beach is located at the center of the southern shore of Upper Erskine Lake. This beach contains a recreational beach area used in the warmer months, including an entire beach island used by swimmers and for the storage of small boats. Various other recreational facilities are in this area including basketball court and picnic areas. The southern portion of the site is bordered by Upper Lakeview Avenue, where one entrance to the site is located. The Upper Lakeview Avenue entrance area of the site contains a large impervious parking lot, as shown in Photo 10. An additional entrance to the site can be found at the end of Bellot Road, shown in Photo 11. The drainage area for this site is a combination of the surrounding residential and roadway areas bordering the site, as well as all impervious areas contained on the site itself. The roadways and asphalt within this drainage area allow for the conveyance of excess sediment and nutrients directly into Upper Erskine Lake from this site.

Photo 100: Upper Erskine Lake Beach Parking Area and Entrance Area

Recommendation Site 8: The recommended Best Management Practice (BMP) is the conversion of a portion of the impervious pavement areas found at the entrance areas, parking lot, and recreation areas into either a vegetated pavement system or a porous pavement system. Refer to figure 40 for potential locations of those pavement conversions within the site. These pavement conversions will filter the surrounding impervious surface runoff into the ground before the sediment and pollutants contained within it prior to discharging into the lake. The conversion of paved surfaces will also disconnect some of the flow across the impervious surfaces which reduces velocities, provides filtration, and provides ecological enhancement to the public space. In addition to the pavement conversions, portions of the beach island could benefit from the introduction of native aquatic plants, potential regrading, and a vegetated buffer to provide increased nutrient uptake by the lake ecosystem and reduce additional nutrient loading from entering the lake.

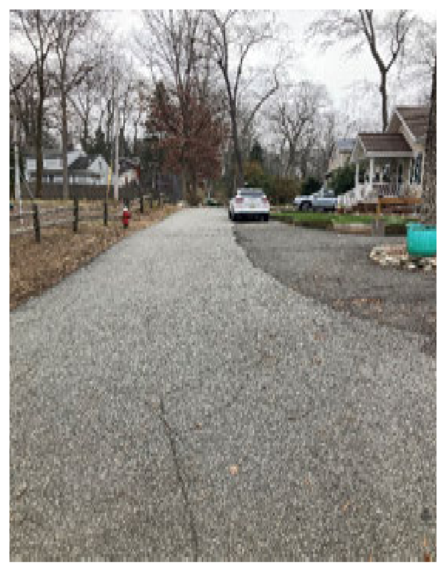

Photo 111: Bellot Road Entrance to Tamarack Cove Boat Launch and Beach.

Figure 40: Overview of Upper Erskine Lake Beach

Estimated Costs Site 8: The approximate cost for design, permitting, and implementation of this BMP recommendation is anticipated to be between $200,000 and $750,000 depending on the amount and type of pavement conversion selected.

8.5 LOWER ERSKINE LAKE

SITE 9: LOWER ERSKINE LAKE – UPPER LAKEVIEW AVENUE BOAT LAUNCH AT LOWER ERSKINE LAKE

The Upper Lakeview Avenue boat launch at Lower Erskine Lake is located at the northern portion of Lower Erskine Lake, and is at the start of Upper Lakeview Avenue. This site is located on Lower Erskine Lake where Upper Erskine discharges. As shown in Photo 13, the site consists of a paved portion of Upper Lakeview Avenue which transitions into the gravel boat launch area used by community members. The street stormwater drainage is collected at various inlets at the site entrance along Lakeview Avenue and discharged directly into the lake via a pipe at the end of the boat launch ramp as shown in Photo 12. Additionally, runoff from the asphalt ramp and gravel boat launch area directly drain into the lake from this location.

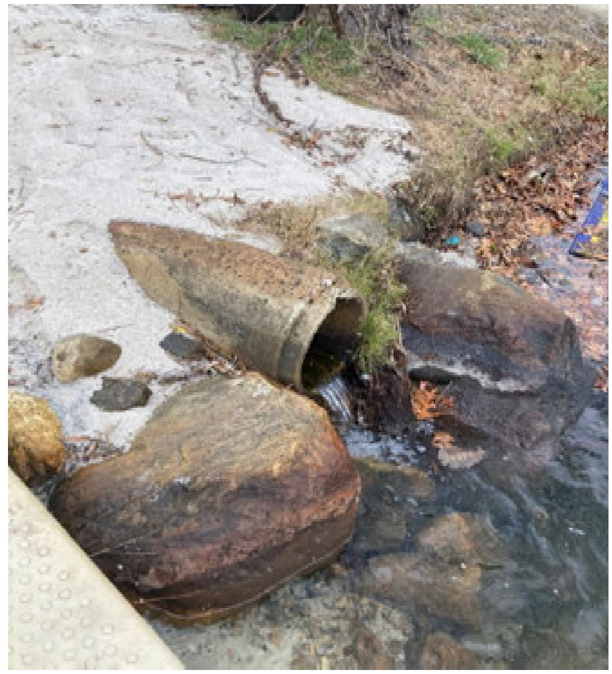

Photo 12: Stormwater Discharge Pipe Location at Lower Erskine Lake

Recommendation Site 9:

Due to the limited open space in this area, and accessibility to connect into the piped conveyance system, the installation of a Manufactured Treatment Device (MTD) to intercept flow along the stormwater discharge pipe is recommended. This MTD would be able to treat the stormwater conveyed in the underground piping system and possibly collect additional surface runoff from the ramp prior to the discharge point into the lake. This allows for less Total Suspended Solids (TSS) and Total Phosphorus (TP) entering the lake, improving water quality, and provides an accessible location to remove the accumulated material. This MTD would be installed in the gravel parking area at the end of the boat ramp for ease of access and maintenance purposes.

Photo 13: Parking Lot of Upper Lakeview Avenue Boat Launch, Facing Away from the Water

Estimated Costs Site 9: The approximate cost for design, permitting, and implementation of this BMP recommendation is anticipated to be between $200,000 and $400,000.

SITE 10: LOWER ERSKINE LAKE – LAKEVIEW AVENUE BOAT LAUNCH AT LOWER ERSKINE LAKE

The Lakeview Avenue Boat Launch site is located on the northeastern side of the Lower Erskine Lake, where Lakeview Avenue intersects with the end of Upper Lakeview Avenue. This site contains a boat ramp that is asphalt which transitions to dirt and grass near the lake edge. The conditions of the boat ramp and site are shown in Photo 14. Portions of Lakeview Avenue, as well as Upper Lakeview Avenue, drain to an inlet at the entrance of the site, shown in Photo 15. This inlet then discharges into Lower Erskine Lake. The drainage area for this site is a combination of the surrounding residential and roadway areas bordering the site, as well as all impervious areas contained on the site itself. The lake edge is bordered by a concrete bulkhead which serves as the headwall of the pipe. One of the challenges with this site is the proximity to the lake edge and the effects of groundwater and tailwater backing up into the BMPs. This will need to be considered with any design.

Photo 14: Site 10 Grassed Area Located at the End of the Boat Ramp

Recommendation Site 10: The recommended BMP for this location would be to install a vegetated paver system at the end of the boat ramp where the impervious surface transitions to dirt and grass, assuming the area is able to have water percolate into the groundwater. This is a surface-based BMP, that would be able to treat the surface stormwater traveling down the boat ramp and prevent it from entering the lake unfiltered. This BMP would also be able to provide more vegetated area to the site instead of dirt, which helps with the reduction of sediment discharge into the lake from this site. Additionally, a manufactured treatment device could be installed on the discharge pipe from the site 10 inlet. The MTD would treat the stormwater conveyed in the pipe system prior to discharging into the lake.

Photo 15: Site 10 Entrance Area and Discharge Inlet

Estimated Costs Site 10: The approximate cost for design, permitting, and implementation of this BMP recommendation is anticipated to be between $300,000 and $600,000.

SITE 11: LOWER ERSKINE LAKE – LAUREL DRIVE

Site 11 can be found bordering the southeastern shore of Lower Erskine Lake, along Lakeview Avenue. This site primarily consists of a storm sewer system and metal discharge pipe, overtopped by a grassed area in between two residences. This site currently has no recreational use, is not a boat launch area, and is not used for parking. A stormwater conveyance system consisting of multiple pipes and inlets conveys runoff from Laurel Place and Lakeview Ave to Lower Erskine Lake at Site 11. The final inlet where the stormwater system converges is shown in Photo 16, before the system discharges directly into the lake via a corrugated metal pipe as shown by Photo 17. The contributing drainage area to the storm sewers is primarily from Laurel Place, which is an uncurbed road that is steeply sloped toward Lower Erskine Lake. The lower portion of the drainage area is residential, containing a mixture of impervious area and grassed/vegetated area. A grassed easement provides cover from the downstream inlet to the conveyance systems discharge point. No existing stormwater treatment measures were located within this system which results in the stormwater discharging untreated runoff directly to the lake.

Photo 16: Grassed Easement from Laurel Place to Erskine Lake

Recommendation Site 11:

For Site 11, the recommended BMP would be a Manufactured Treatment Device (MTD) located near the inlet on the western portion of the intersection of Lakeview Ave and Laurel Place, shown in Photo 16. This MTD could intercept stormwater flow from all contributing locations at this area, treat the stormwater for excess sediment/nutrients, and use the existing conveyance system to discharge the treated stormwater into the Lake. This site would only be viable if there is the ability to conduct construction in the grassed easement area shown in Photo 16, and that area was not privately owned.

Photo 17: Corrugated Metal Pipe Outfall

Estimated Costs Site 11:

The approximate cost for design, permitting, and implementation of this BMP recommendation is anticipated to be between $200,000 and $400,000.

SITE 12: LOWER ERSKINE LAKE – LOWER ERSKINE LAKE BEACH

Photo 18: Parking Lot at the Center of Site 12

Site 12 is located on a peninsula at the south end of Lower Erskine Lake, on Main Beach Road. This is a residential area with a summertime recreational area that includes a beach, basketball court, and a large parking lot located on the center of the site as shown in Photo 18. The drainage area of this site is mostly the asphalt parking lot and roadways contained within and bordering the site. The residential developments surrounding site 12 will also contribute to its drainage area. The northeastern and northwestern portions of the peninsula have steep slopes with high potential for erosion leading into the lake as shown in Photo 19. The roadways entering the site contain small inlet systems that drain to the lake. For the parking lot and recreation area, there were no observed stormwater management measures in place thus these impervious areas sheet flow untreated into the Lake.

Recommendation Site 12:

As shown in figure 41 below, there are several opportunities for pavement conversion around this site. Asphalt can be removed and replaced with porous pavement or a vegetated paver in the parking area and along the roads entering the site. The small inlet systems can serve as overflow pipes for the pavement conversion system implemented in that area. These conversions will reduce overall impervious area on the site, as well as the total volume of unmanaged stormwater leaving the site. Additionally, there are opportunities for shoreline stabilization on the northeastern and northwestern portions of the peninsula to reduce sedimentation in those areas with the addition of riparian zones.

Photo 19: Site 12 Lake Shore Area with High Potential for Erosion.

Figure 41 - Overview of Site 12

Estimated Costs Site 12:

The approximate cost for design, permitting, and implementation of this BMP recommendation is anticipated to be between $250,000 and $750,000. The costs are highly dependent on the areas selected for pavement conversion and the stabilization methodology required for the slopes.

SITE 13: LOWER ERSKINE LAKE – RAMPO PLACE BOAT LAUNCH

The Ramapo Place Boat Launch is located on the southwestern shore of Lower Erskine Lake, next to the intersection of Ramapo Place and Lakeview Avenue. This is a boat launch and boat storage area used by the community during the warmer months as shown in Photo 20. This site contains a stormwater conveyance system consisting of pipes and inlets from surrounding streets that convey stormwater from its drainage area to its discharge point at Lower Erskine Lake. Photo 21 shows the location where the conveyance system converges at the intersection before discharging from the protruding from the concrete bulkhead as shown in Photo 22 adjacent to the boat ramp. Due to the size of the drainage areas on the site, this site will be a significant contributor of unwanted sediment, Total Suspended Solids (TSS), and Total Phosphorus (TP) entering the lake.

Photo 210: Partially Paved Boat Launch Ramp

Recommendation Site 13:

A Manufactured Treatment Device (MTD) located near the inlet on the western portion of the intersection of Lakeview Ave and Ramapo Place is recommended. This MTD will be able to remove excess sediment and nutrients from the stormwater at this intersecting location before the stormwater is conveyed to the lake. Specific consideration should be taken to avoid any conflict with the water supply to the hydrant shown in Photo 21 when evaluating the exact location.

Photo 201: Inlets and Fire Hydrant at the Intersection of Ramapo Place and Lakeside Avenue.

Estimated Costs Site 13:

The approximate cost for design, permitting, and implementation of this BMP recommendation is anticipated to be between $200,000 and $400,000.

Photo 222: Corrugated Metal Pipe Discharging to Erskine Lake.

SITE 14: LOWER ERSKINE LAKE – MOHAWK TRAIL BOAT LAUNCH

Photo 23: Driveway to Boat Launch Area Near Mohawk Trail

Photo 24: End of Boat Launch Area Facing Lower Erskine Lake

The Mohawk Trail Boat Launch Site is an area on the opposite side of Mohawk Trial, at the intersection of Lakeview Avenue and Mohawk Trail. The site consists of a gravel driveway and dirt boat launch area, as shown in Photos 23 and 24. The drainage area for this site consists of the streets near the boat launch and residences bordering the area. Stormwater collects in inlets along Lakeview Ave, Mohawk Trail, and surrounding streets before converging at the inlet system on Lakeview Avenue directly before the boat launch. The stormwater is then piped from the Lakeview Avenue convergence point down the Mohawk Trail boat launch ramp before discharging to the east of the site through a 12-inch diameter concrete pipe.

Recommendation Site 14: Due to the piped conveyance system, the installation of a Manufactured Treatment Device (MTD) along the stormwater pipe on the site would be the recommended practice installed here. This MTD would be installed along the driveway to the boat launch area and could capture stormwater from the surrounding roadway drainage areas before it is discharged into the lake. This would prevent additional sediment, Total Suspended Solids (TSS), and Total Phosphorous (TP), from entering the lake.

Estimated Costs Site 14: The approximate cost for design, permitting, and implementation of this BMP recommendation is anticipated to be between $200,000 and $400,000.

8.6 UPPER SKYLINE LAKE

SITE 15: UPPER SKYLINE LAKE – SKYLINE DRIVE SHOPPING CENTER

The Skyline Drive Shopping Center is an 18-acre shopping center and parking lot on both sides of Skyline Drive

(CR 692), located approximately half a mile to the northeast of Upper Skyline Lake. Site 15 has a drainage area consisting of the entire impervious shopping center area and streets, as well as a vast wooded area surrounding it. Refer to Photo 25 for an example photograph of the parking lot areas. Stormwater is collected from the various parking lots of the entire shopping area through a series of inlets and is discharged into a wetland area southwest of the shopping center. These stormwater pipes also contain a stream that travels under the entire shopping center, daylighting on the eastern portion of the shopping center for a short amount of time before traveling underneath Skyline Drive, which can be shown in Photo 26. This stream passes through the wetland and ultimately drains to Upper Skyline Lake, bringing all the excess sediment and nutrients acquired from the shopping center with it.

Photo 25: Eastern Shopping Complex Parking Lot

Photo 26: Stream Under Shopping Center Daylighting Briefly Before Traveling West Under Skyline Drive

Comparatively, this site has a rather large amount of impervious area within its drainage area. Because of this, this site is a large contributor to excess nutrients and sediment further downstream at Upper Skyline Lake. This practice area can support multiple BMP's due to its size and drainage area. Three types of BMPs can be implemented within the site as shown on Figure 42 below. These solutions include Practice 15A- A proposed retention basin in the location shown in Photo 26 above, Practice 15B- an MTD intercepting the stream and parking lot drainage, and Practice 15C- a vegetated buffer to collect surface runoff from the southwestern portion of the shopping center before that stormwater makes it into the wetland area. Refer to Figure 42 for an overview of the practice area.

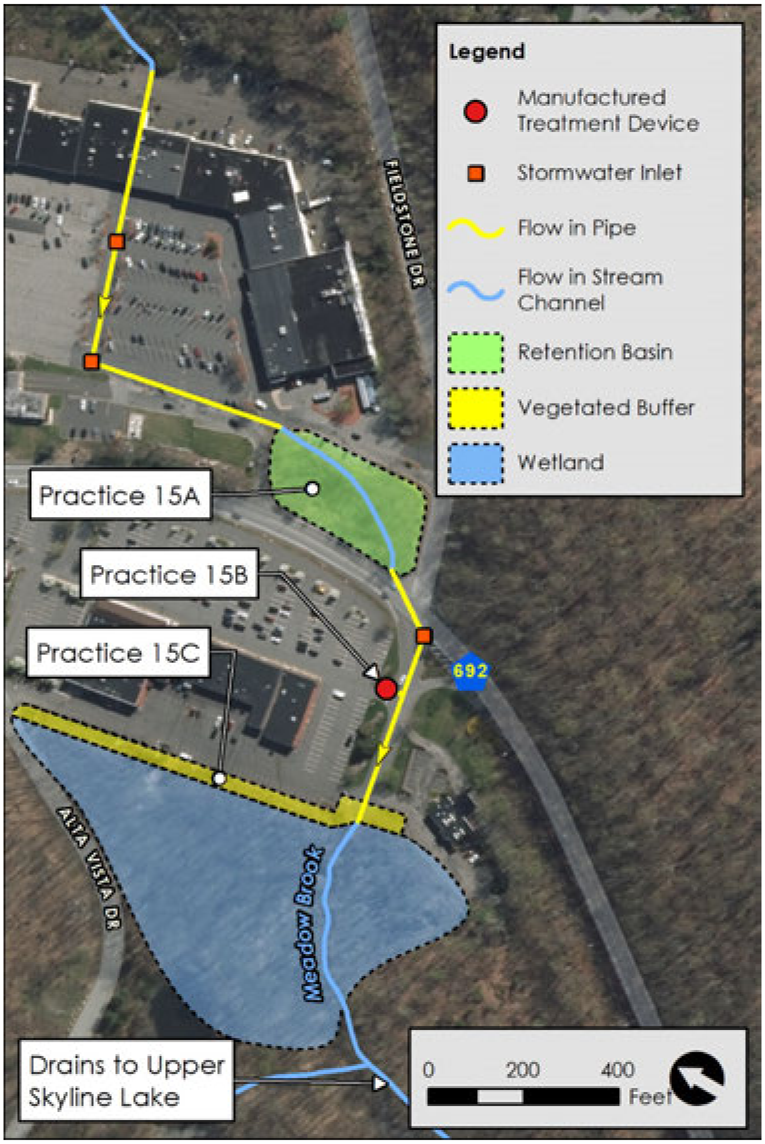

Figure 42: Shopping Complex Parking Lot & Stream System Overview

Recommendation Practice 15A: A recommended Best Management Practice (BMP) for this area would be to convert the vegetated area shown in Figure 42 and Photo 26 into a retention basin. A retention basin retains water from prior to flowing downstream and provides a place for water to collect before continuing its journey into Upper Skyline Lake. This would allow for the settling of sediment and processing of organic nutrients within the basin itself, which will better the conditions of Upper Skyline Lake further downstream by providing another place to sequester sediment and nutrients for part of the Upper Skyline Lake watershed.

Estimated Costs Practice 15A: The approximate cost for design, permitting, and implementation of this BMP recommendation is anticipated to be between $300,000 and $500,000.

Recommendation Practice 15B: This practice would work in combination with practice 15A. Once the piped conveyance system leaves the retention basin and passes under Skyline Drive from the Practice 15A practice area, another BMP system would be installed on the west side of Skyline Drive, as shown in Figure 42 above. The recommended BMP at this location would be to install a Manufactured Treatment Device (MTD) on the piped conveyance system to intercept and treat flow from the pipe before it reaches the wetland area. This would further remove sediment and nutrients from the stormwater before is discharges to the wetland area further downstream.

Estimated Costs Practice 15B: The approximate cost for design, permitting, and implementation of this BMP recommendation is anticipated to be between $200,000 and $400,000.

Recommendation Practice 15C: While practice 15A and 15B can manage the drainage areas of the northeastern parking lot and stream, the southwestern parking lot provides additional opportunities for further stormwater management measures to be implemented, such as Practice 15C. The recommended Best Management Practice (BMP) for this area is to transition a portion of the paved area behind the southeastern parking lot into a vegetated buffer. This would be a surface practice, that filters runoff directly from the surface parking lot behind the storefronts during storm events. The vegetated buffer would filter stormwater runoff from the parking lot to the east of Skyline Drive and reduce the total number of pollutants and sediment that will discharge to the wetland and thus the tributary stream.

Estimated Costs Practice 15C: The approximate cost for design, permitting, and implementation of this BMP recommendation is anticipated to be between $75,000 and $200,000.

SITE 16: UPPER SKYLINE LAKE – UPPER SKYLINE LAKE DAM

This site is located along Skyline Lake Drive, directly to the west to Upper Skyline Lake Dam. The site consists of the Skyline Lakes Clubhouse building, a parking lot, a boat launch ramp, and beach area. The drainage area for this site is a combination of the surrounding residential and roadway areas bordering the site, as well as all impervious areas contained on the site itself. There is a stormwater system on the site that conveys the street drainage from Skyline Lake Drive and empties the stormwater into Upper Skyline Lake through a pipe and inlet system that runs under the parking lot. The outlet of this system can be shown in Photo 28.

Photo 28: Skyline Lakes Clubhouse Parking Lot, Looking West

Photo 27: Outlet of Parking Lot Drainage System and Potential Riparian Zone Area

Recommendation Site 16: The recommended Best Management Practice (BMP) for this site would be to conduct a pavement modification on the sites parking area from regular asphalt pavement to either a porous or vegetated paver to allow stormwater filtration. Switching to a surface practice in the parking lot will allow the water draining to this area to be filtered directly into the subsurface soils, assuming the geotechnical conditions on the site allow for water percolation. Filtering the stormwater at this location into the ground would greatly reduce the amount of TSS and TP that enters the lake, which improves the water quality for Upper Skyline Lake. There are additional opportunities on the site to conduct bank stabilization/riparian plantings along the banks of the lake and/or the installation of a MTD depending on soils conditions on the site for pavement conversion.

Estimated Costs Site 16: The approximate cost for design, permitting, and implementation of this BMP recommendation is anticipated to be between $200,000 and $400,000. The design and installation for the bank stabilization nor MTD are included in this cost.

8.7 LOWER SKYLINE LAKE

SITE 17: LOWER SKYLINE LAKE – LOWER SKYLINE LAKE BEACH

Lower Skyline Lake Beach is located on the western shore of Lower Skyline Lake, adjacent to Skyline Lake Drive. The site includes a beach, parking lot, a basketball court, playground, boat ramp and kayak storage. Photo 29 and Photo 30 show the surrounding site parking lot, as well as the dirt boat ramp respectively. Stormwater from the site is conveyed both as surface flow to the lake and collected through inlets in the parking lot and along Skyline Lake Drive. There is a 12 inch diameter HDPE pipe used for stormwater discharge that is connected to the drainage system on site and which diverts stormwater flow into Lower Skyline Lake.

Photo 29: Parking Lot of Beach Area

Recommendation Site 17: The recommended Best Management Practice (BMP) is to conduct a pavement conversion for the portions of the site to either a vegetated or porous pavement system to allow stormwater infiltration. A part of the asphalt parking lot would be able to be converted to a porous pavement system to manage stormwater runoff from the parking lot area. In addition to the porous pavement system, the boat launch ramp area in the corner of the parking lot could include bank stabilization measures and a vegetated paver system that extends from the parking lot to the lake. A portion of the beach and the northern bank of the site should include bank stabilization to prevent erosion of the bank. This combination of measures will help reduce the amount of excess nutrients and sediment that enter the lake due to stormwater.

Photo 30: Beach Area Boat Launch into Lower Skyline Lake

Estimated Costs Site 17: The approximate cost for design, permitting, and implementation of this BMP recommendation is anticipated to be between $300,000 and $1,000,000. The cost for these BMPs is highly variable and dependent on the size and methodology implemented.

8.8 LAKE RICKONDA

SITE 18: LAKE RICKONDA – LAKE RICKONDA BEACH

Photo 31: Inlet Location Marking Start of Drainage Swale Along Lake Rickonda Drive

Photo 32: Swale from Inlets to Lake Rickonda

Lake Rickonda Beach is located on the northwestern side of Lake Rickonda, with access from Lake Rickonda Drive. The site includes a swimming beach and a small dock. The drainage area for this site consists of the residential area surrounding the site along Lake Rickonda Drive, as well as Lake Rickonda Drive itself. Stormwater is collected from the site via two curb side inlets, one of which is shown in Photo 31. These two inlets discharge into a rock-lined swale which directly connects to Lake Rickonda, as shown in Photo 32.

Recommendation Site 18: The recommended BMP is to convert the existing swale into a vegetated swale, which would filter the runoff from Lake Rickonda Drive, reducing the amount of Total Suspended Solids (TSS) and other pollutants that enter Lake Rickonda. The swale shall also include small pools in areas that are accessible for maintenance to provide a means to sediment prior to entering the lake. Bank stabilization is also recommended along the bank adjacent to the beach to prevent erosion of the bank as it is a steep transition from the bank to the lake. Refer to Figure 43 for an overview of the site.

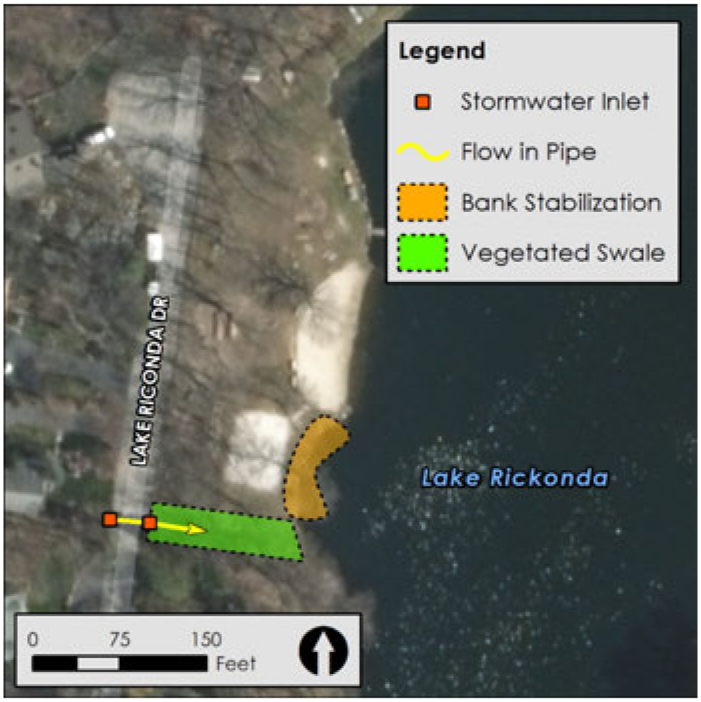

Figure 43: Proposed Practice 18A Overview

Estimated Costs Site 18: The approximate cost for design, permitting, and implementation of this BMP recommendation is anticipated to be between $75,000 and $300,000.

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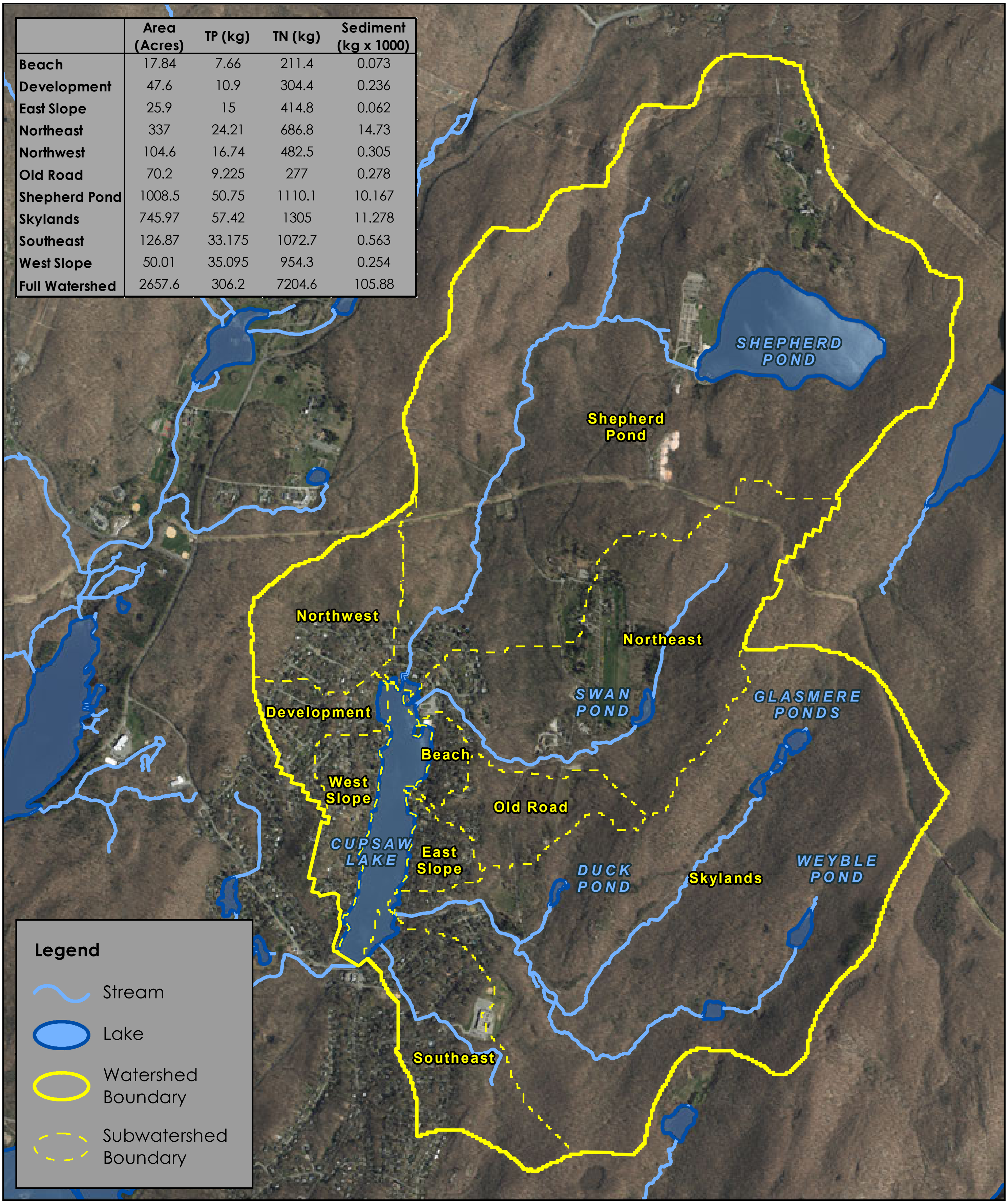
Appendix I:
Ringwood Lake Watershed Maps

CUPSAW LAKE WATERSHED MAP

WATERSHED-BASED LAKE ASSESSMENT
BOROUGH OF RINGWOOD
PASSAIC COUNTY, NEW JERSEY

	Area (Acres)	TP (kg)	TN (kg)	Sediment (kg x 1000)
Beach	17.84	7.66	211.4	0.073
Development	47.6	10.9	304.4	0.236
East Slope	25.9	15	414.8	0.062
Northeast	337	24.21	686.8	14.73
Northwest	104.6	16.74	482.5	0.305
Old Road	70.2	9.225	277	0.278
Shepherd Pond	1008.5	50.75	1110.1	10.167
Skylands	745.97	57.42	1305	11.278
Southeast	126.87	33.175	1072.7	0.563
West Slope	50.01	35.095	954.3	0.254
Full Watershed	2657.6	306.2	7204.6	105.88



NOTES:
1. Watershed and subwatershed boundaries obtained from WikiWatershed, Model My Watershed Application.
2. Streams and lakes obtained from NJDEP GIS website: www.state.nj.us/dep/gis/
3. 2015 orthoimagery obtained from NJ Office of Information Technology (NJOIT), Office of Geographic Information Systems (OGIS).

Map Projection: NAD 1983 StatePlane New Jersey FIPS 2900 Feet

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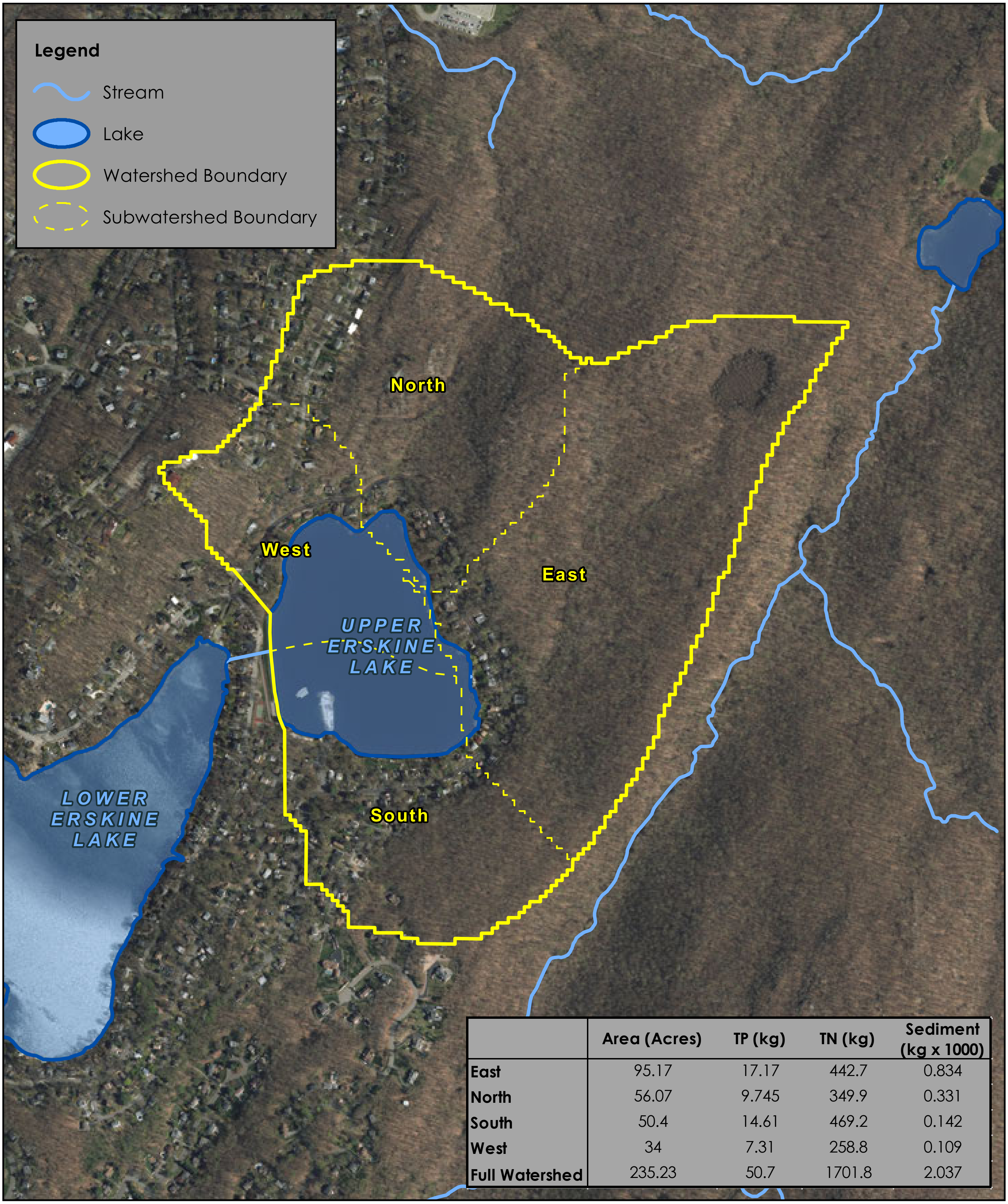

	Area (Acres)	TP (kg)	TN (kg)	Sediment (kg x 1000)
East	95.17	17.17	442.7	0.834
North	56.07	9.745	349.9	0.331
South	50.4	14.61	469.2	0.142
West	34	7.31	258.8	0.109
Full Watershed	235.23	50.7	1701.8	2.037

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UPPER ERSKINE LAKE WATERSHED MAP

WATERSHED-BASED LAKE ASSESSMENT
BOROUGH OF RINGWOOD
PASSAIC COUNTY, NEW JERSEY

NOTES:
1. Watershed and subwatershed boundaries obtained from WikiWatershed, Model My Watershed Application.
2. Streams and lakes obtained from NJDEP GIS website: www.state.nj.us/dep/gis/
3. 2015 orthoimagery obtained from NJ Office of Information Technology (NJOIT), Office of Geographic Information Systems (OGIS).

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Map Projection: NAD 1983 StatePlane New Jersey FIPS 2900 Feet

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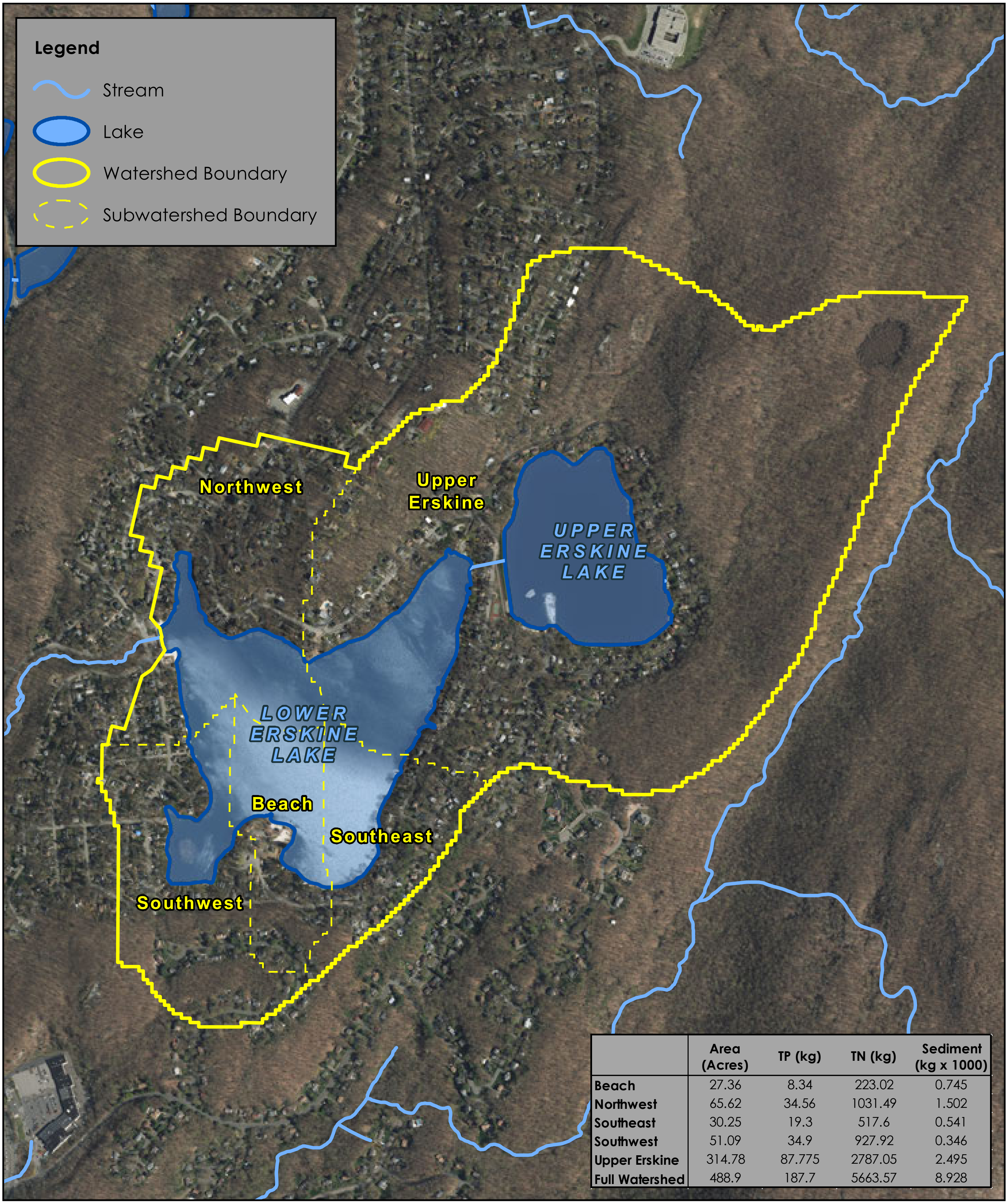

	Area (Acres)	TP (kg)	TN (kg)	Sediment (kg x 1000)
Beach	27.36	8.34	223.02	0.745
Northwest	65.62	34.56	1031.49	1.502
Southeast	30.25	19.3	517.6	0.541
Southwest	51.09	34.9	927.92	0.346
Upper Erskine	314.78	87.775	2787.05	2.495
Full Watershed	488.9	187.7	5663.57	8.928

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NOTES:
1. Watershed and subwatershed boundaries obtained from WikiWatershed, Model My Watershed Application.
2. Streams and lakes obtained from NJDEP GIS website: www.state.nj.us/dep/gis/
3. 2015 orthoimagery obtained from NJ Office of Information Technology (NJOIT), Office of Geographic Information Systems (OGIS).

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Map Projection: NAD 1983 StatePlane New Jersey FIPS 2900 Feet

LOWER ERSKINE LAKE WATERSHED MAP

WATERSHED-BASED LAKE ASSESSMENT
BOROUGH OF RINGWOOD
PASSAIC COUNTY, NEW JERSEY

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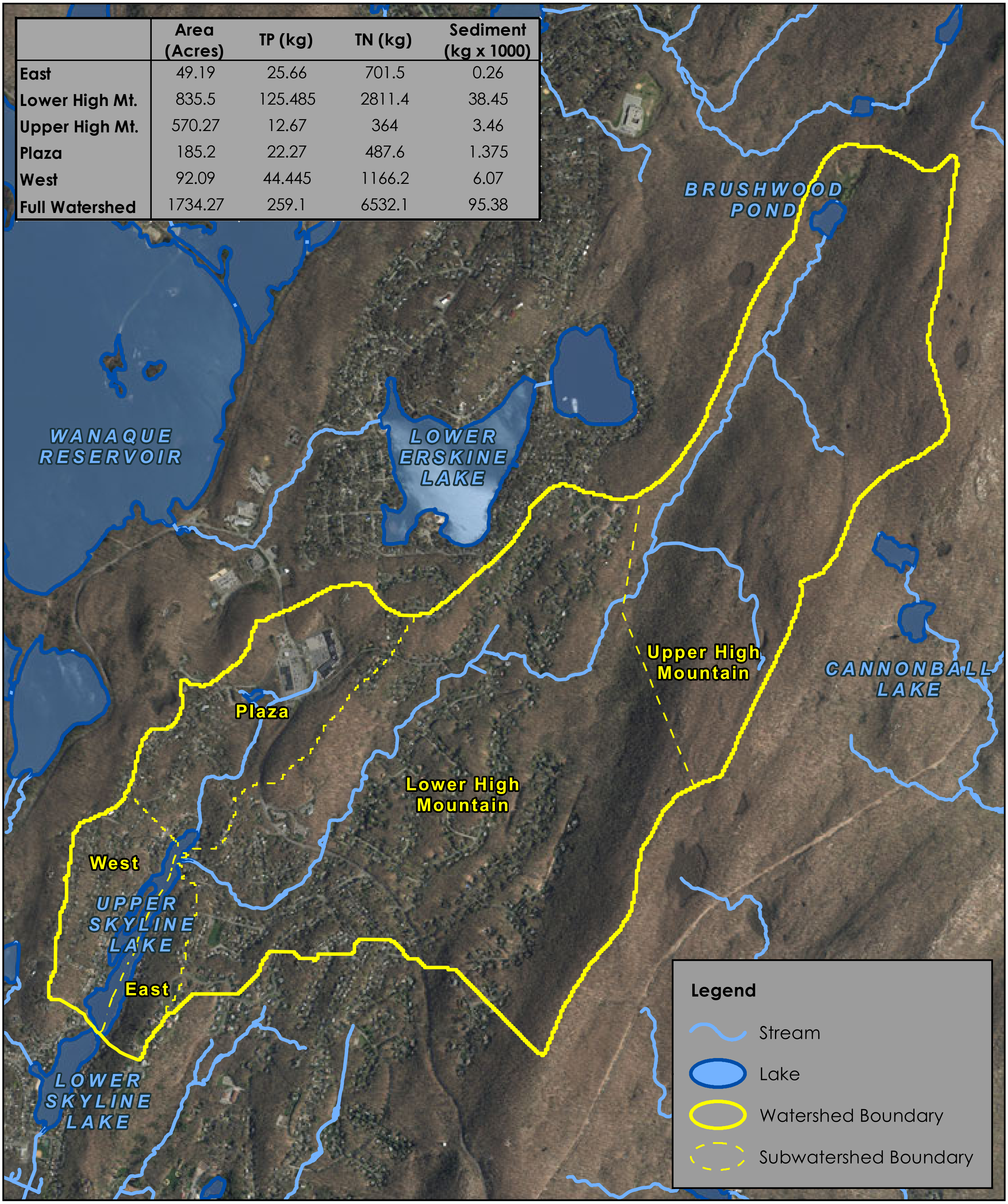
	Area (Acres)	TP (kg)	TN (kg)	Sediment (kg x 1000)
East	49.19	25.66	701.5	0.26
Lower High Mt.	835.5	125.485	2811.4	38.45
Upper High Mt.	570.27	12.67	364	3.46
Plaza	185.2	22.27	487.6	1.375
West	92.09	44.445	1166.2	6.07
Full Watershed	1734.27	259.1	6532.1	95.38



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NOTES:
1. Watershed and subwatershed boundaries obtained from WikiWatershed, Model My Watershed Application.
2. Streams and lakes obtained from NJDEP GIS website: www.state.nj.us/dep/gis/
3. 2015 orthoimagery obtained from NJ Office of Information Technology (NJOIT), Office of Geographic Information Systems (OGIS).

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Map Projection: NAD 1983 StatePlane New Jersey FIPS 2900 Feet

UPPER SKYLINE LAKE WATERSHED MAP

WATERSHED-BASED LAKE ASSESSMENT
BOROUGH OF RINGWOOD
PASSAIC COUNTY, NEW JERSEY

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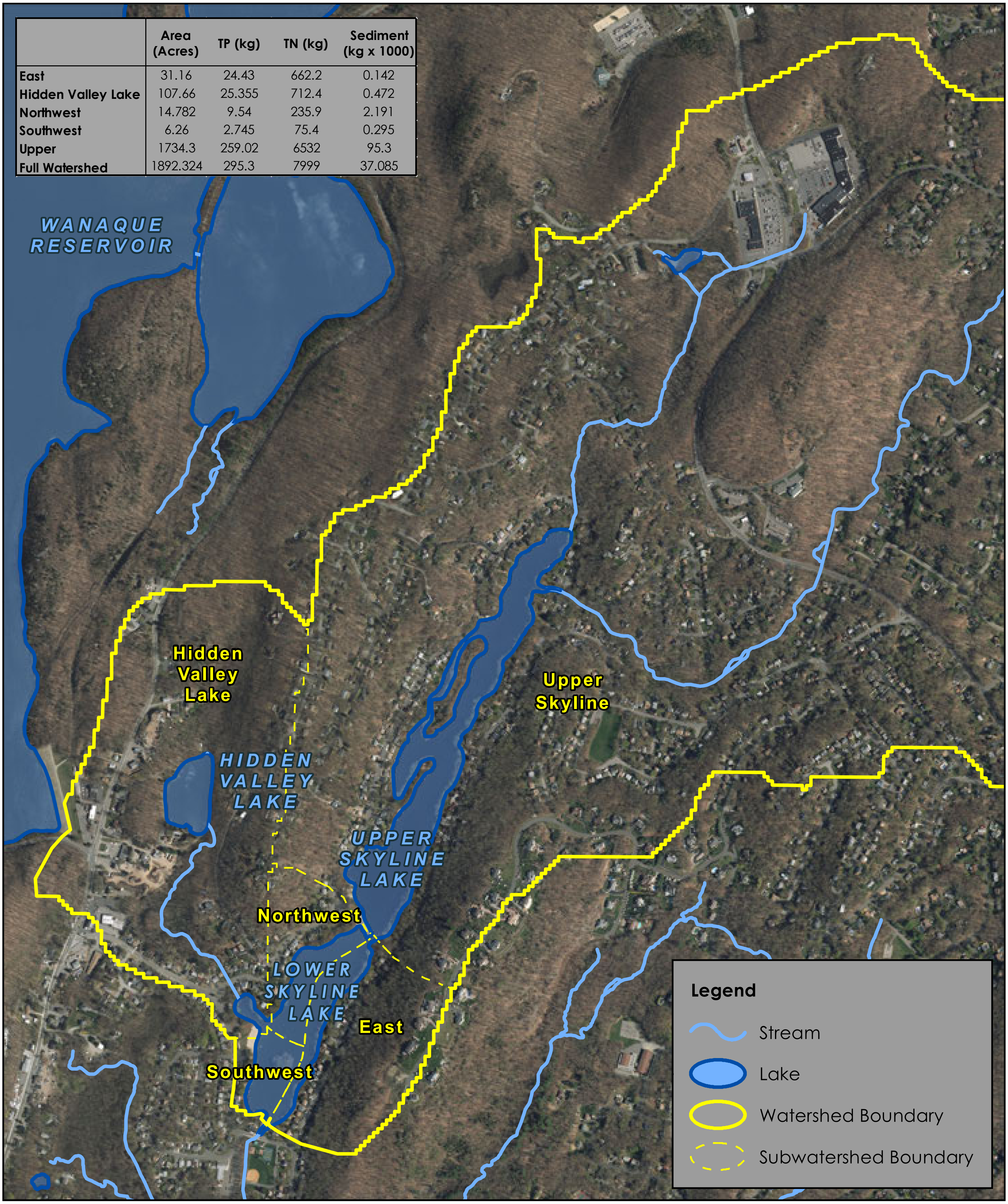

	Area (Acres)	TP (kg)	TN (kg)	Sediment (kg x 1000)
East	31.16	24.43	662.2	0.142
Hidden Valley Lake	107.66	25.355	712.4	0.472
Northwest	14.782	9.54	235.9	2.191
Southwest	6.26	2.745	75.4	0.295
Upper	1734.3	259.02	6532	95.3
Full Watershed	1892.324	295.3	7999	37.085

NOTES:
1. Watershed and subwatershed boundaries obtained from WikiWatershed, Model My Watershed Application.
2. Streams and lakes obtained from NJDEP GIS website: www.state.nj.us/dep/gis/
3. 2015 orthoimagery obtained from NJ Office of Information Technology (NJOIT), Office of Geographic Information Systems (OGIS).

0 500 1,000 Feet

Map Projection: NAD 1983 StatePlane New Jersey FIPS 2900 Feet

LOWER SKYLINE LAKE WATERSHED MAP

WATERSHED-BASED LAKE ASSESSMENT
BOROUGH OF RINGWOOD
PASSAIC COUNTY, NEW JERSEY

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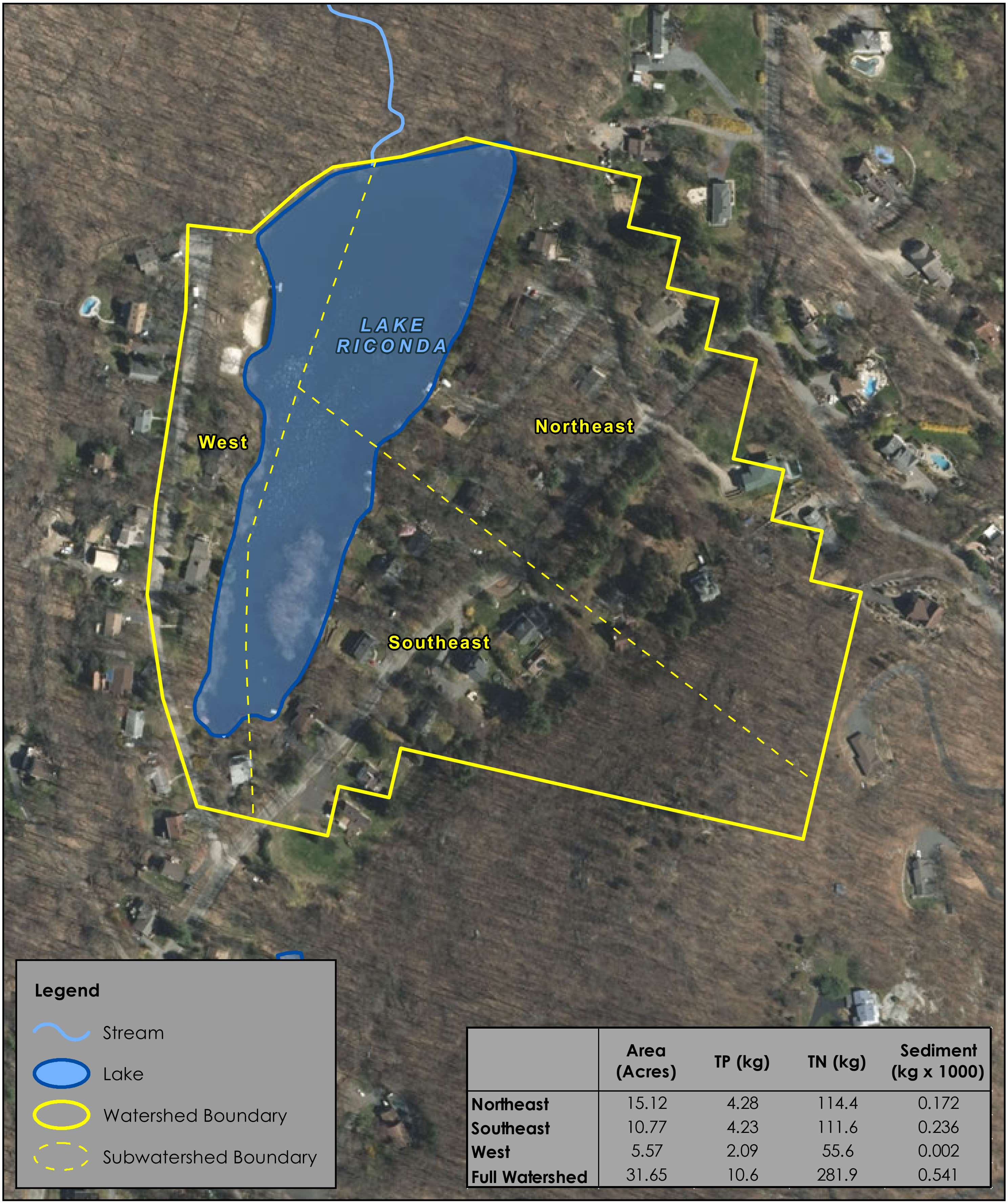

	Area (Acres)	TP (kg)	TN (kg)	Sediment (kg x 1000)
Northeast	15.12	4.28	114.4	0.172
Southeast	10.77	4.23	111.6	0.236
West	5.57	2.09	55.6	0.002
Full Watershed	31.65	10.6	281.9	0.541

NOTES:
1. Watershed and subwatershed boundaries obtained from WikiWatershed, Model My Watershed Application.
2. Streams and lakes obtained from NJDEP GIS website: www.state.nj.us/dep/gis/
3. 2015 orthoimagery obtained from NJ Office of Information Technology (NJOIT), Office of Geographic Information Systems (OGIS).

0 125 250 Feet

Map Projection: NAD 1983 StatePlane New Jersey FIPS 2900 Feet

LAKE RICONDA WATERSHED MAP

WATERSHED-BASED LAKE ASSESSMENT
BOROUGH OF RINGWOOD
PASSAIC COUNTY, NEW JERSEY

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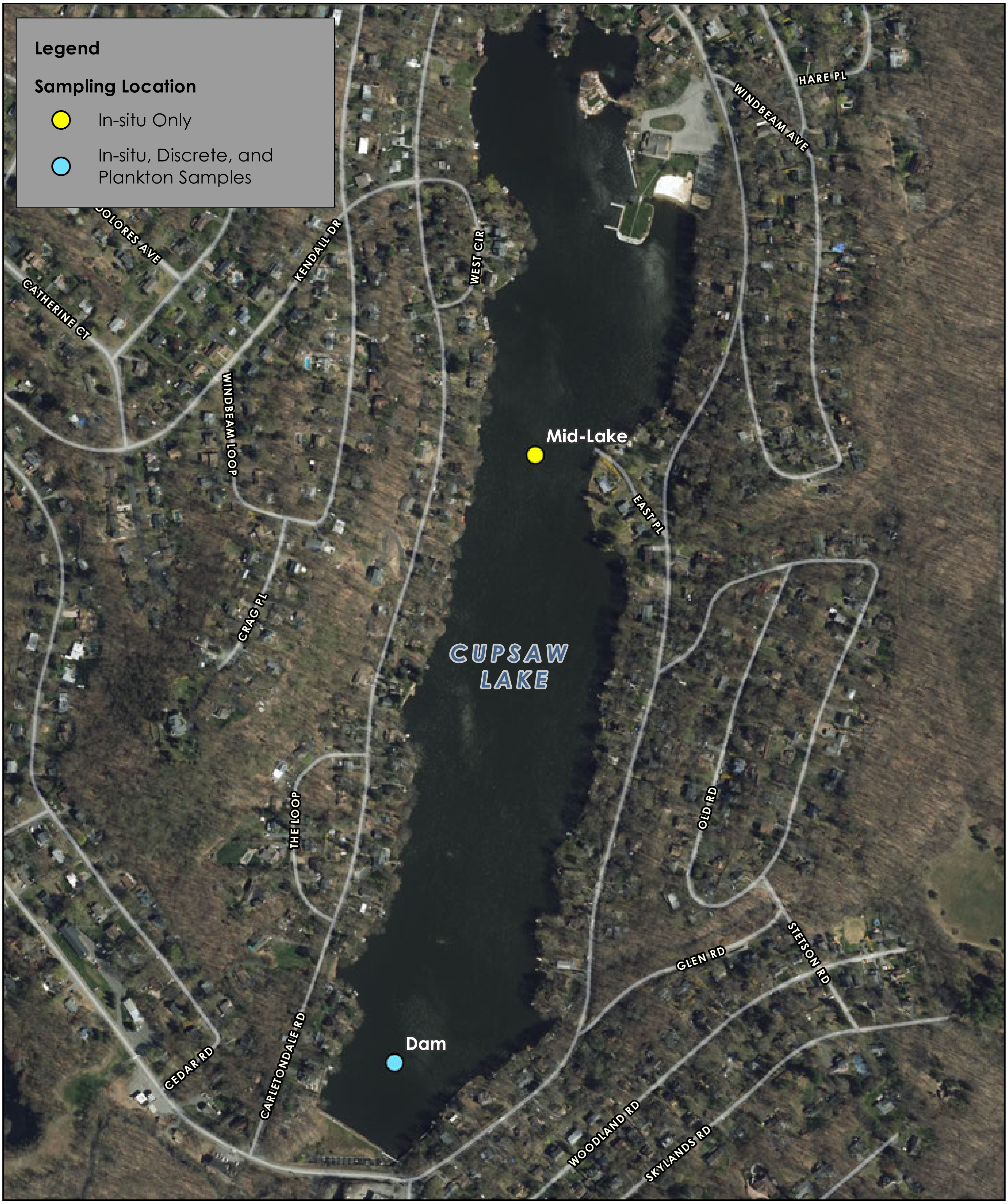
Appendix II:
In-Lake Sampling Maps



File: C:\Users\bsmith.PRINCETONHYDRO\Desktop\GIS\1891002_Ringwood\MXD\Cupsaw_Sampling_Map.mxd, 1/29/2021, Drawn by bsmith, Copyright Princeton Hydro, LLC.

NOTES:
1. Sampling locations are approximate.
2. 2015 orthoimagery obtained from NJ Office of Information Technology (NJOIT), Office of Geographic Information Systems (OGIS).

0 250 500
Feet

Map Projection: NAD 1983 StatePlane New Jersey FIPS 2900 Feet

CUPSAW LAKE SAMPLING MAP

WATERSHED-BASED LAKE ASSESSMENT
BOROUGH OF RINGWOOD
PASSAIC COUNTY, NEW JERSEY

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NOTES:
1. Sampling locations are approximate.
2. 2015 orthoimagery obtained from NJ Office of Information Technology (NJOIT), Office of Geographic Information Systems (OGIS).

Map Projection: NAD 1983 StatePlane New Jersey FIPS 2900 Feet

UPPER ERSKINE LAKE SAMPLING MAP

WATERSHED-BASED LAKE ASSESSMENT
BOROUGH OF RINGWOOD
PASSAIC COUNTY, NEW JERSEY

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File: C:\Users\bsmith.PRINCETONHYDRO\Desktop\GIS\1891002_Ringwood\MXD\Lower_Erskine_Sampling_Map.mxd, 1/29/2021, Drawn by bsmith, Copyright Princeton Hydro, LLC.

NOTES:
1. Sampling locations are approximate.
2. 2015 orthoimagery obtained from NJ Office of Information Technology (NJOIT), Office of Geographic Information Systems (OGIS).

0 200 400 Feet

Map Projection: NAD 1983 StatePlane New Jersey FIPS 2900 Feet

LOWER ERSKINE LAKE SAMPLING MAP

WATERSHED-BASED LAKE ASSESSMENT
BOROUGH OF RINGWOOD
PASSAIC COUNTY, NEW JERSEY

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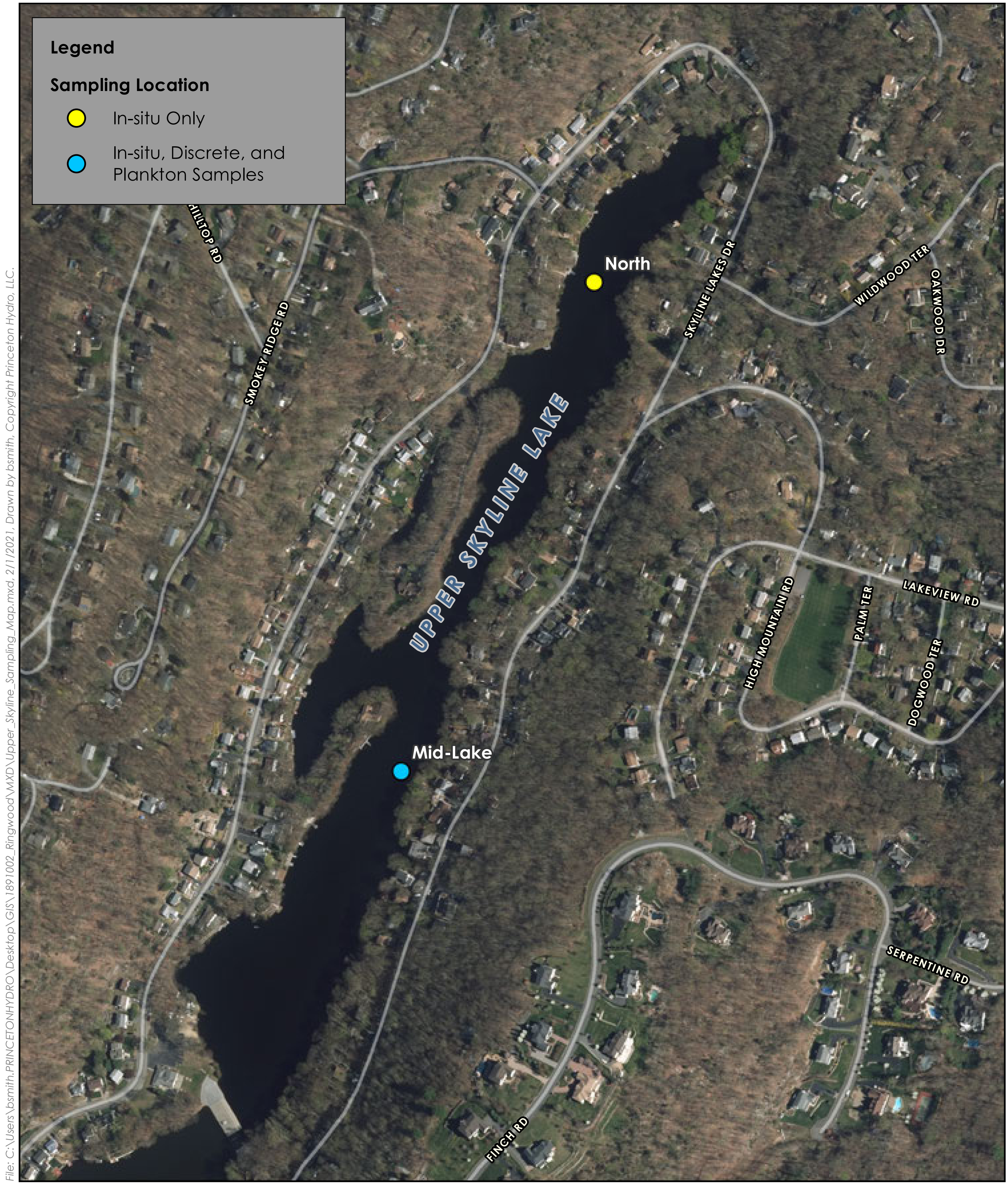

NOTES:
1. Sampling locations are approximate.
2. 2015 orthoimagery obtained from NJ Office of Information Technology (NJOIT), Office of Geographic Information Systems (OGIS).

0 200 400 Feet

Map Projection: NAD 1983 StatePlane New Jersey FIPS 2900 Feet

UPPER SKYLINE LAKE SAMPLING MAP

WATERSHED-BASED LAKE ASSESSMENT
BOROUGH OF RINGWOOD
PASSAIC COUNTY, NEW JERSEY

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NOTES:
1. Sampling locations are approximate.
2. 2015 orthoimagery obtained from NJ Office of Information Technology (NJOIT), Office of Geographic Information Systems (OGIS).

0 100 200 Feet

Map Projection: NAD 1983 StatePlane New Jersey FIPS 2900 Feet

LOWER SKYLINE LAKE SAMPLING MAP

WATERSHED-BASED LAKE ASSESSMENT
BOROUGH OF RINGWOOD
PASSAIC COUNTY, NEW JERSEY

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File: C:\Users\bsmith.PRINCETONHYDRO\Desktop\GIS\1891002_Ringwood\MXD\Riconda_Sampling_Map.mxd, 2/1/2021, Drawn by bsmith, Copyright Princeton Hydro, LLC.

NOTES:
1. Sampling locations are approximate.
2. 2015 orthoimagery obtained from NJ Office of Information Technology (NJOIT), Office of Geographic Information Systems (OGIS).

0 100 200 Feet

Map Projection: NAD 1983 StatePlane New Jersey FIPS 2900 Feet

LAKE RICONDA SAMPLING MAP

WATERSHED-BASED LAKE ASSESSMENT
BOROUGH OF RINGWOOD
PASSAIC COUNTY, NEW JERSEY

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Appendix III:
In-situ water quality data

In-Situ Monitoring for Ringwood Lakes 5/5/2020								
Station	Depth (m)			Temperature	Specific Conductance	Dissolved Oxygen		pH
	Total	Secchi	Sample	°C	mS/cm	mg/L	% Sat.	S.U.
Cupsaw Dam	7.7	2.1	0.0	14.84	0.136	10.44	102.7	8.1
			1.0	14.75	0.138	10.51	103.2	8.07
			2.0	14.54	0.138	10.38	101.4	8.03
			3.0	13.73	0.139	10.86	104.2	8.12
			4.0	10.62	0.142	9.82	87.9	7.78
			5.0	10.11	0.145	8.00	70.8	7.48
			6.0	9.7	0.145	7.36	64.4	7.3
			7.0	9.62	0.145	4.86	42.5	7.07
			7.5	9.62	0.146	3.89	34	6.98
Cupsaw Mid	2.4	2.1	0.0	12.62	0.143	11.12	104.2	8.32
			0.5	12.75	0.141	11.13	104.6	8.32
			1.0	12.68	0.141	10.92	102.4	8.33
			1.5	12.66	0.143	10.91	102.3	8.34
			2.0	12.61	0.143	10.88	101.8	8.32
Lower Erskine Mid	6.8	4.0	0.0	13.94	0.409	10.14	97.9	7.79
			1.0	13.90	0.411	10.17	97.2	8.05
			2.0	13.8	0.408	10.17	97.9	8.08
			3.0	13.62	0.407	10.11	96.9	8.10
			4.0	13.16	0.413	10.09	95.7	8.02
			5.0	12.64	0.411	10.21	95.9	7.99
			6.0	11.21	0.418	8.47	76.7	7.73
			6.5	11.04	0.419	7.79	70.5	7.50
Lower Erskine Dam	4.7	3.8	0.0	13.41	0.41	10.28	98.9	8.15
			1.0	13.86	0.408	10.22	98.5	8.14
			2.0	13.41	0.407	10.31	98.3	8.13
			3.0	13.66	0.41	10.21	96.7	8.09
			4.0	12.87	0.409	9.98	94.1	8.06
			4.5	12.91	0.411	10.07	95.00	7.86
Upper Erskine Mid	3.5	3.4	0.0	15.34	0.226	10.37	103.1	8.29
			1.0	15.07	0.226	10.43	103.4	8.42
			2.0	14.34	0.223	11.13	108.3	8.47
			3.0	13.65	0.226	9.66	92.6	7.90
Upper Erskine Dam	2.6	2.6+	0.0	15.79	0.234	12.24	124.5	9.06
			0.5	15.55	0.235	12.86	128.5	9.19
			1.0	15.05	0.23	13.25	130.9	9.22
			1.5	14.60	0.227	12.36	121.0	9.13
			2.0	14.27	0.23	13.96	135.6	9.36

In-Situ Monitoring for Ringwood Lakes 5/6/20								
Station	Depth (m)			Temperature	Specific Conductance	Dissolved Oxygen		pH
	Total	Secchi	Sample	°C	mS/cm	mg/L	% Sat.	S.U.
Riconda Dam	2.5	1.8	0.0	14.98	0.324	13.24	131.7	9.8
			0.5	14.99	0.323	13.44	133.8	9.81
			1.0	14.95	0.325	13.49	134.2	9.81
			1.5	14.84	0.323	13.89	137.6	9.85
			2.0	13.45	0.324	15.34	147.6	9.96
Riconda South	1.35	1.35+	0.0	14.87	0.324	13.53	134.3	9.84
			0.5	14.88	0.324	13.53	134.4	9.83
			1.0	14.75	0.324	13.32	131.9	9.81
Upper Skyline Mid	7	1.15	0.0	13.72	0.226	12.3	119	8.71
			1.0	13.65	0.228	12.51	120.8	8.7
			2.0	12.35	0.223	13.56	127.3	8.66
			3.0	10.01	0.253	12.71	113	8.42
			4.0	9.27	0.257	9.38	82	8
			5.0	9.05	0.267	8.02	68.9	7.71
			6.0	9.00	0.274	6.71	58.2	7.49
			6.5	8.98	0.276	6.13	53.2	7.24
Upper Skyline North	3.7	1.4	0.0	13.08	0.228	11.61	110.8	8.23
			1.0	11.36	0.229	11.72	107.6	8.13
			2.0	10.58	0.247	11.54	104	7.93
			3.0	10.59	0.241	12.03	108.3	7.94
Lower Skyline Dam	2.5		0.0	14.81	0.241	11.08	109.8	8.96
			0.5	14.77	0.24	11.3	111.8	9.02
			1.0	14.66	0.239	11.23	110.7	9
			1.5	14.56	0.24	10.82	106.6	8.95
			2.0	13.98	0.248	9.26	90.2	8.33
Lower Skyline North	2	0.65	0.0	14.66	0.238	10.93	108.0	8.77
			0.5	14.63	0.238	10.65	105.2	8.82
			1.0	14.51	0.236	10.19	100.3	8.83
			1.5	14.38	0.235	10.16	99.7	8.8

In-Situ Monitoring for Ringwood Lakes 7/8/2020								
Station	Depth (m)			Temperature	Specific Conductance	Dissolved Oxygen		pH
	Total	Secchi	Sample	°C	mS/cm	mg/L	% Sat.	S.U.
Cupsaw Dam	7.9	0.8	0.0	26.97	0.181	5.85	73.2	7.44
			1.0	26.93	0.182	5.98	74.7	7.35
			2.0	26.93	0.18	5.92	74	7.29
			3.0	26.92	0.18	5.76	71.9	7.25
			4.0	26.94	0.181	5.75	71.8	7.21
			5.0	26.94	0.18	5.89	73.6	7.17
			6.0	26.96	0.18	5.87	73.3	7.14
			7.0	26.86	0.18	5.15	64.6	7.08
			7.5	26.82	0.182	3.86	48.2	6.99
Cupsaw Mid	2.3	1	0.0	27.79	0.18	7.98	101.3	6.56
			0.5	27.8	0.177	7.6	96.4	7.08
			1.0	27.77	0.179	7.46	94.7	7.33
			1.5	27.66	0.179	7.63	96.6	7.58
			2.0	27.59	0.178	7.6	96.1	7.66
Lower Erskine Mid	7.9	3.0	0.0	27.47	0.432	8.65	109.3	8.79
			1.0	27.39	0.432	8.54	107.7	8.81
			2.0	27.13	0.431	8.62	108.1	8.74
			3.0	27.08	0.431	8.38	105.0	8.70
			4.0	24.36	0.441	1.79	21.3	7.60
			5.0	19.81	0.435	0.45	4.9	7.30
			6.0	14.74	0.42	2.7	26.6	7.45
			7.0	13.06	0.427	0.82	7.9	7.27
			7.5	12.57	0.438	0.27	2.7	7.11
Lower Erskine Dam	4.3	2.5	0.0	28.26	0.426	8.18	104.8	8.76
			1.0	28.07	0.429	8.40	107.2	8.80
			2.0	28.01	0.425	8.32	106.0	8.81
			3.0	27.90	0.425	8.22	104.5	8.80
			4.0	24.29	0.443	0.67	8.00	7.51
Upper Erskine Mid	3.2	1.6	0.0	28.51	0.249	7.28	93.3	7.35
			1.0	28.46	0.247	7.18	92.2	8.27
			2.0	28.04	0.246	6.87	87.6	8.24
			3.0	25.79	0.27	0.65	7.9	7.07
Upper Erskine Dam	2.2	1.5	0.0	28.07	0.247	6.02	76.8	7.98
			0.5	28.04	0.249	5.86	75.0	7.85
			1.0	27.99	0.25	5.91	75.3	7.82
			1.5	28.01	0.247	5.59	71.2	7.75
			2.0	27.76	0.248	5.34	67.7	7.75

In-Situ Monitoring for Ringwood Lakes 7/9/20								
Station	Depth (m)			Temperature	Specific Conductance	Dissolved Oxygen		pH
	Total	Secchi	Sample	°C	mS/cm	mg/L	% Sat.	S.U.
Riconda Dam	**2.1**	**1.1**	0.0	27.1	0.387	3.91	49	7.27
			0.5	27.04	0.388	3.84	48.1	7.27
			1.0	26.95	0.388	1.41	17.6	7.1
			1.5	26.75	0.389	0.95	11.7	7.11
			2.0	22.84	0.424	0.21	2.5	6.87
Riconda South	**1.1**	**0.7**	0.0	26.68	0.388	4.84	60.3	6.59
			0.5	26.67	0.385	4.06	50.5	6.89
			1.0	26.60	0.385	3.6	44.7	7.04
Upper Skyline Mid	**7**	**2.3**	0.0	26.6	0.334	9.42	117.2	8.73
			1.0	26.75	0.332	9.21	114.4	8.74
			2.0	25.53	0.334	7.44	90.5	8.24
			3.0	21.76	0.35	8.27	94.5	7.79
			4.0	14.94	0.286	0.98	9.7	7.4
			5.0	11.52	0.324	0.27	2.5	6.88
			6.0	10.44	0.35	0.2	1.8	6.72
			6.5	10.33	0.352	0.16	1.4	6.71
Upper Skyline North	**4.1**	**2**	0.0	26.67	0.331	10.02	124.8	8.93
			1.0	26.59	0.334	9.94	123.5	8.94
			2.0	26.09	0.336	8.62	106.1	8.6
			3.0	21.33	0.365	3.30	37.2	7.88
			4.0	15.62	0.325	0.63	6.3	7.4
Lower Skyline Dam*	**2.3**	**0.5**	0.0	27.76	0.287	8.76	111.5	8.9
			0.5	27.77	0.29	9.11	116.0	9.04
			1.0	27.74	0.29	8.97	114.2	8.97
			1.5	27.69	0.29	8.81	112.4	8.82
			2.0	26.98	0.292	2.74	34.4	7.50
Lower Skyline North*	**2**	**0.8**	0.0	25.38	0.311	10.8	131.2	9.07
			0.5	25.00	0.311	10.52	126.8	9.01
			1.0	24.55	0.312	9.85	118.2	8.86
			1.5	24.52	0.316	9.09	109.6	8.8

*Lower Skyline Dam was measured on 7/10/2020 due to meter malfunction that occurred late in the day on 7/9/2020

In-Situ Monitoring for Ringwood Lakes 10/14/20								
Station	**Depth (m)**			**Temperature**	**Specific Conductance**	**Dissolved Oxygen**		**pH**
	Total	**Secchi**	**Sample**	**°C**	**mS/cm**	**mg/L**	**% Sat.**	**S.U.**
Riconda Dam	**2.6**	**2.6**	0.0	14.71	0.285	8.93	88.2	7.19
			1.0	14.39	0.283	8.91	87.4	7.19
			2.0	14.33	0.283	8.84	86.6	7.20
			2.5	14.33	0.283	8.54	83.2	7.20
Riconda South	**1.3**	**1.3**	0.0	13.92	0.281	9.21	89.4	7.40
			0.5	13.78	0.280	9.09	87.9	7.33
			1.0	13.70	0.279	9.05	87.3	7.34
Upper Skyline Mid	**4.5**	**1.1**	0.0	15.41	0.294	8.68	87.2	7.10
			1.0	15.10	0.293	8.13	81.3	6.97
			2.0	15.01	0.292	7.82	77.6	6.95
			3.0	14.98	0.295	7.14	71.1	6.92
			4.1	14.51	0.366	1.23	15.5	6.62
Upper Skyline North	**3.8**	**1.3**	0.0	15.50	0.305	8.34	83.2	7.12
			1.0	14.94	0.301	7.90	78.1	7.12
			2.0	14.75	0.305	7.10	69.9	7.04
			3.0	14.55	0.312	6.36	62.7	6.95
			3.5	14.53	0.315	4.98	46.1	6.84
Lower Skyline Dam	**1.3**	**0.9**	0.0	15.90	0.273	12.77	129.0	8.07
			0.5	14.50	0.265	13.26	130.2	8.12
			1.0	14.22	0.263	13.03	127.1	8.10
Lower Skyline North	**0.9**	**0.8**	0.0	15.87	0.276	12.57	127.0	8.23
			0.5	15.84	0.276	12.59	127.1	8.11

In-Situ Monitoring for Ringwood Lakes 10/15/20								
Station	Depth (m)			Temperature	Specific Conductance	Dissolved Oxygen		pH
	Total	Secchi	Sample	°C	mS/cm	mg/L	% Sat.	S.U.
Cupsaw Dam	**7.8**	**0.9**	0.0	15.59	0.155	10.05	101.0	7.13
			1.0	15.54	0.155	10.05	100.9	7.05
			2.0	15.55	0.155	10.06	100.9	1.04
			3.0	15.49	0.155	10.00	100.3	7.07
			4.0	15.47	0.155	10.01	100.3	7.09
			5.0	15.46	0.155	9.97	100.0	7.11
			6.0	15.45	0.155	9.89	99.0	7.13
			7.0	15.45	0.155	9.85	98.7	7.15
			7.5	15.44	0.155	9.83	98.5	7.19
Cupsaw Mid	**1.6**	**0.9**	0.0	16.08	0.158	11.56	117.4	7.54
			1.0	16.05	0.157	11.43	116.2	7.59
			1.3	16.06	0.157	11.41	115.9	7.60
Lower Erskine Mid	**7.0**	**2.0**	0.0	16.64	0.351	8.85	91.0	7.48
			1.0	16.56	0.351	8.76	89.9	7.37
			2.0	16.43	0.350	8.68	88.9	7.34
			3.0	16.37	0.349	8.61	88.0	7.32
			4.0	16.30	0.348	8.45	86.4	7.31
			5.0	16.25	0.348	8.31	84.8	7.30
			6.0	16.23	0.348	8.23	83.9	7.30
			6.8	16.10	0.349	3.28	31.0	7.13
Lower Erskine Dam	**4.0**	**2.5**	0.0	16.63	0.351	8.79	90.3	7.44
			1.0	16.61	0.351	8.71	89.5	7.46
			2.0	16.58	0.351	8.71	89.4	7.44
			3.0	16.51	0.351	8.71	89.3	7.43
			3.8	16.39	0.354	5.69	5.69	7.28
Upper Erskine Mid	**2.9**	**2.1**	0.0	16.73	0.207	10.51	108.2	7.63
			1.0	16.47	0.206	10.51	107.4	7.36
			2.0	16.15	0.205	10.32	105.0	7.26
			2.5	15.95	0.203	10.08	102.1	7.24
Upper Erskine Dam	**2.5**	**2.2**	0.0	16.16	0.204	10.73	109.3	7.58
			1.0	15.89	0.202	10.47	106.1	7.52
			2.0	15.84	0.202	10.21	103.3	7.45

Appendix IV:
Discrete Water Quality Monitoring Data

Discrete Monitoring Data for Ringwood Lakes - 2020																
Date	Station	TP		SRP		Chl A		NO3-N		NO2-N		NH3-N		TSS	
		S (mg/L)	D (mg/L)	S (mg/L)	D (mg/L)	S (ug/L)	D (ug/L)	S (mg/L)	D (mg/L)	S (mg/L)	D (mg/L)	S (mg/L)	D (mg/L)	S (mg/L)	D (mg/L)
May-20	Cupsaw	0.03	0.03	ND <0.002	0.002	5.7	11.0	0.18	0.18	0.004	0.004	ND <0.01	0.01	ND <2	5
	Upper Erskine	0.02	0.02	0.002	0.002	1.9	3.0	0.24	0.19	0.003	0.004	ND <0.01	ND <0.01	ND <2	5
	Lower Erskine	0.02	0.02	0.002	ND <0.002	2.8	3.8	0.34	0.30	0.006	0.005	0.01	0.01	6	ND <2
	Upper Skyline	0.04	0.04	ND <0.002	ND <0.002	28.0	31.0	1.20	1.30	0.010	0.013	ND <0.01	0.01	9	7
	Lower Skyline	0.06	0.06	ND <0.002	ND <0.002	31.0	42.0	0.75	0.84	0.012	0.011	ND <0.01	ND <0.01	19	12
	Rickonda	0.02	0.03	ND <0.002	ND <0.002	2.0	1.0	0.06	0.06	0.003	ND <0.003	ND <0.01	0.01	7	ND <2
July-20	Cupsaw	0.05	0.06	ND <0.002	ND <0.002	28.0	32.0	0.07	0.09	0.008	0.009	0.02	0.03	11	12
	Upper Erskine	0.04	0.04	ND <0.002	ND <0.002	21.0	20.0	0.03	0.03	0.002	0.002	0.03	0.03	2	ND <2
	Lower Erskine	0.01	0.06	ND <0.002	ND <0.002	6.3	41.0	0.05	0.07	0.005	0.007	0.02	0.05	ND <2	8
	Upper Skyline	0.02	0.83	ND <0.002	0.190	17.0	45.0	0.73	0.26	0.011	0.013	0.03	0.49	ND <2	13
	Lower Skyline	0.10	0.11	ND <0.002	ND <0.002	76.0	53.0	0.05	0.05	0.010	0.010	0.22	0.25	21	16
	Rickonda	0.03	0.08	ND <0.002	0.005	2.3	9.5	0.03	0.04	0.005	0.005	0.02	0.04	2	10
October-20	Cupsaw	0.06	0.06	ND <0.002	ND <0.002	27.0	31.0	0.07	0.07	0.005	0.006	ND <0.01	ND <0.01	ND <2	6
	Upper Erskine	0.04	0.04	ND <0.002	ND <0.002	12.0	11.0	0.05	0.06	0.003	ND <0.003	ND <0.01	ND <0.01	ND <2	3
	Lower Erskine	0.03	0.03	ND <0.002	ND <0.002	10.0	8.4	0.05	0.05	0.004	0.004	ND <0.01	ND <0.01	ND <2	ND <2
	Upper Skyline	0.08	0.56	0.002	0.090	31.0	17.0	0.36	0.35	0.016	0.019	ND <0.01	0.08	5	12
	Lower Skyline	0.07	0.09	ND <0.002	ND <0.002	24.0	37.0	0.32	0.33	0.014	0.015	ND <0.01	0.01	7	7
	Rickonda	0.03	0.03	ND <0.002	0.002	2.1	2.6	0.08	0.08	0.010	0.010	ND <0.01	ND <0.01	ND <2	ND <2

Appendix V:
Plankton Sampling Data

Phytoplankton and Zooplankton Community Composition Analysis

Sampling Location: Ringwood Lakes — **Sampling Date: 5/5 - 6 /2020**

Site 1: Cupsaw Lake — **Site 2: Upper Erskine Lake** — **Site 3: Lower Erskine Lake** — **Site 4: Upper Skyline Lake** — **Site 5: Lower Skyline Lake** — **Site 6: Lake Rickonda**

Phytoplankton																				
Bacillariphyta (Diatoms)	**1**	**2**	**3**	**4**	**5**	**6**	**Chlorophyta (Green Algae)**	**1**	**2**	**3**	**4**	**5**	**6**	**Cyanophyta (Blue-Green Algae)**	**1**	**2**	**3**	**4**	**5**	6
Asterionella	A	R	R	B	B		*Actinastrum*							*Dolichospermum (formerly Anabaena)*				R	R	
Aulacoseira							*Ankistrodesmus*							*Amphanizomen*						
Cocconeis							*Chlamydomonas*				P			*Aphanocapsa*	P		P			
Cyclotella							*Botryococcus*							*Chroococcus*						
Cymatopleura							*Chlorella*							*Cylindrospermum*						
Cymbella							*Coelastrum*							*Lyngbya*						
Denticula							*Eudorina*							*Microcystis*		R				
Fragilaria	A	C	R	P	P	P	*Gloeocystis*			C	P			*Nostoc*						
Frustulia							*Gonium*							*Pseudoanabaena*						
Gyrosigma							*Hydrodictyon*							*Oscillatoria*						
Melosira	C		R	P	A		*Monoraphidium*							*Coelosphaerium*					R	
Nedium							*Mougeotia*	A	C				R	*Spirulina*						
Stauroneis							*Micrasterias*													
Stephanodiscus							*Microspora*													
Sururekka							*Ochromonas*													
Synedra							*Oedogonium*							**Euglenophyta (Euglenoids)**						
Tabellaria	P						*Oocystis*							*Colacium*						
Pinnularia							*Scenedesmus*							*Euglena (Phacus sp)*						
Navicula							*Spirogya*						R	*Euglena sp*			R			
Mastogloia														*Trachelomonas*				P		
							Treubaria													
Chrysophyta (Golden Algae)							*Pediastrum*		C	R		P		**Pyrrhophyta (Dinoflagellates)**						
Dinobryon	A		R				*Volvex*							*Ceratium*	R	P	P	R	P	
Chromulina							*Zygnema*							*Peridinium*						
Mallomonas							*Sphaerocystis*							*Cystodinium*						
							Ulothrix													
Synura							**Desmids (Green Algae)**							**Cryptomonads**						
							Hyalotheca							*Chroomonas*				C		
							Staurastrum		P	P										
							Desmidium													
Unknown filaments							*Staurodesmus*													
Zooplankton																				
Cladocera (Water Fleas)	**1**	**2**	**3**	**4**	**5**	**6**	**Copecoda (Copepods)**	**1**	**2**	**3**	**4**	**5**	**6**	**Rotifera (Rotifers)**	**1**	**2**	**3**	**4**	**5**	6
Bosmina sp.	P		R		R	P	*Cyclops sp.*							*Keratella sp.*	C	C	P	P	C	P
Daphnia sp.	C	A	P			C	*Dipatomus (H)*							*Kellicottia sp.*	R	R				
Eubosmina sp.							*Nauplii*	P	A	C	P	R	A	*Asplanchna sp.*	R		R	C	R	
Chydorus	R	P	R				*Skistodiaptomus sp.*		A	P				*Polyarthra*				P	P	
Diaphniosoma		P					*Microcyclops sp*	C	C	P	R	R	C	*Hexarthra mira*						
Ceriodaphnia	R						*Limnocalanus macrurus*							*Conochilus*	R			P	P	
Leptodora kindti							*Leptodiaptomus sp.*					C		*Tricocerca*				R		
Scapholeberis mucronata							*Unknown Cyclopod*													
Bosmina longirostris							*Unknown Calanoid*							**Arthropoda (Arthropods)**						
Diaphnosoma brachyurum							*Mesocyclops*	R						*Chaoborus punctipennis*						
Diaphanosoma birgei							*Diacyclops*				R			*Ostracoda*						R

Sites:	**1**	**2**	**3**	**4**	**5**	
Total Phytoplankton Genera	8	7	10	9	3	
Total Zooplankton Genera	11	8	8	8	7	
Sample Volume (mL)						

Rickonda sample is dominated by zooplankton

Phytoplankton Key: Bloom (B), Common (C), Present (P), and Rare (R)

Zooplankton Key: Dominant (D), Abundant (A), Present (P), and Rare (R); Herbivorous (H) or Carnivorous (C)

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Phytoplankton and Zooplankton Community Composition Analysis

Sampling Location: Ringwood Lakes | **Sampling Date: 7/8-9/20**

Site 1: Cupsaw Lake | **Site 2: Upper Erskine Lake** | **Site 3: Lower Erskine Lake** | **Site 4: Upper Skyline Lake** | **Site 5: Lower Skyline Lake** | **Site 6: Lake Rickonda**

Phytoplankton																				
Bacillariphyta (Diatoms)	**1**	**2**	**3**	**4**	**5**	**6**	**Chlorophyta (Green Algae)**	**1**	**2**	**3**	**4**	**5**	**6**	**Cyanophyta (Blue-Green Algae)**	**1**	**2**	**3**	**4**	**5**	6
Asterionella							*Actinastrum*							*Dolichospermum (formerly Anabaena)*		C	C	B	A	
Aulacoseira							*Ankistrodesmus*							*Aphanizomenon*	A	P	P	A	A	
Cocconeis							*Chlamydomonas*							*Aphanocapsa*					R	
Cyclotella							*Botryococcus*							*Chroococcus*						
Cymatopleura							*Chlorella*	C				P		*Cylindrospermum*						
Cymbella							*Coelastrum*	R				R		*Lyngbya*		C		R	R	
Eunotia							*Eudorina*	P	P	P	A	P		*Microcystis*	R		P	P	C	
Fragilaria	A	R	P	C	P	P	*Gloeocystis*							*Nostoc*						
Frustulia							*Gonium*				R			*Pseudoanabaena*						
Gyrosigma							*Koliella*							*Oscillatoria*			A			
Melosira	B	C	C	P	A	C	*Haematococcus*		P					*Coelosphaerium*	C	R	P	C	C	
Nedium							*Closterium*		R					*Spirulina*						
Stauroneis							*Micrasterias*													
Stephanodiscus							*Microspora*													
Surirella	R				R	R	*Ochromonas*													
Synedra	P	P				R	*Pandorina*		A	R				**Euglenophyta (Euglenoids)**						
Tabellaria	P		P				*Oocystis*							*Colacium*						
Pinnularia							*Scenedesmus*	R				R		*Euglena (Phacus sp)*		R		R		
Navicula		R				R	*Spirogya*							*Euglena sp*						
Mastogloia														*Trachelomonas*						
							Treubaria													
Chrysophyta (Golden Algae)							*Pediastrum*	A	R	C	P	C	P	**Pyrrhophyta (Dinoflagellates)**						
Dinobryon	C		C				*Volvex*							*Ceratium*	P	P	C	B	P	P
Uroglena			R				*Zygnema*							*Gymnodinium*		P				
Mallomonas							*Sphaerocystis*	C		P				*Cystodinium*						
							Ulothrix													
Synura							**Desmids (Green Algae)**							**Cryptomonads**						
							Hyalotheca							*Cryptomonas*	P		P			
							Staurastrum	P	A	P	P	R	R							
							Desmidium													
Unknown filaments							*Staurodesmus*													
Zooplankton																				
Cladocera (Water Fleas)	**1**	**2**	**3**	**4**	**5**	**6**	**Copecoda (Copepods)**	**1**	**2**	**3**	**4**	**5**	**6**	**Rotifera (Rotifers)**	**1**	**2**	**3**	**4**	**5**	6
Bosmina sp.	C		R	P	C		*Cyclops sp.*							*Keratella sp.*	C	C	C	P	C	R
Daphnia sp.		P	A	C		C	*Dipatomus (H)*	P	R	C	C	P	A	*Filinia*		R				P
Eubosmina sp.							*Nauplii*	C	P	A	P	P	C	*Asplanchna sp.*	P	A	P	P		
Chydorus		R			A		*Skistodiaptomus sp.*							*Polyarthra*	C	R		P	R	
Diaphanosoma					C		*Microcyclops sp*	C	C	A	R	C	P	*Brachionus*			R	A	P	A
Ceriodaphnia	R			R	R	C	*Limnocalanus macrurus*							*Conochilus*		C				
Leptodora kindti							*Leptodiaptomus sp.*							*Tricocerca*	C		P	R	R	
Scapholeberis mucronata							*Unknown Cyclopod*													
Bosmina longirostris							*Unknown Calanoid*							**Arthropoda (Arthropods)**						
							Mesocyclops							*Chaoborus punctipennis*				P	R	
							Diacyclops							*Ostracoda*				R		A

Sites:	**1**	**2**	**3**	**4**	**5**	**6**
Total Phytoplankton Genera	17	17	17	13	16	8
Total Zooplankton Genera	9	10	9	13	12	9
Sample Volume (mL)						

Phytoplankton Key: Bloom (B), Common (C), Present (P), and Rare (R)

Zooplankton Key: Dominant (D), Abundant (A), Present (P), and Rare (R); Herbivorous (H) or Carnivorous (C)

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Phytoplankton and Zooplankton Community Composition Analysis

Sampling Location: Ringwood Lakes — **Sampling Date: 10/14-15/20**

Site 1: Cupsaw Lake | **Site 2: Upper Erskine Lake** | **Site 3: Lower Erskine Lake** | **Site 4: Upper Skyline Lake** | **Site 5: Lower Skyline Lake** | **Site 6: Lake Rickonda**

Phytoplankton																				
Bacillariphyta (Diatoms)	**1**	**2**	**3**	**4**	**5**	**6**	**Chlorophyta (Green Algae)**	**1**	**2**	**3**	**4**	**5**	**6**	**Cyanophyta (Blue-Green Algae)**	**1**	**2**	**3**	**4**	**5**	**6**
Asterionella	P	P	P	P	A		*Actinastrum*							*Dolichospermum (formerly Anabaena*	P	P	C	P	P	
Aulacoseira							*Ankistrodesmus*							*Aphanizomenon*	C	C	C	P	A	
Cocconeis							*Chlamydomonas*		P	P			P	*Aphanocapsa*	C	P	P	P		
Cyclotella							*Botryococcus*							*Chroococcus*						
Cymatopleura							*Chlorella*			P				*Cylindrospermum*						
Cymbella							*Coelastrum*	C						*Lyngbya*						
Eunotia		R			P		*Eudorina*							*Microcystis*		P	C		P	R
Fragilaria	C	P	C	P	C		*Gloeocystis*		C	P		P	P	*Nostoc*						
Frustulia							*Gonium*							*Pseudoanabaena*						
Gyrosigma							*Koliella*	R						*Oscillatoria*						
Melosira	C	P	R	C	C	P	*Monoraphidium*							*Coelosphaerium*	P	P	P			
Nedium							*Mougeotia*	C	C	A		C	P	*Spirulina*						
Stauroneis							*Micrasterias*													
Stephanodiscus							*Microspora*													
Sururekka							*Ochromonas*													
Synedra							*Oedogonium*							**Euglenophyta (Euglenoids)**						
Tabellaria	A	C	C	C			*Oocystis*							*Colacium*						
Pinnularia							*Scenedesmus*							*Euglena (Phacus sp)*						
Navicula							*Spirogya*					P		*Euglena sp*				R		
Mastogloia							*Staurastrum*							*Trachelomonas*						
							Treubaria													
Chrysophyta (Golden Algae)							*Pediastrum*	A	C	P	C	C	P	**Pyrrhophyta (Dinoflagellates)**						
Dinobryon		C		C	C		*Volvex*							*Ceratium*	P	A	A		P	C
Chromulina							*Zygnema*							*Peridinium*				P		
Mallomonas							*Sphaerocystis*							*Cystodinium*						
							Ulothrix													
Synura							**Desmids (Green Algae)**							**Cryptomonads**						
							Hyalotheca							*Cryptomonas*						P
							Staurastrum	C	A	C	P									
							Desmidium													
Unknown filaments							*Staurodesmus*													
Zooplankton																				
Cladocera (Water Fleas)	**1**	**2**	**3**	**4**	**5**	**6**	**Copecoda (Copepods)**	**1**	**2**	**3**	**4**	**5**	**6**	**Rotifera (Rotifers)**	**1**	**2**	**3**	**4**	**5**	**6**
Bosmina sp.	A	R	P		P	P	*Cyclops sp.*	P	P	P				*Keratella sp.*	C	C	C	C	C	A
Daphnia sp.	P	C	C	P	P	P	*Dipatomus (H)*				P	P	C	*Kellicottia sp.*						
Eubosmina sp.							*Nauplii*	C	P	P	C		P	*Asplanchna sp.*	R		P	C	P	P
Chydorus	P		R				*Skistodiaptomus sp.*							*Polyarthra*	C	R	P	P	C	
Diaphniosoma	R						*Microcyclops sp*							*Hexarthra mira*						
Ceriodaphnia	P		R				*Limnocalanus macrurus*							*Conochilus*	C		R			P
Leptodora kindti							*Leptodiaptomus sp.*							*Tricocerca*						
Scapholeberis mucronata							*Unknown Cyclopod*													
Bosmina longirostris							*Unknown Calanoid*							**Arthropoda (Arthropods)**						
Diaphnosoma brachyurum							*Mesocyclops*							*Chaoborus punctipennis*						
Diaphanosoma birgei							*Diacyclops*							*Ostracoda*						

Sites:	1	2	3	4	5	6
Total Phytoplankton Genera	13	17	16	12	13	8
Total Zooplankton Genera	11	6	10	6	6	7
Sample Volume (mL)						

Phytoplankton Key: Bloom (B), Common (C), Present (P), and Rare (R)

Zooplankton Key: Dominant (D), Abundant (A), Present (P), and Rare (R); Herbivorous (H) or Carnivorous (C)

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Appendix VI: Baseline Watershed Monitoring Data

Sample Location	TN (mg/L)	TP (mg/L)	TSS (mg/L)
May 15, 2020			
CUPSAW LAKE			
Glen Brook	0.23	0.01	3
Cascade Brook	0.31	0.01	ND <2
Cupsaw Brook	0.27	ND <0.01	ND <2
UPPER ERSKINE			
North Inlet	0.24	ND <0.01	ND <2
East	0.24	ND <0.01	ND <2
LOWER ERSKINE			
Upper Erskine Outlet	0.38	0.01	2
LOWER SKYLINE			
Hidden Valley	0.58	0.02	3
Upper Skyline Outlet	0.94	0.01	4
UPPER SKYLINE			
Plaza	1.0	0.08	3
High Mt. Brook	1.2	0.021	ND <2
RICKONDA			
N/A			

Sample Location	TN (mg/L)	TP (mg/L)	TSS (mg/L)
August 26, 2020			
CUPSAW LAKE			
Glen Brook	0.53	0.07	5
Cascade Brook	0.64	0.05	ND <2
Cupsaw Brook	0.47	0.06	ND <2
UPPER ERSKINE			
North Inlet	**NO FLOW**		
East	2.7	0.08	ND <2
LOWER ERSKINE			
Upper Erskine Outlet	0.52	0.05	4
LOWER SKYLINE			
Upper Skyline Outlet	0.33	0.04	2
Hidden Valley	0.255	0.09	2
UPPER SKYLINE			
Plaza	0.47	0.10	ND <2
High Mt. Brook	3.9	0.07	ND <2
RICKONDA			
N/A			

Sample Location	TN (mg/L)	TP (mg/L)	TSS (mg/L)
December 16, 2020			
CUPSAW LAKE			
Glen Brook	0.24	0.01	4
Cascade Brook	0.43	ND <0.01	4
Shepherds Brook	0.24	ND <0.01	ND <2
UPPER ERSKINE			
North Inlet	1.3	ND <0.01	2
East	0.64	0.01	2
LOWER ERSKINE			
Upper Erskine Outlet	0.43	0.01	5
LOWER SKYLINE			
Hidden Valley	0.96	0.02	4
Upper Skyline Outlet	NO FLOW – Upper Skyline Lake In Lowered State		
UPPER SKYLINE			
Plaza	2.31	0.03	2
High Mt. Brook	2.31	ND <0.01	ND <2
RICKONDA			
N/A			

Appendix VII:
Stormwater Monitoring Data

Sample Location	TN (mg/L)	TP (mg/L)	TSS (mg/L)
April 13, 2020 (Total Precipitation = 1.33")			
CUPSAW LAKE			
Glen Brook	1.12	0.42	290
Cascade Brook	0.47	0.24	150
Cupsaw Brook	0.40	0.16	120
UPPER ERSKINE			
North Inlet	1.69	0.10	33
East Inlet	0.74	0.04	28
Beach	0.91	0.15	2
LOWER ERSKINE			
Southwest Pipe	0.56	0.10	21
North Pipe	1.93	0.06	29
Outlet from Upper	0.42	0.01	5
LOWER SKYLINE			
Hidden Valley Out	0.48	0.24	70
Mountain Glen Road	0.20	0.17	80
Beach	0.09	0.07	16
UPPER SKYLINE			
Plaza	0.83	0.69	220
Smoky Run	2.41	0.12	28
High Mt. Brook	1.96	0.29	210
RICONDA			
Willow Lane	1.65	0.21	270
South Drain	0.45	0.12	94

Sample Location	TN (mg/L)	TP (mg/L)	TSS (mg/L)
July 10, 2020 (Total Precipitation = 0.80")			
CUPSAW LAKE			
Glen Brook	1.03	0.21	54
Cascade Brook	0.76	0.22	52
Cupsaw Brook	0.70	0.13	26
UPPER ERSKINE			
North Inlet	1.22	0.42	17
East Inlet	1.18	0.22	110
Beach	0.66	0.27	29
LOWER ERSKINE			
Southwest Pipe	0.26	0.23	27
North Pipe	1.16	0.27	15
Outlet from Upper	2.43	0.12	15
LOWER SKYLINE			
Hidden Valley Out	0.72	0.14	53
Mountain Glen Road	1.52	0.46	30
Beach	1.48	0.32	80
UPPER SKYLINE			
Plaza	0.80	0.18	18
Smoky Run	1.76	0.18	10
High Mt. Brook	2.60	0.18	16
RICONDA			
Willow Lane	1.08	0.81	75
South Drain	0.44	0.13	430

Sample Location	TN (mg/L)	TP (mg/L)	TSS (mg/L)
October 12, 2020 (Total Precipitation = 0.38")			
CUPSAW LAKE			
Glen Brook	0.706	0.06	4
Cascade Brook	1.113	0.07	4
Cupsaw Brook	0.337	0.08	2
UPPER ERSKINE			
North Inlet	No Flow		
East Inlet	1.005	0.09	2
Beach	No Flow		
LOWER ERSKINE			
Southwest Pipe	No Flow		
North Pipe	2.308	0.45	ND <2
Outlet from Upper	0.163	0.04	2
LOWER SKYLINE			
Hidden Valley Out	0.526	0.20	3
Mountain Glen Road	No Flow		
Beach	No Flow		
UPPER SKYLINE			
Plaza	0.997	0.10	ND <2
Smoky Run	2.5	0.30	ND <2
High Mt. Brook	4.00	0.07	3
RICONDA			
Willow Lane	0.801	0.45	73
South Drain	0.243	0.23	ND <2