TIBBETTS POND RESTORATION AND MANAGEMENT PLAN

CITY OF YONKERS, WESTCHESTER COUNTY, NEW YORK

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1. INTRODUCTION

Tibbetts Pond, located in Tibbetts Brook Park, Westchester County, NY, consists of a larger lower basin and a smaller upper basin covering an area of approximately 14 acres, connected by a small stream. One of the first parks created in Westchester County, these waterbodies and the park proper are managed for recreational uses, such as fishing and hiking (https://parks.westchestergov.com/tibbetts-brook-park). It should be noted, however, that a portion of this lake's watershed was at one time also used as a refuse dump for the surrounding urban area. As of 2018, this lake and the portions of Tibbetts are not listed on the NYSDEC 303(d) list of impaired/TMDL waters due to a lack of data.

As with many waterbodies in the Lower Hudson River Drainage, the Lower Tibbetts Pond has experienced an infestation with the invasive floating plant water chestnut (*Trapa natans*) in recent years. This plant was observed to cover about 80% of the water surface at the peak of the growing season in 2020. Due to the impacts such severe infestations have on water quality, ecological health, visual aesthetics, and even human health, the Westchester Parks Foundation (WPF) has expressed a desire to develop an updated approach to managing Tibbetts Pond. Such management should be conducted in a scientific, pro-active manner and be based on the collection and assessment of consistent water quality and biological data.

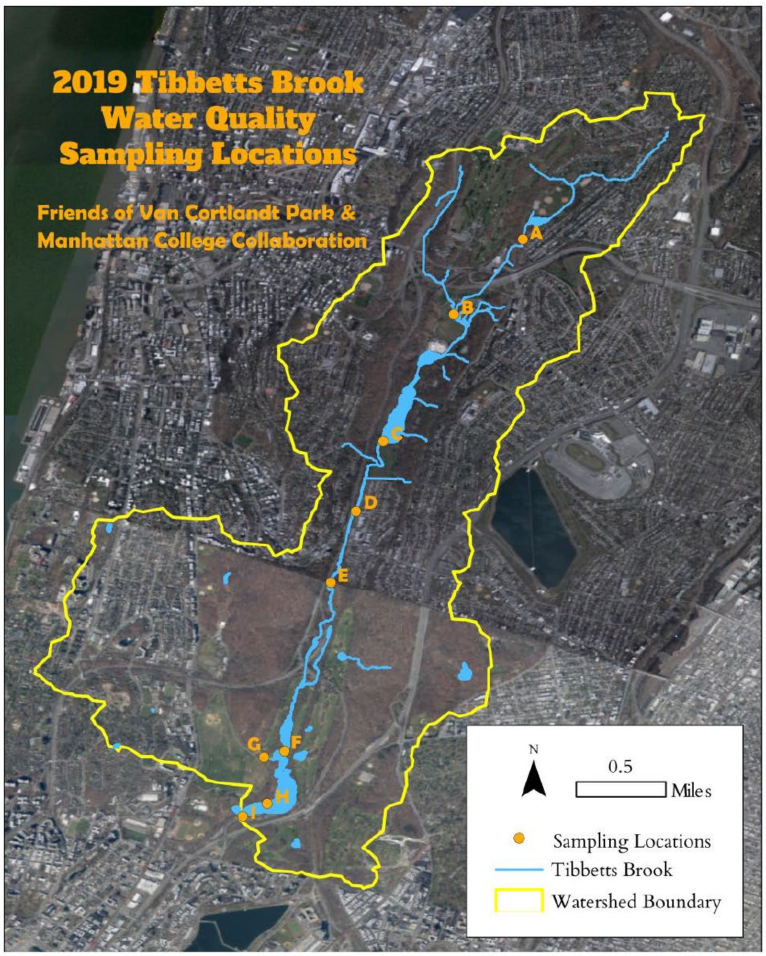
The balance of this Restoration and Management Plan details the results of Princeton Hydro's assessments of Tibbetts Pond and its watershed as they relate to impacts on the waterbodies' water quality, ecological condition, and current uses. Using this data, impairments to Tibbetts Pond's uses are identified, and recommendations for managing these impairments are provided. This is accomplished over the following 4 main sections:

- **Historical Data Review:** A summary of data from other studies within Tibbetts Pond and its watershed are provided. This allows for the potential establishment of already-known problem areas and allows Princeton Hydro and the Westchester Parks Foundation to make comparisons with data collected during this study.
- **Bathymetric Survey:** Water and bottom sediment depths are measured and mapped. In addition to the creation of bathymetric maps, this allows for the calculation of a waterbody's estimated water and sediment volumes, which are necessary for hydrologic and nutrient modeling and for establishing dredging plans.
- **Water Quality Assessment:** This section is broken down into the collection of water quality data in the field and the modeling of hydraulic and nutrient loads. Field events are conducted in order to better assess the present condition of Tibbetts Pond and to collected water quality data. In modeling efforts, the Watersheds of both basins are assessed for their hydrology and the amount of nutrients and sediment they yield to each waterbody. Loading of phosphorus from processes within the southern waterbody are also modeled. The results of both elements of this task are used to identify sources of nutrients and sediment from both the watershed and within the waterbodies in order to develop management implementations that may be used to reduce these pollutants.
- **Management Plan:** Based on the results of field sampling and hydrologic and nutrient modeling, Princeton Hydro has presented several management solutions, both watershed-based and within the waterbodies themselves that aim to reduce loads of nutrients and sediment, as well as aid in future on-going management of the waterbodies.

2. HISTORICAL DATA REVIEW

In 2019, the Van Cortlandt Park Alliance conducted a fourth annual round of water quality sampling events in multiple locations along Tibbetts Brook. One of the locations in this study was at the outflow from Tibbetts Pond, while two other locations were upstream within the park, near the confluence of the two main tributaries to the main stem of the creek. Yet another was located along the eastern branch north of the park at Rumsey Ave. and Summerfield Street in Yonkers. This study concluded that Tibbetts Brook Pond settles out and retains much of the phosphorus that is conveyed by the brook to that point. A site in the northern area in the park (Site B in Figure 1 below) was measured in this survey to yield high concentrations of phosphorus, ranging from approximately 0.5 mg/L to 2.0 mg/L, as compared to other sites which typically ranged from approximately 0.2 to 1.0 mg/L.

Monitoring Sites:



A - Rumsey Ave and Summerfield Str in Yonkers. Coordinates: 40.935520, -73.870311
B - Northern Tibbetts Brook Park, under walking bridge. Coordinates: 40.929499, -73.875819
C - Southern end of Tibbetts Brook Park Lake. Coordinates: 40.919334, -73.881494
D - Alan B. Shepard Jr. Place enterance to South County Trail. Coordinates: 40.913718, -73.883731
E - Border of Bronx and Yonkers. Coordinates: 40.907970, -73.885654
F - Van Cortlandt Park birding bridge. Coordinates: 40.894439, -73.889609
G - Tributary from West, under Parade Ground. Coordinates: 40.894105, -73.890947
H - Western side of Van Cortlandt Lake. Coordinates: 40.890283, -73.890768
I - Eastern side of Van Cortlandt Lake, by stormwater outfall. Coordinates: 40.889158, -73.892859

Figure 1. Sampling locations along Tibbetts Brook sampled during a study by friends of Van Cortlandt Park

3. BATHYMETRIC SURVEY

A bathymetric survey is the mapping of water depth and the volume of accumulated unconsolidated sediment (top of sediment to bottom of sediment) in a water body or water course. The data from this survey can be modeled to produce topographic contours of water depth and sediment thickness, and statistics such as mean depth and volume of water and sediment. The study areas for this project are both the Upper and Lower Basins.

3.1 METHODS

In order for this survey and subsequent plans and data analyses to be utilized for any future permitted activities, or to compare against future bathymetric surveys, all data must be registered in both a horizontal and vertical datum. All data was collected with a GPS unit, which recorded in the horizontal projection of the North American Datum of 1983 (NAD83), Stateplane New York East. In order to convert water and sediment depths measured from feet to proper elevations, the Water Surface Elevation (WSEL) of each pond needed to be calculated just before the surveys began. This was accomplished by setting benchmarks at each pond, adjacent to the shoreline. The elevations of each benchmark were calculated with a Leica GS14 survey grade GPS unit in the North American Vertical Datum of 1988 (NAVD88). The WSEL was calculated with using the benchmark, a site level and a Philadelphia rod. The Philadelphia rod was placed on top of the benchmark and read by the site level to calculate the elevation of the site level. Then the Philadelphia rod was held at the edge of the surface water where it was again read by the site level. Subtracting site level reading of the edge of water from the known elevation of the site level produced the WSEL in NAVD88 for each pond.

The survey was conducted on 4 November 2019 by Princeton Hydro personnel. A twelve -foot jon boat was used to access both ponds. Data was collected along pre-determined transects; the transects in the Lower Basin ran at one hundred- and fifty-foot intervals, while transects in the Upper Basin were spaced at fifty-foot intervals. Individual data collection points were taken along each transect at approximately every twenty to thirty feet. A calibrated survey rod was utilized to determine both water depth and depth to the bottom of unconsolidated sediment. The locations of each individual data collection point were recorded with a Lecia GS14 survey grade GPS unit. The calibrated survey rod was lowered into the water until it reached the top of the sediment. This water depth – in feet – was recorded on the GPS unit as an attribute. The survey rod was then pushed down into the sediment until the point of refusal. This bottom of unconsolidated sediment depth, again in feet, was also recorded on the GPS as an attribute.

Once all field work was collected, all collected data was downloaded from the GPS unit and imported into ESRI's ArcGIS Geographic Information System program. In GIS, the data collection points are not only displayed on screen, but a database with the water depth and bottom of sediment depths are stored is also available. The WSEL of each pond was assigned to the appropriate points, and the NAVD88 elevations of the top of sediment and bottom of sediment was calculated by simply subtracting the respective depths, in feet, from the WSEL.

After all depths were converted to NAVD88 elevations, Triangulated Irregular Network (TIN) 3D models were created for both the top of sediment and bottom of sediment elevations. These two models were then contrasted to produce a third TIN of sediment thickness, this time in feet, not in NAVD88 elevations. The TIN 3D models were also used to create contours for both top of sediment and sediment thickness producing the maps in Appendix I, as well as calculate survey statistics for each pond.

3.2 RESULTS

The morphological statistics resulting from the bathymetric survey are as follows:

Table 1. Lake and Watershed Characteristics for Tibbetts Pond		
Parameter	**Upper Basin**	**Lower Basin**
Waterbody Surface Area	2.6 Acres	11.1 Acres
Watershed Area	852.2 Acres	1,027.8 Acres
Mean Depth	1.4 Feet	2.9 Feet
Maximum Depth	3.0 Feet	6.0 Feet
Waterbody Volume	1.2 Million Gallons	10.3 Million Gallons
Sediment Volume	18,700 Cubic Yards	50,000 Cubic Yards
Mean Sediment Thickness	4.5 feet	2.8 feet
Annual Hydraulic Residence Time	0.95 Days	6.9 Days
Annual Flushing Rate	384.2 times a year	53.1 times a year
Watershed Area/Waterbody Surface Area Ratio	327.8	92.6

Both basins feature watersheds that are large relative to their surface area (Table 1). This creates an inherent impact on water quality, as high amounts of runoff will enter the waterbodies with each precipitation event, resulting in increased watershed-based loading of nutrients and sediment. Both basins are relatively shallow, with the southern basin's deepest point measuring only 6 feet deep near the dam on the southern end of the waterbody, and the Upper Basin measuring only 3 feet deep in the center of the waterbody, as well as near the dam in the southwest corner. Due to a combination of overall shallow depths and relatively small surface areas, both ponds are estimated to contain relatively low total volumes of water. This, in addition to the basins' relatively large watersheds, results in a very high flushing rate, with the lower basin's water capacity replacing itself about 53 times a year and the upper basin flushing 384 times a year, over once per day. This will be further discussed below in the hydrologic modeling subsection. The waterbodies have a high sediment volume, with the lower basin featuring a mean sediment thickness similar to its mean water depth, and the upper basin featuring a mean sediment thickness over three times its mean water depth. This suggests that the upper basin serves as a sedimentation basin, and probably allows a relatively large portion of sediment to settle from incoming flows before they continue to the lower basin. With such shallow depths and size, as well as a large quantity of bottom sediments, however, the waterbody may also serve as a source of sediment to the lower basin, particularly during large storm events that yield high incoming flows and resuspend bottom sediments. As will be discussed in the recommendations section, removal of some of this accumulated sediment may yield significant benefits to both basins.

4. WATER QUALITY ASSESSMENT

4.1 COLLECTION OF WATER QUALITY DATA

4.1.1. METHODS

In-lake water quality monitoring was conducted during six sampling events at Tibbetts Pond during the 2020 growing season. These events were conducted on 28 May, 30 June, 20 July, 5 August, 1 October and 26 October 2020. Overall, three stations were repeatedly sampled during each water quality event, including the Dam station, North Station and Upper Basin. Sampling locations are provided in Appendix II. Samples were collected at the Gazebo station during the first event, however, this station became obstructed by water chestnut causing a shift to the North station by June. A calibrated multi-probe water quality meter was used to monitor the *in-situ* parameters dissolved oxygen (DO), temperature, pH, and specific conductance during each sampling event. Data were recorded at 0.5 to 1.0 m increments from the water's surface through the lake sediments at each station during each sampling date. In addition, water clarity was measured at each sampling station with a Secchi disk. *In situ* water quality data is provided in Appendix III.

Discrete samples were collected from the surface and above the sediment at the Dam station using a Van Dorn sampling device during each sampling event. Discrete water samples were appropriately preserved, stored on ice, and transported to a NYSDEC ELAP certified lab (Upstate Freshwater Institute) for the analysis of the following parameters:

- Total suspended solids
- Total phosphorus-P
- Soluble reactive phosphorus-P
- Nitrate+nitrite-N
- Ammonia-N
- Chlorophyll *a*

All laboratory analyses were performed in accordance with *Standard Methods for the Examination of Water and Wastewater, 18th Edition* (American Public Health Association, 1992). Discrete water quality analysis results are provided in Appendix IV. During each sampling event, phytoplankton and zooplankton samples were collected utilizing a vertical plankton tow net to assess the community throughout the water column at the Dam station. The collected phytoplankton samples were the analyzed by Princeton Hydro for community composition. The results of each event's plankton assessment are provided in Appendix V.

4.1.2. OBSERVATIONS

During the 28 May sampling event, curly-leaf pondweed (*Potamogeton crispus*) was present throughout the southern portion of the waterbody, while water chestnut (*Trapa natans*) was present throughout many of the shallower areas. Also present along the shoreline is the invasive ornamental yellow flag iris (*Iris pseudacorus*). Filamentous algae (*Spirogyra*) was also observed on the lake bottom in the northern portion of the lower basin. By the 30 June event, approximately 75-80% of the waterbody's surface was covered with water chestnut (Figure 1), and the northern-most sampling point on the lower basin was moved approximately 100' south due to difficulty accessing the northern portion of the waterbody. Additionally, curly-leaf pondweed was still present throughout the waterbody, however these plants were senescing. Additionally, duckweed (*Lemna sp.* and *Spirodela sp.*) was observed throughout the waterbody between water chestnut rosettes and coontail (*Ceratophyllum demersum*) was observed in the mid-lake sampling location in the lower basin.

Figure 2. Water Chestnut Densities on 30 June 2020

By the July sampling, water chestnut still comprised approximately 50% of the surface area in the main basin, dominating the North station. Duckweed was present at both sampling stations, and some trace curly-leaf pondweed was noted at the North station. Water chestnut harvesting took place during the 5 August sampling, including both hand-pulling and mechanical harvesting. The bulk of this invasive was removed from the middle of the waterbody. By the final sampling event, water chestnut was not observed.

4.1.3. *IN-SITU* RESULTS

TEMPERATURE

Water temperature is an important attribute of a lake due to the fact that most chemical and biologic processes in aquatic ecosystems are driven by and are directly affected by increases or decreases in water temperature. In general, there is a greater amount of biological productivity and cumulative aquatic community respiration in warm versus cool or cold water. Due to the specific heat properties of water, lakes take time to warm up and time to cool down. Water therefore provides a relatively stable environment for aquatic life. Even though a lake's surface water temperature will change seasonally with air temperature, daily differences in water temperature tend to be gradual, increasing from winter through the summer.

Thermal stratification is a condition where the warmer surface waters (called the epilimnion) are separated from the cooler bottom waters (called the hypolimnion) through differences in density, and hence, temperature. Thermal stratification separates the bottom waters from the surface waters with a layer of water that displays a sharp decline in temperature with depth (called the metalimnion or thermocline). In turn, this separation of the water layers can have a substantial impact on the ecological processes of a lake (for details see below). Thermal stratification tends to be most pronounced in the deeper portions of a lake.

Strong and extensive amounts of thermal stratification can effectively "seal off" the bottom waters from the surface waters and overlying atmosphere, which can result in a depletion of dissolved oxygen (DO) in the bottom waters. With the exception of a few groups of bacteria, all aquatic organisms require measurable amounts of DO (> 1 mg/L) to exist. Thus, once the bottom waters of a lake are depleted of DO, a condition termed anoxia, that portion of the lake is not oxygenated.

Temperatures were generally well-mixed at the Dam station due to the shallowness of the basin (Figure 3). Thermal stratification was observed during the 20 July sampling event, declining from surface temperatures of 27.58°C to 23.73°C at 1 m. Weak thermal stratification was also observed during the 5 August event, dropping 1.41°C from surface to sediment. The remaining sampling events were thermally mixed. The North station also experienced thermal stratification during the July and August events despite the shallow depths noted at this station. Overall, extreme temperatures were not noted at any sampling stations during the 2020 sampling period.

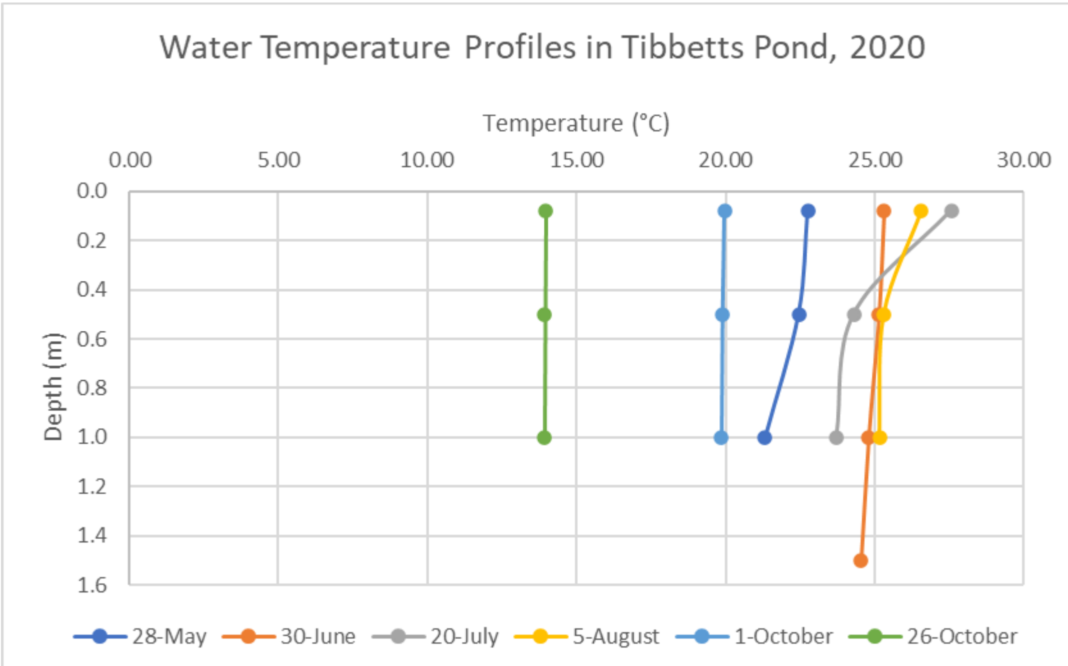


Figure 3. Water temperature profiles collected at the Dam sampling station in 2020.

DISSOLVED OXYGEN

Atmospheric oxygen enters water by diffusion from the atmosphere, facilitated by wind and wave action and as a by-product of photosynthesis. Adequate dissolved oxygen (DO) is necessary for acceptable water quality. Oxygen is a necessary element for most forms of life. As DO concentrations fall below 4.0 mg/L, aquatic life is put under stress. DO concentrations that remain below 1.0 – 2.0 mg/L for a few hours can result in large fish kills and loss of other aquatic life. Although some aquatic organisms require a minimum of 1.0 mg/L of DO to survive, DO concentrations greater than 4.0 mg/L are considered necessary for a healthy and diverse aquatic ecosystem.

In addition to a temporary loss of bottom habitat, anoxic conditions (DO < 1 mg/L) can produce chemical reactions that result in a release of dissolved phosphorus from the sediments and into the overlying waters. In turn, a storm event can transport this phosphorus to the upper waters and stimulate additional algal growth. This process is called internal loading. Given the temporary loss of bottom water habitat and the increase in the internal phosphorus load, anoxic conditions are generally considered undesirable in a lake.

Tibbetts Brook Pond and all portions of Tibbetts Brook are classified as a Class B waterbody (6 CRR-NY 890.6), meaning it is best used for recreation and fishing, and should be suitable for habitation by fish, shellfish, and other wildlife (6 CRR-NY 701.7). The New York Surface Water Quality Standards State that dissolved oxygen concentrations in Tibbetts Pond and other Class B waterbodies shall not less than 4.0 mg/L at any time (6 CRR-NY 703.3).

Surface DO was variable throughout the season at the Dam station, ranging from 3.78 mg/L to 14.19 mg/L (Figure 4). Seasonal maximum DO was noted during the 28 May sampling, with supersaturated (DO>100%) concentrations of 14.19 mg/L at the surface. DO declined slightly with depth, remaining well-oxygenated throughout the water column. By the 30 June sampling, DO declined through the water column, dropping below the 4.0 mg/L surface water quality standard at 1 m before declining to anoxic conditions above the sediment. Anoxia persisted in the bottom waters of this station during the 20 July sampling. By the August event, DO fell below the 4.0 mg/L standard throughout the water column, ranging from 2.35 mg/L to 3.78 mg/L. DO increased above this threshold during the remaining October sampling events.

DO in the surface waters of the North stations were also variable throughout the season, with measures between 2.17 mg/L and 7.00 mg/L. DO fell below the 4.0 mg/L threshold during June, July, and the deeper waters of August. Surface DO in the Upper Basin were relatively consistent throughout the season, ranging from 4.67 mg/L during the 20 July event to 6.90 mg/L during the 30 June event.

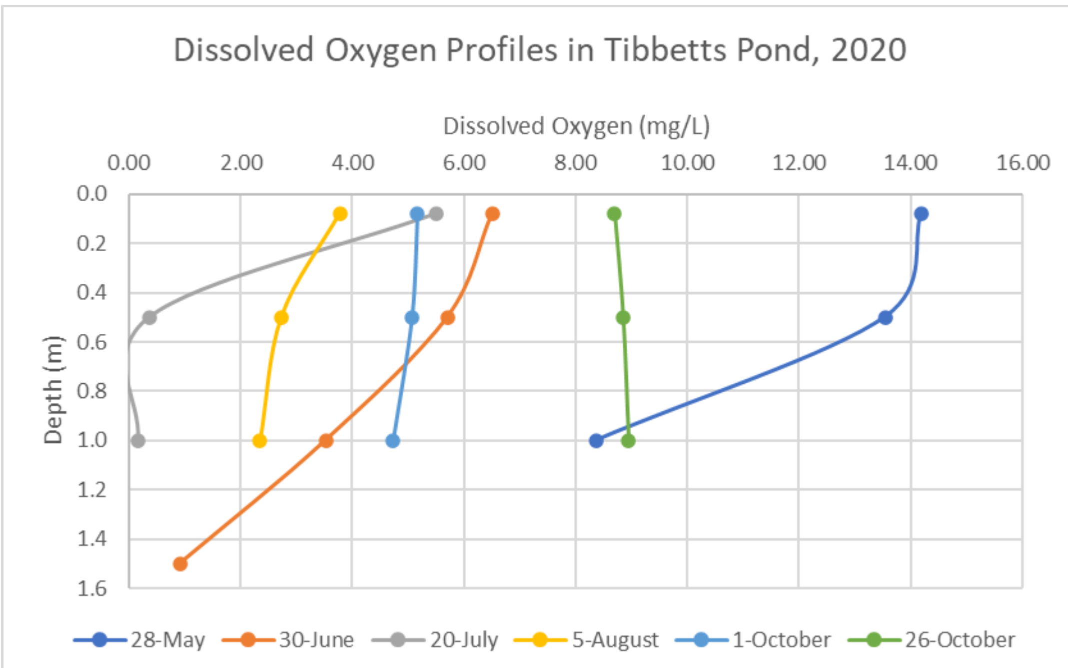


Figure 4. Dissolved oxygen profiles collected at the Dam sampling station in 2020

pH

pH is a measurement representing the negative base 10 log of the concentration of free hydrogen ions present in water. It is expressed on a logarithmic scale from 1 to 14. Each one-unit change in pH represents a ten-fold increase or decrease in hydrogen ion concentration. The pH of distilled water is 7, which is considered neutral. Water with a pH of 6 is ten times more acidic than distilled water, whereas water with a pH of 8 is ten times more alkaline than distilled water. Most water bodies in the northeast typically feature pH values between 6 and 9. The optimal pH for most aquatic organisms ranges between 6.5 and 8.5. This is also the range of acceptable pH for Class B waterbodies according to the New York Surface Water Quality Standards (6 CRR-NY 703.3). The amount of pH fluctuation that occurs in a lake temporally is determined in part by the waterbody's alkalinity. More alkaline, hard water lakes (having greater amounts of $CaCO_3$), are bettered buffered than low alkalinity, soft water lakes, and thus less prone to large temporal and spatial shifts in pH.

Storm water runoff, direct precipitation, wastewater and industrial discharges, along with groundwater intrusion can affect the pH of a lake. Chemical parameters that are significantly influenced by pH include phosphorus, ammonia, iron, and trace metals. The pH of a lake will also fluctuate as a result of photosynthesis, increasing as the amount of weed and algae growth increases. It is therefore not unusual to record high pH values in a lake experiencing an intense algae bloom or supporting dense aquatic weed growth. As a result of this link between higher pH and greater productivity, it is also not unusual to measure the highest pH reading in a lake later in the growing season when weed and algal communities reach their peak densities. Similarly, peak pH readings usually occur around mid-day when in-lake productivity peaks. Thus, pH is an important water quality indicator as it both affects and is affected by a lake's chemical and biological processes.

Elevated pH was observed during the first sampling event at the Dam station with surface measures of 9.00, declining slightly with depth to 8.09 at 1 m. Surface values during this event contravened the Water Quality Standard range of 6.5 to 8.5. The remaining sampling events yielded pH values within the optimal range, with surface measures between 6.71 and 7.94. The North and Upper Basin stations also remained within the optimal range throughout the 2020 season.

SPECIFIC CONDUCTIVITY

Conductivity is a measure of water's ability to conduct electric current and is a proxy of ions, typically salts and other inorganic substances, dissolved in lake water. While the majority of the dissolved solids measured in lake water are the result of natural processes, road salts, nutrients and/or sediment loads entering with storm water runoff can cause conductivity to spike. Similar to pH, a lake's conductivity can also be influenced by the amount of productivity and vice versa. As such, waterbodies with extremely low levels of productivity typically have conductivity values less than 0.1 mS/cm; while highly productive waterbodies usually have conductivity values greater than 0.5 mS/cm. The conductivity of most lakes in the northeast is typically in the 0.2 – 0.3 mS/cm range. All provided specific conductivity values are corrected for 25°C water temperature.

Specific conductance was variable throughout the season, with more elevated values noted during the spring, declining through the fall. Overall, surface conductivity at the Dam station ranged from minimum measure of 0.290 mS/cm during the 26 October event to maximum measures of 0.745 mS/cm during the 30 June event. Conductance was relatively consistent through the water column during each event. Conductivity at the North and Upper Basin stations were overall comparable to those observed at the Dam station.

WATER CLARITY (AS MEASURED WITH A SECCHI DISK)

Secchi depth is a standard measure of water clarity obtained by lowering a Secchi disk (a 9" diameter disk of contrasting black and white quadrants) through the water column. The average depth between which the disk is no longer visible and where it can once again be seen is considered the Secchi depth. This depth equates to approximately the point at which the incident sunlight is only about 10% of that measured at the surface, which equates to the depth at which photosynthesis becomes highly limited. As such, depths greater than the Secchi depth little algae, phytoplankton or SAV growth is expected to occur. Based on Princeton Hydro's in-house database of northern New Jersey/southern New York lakes, most lake users perceive a waterbody as having unacceptable clarity when the Secchi depth is less than 1 meter (3.3 feet).

Clarity fell below the 1 m threshold throughout the season at the Dam station, as brown and/or clouded conditions were observed during most sampling events. Overall, Secchi depths ranged from a minimum of 0.3 m during 1 October to a maximum of 0.9 m during the July event. Highest clarity was observed during the first half of the season. A productive phytoplankton community was noted throughout the majority of the season, contributing to the reduced clarity. Large rain events were also noted the day prior to the 5 August (1.30") and 1 October (1.46") sampling events (climod2.nrcc.cornell.edu: Palisades Park 0.2 WNW, NJ), resulting in increased turbidity and poorer clarity. Water clarity was consistently clear to the sediments at the North and Upper stations during each sampling event.

4.1.3. DISCRETE PARAMETERS

NITROGEN (NH3-N, NO3+NO2-N)

While phosphorus is considered the limiting nutrient for algal and plant growth, nitrogen is also very important with respect to defining primary productivity of lake ecosystems. Nitrogen generally occurs at higher concentrations in lake environments than phosphorus due to the high solubility of nitrate in water. Groundwater can be an important source of nitrogen loading to lakes, especially for lake communities that rely on septic systems.

Nitrate (NO3-N) is the most common form of nitrogen measured in lakes because other species of nitrogen tend to oxidize to nitrates and it is produced through microbial nitrification. Nitrogen may also be fixed from atmospheric nitrogen gas by various soil microbes and cyanobacteria. Other sources of nitrogen include atmospheric dryfall and wetfall, runoff enriched with fertilizers, and septic effluent. Nitrate concentrations of less than 0.3 mg/L are typically associated with low to moderately productive lakes, whereas concentrations exceeding 0.5 mg/L are characteristic of more productive lake ecosystems. We have found that concentrations of nitrate as low as 0.3 mg/L are associated with streams displaying evidence of eutrophication (algae buildup on rocks, excessive vegetation growth, etc.). Therefore, it does not take a lot of nitrate-N to stimulate or support algae and plant related problems. For comparative purposes, the USEPA drinking water quality standard for nitrate is 10.0 mg/L, however this is in regards to human health and is not reflective of ecological effects.

Surface water NH3-N concentrations above 0.05 mg/L tend to stimulate elevated rates of algal growth. Excessively high concentration of NH3-N in the deep (hypolimnetic) waters can often be attributed to the depletion of DO and the bacterial decomposition of the organic matter raining to the bottom from the surface waters. While these forms of nitrogen are important for algae growth, in most lakes, phosphorus is a more limiting factor and is what drives the majority of algae growth.

Nitrate-nitrite concentrations were very low during the first half of the season with non-detectable concentrations (ND<0.01 mg/L) measured in the surface waters. Deep water samples also yielded very low NO3-NO2 measures during these events. A slight increase to 0.04 mg/L in the surface and deep waters was observed during the August event, before spiking to seasonal maximums of 0.22 mg/L during the 1 October event. These NO3-NO2 concentrations persisted through the final event. Higher nitrogen concentrations observed during the 1 October event can be attributed to heavy rainfall the day prior causing an increase of stormwater inputs. Between the nitrate-nitrite and ammonia undergoing nitrification from the stormwater of that event and a very wet October, NO3-NO2 remained elevated during the final event. Overall, these measures were consistent from surface to sediment during each event. While NO3-NO2 concentrations were variable, each sampling event remained below the 0.3 mg/L nitrogen loading threshold and did not contravene the USEPA drinking water standard.

Similar to the other nutrients, ammonia concentrations were variable throughout the 2020 sampling period. Surface concentrations ultimately ranged from 0.04 mg/L during the June and July events to 0.27 mg/L during the 1 October event. Each sampling event, with exception to June and July, exceeded the recommended 0.05 mg/L threshold in the surface waters. Ammonia concentrations spiked during the 1 October event due to the rain event that occurred the day before sampling. Deep water concentrations were consistently lower than their surface counterparts, ranging from 0.02 mg/L to 0.21 mg/L.

PHOSPHORUS (TP, SRP)

Phosphorus has been identified as the primary limiting nutrient for most algae and macrophyte growth. Essentially, a small increase in the phosphorus load will result in a substantial increase in algal and aquatic plant growth. For example, one pound of phosphorus can generate as much as 1,100 lbs of wet algae biomass. TP concentrations as low as 0.03 mg/L can trigger nuisance algal blooms. The intensity and frequency of nuisance algal blooms typically increase once TP concentrations exceed 0.06 mg/L.

Two (2) forms of phosphorus were measured in the Lake; total phosphorus (TP), and soluble reactive phosphorus (SRP). Soluble reactive phosphorus represents the dissolved inorganic portion of total phosphorus metrics. This species of phosphorus is readily available for assimilation by all algal forms for growth and is therefore normally present in limited concentrations except in very eutrophic lakes. Princeton Hydro recommends concentrations of SRP not exceed 0.005 mg/L to prevent nuisance algal blooms.

TP concentrations were elevated throughout the growing season, at least doubling the Princeton Hydro recommended 0.03 mg/L threshold during each event (Figure 5). Lowest TP values were measured during the 28 May sampling event, with surface concentrations of 0.06 mg/L and 0.11 mg/L in the deep waters. Surface TP increased as the season progressed through August yielded TP concentrations of 0.15 mg/L. A slight decline was noted during the 1 October event before greatly spiking to maximum measures of 0.31 mg/L on 28 October. TP increased with depth during the majority of sampling events, with the largest deviation from surface concentrations in July. Deep water TP increased from 0.14 mg/L to 0.23 mg/L during this event, which can likely be attributed to thermal stratification causing increased internal loading.

SRP concentrations were more highly variable than TP, with surface concentrations ranging from 0.002 mg/L during the final sampling to 0.174 mg/L during the 1 October sampling. Deep water SRP was also elevated throughout the season, albeit less than their surface counterparts for most samplings. Excessive SRP observed during the 1 October event can be attributed to heavy rainfall the day before increasing stormwater inputs and increasing SRP in the surface waters. Only the final sampling event yielded SRP concentrations below the recommended 0.005 mg/L threshold. Overall, the nutrient data indicates Tibbetts Pond is a eutrophic or hypereutrophic waterbody.

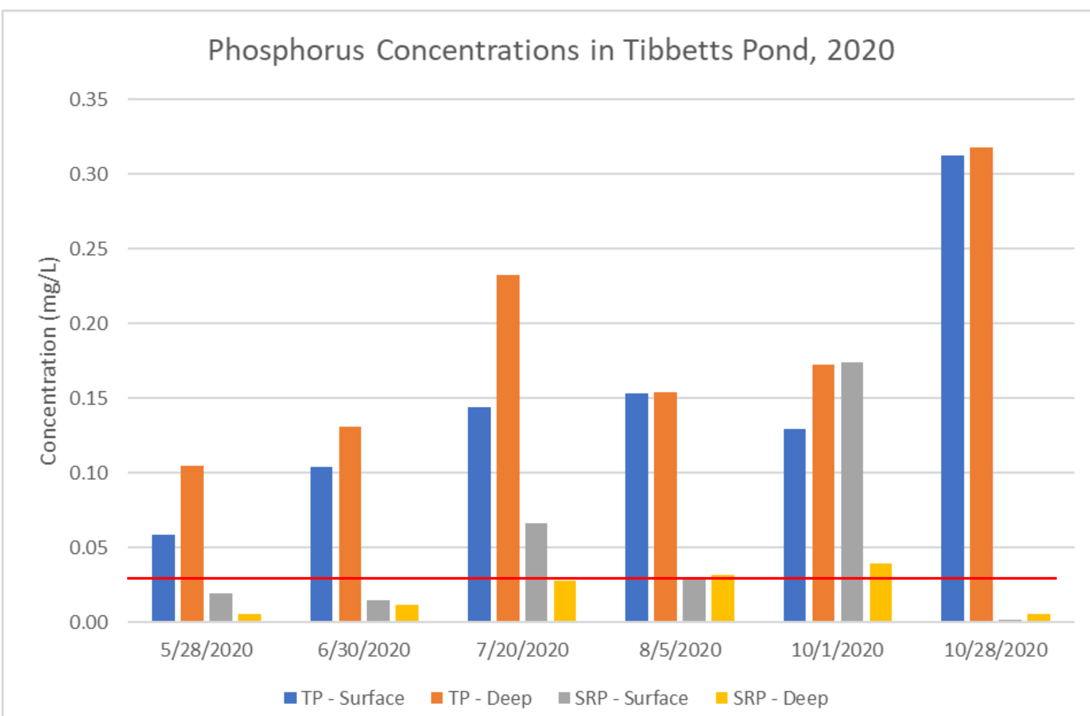


Figure 5. Total and soluble reactive phosphorus concentrations sampled at the surface of the Dam station in Tibbetts Pond over the course of the 2020 growing season. The red line represents Princeton Hydro's recommended management threshold of 0.03 mg/L for total phosphorus.

CHLOROPHYLL A

Chlorophyll a is the primary photosynthetic component of all algae and as such is often used as a proxy indicator of total algal biomass. Increases in chlorophyll a concentration are generally attributable to increases in total algal biomass and are highly correlated with increasing nutrient concentrations. As such, elevated chlorophyll a concentrations are a visible indicator of increased nutrient loading within a waterbody.

Chlorophyll a concentrations above 6 µg/L are generally associated with eutrophic conditions. Through analysis of many regional waterbodies Princeton Hydro has determined that concentrations above 20 µg/L are generally perceived as water quality issues by those who utilize the lake. Concentrations above this amount are generally attributed to excessive phosphorus loading and are therefore a visible sign of nutrient impairment.

Elevated chlorophyll a concentrations were observed throughout the 2020 season (Figure 6). Surface concentrations at the Dam ranged from 36.3 µg/L during the 1 October sampling to 78.7 µg/L during the 28 October event. A similar range was noted in the deep-water samples, ranging from 31.3 µg/L to 73.4 µg/L. The majority of sampling events were characterized by dense algal biomass, often dominated by green algae. Chlorophyll a measures contravened the recommended 20 µg/L threshold at the surface and deep during each sampling event. The large spike noted during the final event can be attributed to the excessive phosphorus concentrations observed during that event.

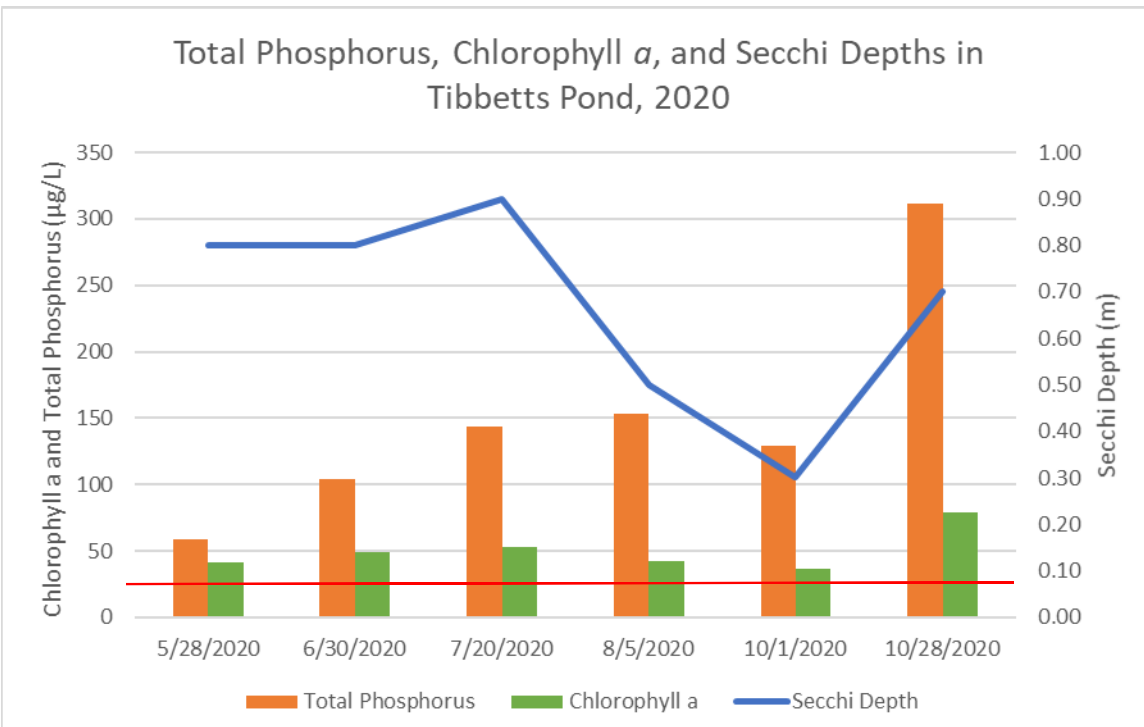


Figure 6. Total phosphorus and chlorophyll a concentrations and Secchi depths sampled at the surface of the Dam station in Tibbetts Pond over the course of the 2020 growing season. The red line represents Princeton Hydro's recommended management threshold of 20 µg/L for chlorophyll *a*.

TOTAL SUSPENDED SOLIDS

The concentration of suspended particles in a waterbody that will cause turbid or "muddy" conditions, total suspended solids is often a useful indicator of sediment erosion and stormwater inputs into a waterbody. Because suspended solids within the water column reduce light penetration through reflectance and absorbance of light waves and particles, suspended solids tend to reduce the active photic zone of a lake while contributing a "muddy" appearance at values over 25 mg/L. Total suspended solids measures include suspended inorganic sediment, algal particles, and zooplankton particles.

Surface TSS at the Dam station was overall low throughout the 2020 season, ranging from a minimum concentration of 6.8 mg/L during the 28 May event to a relatively elevated 17 mg/L during the 5 August event. TSS was highest during the August and 1 October event, which immediately followed large rain events. Deep water samples collected at this station had a wider range, with concentrations between 7.2 mg/L and 23 mg/L. TSS increased slightly compared to the surface during the majority of samplings, with exception to the August sampling. Overall, each sampling yielded TSS values below the recommended 25 mg/L threshold.

4.1.4. BIOLOGICAL PARAMETERS

PHYTOPLANKTON

Phytoplankton are algae that are freely floating in the open waters of a lake or pond. These algae are vital to supporting a healthy ecosystem since they are the base of the aquatic food web. However, high densities of phytoplankton can produce nuisance conditions. The majority of nuisance algal blooms in freshwater ecosystems are the result of cyanobacteria, also known as blue-green algae. Some of the more common water quality problems created by blue-green algae include bright green surface scums, taste and odor problems and the generation of cyanotoxins.

Overall low densities of phytoplankton were observed during the 28 May sampling event, with five identified genera all listed as present or rare. This community was made up of primarily diatoms and low densities of the green algae *Pediastrum*. A more diverse community assemblage was observed during the 30 June event, with eleven identified genera represented by diatoms, chrysophytes, green algae and dinoflagellates. Co-dominance was exerted by the diatom *Melosira* chrysophyte *Dinobryon* and green algae *Golenkinia* during this event. By the July sampling event, green algae dominated the community, making up ten of the twelve identified genera. The single cell green algae *Chlorella* dominated the community with moderate densities of a variety of other green algae. The diatom *Fragilaria* and dinoflagellate *Ceratium* were also identified at this time. Peak seasonal richness was observed during the 5 August sampling, with eighteen identified genera, represented by diatoms, chrysophytes, green algae, cryptomonads, cyanobacteria and euglenoids. Co-dominance was exerted by *Dinobryon*, *Actinastrum* and *Euglena* during this event. Four genera of cyanobacteria were identified during this sampling in low to moderate densities, including *Dolichospermum* (formerly *Anabaena*), *Coelosphaerium*, *Microcystis* and *Oscillatoria*. Many of these genera are known for producing cyanotoxins, such as microcystin, cylindrospermopsin and anatoxins. Densities declined overall by the 1 October event with representations from diatoms, green algae and euglenoids. Moderate densities of the green algae *Chlamydomonas* and *Scenedesmus* were observed while the remaining eight genera were identified as present. The final sampling event was characterized by eleven identified genera, comprised of diatoms, green algae, and cyanobacteria. Moderate densities of *Melosira* and *Chlorella* were noted, while the remaining genera were listed as present. *Dolichospermum* was identified if low densities during this event.

ZOOPLANKTON

A lake's zooplankton community is an important element of the waterbody's overall food web. These microscopic organisms graze on phytoplankton. This can help keep certain phytoplankton densities in check. Zooplankton are in turn grazed upon by other aquatic organisms, in particular both juvenile and adult fish. Of particular significance are the large-bodied, herbivorous taxa, such as the cladoceran *Daphnia* and the copepod *Diaptomus*. These taxa feed heavily on many phytoplankton genera (cyanobacteria being a notable exception). In addition, many of these large-bodied zooplankton are also herbivorous (i.e. algae eating) and can function as a natural means of controlling excessive algal biomass.

The May zooplankton assemblage consisted of a mixture of cladocerans, copepods, rotifers and arthropods, with six identified genera. Moderate densities of the rotifer *Brachionus* and copepods *Microcyclops* and nauplii were noted during this event. Copepods and rotifers dominated the June sampling, with co-dominance exerted once again by *Brachionus* and copepod nauplii. Species richness declined to seasonal lows during the July sampling with four identified genera. This event was dominated by copepod nauplii and moderate densities of other copepods and rotifers. Peak seasonal richness was observed during the 5 August event, reestablishing a mixture of cladocerans, copepods and rotifers. *Microcyclops* and *Filinia* dominated the community at this time, accompanied by relatively low densities of the remaining ten genera. A decline to four genera was again observed during the 1 October event. Low to moderate densities of cladocerans, copepods and rotifers were noted during this event. By the final event, five genera of rotifers made up the community. Dominance was once again exerted by *Brachionus* with moderate densities of *Polyarthra* also noted. The community assemblage throughout the season was typically made up of smaller bodied zooplankton, often dominated by rotifers. Genera such as *Daphnia* and *Diaptomus* were consistently absent.

4.2 HYDROLOGIC AND POLLUTANT LOADING ANALYSIS

4.2.1. WATERSHED DESCRIPTION AND LAND-USE

A watershed is the total area that drains to a point, in this case into a waterbody. The size of a watershed relative to the waterbody and land-use types within in can have a large bearing on water quality, as this determines the types and amount of allochthonous (external) material that enter the waterbody. Waterbodies that have large watersheds relative to their size typically receive a large external load of nutrients and sediment. Several qualities of a watershed can either further exacerbate the loads of nutrients or sediments entering a waterbody or lessen them; large amounts of residential or urban land-use contain large amounts of impervious land-cover, which can increase runoff and, therefore, concentrations of nutrients or sediments flowing downstream. While agricultural land does not contain significant amounts of impervious land-cover, it is often associated with large loads of nutrients and sediment. Conversely, wetlands can serve to remove some of the nutrients or sediments moving through them. Many drinking water reservoirs will try to maintain a watershed that is largely or entirely forested in order to minimize the amount of nutrients and sediment entering the waterbody. By breaking down a full watershed into subwatersheds and assessing them individually, problematic areas of the full watershed can be identified and targeted for restoration efforts.

METHODS

Full watersheds for the upper and lower basin were delineated from digital elevation models using Esri ArcMap's watershed tools. Subwatersheds were edited from the resulting shapefiles using ArcMap and QGIS. A map displaying the full extent of the total watershed and each subwatershed is provided in Appendix VI. Watershed and subwatershed shapefiles were entered into the Stroud Water Research Center's Model My Watershed tool. Resulting .gms files were entered into the Generalized Watershed Loading Functions-Enhanced (GWLF-E) model, which produced acreages and percentages of each land-use type for each watershed or subwatershed.

RESULTS

The full watershed for the lower basin consists of a 1,027.8-acre area dominated by low-density open space, with a large percentage also consisting of low- and medium-density mixed residences (Table 2). The watershed for the upper basin consists of an 852.2-acre area, also largely urbanized (Table 3). As described above, both basins are relatively small compared to their watersheds, and, as a result, are more likely to receive a larger amount of external nutrients and sediment. Additionally, because both watersheds contain high percentages of urban land-use, they both contain higher amounts of impervious land-cover, such as pavement or concrete, than other land-use types. This causes a reduction of infiltration of precipitation into groundwater and an increase in runoff rate and volume, which in turn is able to move more materials downstream and cause increased erosion to streambanks.

Table 2: Land-use acreage within Lower Tibbetts Pond's full and subwatersheds

Source	Full Lower-basin Watershed	Lower-East	Lower-West	Upper
	Area (Acres)			
Open Water	0.0	0.0	0.0	0.0
Hay/Pasture	0	0	0	0
Cropland	0	0	0	0
Forest	144.8	30.6	26.4	87.2
Wetland	3	0	2	1
Open Land	0	0.0	0.0	0.0
Barren Land	0	0.0	0.0	0.0
Low-Density Mixed	246.9	30.4	11.6	204.9
Medium-Density Mixed	221.4	22	4	195.7
High-Density Mixed	47.7	4	0	43.7
Low-Density Open Space	364	25	22.5	316.8
Total	**1027.8**	**112.0**	**66.5**	**849.3**
Source	**Full Lower-Basin Watershed**	**Lower-East**	**Lower-West**	**Upper**
	Area (%)			
Open Water	0.0	0.0	0.0	0.0
Hay/Pasture	0.0	0.0	0.0	0.0
Cropland	0.0	0.0	0.0	0.0
Forest	14.1	27.3	39.7	10.3
Wetland	0.3	0.0	3.0	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	24.0	27.1	17.4	24.1
Medium-Density Mixed	21.5	19.6	6.0	23.0
High-Density Mixed	4.6	3.6	0.0	5.1
Low-Density Open Space	35.4	22.3	33.8	37.3

Table 3: Land-use acreage within the Upper Tibbetts Pond's full and subwatersheds				
Source	**Full Watershed**	**Upper-East**	**Upper-West**	**Far North**
	Area (Acres)			
Open Water	0.0	0.0	0.0	0.0
Hay/Pasture	0	0	0	0
Cropland	0	0	0	0
Forest	87.2	15.6	19.5	52.1
Wetland	0	0	0	0
Open Land	0	0.0	0	0.0
Barren Land	0	0.0	0.0	0.0
Low-Density Mixed	206.3	38.5	38.5	129.2
Medium-Density Mixed	196.7	47.2	31.4	118.1
High-Density Mixed	43.5	13.6	7.4	22.5
Low-Density Open Space	318.5	36.1	65.5	216.7
Total	852.2	151.0	162.3	538.6
Source	**Full Watershed**	**Upper-East**	**Upper-West**	**Far North**
	Area (%)			
Open Water	0.0	0.0	0.0	0.0
Hay/Pasture	0.0	0.0	0.0	0.0
Cropland	0.0	0.0	0.0	0.0
Forest	10.2	10.3	12.0	9.7
Wetland	0.0	0.0	0.0	0.0
Open Land	0.0	0.0	0.0	0.0
Barren Land	0.0	0.0	0.0	0.0
Low-Density Mixed	24.2	25.5	23.7	24.0
Medium-Density Mixed	23.1	31.3	19.3	21.9
High-Density Mixed	5.1	9.0	4.6	4.2
Low-Density Open Space	37.4	23.9	40.4	40.2

4.2.2. HYDROLOGIC ANALYSIS

A watershed's size and land-use consistency, as well as weather patterns in the region, determine the amount of water that enters the waterbody, as well as the timing at which it enters. Certain land-use types such as forested areas allow water to infiltrate into groundwater, thus reducing runoff and erosion and, as a result, nutrient and sediment loads. By assessing the annual hydraulic load, or the amount of water that enters a waterbody from its watershed and from direct precipitation each year, the flushing rate and retention time of a waterbody can be determined.

METHODS

Modeled data for a 30-year weather database for each full and subwatershed was obtained using the Stroud Water Research Center's Model My Watershed tool. Resulting .gms files were entered into the Generalized Watershed Loading Functions-Enhanced (GWLF-E) model, which produced average monthly hydrological and nutrient loading data. The resulting hydrologic data produced by the GWLF-E model was assessed to determine the total estimated streamflow entering each waterbody, as well as the gains and losses directly to each waterbody as an effect of direct precipitation and evapotranspiration, resulting in the total estimated annual net hydrologic load for each waterbody. The total annual hydrologic load was subsequently used in conjunction with the estimated volume of water in each basin to calculate hydraulic flushing rate and retention time.

RESULTS

Both the upper and lower basins' watersheds feature similar rates of runoff throughout the year, however the Upper-east subwatershed in the Upper Basin's watershed features an estimated runoff about 1/4-1/2 cm greater than the other subwatersheds in this watershed, while the Lower-west watershed features an estimated runoff of about ¼-1/2 cm lower than those of the other subwatersheds in the south watershed (Figures 8, 10). When direct precipitation and evapotranspiration to the waterbodies are accounted for, the Lower Basin is estimated to receive a yearly hydrologic load of 2,071,400 m³ or 547.2 million gallons, while the Upper Basin is estimated to receive approximately 1,706,217 m³ or 450.7 million gallons.

Table 4. Total Hydrology in the Lower Tibbetts Pond watershed

Month	Precipitation	Evapotranspiration	Groundwater	Runoff	Streamflow	
	cm	cm	cm	cm	cm	cfs
Jan	8.75	0.77	4.11	2.47	6.58	3.6
Feb	8.04	1.07	4.68	2.31	6.98	3.8
Mar	10.16	3.08	5.86	2.4	8.26	4.5
Apr	10.35	6	5.47	1.23	6.7	3.7
May	10.98	10.78	3.56	0.76	4.33	2.4
Jun	8.76	12.3	1.61	0.58	2.19	1.2
Jul	11.24	10.48	0.53	1.16	1.69	0.9
Aug	10.24	9.37	0.16	1.04	1.2	0.7
Sep	9.66	6.28	0.24	1.18	1.42	0.8
Oct	8.4	4.81	0.41	1.01	1.42	0.8
Nov	10.44	2.72	1.14	2.1	3.23	1.8
Dec	9.34	1.39	3.23	2.05	5.28	2.9
Total	116.4	69.1	31.0	18.3	49.3	2.3

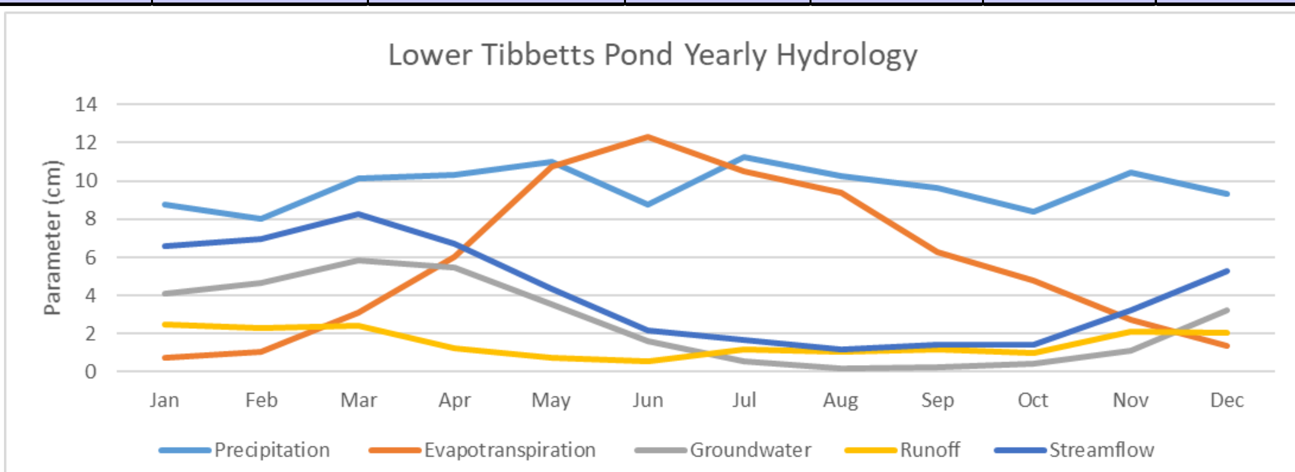


Figure 7. Estimated hydrologic parameters over the course of an average year for the Lower Tibbetts Pond Watershed

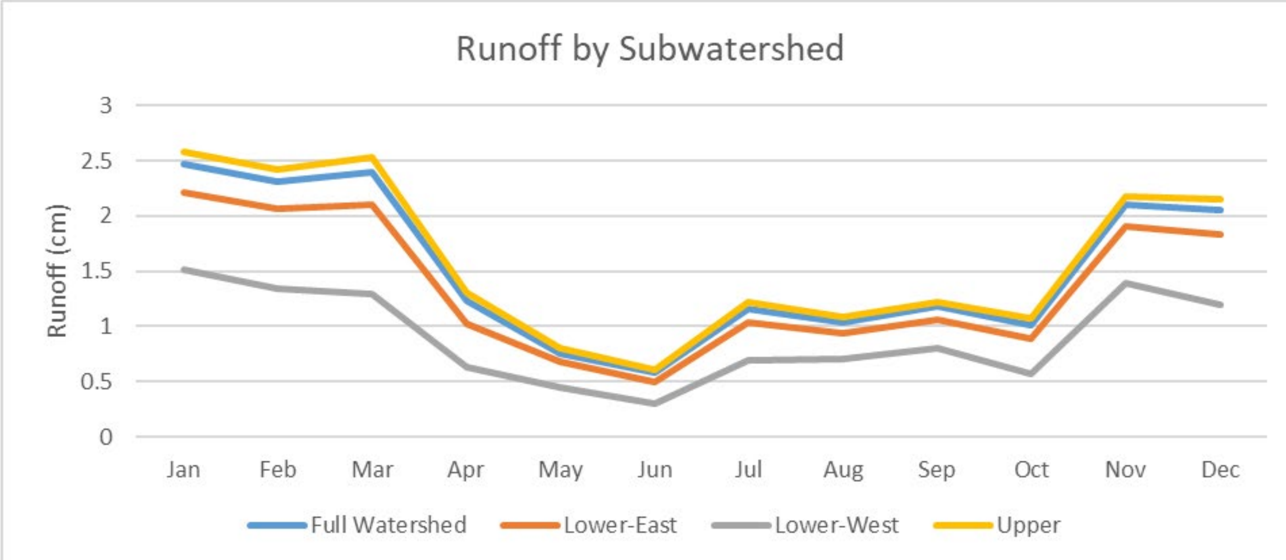


Figure 8. Estimated runoff over the course of an average year for the subwatersheds of Lower Tibbetts Pond

Table 5. Total Hydrology in the Upper Tibbetts Pond Watershed						
Month	**Precipitation**	**Evapotranspiration**	**Groundwater**	**Runoff**	**Streamflow**	
	cm	**cm**	**cm**	**cm**	**cm**	**cfs**
Jan	8.75	0.78	4	2.58	6.58	3.0
Feb	8.04	1.09	4.57	2.42	6.99	3.5
Mar	10.16	3.13	5.73	2.53	8.27	3.8
Apr	10.35	6.06	5.36	1.31	6.67	3.1
May	10.98	10.86	3.48	0.8	4.28	1.9
Jun	8.76	12.3	1.56	0.61	2.17	1.0
Jul	11.24	10.44	0.51	1.22	1.73	0.8
Aug	10.24	9.31	0.15	1.08	1.23	0.6
Sep	9.66	6.27	0.23	1.22	1.45	0.7
Oct	8.4	4.85	0.38	1.07	1.45	0.7
Nov	10.44	2.74	1.07	2.18	3.25	1.5
Dec	9.34	1.41	3.12	2.15	5.27	2.4
Total	116.4	69.2	30.2	19.2	49.3	1.9

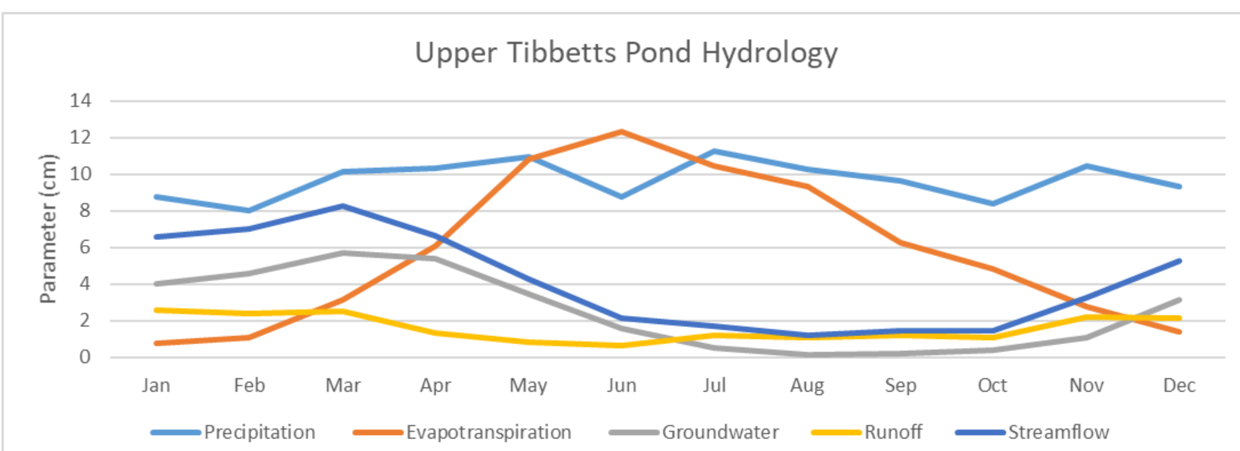


Figure 9. Estimated hydrologic parameters over the course of an average year for the Upper Tibbetts Pond Watershed

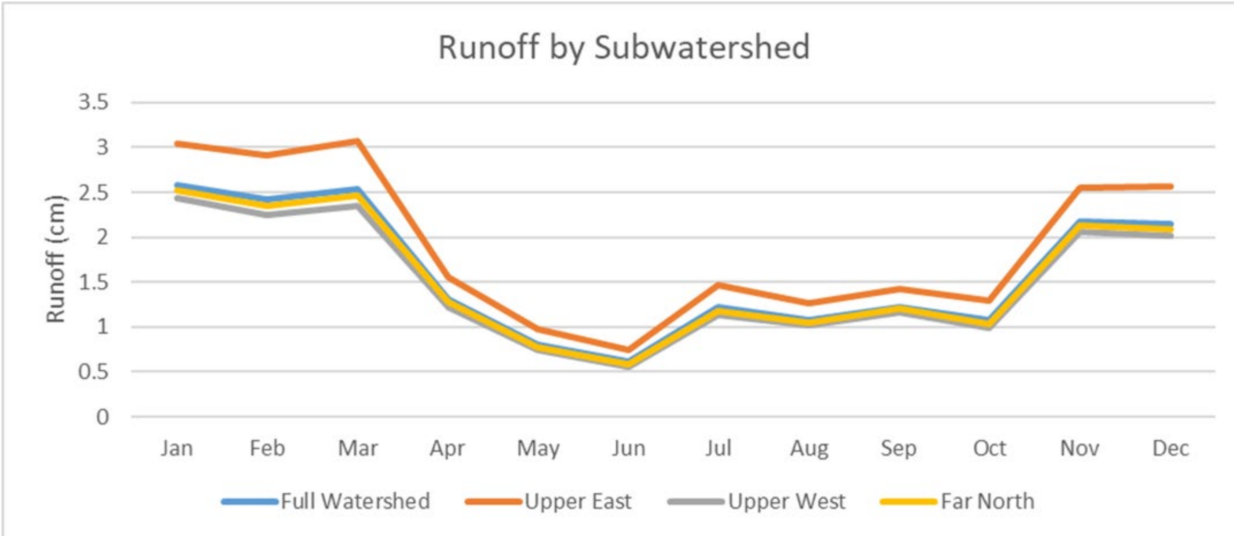


Figure 10. Estimated runoff over the course of an average year for the subwatersheds of Upper Tibbetts Pond

Waterflow entering the Lower Basin is, on average, highest during the month of March, while the lowest flows typically occur in August. The estimated annualized flushing rate tracks discharge into the waterbody, with the lowest flushing rate typically occurring in August, when the least amount of flow enters the water body. The annualized retention period is the inverse of the flushing rate, reflecting the number of days it takes a waterbody to flush completely. The retention period for the Lower Basin is estimated to be the highest during August (Figure 11). During this time of year, reduced flushing rates in lakes in this region typically result in increased problems with harmful algae blooms, as the stagnant conditions promote warmer water and a greater retention of phosphorus. Overall, the lower basin flushes approximately 53.1 times a year and has a hydraulic residence time of approximately 6.9 days. Upper Tibbetts Pond follows a similar trend, however estimated flushing rates are overall higher and retention periods are overall lower, due to the waterbody's relatively low volume (Figure 12). Overall, this basin flushes approximately 384.2 times a year and has an estimated hydraulic residence time of slightly less than a day. This is much higher than many other deeper waterbodies that may flush once a year, and is likely due to both basins' relatively shallow depths and large watersheds.

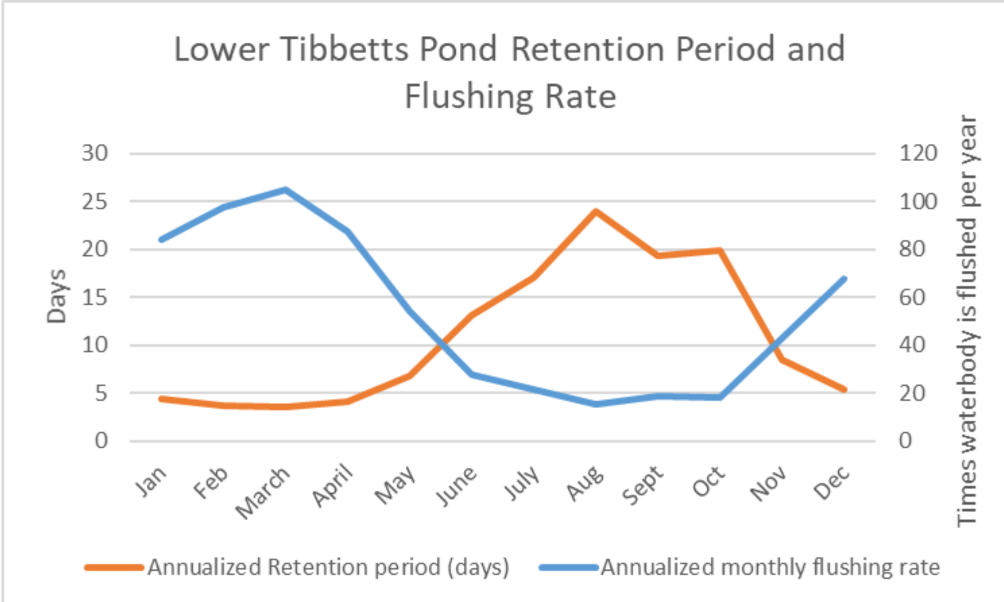


Figure 11. Variations in annualized retention period and flushing rate in Lower Tibbetts Pond over the course of an average year.

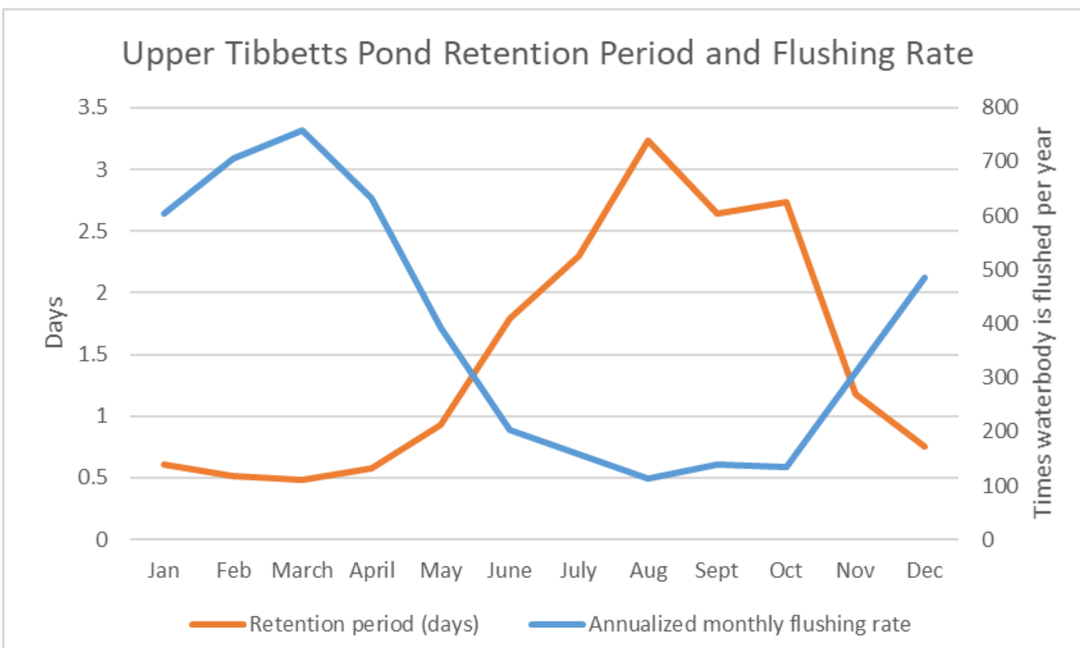


Figure 12. Variations in annualized retention period and flushing rate in Upper Tibbetts Pond over the course of an average year.

4.2.3. COMPUTATION OF SUB-WATERSHED SPECIFIC SEDIMENT, PHOSPHORUS, AND NITROGEN LOADS

The nutrients phosphorus and nitrogen are some of the basic building-blocks for life. When dissolved in water in certain bioavailable forms, these nutrients can result in growth of algae and cyanobacteria. These drive the trophic state of the ecosystem in lakes, and large increases in these nutrients can result in increases in algae and cyanobacteria populations. Sediment, mainly small particles of silt, clay, and organic matter, can reduce water clarity when suspended in the water column. Once water flows slow, such as when a stream enters a lake, sediment will usually settle or "drop out" of the water column and accumulate on the lake bottom. Over a long period of time (usually several years), this sediment will build up on the lake bottom. Speaking in terms of very long periods of time (usually over the course of decades in smaller waterbodies and centuries in bigger ones), virtually all lakes and ponds in the northeast will naturally gradually become shallower as they "fill in" with sediment and organic matter. This process can be slowed very slightly, however, by careful management of the amount of sediment entering a waterbody from a watershed, as well as by removing accumulated sediment through dredging.

As mentioned above, the land-use, size, and hydrology of a watershed largely determine the amount of nutrients and sediment that enter a waterbody from its watershed. Modeling techniques can be utilized to obtain an estimate of the amount of these pollutants that enter a waterbody each year from its watershed based on land-use and hydrology. By assessing subsections of the watershed (subwatersheds) separately, areas yielding the largest amounts of nutrients and sediment can be identified, and watershed-based management implementations can be designed and prioritized for the greatest sources.

In addition to loading from the watershed, nutrients, particularly phosphorus, can also re-enter the water column from lake sediments through a variety of processes; this is referred to at large as internal loading. One of the largest processes determining the internal load of phosphorus in waterbodies in the northeast is anoxic loading. As the water in the hypolimnion becomes anoxic, redox reactions occur that allow phosphorus normally bound to elements in the bottom sediments to dissolve into the water above these sediments at a greatly increased rate. As the area of the lake bottom at which bottom anoxia in a lake increases, the total load of phosphorus entering the water column increases and can result in large algae and cyanobacteria blooms when mixed to the top of the water column. Additionally, phosphorus bound in bottom sediments can reenter the water column when the sediment is resuspended or "stirred up". Some animals can cause this when feeding in a process called bioturbation; in particular the invasive fish common carp (*Cyprinus carpio*) can add significant amounts of phosphorus back to the water column as a result of their bottom-feeding habits and their tendency to form large populations.

METHODS

The GWLF-E tool used to generate average hydrology data was also used to produce estimated nutrient loads for each watershed. The contribution of each source of nutrients within the watershed (e.g. runoff from different landuse types, groundwater, etc.) was also modeled.

Internal loading of phosphorus in each basin was calculated using a metric that utilizes a loading coefficient of 6 mg TP/m^2/day for loading of phosphorus into the water column from sediments under anoxic conditions, whereas minor loading under oxic conditions during the growing season (May-September, 153 days) is represented by a loading coefficient of 0.6 mg TP/m^2/day. The number of days the waterbodies were estimated to experience bottom anoxia, as well as the area of each waterbody at which anoxic conditions were estimated to occur, were determined based on dissolved oxygen data collected in the field during water quality sampling events and by the results of the bathymetric survey.

During field events, Princeton Hydro staff observed a population of common carp and goldfish (*Carassius auratus*) to be present in the lower basin. These fish can cause additional loading of phosphorus into the water column when feeding via bioturbation. As no recent fisheries surveys have been conducted on the lower basin, Princeton Hydro estimated for a loading rate of 5 mg TP/m²/Day based on a loading study conducted by Lamarra (1975).

RESULTS

Watershed-based phosphorus is estimated to runoff into the lower basin largely from urbanized land-use types, particularly medium-density mixed housing (Table 6). Notable loads also originate from stream bank erosion and groundwater. These are likely largely products of the relatively high amount of impervious cover within the watershed. Because of lower infiltration of incoming rainwater into the ground, flashier, higher-volume runoff occurs at lower amounts of rain and allows for materials to be moved by flows more easily. This also allows for faster erosion of streambanks. The Lower-east subwatershed is estimated to yield a larger load than the lower-west watershed, most likely due to a higher amount of medium-density mixed housing (Table 7). The Upper Pond was estimated to receive watershed-based phosphorus from similar sources, with large concentrations originating in urbanized areas, groundwater, and streambank erosion (Table 8). The far-north subwatershed was estimated to produce the largest yearly load of phosphorus, although all three of the upper basin's subwatersheds yielded a notable phosphorus load from urbanized areas (Table 9).

Table 6. Annual Watershed-based Phosphorus Loads for Lower Tibbetts Pond

Category	Description	Total Phosphorus	
		kg	%
Runoff	Hay/Pasture	0.00	0.0
	Cropland	0.00	0.0
	Forest	0.43	0.8
	Wetland	0.03	0.1
	Open Land	0.00	0.0
	Barren Land	0.00	0.0
	Low-Density Mixed	3.21	6.1
	Medium-Density Mixed	10.91	20.6
	High-Density Mixed	2.35	4.4
	Low-Density Open Space	4.74	9.0
Other Sources	Farm Animals	0.00	0.0
	Stream Bank	11.00	20.8
	Groundwater	20.20	38.2
	Septic Systems	0.00	0.0
Total		**52.9**	**100.0**

Table 7. Annual External Phosphorus Loads entering Lower Tibbetts Pond by Subwatershed					
Category	**Description**	**Full Watershed**	**Lower-east**	**Lower-west**	**Upper**
		kg	**kg**	**kg**	**kg**
Runoff	Hay/Pasture	0.0	0.0	0.0	0.0
	Cropland	0.0	0.0	0.0	0.0
	Forest	0.4	0.2	0.2	0.2
	Wetland	0.0	0.0	0.0	0.0
	Open Land	0.0	0.0	0.0	0.0
	Barren Land	0.0	0.0	0.0	0.0
	Low-Density Mixed	3.2	0.6	0.2	2.4
	Medium-Density Mixed	10.9	1.3	0.2	8.8
	High-Density Mixed	2.4	0.2	0.0	2.0
	Low-Density Open Space	4.7	0.5	0.3	3.7
Other Sources	Farm Animals	0.0	0.0	0.0	0.0
	Stream Bank	11.0	0.0	0.0	9.0
	Groundwater	20.2	2.1	1.7	15.9
	Septic Systems	0.0	0.0	0.0	0.0
Totals		52.9	4.8	2.6	41.9

Table 8. Annual Watershed-based Phosphorus Loads for Upper Tibbetts Pond			
Category	**Description**	**Total Phosphorus**	
		kg	**%**
Runoff	Hay/Pasture	0	0.0
	Cropland	0	0.0
	Forest	0.25	0.5
	Wetland	0	0.0
	Open Land	0	0.0
	Barren Land	0	0.0
	Low-Density Mixed	3.04	5.8
	Medium-Density Mixed	11.04	21.0
	High-Density Mixed	2.44	4.6
	Low-Density Open Space	4.69	8.9
Other Sources	Farm Animals	0	0.0
	Stream Bank	11	20.9
	Groundwater	20.05	38.2
	Septic Systems	0.0	0.0
	Total	52.5	100.0

Table 9. Annual External Phosphorus Loads entering Upper Tibbetts Pond by Subwatershed					
Category	**Description**	**Full Watershed**	**Upper East**	**Upper West**	**Far North**
		kg	**kg**	**kg**	**kg**
Runoff	Hay/Pasture	0.0	0.0	0.0	0.0
	Cropland	0.0	0.0	0.0	0.0
	Forest	0.3	0.1	0.1	0.2
	Wetland	0.0	0.0	0.0	0.0
	Open Land	0.0	0.0	0.0	0.0
	Barren Land	0.0	0.0	0.0	0.0
	Low-Density Mixed	3.0	0.7	0.6	1.8
	Medium-Density Mixed	11.0	2.9	1.9	6.4
	High-Density Mixed	2.4	0.8	0.5	1.2
	Low-Density Open Space	4.7	0.6	1.0	3.1
Other Sources	Farm Animals	0.0	0.0	0.0	0.0
	Stream Bank	11.0	0.0	0.0	8.0
	Groundwater	20.1	2.8	6.1	11.1
	Septic Systems	0.0	0.0	0.0	0.0
	Total (kg)	52.5	7.9	10.2	31.7

Nitrogen was contributed largely by groundwater in all of the lower basin's subwatersheds (Tables 10, 11). Groundwater often contains relatively high nitrogen concentrations due to nitrogen's high solubility in water (compared to Phosphorus's tendency to adhere to sediment). As with phosphorus, runoff from urbanized areas also contributed a relatively high annual nitrogen load. The Upper Basin's watershed followed a similar pattern, with the far-north subwatershed yielding the highest yearly concentration (Tables 12, 13).

Table 10. Annual Watershed-based Nitrogen Loads for Lower Tibbetts Pond			
Category	**Description**	**Total Nitrogen**	
		kg	**%**
Runoff	Hay/Pasture	0.00	0.0
	Cropland	0.00	0.0
	Forest	4.11	0.3
	Wetland	0.51	0.0
	Open Land	0.00	0.0
	Barren Land	0.00	0.0
	Low-Density Mixed	34.38	2.3
	Medium-Density Mixed	122.73	8.2
	High-Density Mixed	26.44	1.8
	Low-Density Open Space	50.69	3.4
Other Sources	Farm Animals	0.00	0.0
	Stream Bank	9.00	0.6
	Groundwater	1250.49	83.5
	Septic Systems	0.00	0.0
Total		**1498.4**	**100.0**

Table 11. Annual External Nitrogen Loads entering Lower Tibbetts Pond by Subwatershed					
Category	Description	Full Watershed	Lower-east	Lower-west	Upper
		kg	kg	kg	kg
Runoff	Hay/Pasture	0.0	0.0	0.0	0.0
	Cropland	0.0	0.0	0.0	0.0
	Forest	4.1	0.9	0.8	2.4
	Wetland	0.5	0.0	0.4	0.1
	Open Land	0.0	0.0	0.0	0.0
	Barren Land	0.0	0.0	0.0	0.0
	Low-Density Mixed	34.4	5.3	1.6	27.3
	Medium-Density Mixed	122.7	12.6	1.8	105.1
	High-Density Mixed	26.4	2.3	0.0	23.5
	Low-Density Open Space	50.7	4.4	3.2	42.2
Other Sources	Farm Animals	0.0	0.0	0.0	0.0
	Stream Bank	9.0	0.0	0.0	9.0
	Groundwater	1250.5	51.4	58.3	1188.8
	Septic Systems	0.0	0.0	0.0	0.0
Totals		1498.4	76.8	66.1	1398.5

Table 12. Annual Watershed-based Nitrogen Loads for Upper Tibbetts Pond			
Category	Description	Total Nitrogen	
		kg	%
Runoff	Hay/Pasture	0.0	0.0
	Cropland	0.0	0.0
	Forest	2.6	0.2
	Wetland	0.0	0.0
	Open Land	0.0	0.0
	Barren Land	0.0	0.0
	Low-Density Mixed	29.8	2.0
	Medium-Density Mixed	114.1	7.5
	High-Density Mixed	25.2	1.7
	Low-Density Open Space	46.1	3.0
Other Sources	Farm Animals	0.0	0.0
	Stream Bank	10.0	0.7
	Groundwater	1299.1	85.1
	Septic Systems	0.0	0.0
	Total	1526.9	100.0

Table 13. Annual External Nitrogen Loads entering Upper Tibbetts Pond by Subwatershed					
Category	**Description**	**Full Watershed**	**Upper-east**	**Upper-west**	**Far North**
		kg	**kg**	**kg**	**kg**
Runoff	Hay/Pasture	0.0	0.0	0.0	0.0
	Cropland	0.0	0.0	0.0	0.0
	Forest	2.6	1.1	0.6	1.6
	Wetland	0.0	0.0	0.0	0.0
	Open Land	0.0	0.0	0.0	0.0
	Barren Land	0.0	0.0	0.0	0.0
	Low-Density Mixed	29.8	6.3	5.6	18.2
	Medium-Density Mixed	114.1	28.6	18.8	67.5
	High-Density Mixed	25.2	8.2	4.4	12.9
	Low-Density Open Space	46.1	5.9	9.5	30.5
Other Sources	Farm Animals	0.0	0.0	0.0	0.0
	Stream Bank	10.0	0.0	0.0	9.0
	Groundwater	1299.1	78.6	556.8	595.8
	Septic Systems	0.0	0.0	0.0	0.0
Totals		1526.9	128.7	595.6	735.4

Over 80% of the lower basin's annual sediment load was estimated to originate from stream bank erosion, with another almost 18% estimated to runoff from urbanized areas (Table 14). While a majority of this sediment originates north of the upper basin, the lower-east basin was estimated to yield a notable annual load from urbanized areas in the watershed (Table 15). The upper basin followed a similar pattern, with a majority of the sediment load originating from eroded streambanks, as well as a smaller but notable load originating in urbanized areas within the watershed (Table 16).

Table 14. Annual Watershed-based Sediment Loads for Lower Tibbetts Pond			
Category	**Description**	**Sediment**	
		kgx1000	**%**
Runoff	Hay/Pasture	0	0.0
	Cropland	0	0.0
	Forest	0.13	0.5
	Wetland	0.0	0.0
	Open Land	0.0	0.0
	Barren Land	0.0	0.0
	Low-Density Mixed	0.62	2.2
	Medium-Density Mixed	2.82	10.0
	High-Density Mixed	0.61	2.2
	Low-Density Open Space	0.91	3.2
Other Sources	Farm Animals	0.0	0.0
	Stream Bank	23.174	82.0
	Groundwater	0.0	0.0
	Septic Systems	0.0	0.0
Total		**28.264**	**100.0**

Table 15. Annual External Sediment Loads entering Lower Tibbetts Pond by Subwatershed					
Category	Description	Full Watershed	Lower-east	Lower-west	Upper
		kg x 1000	kg x 1000	kg x 1000	kg x 1000
Runoff	Hay/Pasture	0.00	0.00	0.00	0.00
	Cropland	0.00	0.00	0.00	0.00
	Forest	0.13	0.12	0.12	0.03
	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	0.62	0.20	0.07	0.25
	Medium-Density Mixed	2.82	0.66	0.10	1.22
	High-Density Mixed	0.61	0.12	0.00	0.27
	Low-Density Open Space	0.91	0.16	0.13	0.39
Other Sources	Farm Animals	0.00	0.00	0.00	0.00
	Stream Bank	23.17	0.08	0.04	9.79
	Groundwater	0.00	0.00	0.00	0.00
	Septic Systems	0.00	0.00	0.00	0.00
Totals		28.26	1.34	0.46	11.95

Table 16. Annual Watershed-based Sediment Loads for Upper Tibbetts Pond			
Category	Description	Sediment	
		kgx1000	%
Runoff	Hay/Pasture	0	0.0
	Cropland	0	0.0
	Forest	0.11	0.2
	Wetland	0	0.0
	Open Land	0	0.0
	Barren Land	0	0.0
	Low-Density Mixed	0.93	2.1
	Medium-Density Mixed	4.51	10.2
	High-Density Mixed	1	2.3
	Low-Density Open Space	1.43	3.2
Other Sources	Farm Animals	0.0	0.0
	Stream Bank	36.15	81.9
	Groundwater	0.0	0.0
	Septic Systems	0.0	0.0
	Total	44.130	100.0

Table 17. Annual External Sediment Loads entering Upper Tibbetts Pond by Subwatershed					
Category	Description	Full Watershed	Upper-east	Upper-west	Far North
		kg x 1000	kg x 1000	kg x 1000	kg x 1000
Runoff	Hay/Pasture	0.00	0.00	0.00	0.00
	Cropland	0.00	0.00	0.00	0.00
	Forest	0.11	0.03	0.06	0.06
	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	0.93	0.24	0.23	0.51
	Medium-Density Mixed	4.51	1.41	0.95	2.44
	High-Density Mixed	1.00	0.41	0.22	0.46
	Low-Density Open Space	1.43	0.22	0.38	0.86
Other Sources	Farm Animals	0.00	0.00	0.00	0.00
	Stream Bank	36.15	1.27	0.12	22.67
	Groundwater	0.00	0.00	0.00	0.00
	Septic Systems	0.00	0.00	0.00	0.00
Totals		44.13	3.58	1.96	27.00

Internal phosphorus loading in the lower basin was estimated to occur at an accelerated rate for at least two months during the Summer of 2020, with the most severe loading estimated to occur in July. The water column near the pond's dam in June was measured to be anoxic after 1.5 meters or 4.9 ft of depth, suggesting that only 10% of the pond's total area was yielding phosphorus at an accelerated daily rate. July, however, saw the pond experience anoxia after only 0.5 m (1.6 ft) of water depth, suggesting that approximately 80% of the pond was yielding an advanced daily rate of phosphorus. Combining the estimated loads of phosphorus for these two months during anoxia with the reduced phosphorus loading that occurred during the remainder of the growing season and in areas of the pond that remained oxygenated yielded an estimated yearly internal phosphorus load of 10.87 kg. If a growing season were to occur with no bottom anoxia occurring, the lake's internal phosphorus load would be an estimated 4.12 kg. The upper basin was not measured in 2020 to feature bottom anoxia during any sampling event, and was estimated to only feature a lesser internal loading rate of 0.6 mg TP/m²/day throughout, resulting in an estimated yearly internal load of 0.97 kg of phosphorus.

As noted above, Princeton Hydro utilized an estimated loading rate of 5 mg TP/m²/day to represent phosphorus being moved back into the lower basin's water column due to bioturbation from carp. If it is assumed that this occurs during the time of the year where carp are most active (approximately 245 days), and that approximately three-quarters of this phosphorus immediately settles back to the bottom (the relatively high plant density likely allows for an increased rate of sediment settling, this results in an additional load of 13.76 kg/year of phosphorus. This analysis was not run on the upper basin, as it is not known if this shallow waterbody contains a significant population of carp or goldfish.

Table 18. Estimated sources of Phosphorus for both basins of Tibbetts Pond		
Source	**Lower Basin**	**Upper Basin**
	kg/yr	**kg/yr**
Watershed	52.9	52.5
Internal Loading	10.87	0.97
Carp	13.8	-
Total	**77.57**	**53.47**

4.2.4. PREDICTIVE PHOSPHORUS MODELING

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

METHODS

Lastly, the results of the hydrologic loading models were used as part of the Kirchner-Dillon model, which yields a phosphorus retention coefficient (R) (Kirchner and Dillon, 1975).

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

Where R = the phosphorus retention coefficient and qs = the areal water load, calculated as the total annual hydrologic input divided by the total surface area of the waterbody. For the lower basin, qs is approximately 46.1 m; for the upper basin, qs is approximately 162.2 m.

This value is subsequently used in conjunction with modeled phosphorus loads as part of the Dillon-Rigler model, which provides an estimate for predicted concentrations of phosphorus in the water column (Dillon and Rigler, 1975).

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

Where [TP] = annual mean phosphorus concentration (mg/L), L = areal phosphorus loading ($g/m^2/yr$), R = phosphorus retention, and T = Water retention time in years. For the lower basin, L is 1.34 $g/m^2/yr$ when only considering external loading and 1.89 $g/m^2/yr$ when considering all phosphorus loading, while T is approximately 0.02 years. For the upper basin, L is approximately 5 $g/m^2/yr$ if only external loads are considered and 5.1 if all phosphorus loading is considered, while T is 0.003 years.

RESULTS

When lake morphology and the total hydraulic load discussed above in previous subsections were entered into the Kirchner-Dillon equation, the model yielded a phosphorus retention coefficient (R) of 0.37, suggesting that the waterbody retains approximately 37% of all phosphorus that enters it. The remaining phosphorus is assumed to eventually flush from the waterbody. If this resulting R-value is entered into the Dillon-Rigler equation, along with the calculated total annual phosphorus load converted into a concentration and the lake's annual hydraulic retention period and average depth, the model yields a predicted phosphorus concentration of 0.022 mg/L. If only the external phosphorus load is considered, the predicted phosphorus concentration is 0.016 mg/L. Samples collected in the field were consistently much higher than this, suggesting that additional or increased sources of phosphorus may be present that are not accounted for in the models. This may be the product of increased retention of sediment in the waterbody due to high macrophyte coverage. Phosphorus often is bound to sediment particles under oxic conditions, and high densities of macrophytes can cause rapid settling of sediments from the water column. Additionally, areas within the Tibbetts Pond watershed were at one time used as a dumping area by the surrounding community. The exact area that this affected is unknown, but this may result in an increased loading of phosphorus from this area compared to that which can be identified by the watershed model. Higher concentrations of phosphorus identified by the 2019 study by the Van Cortlandt Park Alliance in an area north of the pond within the park further support this hypothesis.

Due to its higher flushing rate, the upper basin yielded an R-value of 0.12, suggesting that the waterbody only retains approximately 12% of any phosphorus that enters. As such, the predicted phosphorus concentration for this waterbody is approximately 0.012 mg/L.

4.2.5. CARLSON'S TROPHIC STATE INDEX

Trophic state as it applies to lakes refers to the amount of nutrients in a lake and the primary productivity (growth of photosynthetic organisms) that results. This is the base of a food web in a lake from which consumers (higher organisms such as macroinvertebrates and fish) feed in order to maintain their own populations within the lake. Low levels of primary productivity in a lake result in an oligotrophic state. This usually occurs in glacial kettle ponds and lakes and are characterized by low amounts of plants and algae, very high water clarities, and a fisheries consisting of salmonids and/or other cold-water fish. Conversely, high levels of primary productivity in a lake result in a eutrophic state. Most waterbodies in the northeast that are similar to Tibbett's Pond are typically eutrophic, featuring relatively high nutrient loads, lower water clarities, and a higher propensity for algae blooms. Mesotrophic lakes refer to those with primary productivity levels between oligotrophy and eutrophy. As with shallowing via sedimentation (and in part because of it), most lakes in the northeast are naturally moving towards eutrophic conditions over the course of very long periods of time. While this is natural, it can also be caused more quickly by excess nutrient loads entering the waterbody as a product of anthropogenic activities in the watershed. This is known as "cultural eutrophication". A model known as Carlson's Trophic Index assesses the trophic state of lakes by correcting concentrations of phosphorus and chlorophyll *a*, as well as Secchi depths, into values that relate to each other on a similar scale (Carlson, 1977). The higher these numbers are, the more representative they are of eutrophic conditions.

METHODS

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

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

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

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

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

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

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

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

Where *TSI* = Trophic State Index Result for Secchi depth and *SD* = Secchi depth in meters.

The resulting TSI values represent the trophic state of the waterbody (eutrophic, mesotrophic, or oligotrophic). As phosphorus and chlorophyll *a* data was not collected for the upper basin, this analysis was only performed on the lower basin.

RESULTS

Total phosphorus concentrations were consistently elevated throughout the season, resulting in a TP trophic state index consistently over 60 for every sampling event (Figure 13). From mid-July through the end of October, this value was over 70, which is indicative of hypereutrophic conditions. The trophic state index for chlorophyll *a* was consistently in the high 60's throughout the season, exceeding 70 in late October, also indicating eutrophic conditions. Secchi depth never exceeded a meter, resulting in Secchi depth-base trophic index scores of over 60 throughout the season, again indicating eutrophic conditions. Such conditions are generally the product of an abundance of nutrients in the water column, which, as a result, foster advanced growths of macrophytes and algae. However, for smaller waterbodies with high vegetation densities, such as Tibbetts Pond, the chlorophyll *a* TSI metric will likely track with the TP TSI metric less, as less of the biomass is present in the water itself (Carlson and Simpson, 1996).

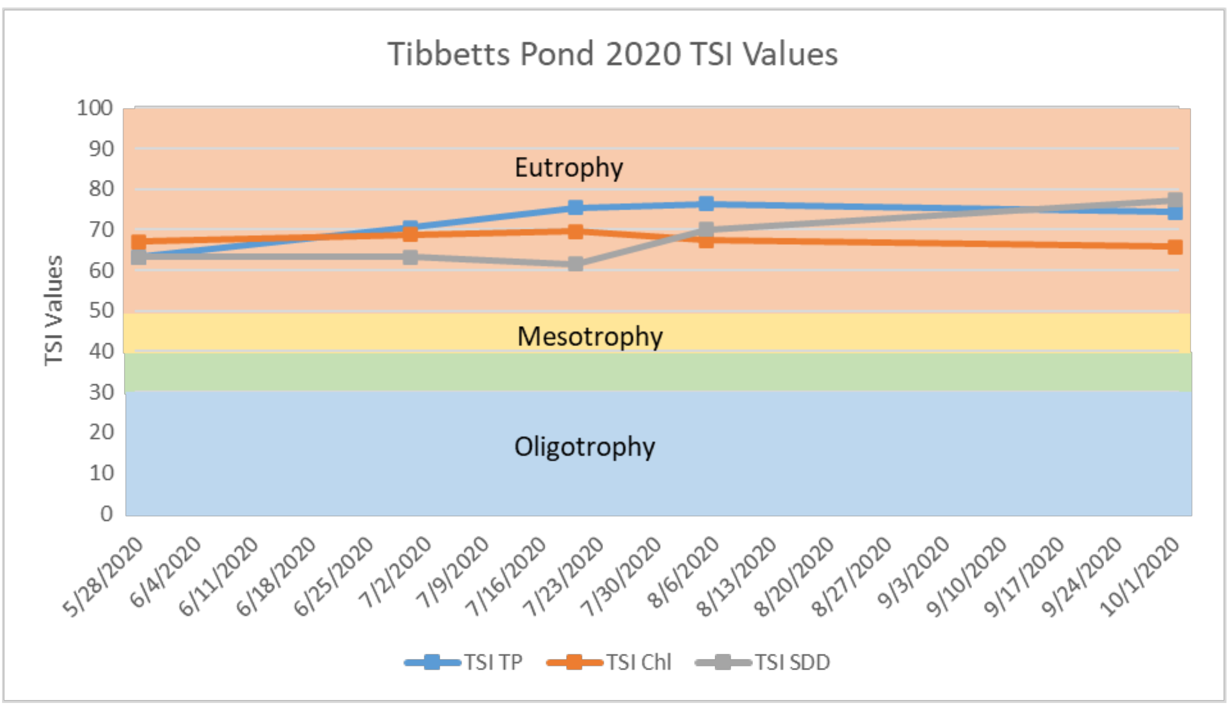


Figure 13. Carlson's Trophic State Indices for the Lower Basin of Tibbett's Pond over the course of 2020

An analysis of the residuals (differences) between the results of a TSI analysis can be suggestive of other conditions affecting the waterbody's trophic state. The differences between the chlorophyll-based TSI and the Secchi-based TSI and between the Chlorophyll-based TSI and the Phosphorus-based TSI can be plotted on an axis for either several dates in a year or for several years. As demonstrated in Figure 14 by Carlson and Havens (2005), the location of events in one of the "quadrats" on the graph, relative to the axis, may suggest differences in conditions during those particular events.

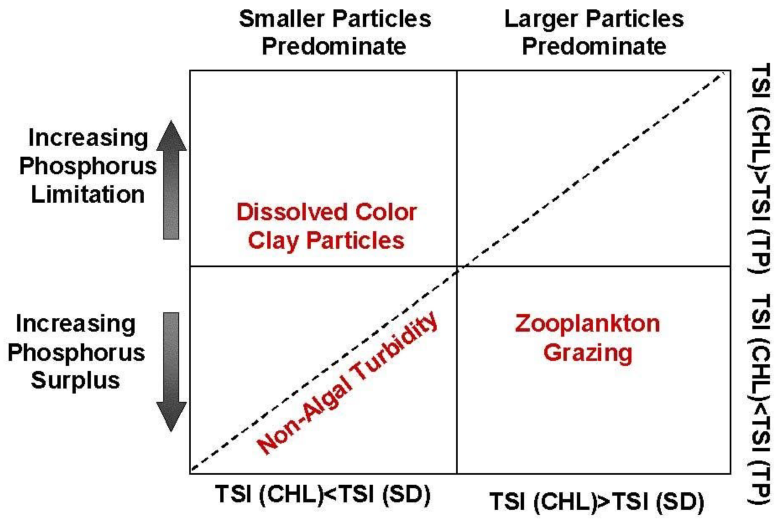


Figure 14. Carlson and Havens (2005) display possible interpretations for differences in trophic state indices when plotted on an axis.

The point representing the May sampling event yielded a chlorophyll *a* concentration that was greater than the event's Secchi depth or total phosphorus concentration would suggest according to the trophic state index (Figure 15). In many larger lakes, these results present conditions under which phosphorus is likely a limiting nutrient and larger algal particles, such as cyanobacteria, are likely present. In Tibbetts Pond, however, these results were obtained early in the year when plankton communities were not especially dense. In this case, elevated chlorophyll *a* concentrations may be due to decomposing plant material in the water column. The two sampling events after this, as well as the late-October sampling event, however, are located in the lower-right quadrat, suggesting that during these events, phosphorus might had not been the limiting nutrient, and a lack of smaller algal particulates may, in other waterbodies, had been the product of grazing by zooplankton. The zooplankton samples did not contain high numbers of large-bodied, herbivorous taxa, however, suggesting that algae growth might had been limited by another factor. The results of the events from early-August and early-October are located in the lower-left quadrat, suggesting that phosphorus was not a limiting factor for algae growth, and that suspended solids might have in fact been the cause of lower water clarity. The elevated surface concentrations of TSS collected at the surface during these two events further suggests this to have been a significant factor. TSS concentrations above 6.5 mg/L and Secchi depths below 1 m were present throughout the 2020 growing season, suggesting that non-algal turbidity was a factor, possibility due to bioturbation by carp. As discussed above, chlorophyll *a* values may also had been lower than phosphorus concentrations would otherwise suggest due to the dominance of macrophytes rather than algae in this system.

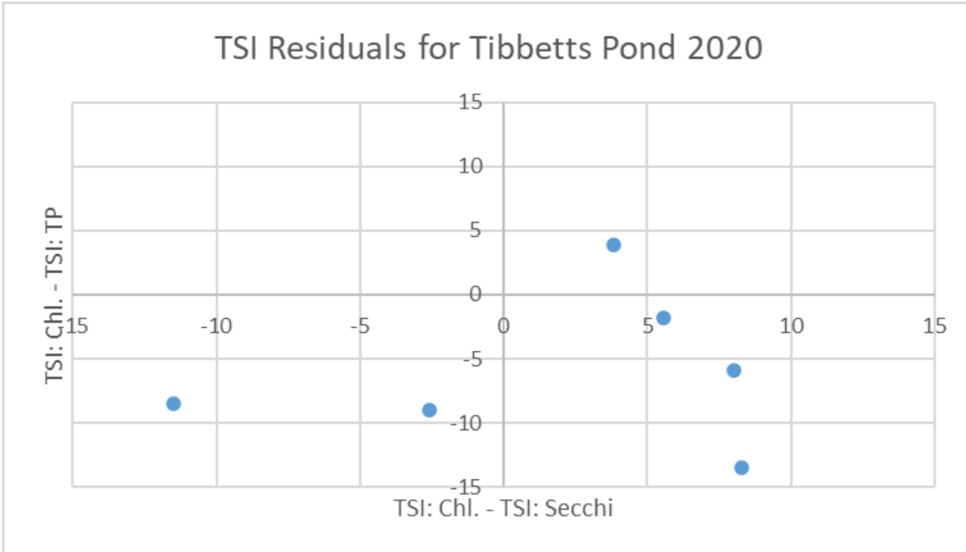


Figure 15. Differences in trophic state indices obtained from data collected at the lower basin of Tibbetts Pond in 2020

5. WATERSHED-BASED RECOMMENDATIONS

5.1 MANAGEMENT MEASURES

This section consists of a description of the management measures necessary in the Tibbetts pond watershed to achieve load reductions as well as a description of the areas where those measures will be implemented. This is one of the most important components of this document and consists of a list of projects that could be designed and implemented to reduce Total Suspended Solids (TSS), Total Phosphorus (TP), and other pollutant loads entering the lakes.

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

Princeton Hydro evaluated and identified sites within the watersheds of the upper and lower basins of Tibbetts Pond. Figure 16 below depicts recommended site locations within the watershed; these will be described in more detail in the subsequent sections. Table 19 presents a list of the proposed Best Management Practice (BMP), the amount of TSS removed, and an estimated price. *Please note, the numbering of the recommended project site is in order of priority.*

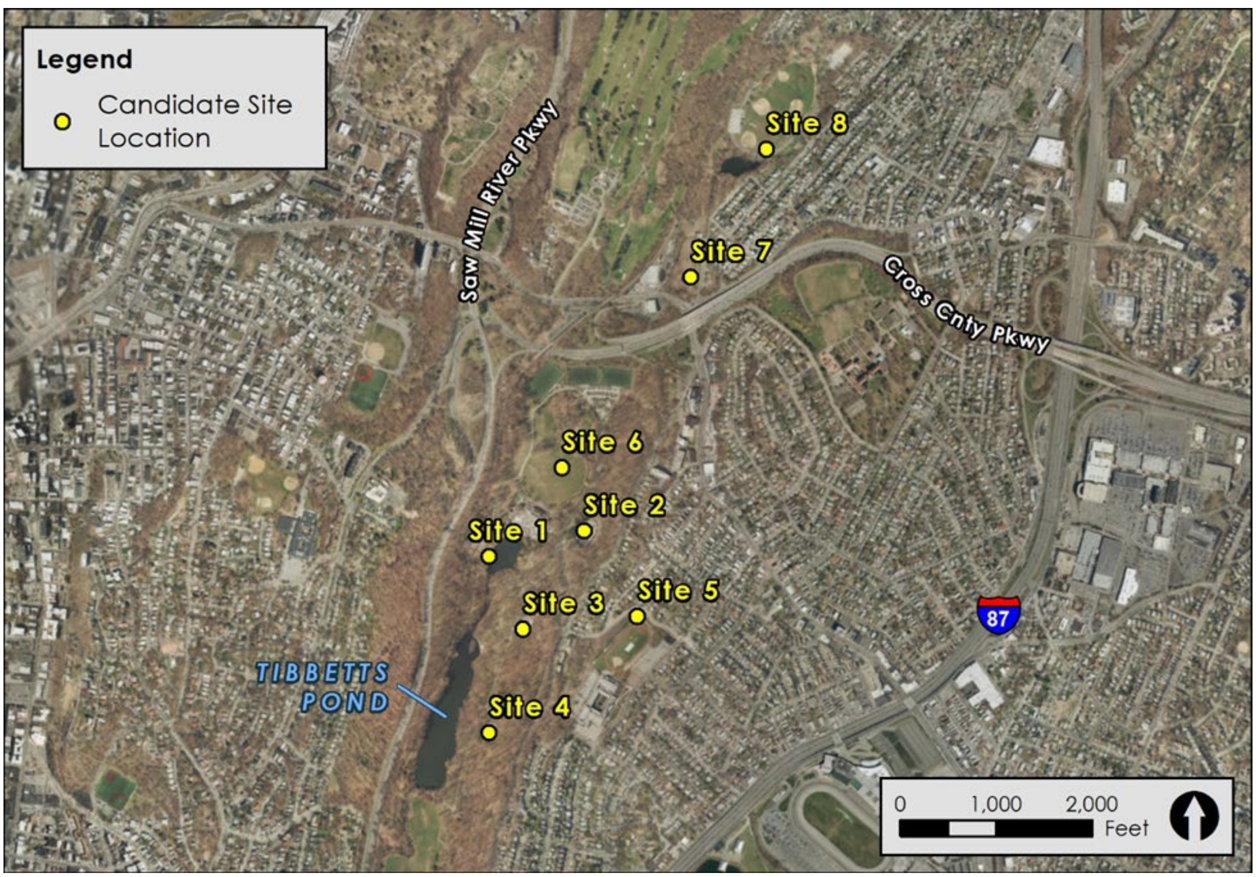


Figure 16. Site Overview of Tibbetts Pond Area.

Site[1]	Proposed BMP	Approximate Drainage Area (Acres)[2]	TSS Removal Rate (%)[3]	Potential Project Cost ($)[4]
1	Site 1: Tibbetts Brook Park Aquatic Complex Retention Pond Sediment Forebay, Riparian Plantings, Vegetated Conveyance System	700	60-80	750,000 - 1,050,000
2	Site 2: Recreation Center Parking Lot Stabilized Vegetated Conveyance System	5	60-80	150,000 - 300,000
3	Site 3: Tibbetts Pond Northern Parking Lot Stabilized Vegetated Conveyance System	5	60-80	100,000 - 200,000
4	Site 4: Tibbetts Pond Southern Parking Lot Stabilized Vegetated Conveyance System	7.5	60-80	100,000 - 200,000
5	Site 5: Teresa Avenue Grassed Area Rain Garden	15	60 - 90	150,000 - 250,000
6	Site 6: Tibbetts Brook Park Wetland System Stream Channel Stabilization, Wetland and Floodplain Enhancement	650	60 - 90	2,000,000 - 3,000,000
7	Site 7: Cook Avenue Wetland Area Stream Channel Stabilization, Wetland and Floodplain Enhancement	400	50 - 80	2,000,000 - 3,000,000
8	Site 8: HF Redmond Jr. Memorial Park Stream Channel Stabilization	250	80	500,000 - 750,000

Notes:

1. Site locations are located on Figure 16.

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 19. Best Management Practice (BMP) site summary

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

- **Site Investigations** – Part of the design process includes several different onsite investigation efforts including topographic survey, wetland delineation, and soils investigations. These investigations and the information gathered during them provide an understanding of the site conditions, any potential design challenges, and permitting pathways for the site.
    - **Depth to Bedrock** – The presence of shallow bedrock can result in implementation complications and a substantial increase in implementation costs.
    - **Depth to Water Table** – The presence of a shallow water table may indicate the presence of a wetland and/or recharge area for groundwater. Thus, this can result in complications as well as an increase in permitting and implementation costs.
    - **Utility Conflicts** – Location of sewer lines, gas lines, power lines, fiber optic lines all need to be located and mapped before any earth-moving or infrastructure work can be initiated. Without such information results could be extremely costly and even disastrous.
    - **Permit Requirements** – Depending on the site features and its location relative to the lake and associated waterways, regulatory permitting can vary from none to minimal to substantial. Thus, the potential required permitting must be determined to quantify the total costs associated with the design phase. While general permitting costs were estimated in the proposed cost for each project, the fees can vary based on access, size of the overall project and project type which have not been determined at this phase. The costs do not include permits specific to the Highlands

Region. Due to the location of lakes and their watersheds being in the protected Highlands Region, additional permitting may be required.

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

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

5.2 SITE RECOMMENDATIONS

5.2.1. PROPOSED SITE MODIFICATIONS

SITE 1: UPPER BASIN AND TIBBETS BROOK PARK AQUATIC COMPLEX

The Tibbetts Brook Park Aquatic Complex is located directly to the north of Tibbetts Pond. This complex contains various recreation facilities used during the warmer months including a main building, a small water park, tennis courts, and playground area. The main complex building is bordered by a field to the north, and the upper basin of Tibbetts Pond to the south. The upper basin is the discharge location of Tibbetts Brook, which flows into the pond from the northern field area. Tibbetts Brook acquires sediment and pollutants along its journey south from its drainage area, comprised mostly of residencies, highways, and field areas. Tibbetts Brook ultimately deposits these pollutants and sediment into the upper basin. This waterbody then conveys water over a weir structure at its southern end into the lower basin via a small stream. Combine that pollutant addition with direct runoff flows from areas surrounding the retention pond, and the result is an area that contributes a high amount of sediment, nutrients, TSS, and TP into the lake. Stormwater Best Management Practices (BMP's) around the upper basin and bordering facilities will be the areas of focus for Site 1 in order to reduce that contribution. Refer to Figure 17 for an overview of the area and proposed BMP's.

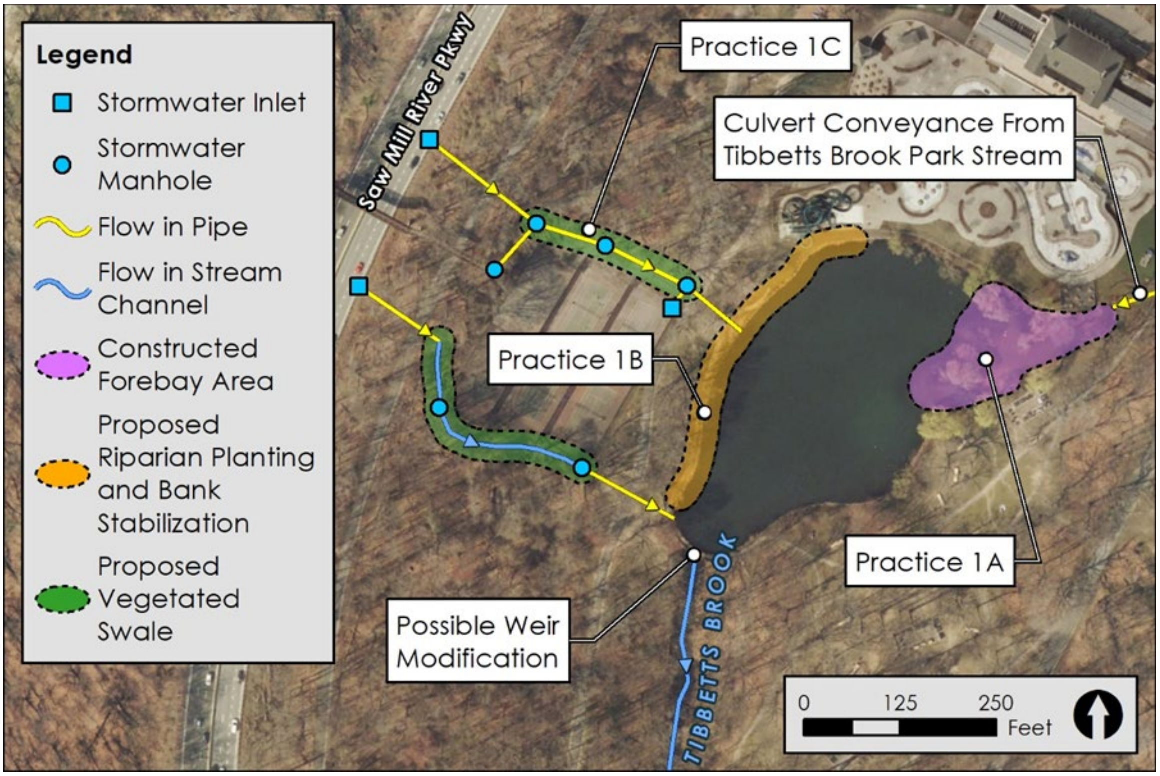


Figure 17: Site 1 Best Management Practice overview

Due to this site's larger drainage area, this site is a large contributor to excess pollutants that enter Tibbetts Pond. Because of this, the practice area can support multiple BMP's to help reduce pollutant loading into the retention pond. Three solutions proposed can be found in Figure 17 above. These solutions include Practice 1A- a constructed forebay area, Practice 1B- a riparian planting and bank stabilization zone, and Practice 1C- two vegetated swales to collect surface runoff from the impervious tennis court area.

Recommendation Site 1A: The recommended BMP here would be to construct a sediment forebay area at the discharge location of the Tibbetts Brook Park stream into the upper basin. As shown in Photo 1 below, this area contains a significant amount of sediment at the outfall and along the banks. The construction of a sediment forebay at this location would allow for that sediment entering the upper basin to be contained within a specified area. This forebay would involve the excavation and construction of a stone berm shown in the region shown in Figure 17 above. The discharge pipe and end section may be pulled back to allow for the installation without impeding flow within the channel. This forebay, if maintained properly, would be able to contain a large amount of sediment and TSS from the brook while allowing stream flow to continue into the upper basin. Inspection and maintenance of a forebay is recommended on an annual basis, and after significant rainfall events. This will greatly reduce the amount of sediment and pollutants entering the upper basin from this location.

To complement the construction of a forebay, it may be necessary to modify the outlet structure of the pond to facilitate control of the water surface elevation. The forebay operates by detaining runoff to allow for the precipitation of sediment. Water will overtop the berm during larger storm events. If the permanent pool of the pond is above the forebay, it may interfere with the operation of the BMP. There are many environmental constraints to consider by performing this weir modification, which includes detrimental effects to aquatic life and vegetation if the pond elevation is lowered.

Photo 1: Area of Bank Stabilization and Riparian Improvements, Facing Towards Recreation Center

Recommendation Site 1B: To compliment the sediment forebay construction, riparian plantings and bank stabilization would be introduced to the site at this location. As shown in Photo 2 below, this location contains a rock embankment with a grassed area and dirt walkway near the Tibbetts Brook Park recreation building. Since this area is not highly vegetated along the upper basin banks, stormwater runoff from the surrounding grass and paved areas gets conveyed directly into the pond. Without a stabilized bank or riparian area, this location contributes many additional pollutants and sediment into the upper basin area here. Riparian plantings and bank stabilization would address that issue by creating a buffer between the unfiltered stormwater runoff and the pond itself. This buffer would be able to lower the amount of sediment entering the lake at this location, as well as filter any unwanted nutrients with the vegetated riparian area.

Photo 2: Tibbetts Brook Discharge Location Into the upper basin

Recommendation Site 1C: A third location contributing additional runoff into the upper basin is the tennis court drainage system bordering the upper basin area. The tennis courts are surrounded by a drainage system containing a mixture of pipe and channel features. These systems convey runoff from the Saw Mill River Parkway, tennis courts, recreational paths, and the surrounding forested area into the upper basin. Runoff from the impervious asphalt areas contains sediment and pollutants, which are discharged into the drainage system without any filtration. These would be replaced with a vegetated swale that would contain appropriate planted vegetation to filter any additional sediment or pollutants added to this conveyance system from the Parkway and the tennis courts. The construction of velocity controls like stone check dams can serve to minimize erosion from steep slopes and provide an additional measure to trap sediment.

Estimated Costs Site 1A: The approximate cost for design, permitting, and implementation of this BMP recommendation is anticipated to be between $125,000 and $150,000.

Estimated Costs Site 1B: The approximate cost for design, permitting, and implementation of this BMP recommendation is anticipated to be between $200,000 and $300,000.

Estimated Costs Site 1C: The approximate cost for design, permitting, and implementation of this BMP recommendation is anticipated to be between $425,000 and $600,000.

SITE 2: RECREATION CENTER PARKING LOT

Located at the entrance to the park area is Site 2, the parking lot for the Tibbetts Pond Recreation Center. This parking lot is located directly to the east of the recreation center and is paved with impervious asphalt. A drainage swale has been constructed around the sides of the lot. Photo 3 shows the conditions of the parking lot, and Photo 4 shows the drainage swale itself to the right. The swale borders the entire parking lot at a lower elevation, with the parking lot runoff draining into it. This swale contains a small asphalt bottom, with grass or exposed soil along the side of it. The swale drains to a catch basin along the edge of County Park Road, which in turn connects to Tibbets Pond Brook. In addition to the parking lot drainage, much of the surrounding forested area drains to this parking lot swale. The forested area has limited understory growth and many sections of bare soil. The impervious area of the parking lot itself combined with the surrounding drainage of the forested area add excess sediment and nutrients to the swale area, which does not filter them from the stormwater runoff before conveying these excess pollutants into the upper basin.

Photo 3: Parking Lot Area for Site 2

Photo 4: Asphalt Drain Ditch on Side of Parking Lot

Recommendation Site 2: The recommended Best Management Practice (BMP) for this site is to convert the asphalt and dirt swale around the edges of the parking lot to a stabilized vegetated conveyance system. Instead of containing an asphalt bottom, the conveyance system would contain various plants and vegetation to help filter nutrients from the stormwater passing through it. Additionally, this would serve as a buffer between the surface runoff from the parking lot and the conveyance system to Tibbetts Pond Brook, reducing the initial influx of polluted rainwater to Tibbetts Pond during the "first flush" of a storm event. The first flush runoff produces the most pollution in bodies of water from surface runoff. Reducing the first flush volume of water during storm events and filtering any rainwater in the conveyance system with vegetation will greatly reduce the amount of TSS and pollutants entering Tibbetts Pond. To provide additional pollutant and sediment removal, the catch basin at the end of the swale can be retrofitted to provide a sump or other sediment trapping device and replacing the existing casting and grate with one that has smaller openings to prevent debris from entering the discharge pipe. Inspection and maintenance of the catch basin is recommended on a quarterly basis, and after significant rainfall events. This will greatly reduce the amount of sediment and pollutants entering the pond from this location.

Estimated Costs Site 2: The approximate cost for design, permitting, and implementation of this BMP is anticipated to be between $150,000 and $300,000.

SITE 3: *LOWER BASIN* NORTHERN PARKING LOT

The lower basin of Tibbetts Pond is home to two parking lots on the eastern side of the pond area. Site 3 refers to the northern parking lot out of those two, shown in Photo 5. This parking lot is one of two main parking lots used by Tibbetts Pond visitors to access the pond and playground area. Similar to Site 2, this parking lot also contains a grassed swale area around the perimeter, which collects much of the impervious parking lot runoff. The parking lot area also has various natural swales extending from it, providing multiple paths for stormwater to drain from the parking lot and travel to Tibbets Pond. In addition to the impervious parking area, this sites drainage area also consists of the surrounding wooded areas bordering the parking lot, which collect stormwater in the swale as well. The forested area has limited understory growth and many sections of bare soil. Once the runoff is collected in the swale, it discharges to the park pathway area shown in Photo 6. From there its travels down the side of the path and eventually makes its way into the lower basin. Due to the impervious area of the parking lot and lack of filtration of runoff before discharging, this site will contribute a high amount of sediment and pollutants into the lower basin during storm events.

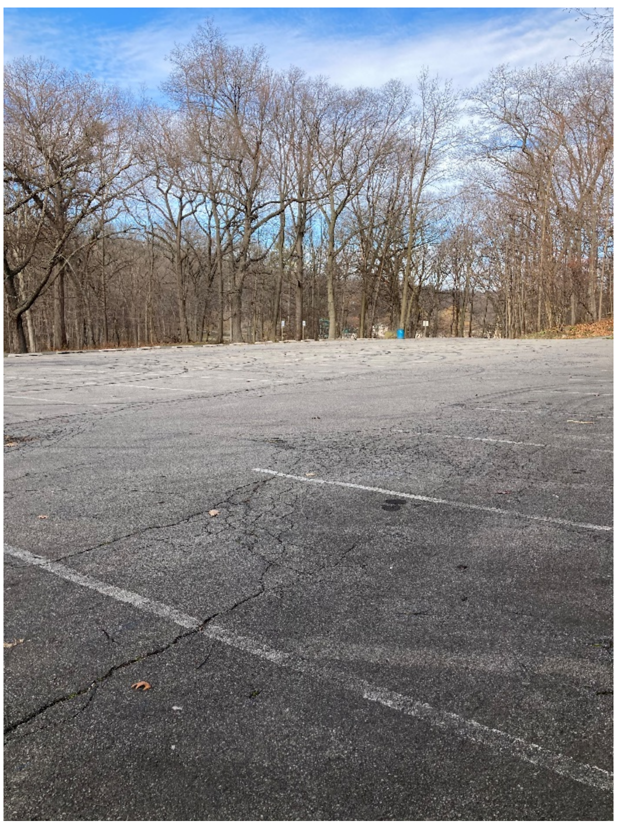


Photo 5: Parking Lot Area For Site 3

Photo 6: Site 3 Swale Discharge Location

Recommendation Site 3: The recommended Best Management Practice (BMP) for this site is to construct a stabilized vegetated conveyance system around the border of the parking lot, improving the natural drainage swale that is already there. The existing swale can be modified with added vegetation, while having its soil sides stabilized with water tolerant plants or other media such as river stone. Additionally, the stabilized vegetated conveyance system can extend to the park path and other natural swales in the area depending on use a need for additional runoff volume management. This vegetated conveyance system will be able to filter sediment and nutrient runoff from the impervious parking lot or from the wooded area before discharging the runoff to the lower basin, lowering the total sediment and pollutant loads into the waterbody.

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: LOWER BASIN SOUTHERN PARKING LOT

Site 4 is the southern parking lot on the east side of the lower basin of Tibbetts Pond. Like Site 3, this site is one of two parking lots that serve the Tibbetts Pond recreation area. This asphalt parking lot contains parking spots for park attendees to use and contains a similar grassed swale configuration as Site 2 and Site 3 to handle the drainage. Photo 7 depicts the current condition of the parking lot. The forested area surrounding this parking lot, combined with the impermeable parking lot, make up the drainage area for this site. The stormwater runoff is then conveyed through a series of naturally made swales bordering the lot until it discharges into the lower basin. The swale system exiting the parking lot can be shown in Photo 8. Due to the large impervious area provided by the parking lot combined with a wooded drainage area with limited understory growth and exposed soil, this site will contribute excess sediment and nutrients into the lower basin.

Photo 7: Parking Lot Area for Site 4

Photo 8: Natural Drainage Swale Which Drains From Parking Lot to Tibbetts Pond

Recommendation Site 4: The recommended Best Management Practice (BMP) for Site 4 is to modify the existing natural drainage swales surrounding the parking area to provide a stabilized vegetated conveyance system for the water to drain from the parking lot and travel to the pond. Instead of having a soil and rock bottom, as shown in Photo 7, the drainage system will be lined with vegetation that filter pollutants and conveyance features to slow sediment transport into the lower basin. This will allow for the volume of water conveyed to the pond during storm events to be reduced and more spread out over time, as the BMP will include features such as riprap and stone check dams to slow the flow of water as it drains from the parking lot to the stream. These measures will reduce the overall amount of pollutants and TSS entering the pond.

Estimated Costs Site 4: The approximate cost for design, permitting, and implementation of this BMP is anticipated to be between $100,000 and $200,000

SITE 5: TERESA AVENUE GRASSED AREA

Site 5 is located at the intersection of Borghild Avenue and Teresa Avenue, next to Lincoln High School. At the intersection, there is a grassed area next to the sidewalk that contains the discharge points for several underdrains stemming from Lincoln High School. These underdrains service the Lincoln High School track and field area and can be shown in Photo 9. As shown, these underdrains convey excess water from the high school field and discharge them on to this grass area. Additionally, there is an inlet at this location that captures runoff from Teresa Avenue. The underdrains and inlet both convey stormwater to a piped stormwater conveyance system that runs down the center of Teresa Avenue, eventually discharging to Tibbetts Pond. The drainage area for the underdrain and stormwater conveyance system consists of the field area of Lincoln High School, Teresa Avenue, as well as the surrounding streets of Borghild Avenue, Patricia Place, and Frum Avenue. The high amount of impervious asphalt contained in this drainage area results in a high amount of sediment and pollutants discharged into the stormwater from this location. The underdrain system under the field complex can contain undesirable pollutants from fertilization, that directly impacts the water quality of a receiving body of water.

Photo 9: Grassed Area Off of Teresa Avenue, With Underdrains Stemming from the Wall Area

Recommendation Site 5:
Due to the grassed shoulder and the potential usefulness of a filtration-based system, the proposed Best Management Practice (BMP) for this location would be the installation of a rain garden. This rain garden would replace the grassed area shown above and would be constructed with vegetation to increase pollutant filtration from stormwater. Additionally, the inlet on Teresa Avenue will be retrofitted to divert runoff into the rain garden system in order to filter as much stormwater from the road as possible. This rain garden would be able to discharge runoff from larger storm events into the stormwater sewer system further down the road. This addition would allow

for the filtration of stormwater runoff from the surrounding impervious street areas, as well as the collection of pollutants from the field underdrain area before that water travels to Tibbetts Pond.

Estimated Costs Site 5: The approximate cost for design, permitting, and implementation of this BMP is anticipated to be between $150,000 and $250,000

SITE 6: TIBBETTS BROOK PARK WETLAND SYSTEM

The entire Tibbetts Brook Park wetland system is the location for Site 6. Located north of the Tibbetts Brook Aquatic Complex, this site consists of Tibbetts Brook, a surrounding wetland area, a grass field, a gravel parking lot, and various turf fields bordering the northern portion of the site. This site is used for recreation, with sporting events conducted on the fields, and walking paths throughout the wetland portion of the site. The layout of this site can be seen in Figure 18 below. The wetland system is comprised of three branches of Tibbetts Brook, all conveying from different locations around Yonkers. Encompassing the drainage area for this site, these three branches extend from various underground conveyance systems, with the middle branch near the parking lot containing the highest flow. These conveyance systems acquire stormwater from residential areas, as well as impervious roads further upstream of the site. The branches then converge on the eastern side of the side, before traveling south and discharging into the retention pond at the Tibbetts Brook Aquatic Complex, after traveling under one final culvert conveyance system. Site 6 would be the greatest contributor of additional sediment and unwanted nutrients into Tibbetts Pond for this entire practice area, due to it containing the largest drainage area.

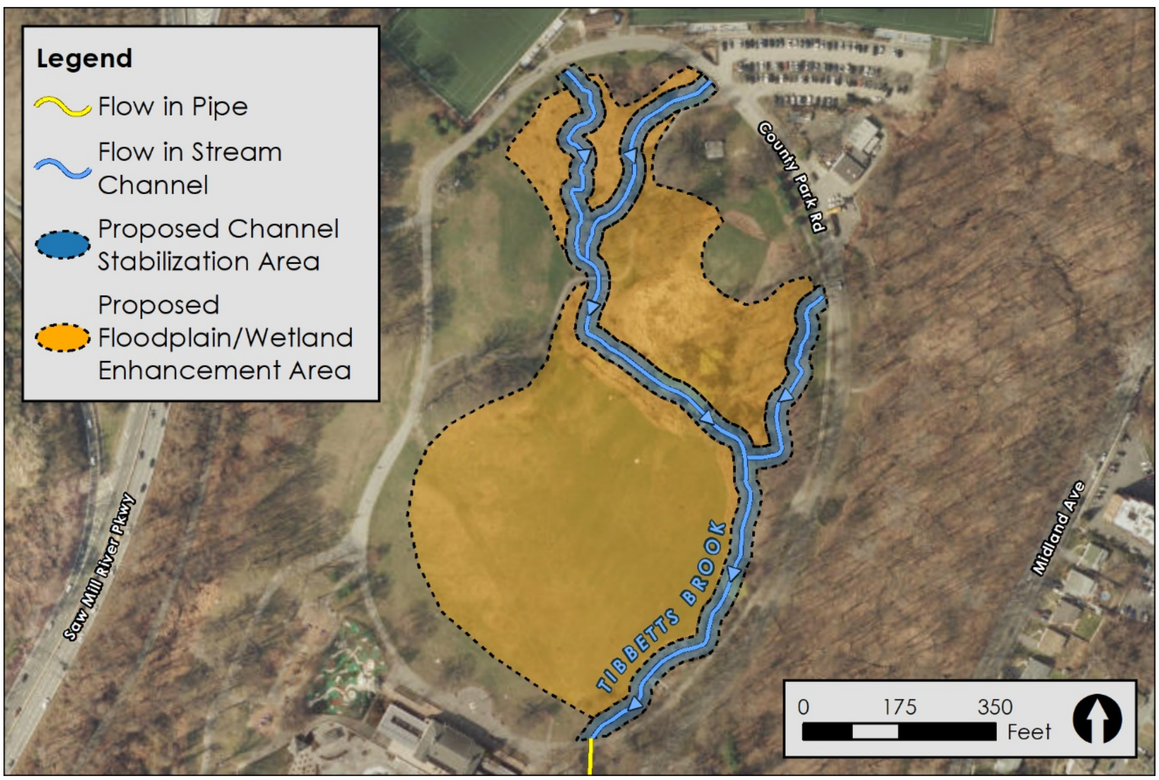


Figure 18: Site 6 Wetland System BMP Overview

Recommendation Site 6 Wetland Area:

The Site 6 wetland area BMP improvements can be shown above in Figure 18. These improvements will center around the three stream branches extending on to the site. The areas closest to the stream branches will undergo channel stabilization, shown in blue on Figure 18. This measure will modify the stream channel to allow for more stable stream banks by re-shaping them or adding riprap material to them, which can reduce sediment that flows into the stream during storm events. The stream banks will also contain aquatic vegetation, to aide in the stabilization of the stream bank, as well as to filter any pollutants from the stream system before its conveyed into Tibbetts Pond.

To compliment this, a wetland and floodplain enhancement will be conducted on surrounding applicable areas, shown in orange on Figure 18. The enhancement will include earthwork to create a more complex wetland environment surrounding the stream system. This process includes the introduction of new areas for water to pool, as well as re-grading areas where drainage could be improved. This allows for water flowing through these three tributary streams to be contained within this site longer, reducing the "first flush" runoff volume from storms, which contribute high amounts of sediment and pollutants into aquatic systems when they occur. Native plants will be planted in this area, adding a necessary natural aquatic filtration mechanism into the wetland system. This will greatly reduce the amount of sediment, TSS, TP, and any other pollutants entering Tibbetts Pond from this location.

PHOTO 10: GRAVEL PARKING LOT ON NORTHERN SIDE OF SITE 6

Recommendation Site 6 Parking Area:
To add to the stream stabilization and wetland BMP's above, the gravel parking lot located on the north portion of the site will also be modified. This modification will include the conversion of the center area of the parking lot, shown in Photo 10, into a rain garden. This parking lot is graded so that all stormwater runoff will drain to the middle Branch of Tibbetts Brook in the Site 6 wetland system. Adding a rain garden in this location will give the gravel parking lot an area to drain and filter all stormwater runoff before the runoff reaches the mouth of the tributary stream. Rain gardens work by collecting stormwater within their surface system, and filtering it through their soil, plant, and stone filter systems before discharging. Gravel parking lots contain a high amount of sediment and pollutants from parked cars, so treating this area with a rain garden before conveying the stormwater to the wetland system and beyond will improve water quality further downstream at Tibbetts Pond. **Estimated Costs Wetland Area:** The approximate cost for design, permitting, and implementation of this BMP recommendation is anticipated to be between $1,750,000 and $2,700,000.

Estimated Costs Parking Area: The approximate cost for design, permitting, and implementation of this BMP recommendation is anticipated to be between $250,000 and $300,000.

SITE 7: COOK AVENUE WETLAND AREA

Site 7 is located to the north of Site 6, on the other side of the Cross County Parkway, and is the upstream extension of Tibbetts Pond Brook. This site is located to the west of Cook Avenue, containing a wetland area and a pump/treatment station. An overview of the site can be shown on figure 19. The surrounding residential areas, commercial areas, and impervious roads make up this site's drainage area. Additionally, Tibbetts Pond Brook conveys water into the site from HF Redmond Jr. Memorial Park further upstream. Once the water from the park reaches this site and passes through the pump/treatment station, it continues its path further south to a large underground culvert that crosses under the Cross County Parkway. This culvert discharges to the middle stream of Site 6, before continuing to Tibbetts Pond. Due to the high amount of impervious areas that drain to this location, as well as the sites large drainage area, this site is a large contributor of sediment and pollutants that enter Tibbetts Pond.

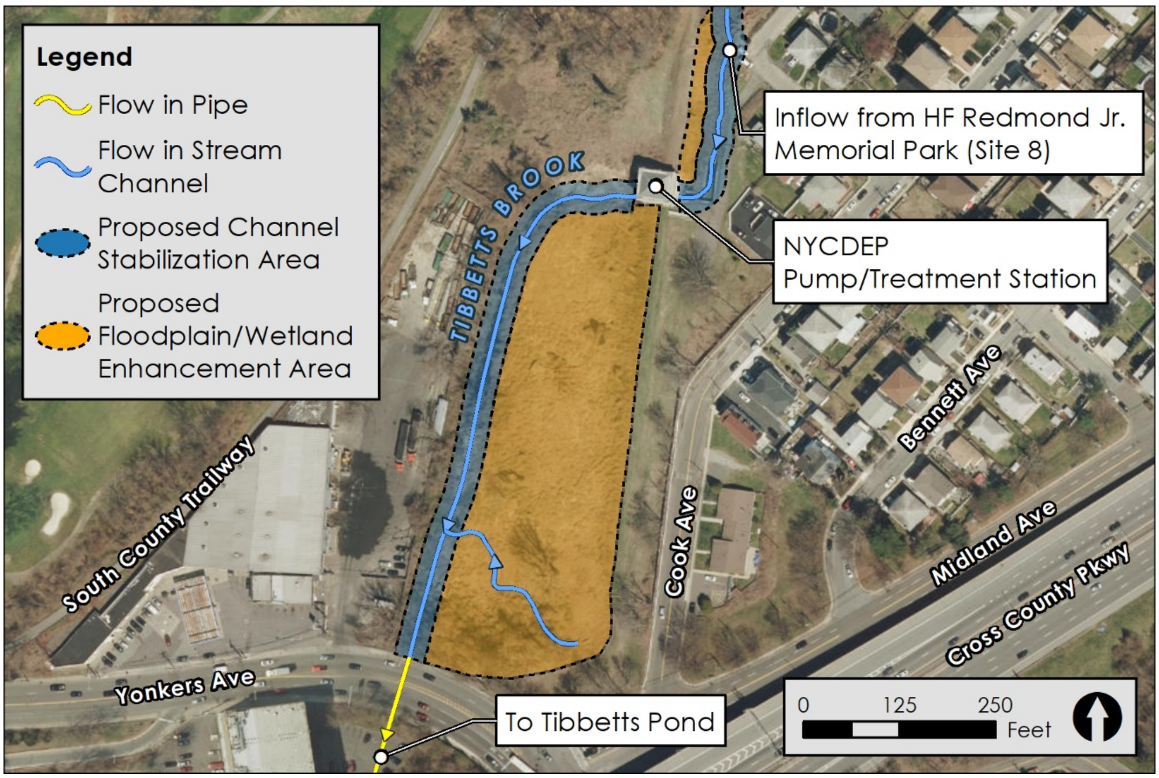


Figure 19: Site 7 Overview

Recommendation Site 7: Due to the large open wetland and stream area, conducting a stream stabilization and wetland enhancement procedure is recommended. Site 7 will have measures similar to the wetland area within Site 6. Shown in the blue area of Figure 19 above, areas closest to the stream will receive stream channel stabilization measures. These measures are a combination of earthwork to reduce steep channel bank slopes, as well as the addition of various channel bank features, such as riprap and aquatic vegetation. In appropriate areas, floodplain and wetland enhancement can occur for this site. Typical enhancement features include constructing berms and dikes to provide shallow pools, planting wetland vegetation to provide water quality benefits and wildlife habitats, and water control structures to control the permanent pool volumes and manage runoff from larger storm events. The combination of channel stabilization efforts and wetland enhancement will reduce the runoff volume conveyed downstream from this site due to storm events by allowing the water volume to stay in the wetland area longer. These actions would reduce the sedimentation and pollution addition into the pond further downstream by providing more natural filtration mechanisms, as well as allow more time for stormwater runoff to be filtered. The addition of native plants and vegetation will also greatly reduce the pollutant volume of the water contained in the water column as it leaves this site as well, to aide in this effort.

Estimated Costs Site 7: The approximate cost for design, permitting, and implementation of this BMP recommendation is anticipated to be between $2,000,000 and $3,000,000.

SITE 8: HF REDMOND JR. MEMORIAL PARK

Located north of Site 7, and to the east of the Dunwoodie golf course, is Site 8. This site is HF Redmond Jr. Memorial Park, which contains various recreational facilities and grassed baseball fields used by park-goers. Tibbetts Pond Brook passes through this site on its way south towards Site 7 and Tibbetts Pond. The location of the brook within the site can be shown in Photo 11. This sites drainage area is comprised of the grassed field areas from the park itself, as well as a large number of residential areas and roadways, which drain into Tibbetts Pond Brook further north of the site. The portion of the brook passing through Site 8 contains no buffer area between the grassed slopes and the brook itself. Because of this, stormwater runoff from the surrounding impervious and grassed areas can flow directly into the brook, adding unnecessary pollutants into the brook from this location.

Photo 11: Tibbetts Brook Flowing Through HF Redman Memorial Park

Recommendation Site 8: The conversion of a portion of the surrounding grassed stream bank to a stream stabilization area would be the recommended Best Management Practice (BMP) for this location. This measure would replace the grassed sides of the stream channel with riprap or other material, and have earthwork conducted in this location for stabilization purposes. Plants that support a healthy stream ecosystem would be brought into this area and planted as well to support streambank life. This vegetated stream stabilization area will provide a buffer for the runoff from the grassed areas, reducing the amount of sediment and pollutants directly entering the brook from surface flow. These plants will also be able to sequester any excess nutrients from the brook that were added into it further north from the residential areas. Improvements like these along Tibbetts

Pond Brook will help improve water quality for Tibbetts Pond further south by reducing harmful sediment and pollutant additions into the watershed system from this location.

Estimated Costs Site 8: The approximate cost for design, permitting, and implementation of this BMP recommendation is anticipated to be between $500,000 and $750,000.

5.2.2. GENERAL RECOMMENDATIONS

Along with the specific practices listed for the Best Management Practices (BMP's) at all 8 sites, Princeton Hydro also provides the following general recommendations for bank stabilization and riparian zone enhancement 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 vegetation resides. Sometimes, these locations can have vegetation enhancements to introduce more of these type of aquatic plants into a specific area. Additionally, applying bank stabilization measures of reducing bank slopes and stabilizing areas of exposed soil near bodies of water will aide in this riparian zone enhancement process. While some areas are specifically defined within the following sites, this recommendation should be broadly applied to any area within the watershed that would need it. *Please note, these general recommendations are listed in order of priority*.

DEFINED STABLIZED ACCESS POINTS

Throughout the park there are multiple locations for the 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.

RIPARIAN ZONE ENHANCEMENT

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

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 owned park.

6. CONCLUSIONS AND ADDITIONAL RECOMMENDATIONS

Tibbetts Pond, despite being immediately surrounded by parkland, features a developed watershed that contributes a relatively high nutrient and sediment load. Over the course of the pond's history, this has resulted in the sedimentation and shallowing of the waterbody and the advancement of the eutrophication process. The lower basin features a very large population of invasive water chestnut that covers almost the entirety of the waterbody at peak seasonal growth. In addition to watershed-based loads, significant internal loading of phosphorus also occurs each year due to periods of bottom anoxia and bioturbation by carp and goldfish. Water quality surveys yielded consistently high total phosphorus concentrations and low Secchi depths, as well as elevated concentrations of chlorophyll *a*. While the plankton community was often observed to contain abundant densities of green algae and diatoms, cyanobacteria were typically not observed in high densities, with only the early August event yielding a common density of *Dolichospermum*.

In addition to the watershed-based implementations listed above, Princeton Hydro recommends the following. *Please note, these general recommendations are listed in order of priority.*

6.1 CONTINUED HARVESTING AND MANAGEMENT OF WATER CHESTNUT POPULATIONS

As mentioned above, the Westchester Parks Foundation conducts both mechanical harvesting and hand-harvesting events on the lower basin of Tibbetts Pond to control the growth of the invasive plant water chestnut. Princeton Hydro highly recommends the continuation of this practice. Water chestnut not only negatively impacts the recreational value of a waterbody by reducing boat navigability and posing a physical hazard, but also can have numerous ecological impacts. For example, it is likely that the low dissolved oxygen observed during parts of 2020 was likely in part a product of reduced atmospheric mixing caused by the dense mats of water chestnut. Removal efforts should begin in June when plants have begun to grow to the water's surface but have not yet begun forming their characteristic sharp fruit. Benefits may result from conducting several removal events prior to mid-July or August when the plants begin dropping these reproductive structures, adding to the seedbank. With a population as high as the one observed in Tibbetts Park Pond, the population's seedbank is likely very high, and aggressive removal efforts will likely need to continue for several consecutive years before visible reductions in the population are observed. Treatments with an herbicide such as 2,4-D, Clipper or Procellacor may also aid in reducing the seasonal biomass, however these treatments do not usually affect fruit in the bottom sediment.

Should the Westchester Parks Foundation conduct a dredging effort on the lower basin, a large percentage of the water chestnut seed bank will likely be removed. Princeton Hydro strongly recommends continuing to survey for and remove water chestnut plants for several years after dredging, however, in order to reduce the remaining population and prevent the seedbank from increasing to pre-dredging numbers.

6.2 ASSESSMENT AND REMOVAL OF CARP POPULATIONS

As discussed in a previous section, a large population of carp or goldfish can result in a significant increase to a lake or pond's seasonal phosphorus load due to these species' tendency to churn bottom sediments when feeding. As such, reductions in seasonal phosphorus loads maybe achieved through the removal of a significant portion of the pond's carp and goldfish population. The lowering of the pond prior to a dredging operation would be an opportune time to conduct a removal effort, as fish will be condensed into a smaller area. Fish can be removed using various methods, such as the employment of gill-nets or by electrofishing. Prior to removal efforts however, a fisheries survey should be conducted on the pond in order to assess the current population and obtain a more accurate estimate of carp and goldfish biomass. This will both allow for a more accurate estimation of annual carp-based phosphorus loading and assist the Westchester Parks Foundation in setting goals for removal and predicted decreases in phosphorus. A small fish survey should also be conducted on the upper basin; should this pond have a higher number of these fish than initially thought, a removal may need to occur here as well in order to prevent the re-establishment of a larger population downstream in the lower basin. Permits will need to be obtained from the NYDEC by the Westchester Parks Foundation for the scientific collection of fish prior to any surveys or removals.

6.3 FLOATING WETLAND ISLANDS

A potential solution for nutrient removal within either the upper or lower basin of Tibbetts Pond 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 a public park setting such as Tibbetts Pond, FWIs have the added benefit of being potentially useful as an interpretive/educational piece for park users, particularly if accompanied by on-shore interpretive signage. FWIs are often an option recommended for the control of smaller concentrations of phosphorus after other management methods have been enacted, and, as such, this is likely a project the Westchester Parks Foundation may want to pursue in the future, after the lower basin has been dredged and any watershed-based solutions have been implemented.

6.4 DREDGING

Dredging is the removal of sediments that have accumulated on the bottom of a waterbody. The Westchester Parks Foundation has expressed interest in dredging the lower basin due to the accumulation of sediment and the subsequent growth of a large population of water chestnut. A bathymetry of the lower basin conducted in November of 2019 showed the lower basin's average sediment depth to be 2.8', with areas of 4' of sediment present along the east and western edges of the southern portion of the waterbody, as well as in the northern shallower areas. Dredging a waterbody can have a variety of positive effects, including the physical removal of a large amount of nutrients and a potentially large reduction in the water chestnut seedbank. However, prior to dredging operations various local and state-level permits will need to be obtained. Additionally, the Westchester Park Foundation will need to conduct a dredging feasibility study, in which any additional topographic information is collected in order to generate the signed and sealed engineering drawings required for the permit. This also includes detailed chemical tests of sediment samples in order to assess for containments and physical qualities, as these will in part determine where and how dredge spoils can be disposed of.

While the upper basin does not contain a dense population of water chestnut, dredging efforts in this waterbody would nonetheless have benefits to both waterbodies. As discussed above, the upper basin likely serves as a sedimentation basin, allowing a bulk of the sediment from incoming stormwater flows to settle before entering the lower basin. However, overall sediment thickness throughout the basin, as found during the bathymetry, has accumulated to a point where the basin likely becomes a source of excess sediment to the lower basin, particularly as flows increase during larger storm events.

6.5 STORMWATER SAMPLING

In order to assess the effectivity of the watershed implementations detailed above, Princeton Hydro recommends the collection of water quality samples during storm events. While the watershed model allows for estimates in nutrient and sediment loads entering a waterbody over the course of an entire year, stormwater sampling provides a "snapshot" of nutrient concentrations as they enter the lake from specific areas. Conducting several of these events over time downstream of proposed watershed implementations can allow for the tracking of nutrient and sediment concentrations as an assessment of pollutant being removed by each management practice. Usually, stormwater samples are analyzed by a certified laboratory for concentrations of total phosphorus, total nitrogen, and total suspended solids.

6.6 CONTINUED WATER QUALITY SAMPLING

Princeton Hydro recommends the continued sampling of in-pond water quality in a fashion similar to that conducted in 2020. This not only allows for the establishment of long-term trends, but allows the Westchester Parks Foundation 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 five events occurring over the course of a year, and each event featuring the sampling of *In-situ* and discrete water quality data. A long-term water quality monitoring plan such as this one can be used to assess the changes in water quality post-dredging and/or as an effect of one or more of the other watershed or in-pond recommendations made above.

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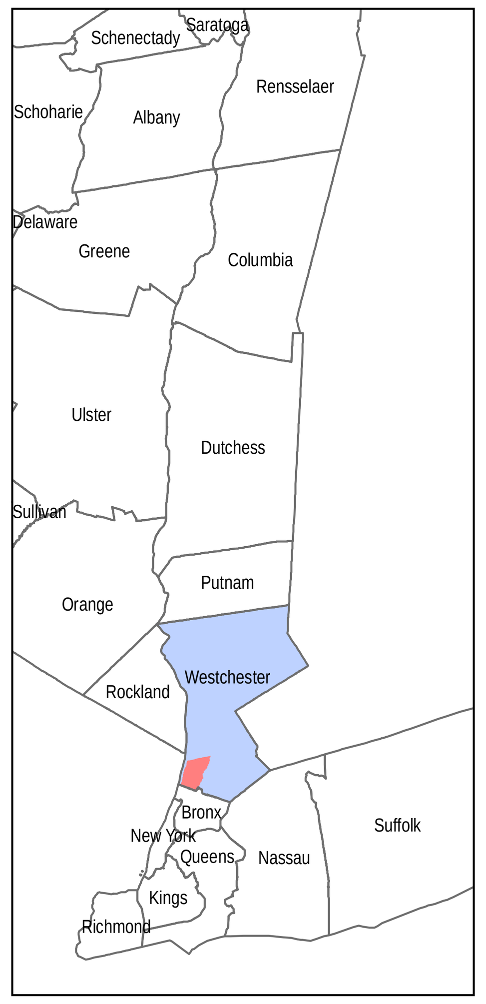
Appendix I:

Tibbetts Pond Bathymetric Maps

File: \\ph-dc-sic\Projectfiles\1924\Projects\1924001\GIS\MXD\Lower_TOS.mxd, 12/9/2019, Drawn by jpbell, Copyright Princeton Hydro, LLC.

NEW YORK COUNTY MAP



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NEW JERSEY, 08081
*with offices in NJ, PA and CT

N

1 inch = 60 feet

0 60 120 Feet

NOTES:

Bathymetric study conducted by Princeton Hydro on November 4, 2019. Study conducted with a calibrated survey rod and a Leica GS14 survey grade GPS unit.

Water Surface Elevation (WSEL) at time of study: 40.5 NAVD88. A bench mark was set adjacent. Elevation of benchmark collected with a Leica GS14 GPS unit. WSEL calculated with the bench mark, a site level and Philadelphia rod.

All data modeling, contouring and volume analyses completed with ESRI's ArcGIS software.

Map Projection:
NAD 1983 StatePlane New York East FIPS 3101 Feet

LOWER TIBBETTS POND
TOP OF SEDIMENT
ELEVATION CONTOURS

WESTCHESTER PARKS FOUNDATION
TIBBETTS BROOK PARK
LAKE MANAGEMENT PLAN
YONKERS, WESTCHESTER CO, NY

Legend

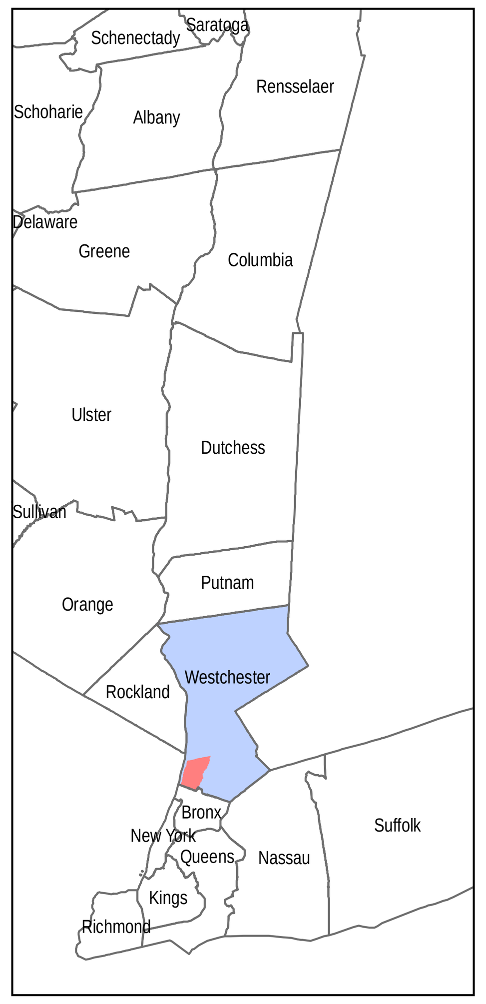
Study Area Boundary

Top of Sediment Contours

DRAFT

File: \\ph-dc-sic\Projectfiles\1924\Projects\1924001\GIS\MXD\Lower_Sediment.mxd, 12/9/2019, Drawn by jpbell, Copyright Princeton Hydro, LLC.

NEW YORK COUNTY MAP



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All data modeling, contouring and volume analyses completed with ESRI's ArcGIS software.

Map Projection:
NAD 1983 StatePlane New York East FIPS 3101 Feet

LOWER TIBBETTS POND
SEDIMENT THICKNESS
CONTOURS

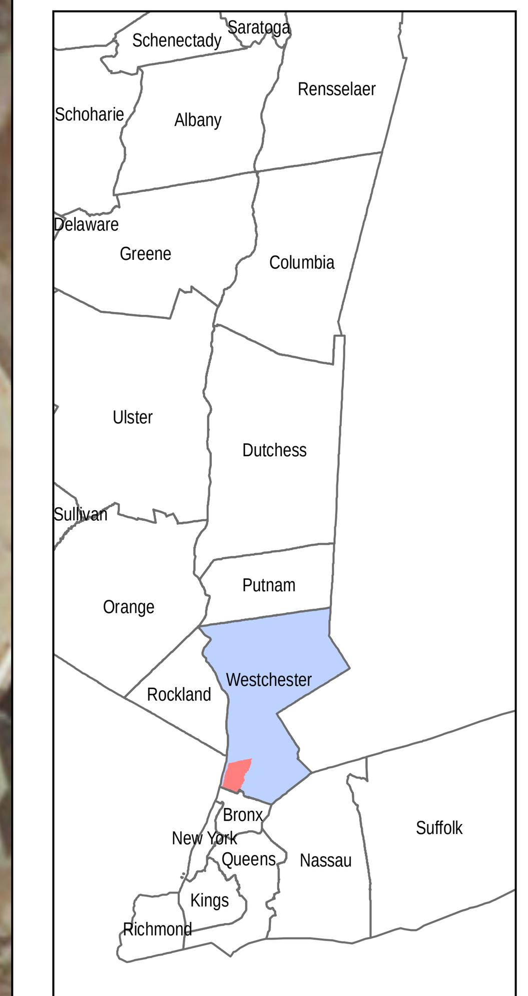
WESTCHESTER PARKS FOUNDATION
TIBBETTS BROOK PARK
LAKE MANAGEMENT PLAN
YONKERS, WESTCHESTER CO, NY

Legend
- Study Area Boundary
- Sediment Thickness Contours (in Feet)

DRAFT

File: \\ph-dc-sic\Projectfiles\1924\Projects\1924001\GIS\MXD\Upper_TOS.mxd, 12/9/2019, Drawn by jpbell, Copyright Princeton Hydro, LLC.

NEW YORK COUNTY MAP



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N

1 inch = 30 feet

0 30 60 Feet

NOTES:

Bathymetric study conducted by Princeton Hydro on November 4, 2019. Study conducted with a calibrated survey rod and a Leica GS14 survey grade GPS unit.

Water Surface Elevation (WSEL) at time of study: 55.2 NAVD88. A bench mark was set adjacent. Elevation of benchmark collected with a Leica GS14 GPS unit. WSEL calculated with the bench mark, a site level and Philadelphia rod.

All data modeling, contouring and volume analyses completed with ESRI's ArcGIS software.

Map Projection:
NAD 1983 StatePlane New York East FIPS 3101 Feet

UPPER TIBBETTS POND
TOP OF SEDIMENT
ELEVATION CONTOURS

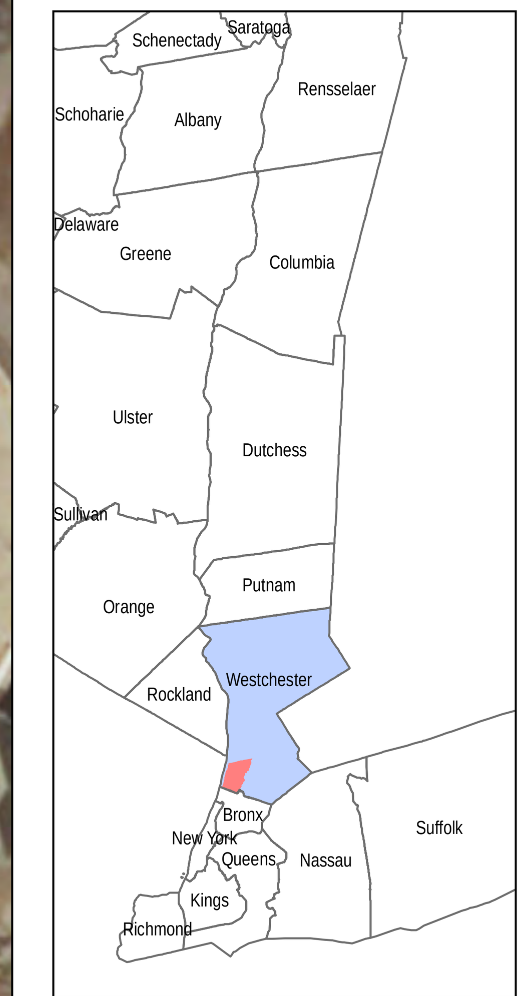
WESTCHESTER PARKS FOUNDATION
TIBBETTS BROOK PARK
LAKE MANAGEMENT PLAN
YONKERS, WESTCHESTER CO, NY

Legend
Study Area Boundary
Top of Sediment Contours

DRAFT

File: \\ph-dc-sic\Projectfiles\1924\Projects\1924001\GIS\MXD\Upper_Sed.mxd, 12/9/2019, Drawn by jpbell, Copyright Princeton Hydro, LLC.

NEW YORK COUNTY MAP



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N
1 inch = 30 feet
0 30 60 Feet

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All data modeling, contouring and volume analyses completed with ESRI's ArcGIS software.

Map Projection:
NAD 1983 StatePlane New York East FIPS 3101 Feet

UPPER TIBBETTS POND SEDIMENT THICKNESS CONTOURS

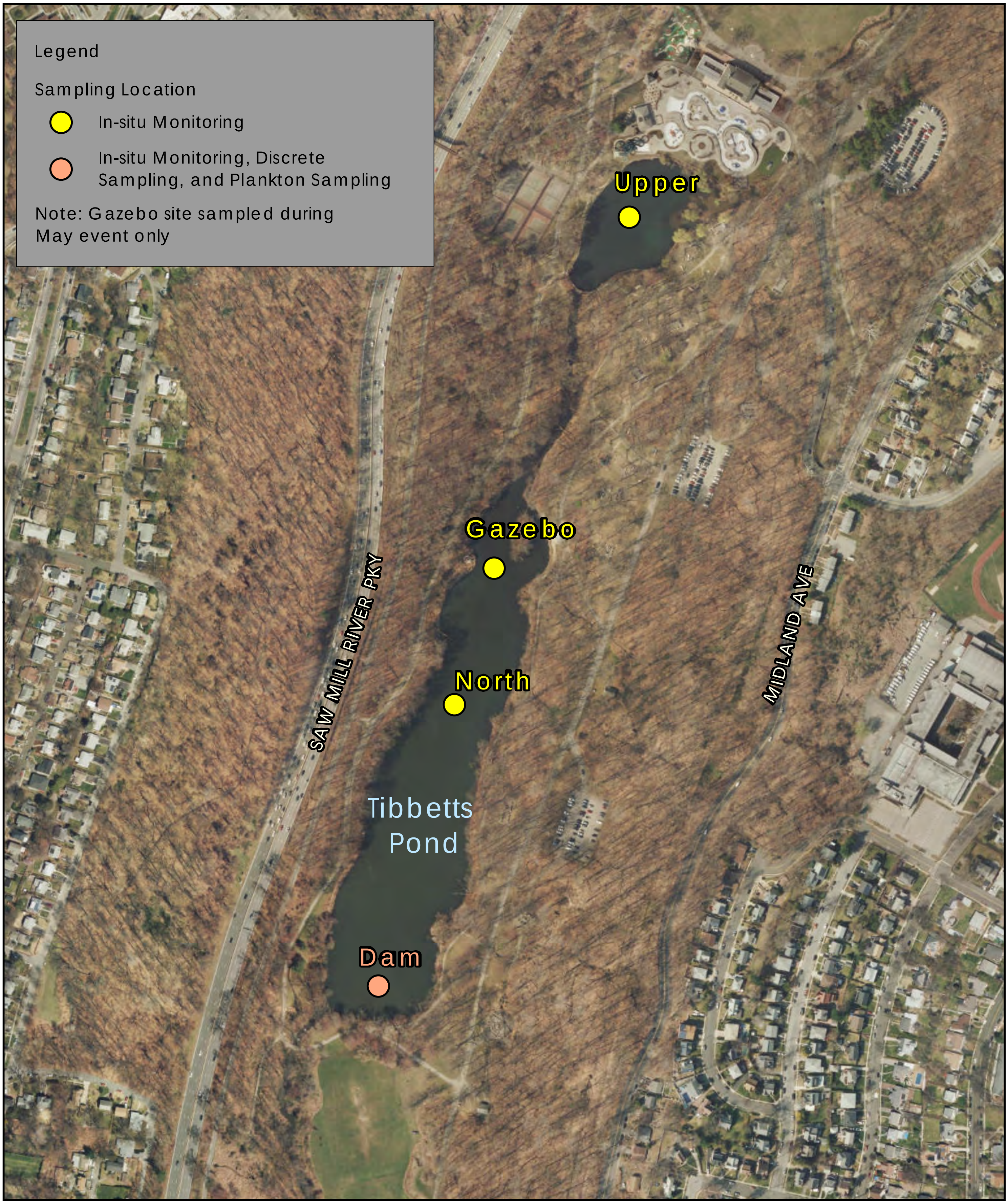
WESTCHESTER PARKS FOUNDATION
TIBBETTS BROOK PARK
LAKE MANAGEMENT PLAN
YONKERS, WESTCHESTER CO, NY

Legend
- Study Area Boundary
- Sediment Thickness Contours (in Feet)

DRAFT

Appendix II:

Water Quality Sampling Locations



NOTES:
1. Sampling locations are approximate.
2. Aerial imagery obtained from ESRI World Imagery.

SAMPLING MAP

0 200 400 Feet

Map Projection: NAD 1983 2011 StatePlane New York East FIPS 3101 Ft US

TIBBETTS POND RESTORATION AND MANAGEMENT PLAN
WESTCHESTER PARKS FOUNDATION
CITY OF YONKERS
WESTCHESTER COUNTY, NEW YORK

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Appendix III:

In-situ Water Quality Data

In-Situ Monitoring for Tibbetts Pond 5/28/2020								
Station	DEPTH (meters)			Temperature	Specific Conductance	Dissolved Oxygen		pH
	Total	Secchi	Sample	°C	mS/cm	mg/L	% Sat.	S.U.
Dam	1.50	0.80	0.1	22.77	0.668	14.19	163.6	9.00
			0.5	22.46	0.690	13.54	155.5	8.88
			1.0	21.33	0.749	8.36	93.8	8.09
Gazebo	0.20	0.20	0.1	21.04	0.780	6.37	71.1	7.65
Upper	0.45	0.45	0.1	19.64	0.736	5.47	59.2	7.54

In-Situ Monitoring for Tibbetts Pond 6/30/2020								
Station	DEPTH (meters)			Temperature	Specific Conductance	Dissolved Oxygen		pH
	Total	Secchi	Sample	°C	mS/cm	mg/L	% Sat.	S.U.
Dam	1.50	0.80	0.1	25.31	0.745	6.51	74.2	6.71
			0.5	25.14	0.743	5.71	69.5	7.03
			1.0	24.80	0.741	3.53	42.6	6.99
			1.5	24.55	0.766	0.92	11.5	6.61
North	0.70	0.70	0.1	24.21	0.701	2.17	25.9	7.02
			0.5	23.37	0.705	1.68	19.7	6.89
Upper	0.50	0.50	0.1	24.14	0.673	6.90	82.4	7.54

In-Situ Monitoring for Tibbetts Pond 7/20/2020								
Station	DEPTH (meters)			Temperature	Specific Conductance	Dissolved Oxygen		pH
	Total	Secchi	Sample	°C	mS/cm	mg/L	% Sat.	S.U.
Dam	1.50	0.90	0.1	27.58	0.441	5.51	70.8	6.96
			0.5	24.31	0.537	0.38	4.6	6.66
			1.0	23.73	0.549	0.17	2.0	6.69
North	0.80	0.80	0.1	26.07	0.552	3.03	36.0	6.85
			0.5	24.12	0.668	0.72	9.7	6.78
Upper	0.40	0.40	0.1	27.63	0.687	4.67	59.2	7.11

In-Situ Monitoring for Tibbetts Pond 8/5/2020								
Station	**DEPTH (meters)**			**Temperature**	**Specific Conductance**	**Dissolved Oxygen**		**pH**
	Total	**Secchi**	**Sample**	**°C**	**mS/cm**	**mg/L**	**% Sat.**	**S.U.**
Dam	**1.50**	**0.50**	**0.1**	26.57	0.547	3.78	47.3	7.21
			0.5	25.31	0.552	2.73	33.3	7.12
			1.0	25.16	0.543	2.35	28.1	7.06
North	**0.80**	**0.80**	**0.1**	27.20	0.534	4.05	58.8	7.28
			0.5	24.89	0.411	1.72	20.9	7.09
Upper	**0.50**	**0.50**	**0.1**	25.24	0.481	5.43	66.4	7.42

In-Situ Monitoring for Tibbetts Pond 10/1/2020								
Station	**DEPTH (meters)**			**Temperature**	**Specific Conductance**	**Dissolved Oxygen**		**pH**
	Total	**Secchi**	**Sample**	**°C**	**mS/cm**	**mg/L**	**% Sat.**	**S.U.**
Dam	**1.40**	**0.30**	**0.1**	19.96	0.367	5.17	56.9	7.17
			0.5	19.89	0.330	5.07	55.8	7.06
			1.0	19.85	0.337	4.73	51.9	7.00
North	**0.50**	**0.50**	**0.1**	18.48	0.303	5.07	54.2	7.21
Upper	**0.50**	**0.50**	**0.1**	17.95	0.377	5.49	58.8	7.18

In-Situ Monitoring for Tibbetts Pond 10/26/2020								
Station	**DEPTH (meters)**			**Temperature**	**Specific Conductance**	**Dissolved Oxygen**		**pH**
	Total	**Secchi**	**Sample**	**°C**	**mS/cm**	**mg/L**	**% Sat.**	**S.U.**
Dam	**1.50**	**0.70**	**0.1**	13.95	0.290	8.70	84.3	7.94
			0.5	13.94	0.291	8.85	86.0	7.77
			1.0	13.93	0.290	8.95	86.7	7.62
North	**0.40**	**0.40**	**0.1**	12.74	0.361	7.00	65.3	7.49
Upper	**0.50**	**0.50**	**0.1**	12.73	0.374	6.80	63.5	7.61

Appendix IV:
Discrete Water Quality Data

Tibbetts Pond - 2020 Discrete Data							
Date	**STATION**	**Chlorophyll a (ug/L)**	**NH3-N (mg/L)**	**NO2+NO3-N (mg/L)**	**SRP (mg/L)**	**TP (mg/L)**	**TSS (mg/L)**
5/28/2020	Dam Surface	41.0	0.09	ND<0.01	0.019	0.06	6.8
	Dam Deep	35.6	0.02	0.01	0.006	0.11	7.2
6/30/2020	Dam Surface	49.0	0.04	ND<0.01	0.015	0.10	10
	Dam Deep	67.3	0.03	ND<0.01	0.012	0.13	12
7/20/2020	Dam Surface	52.8	0.04	ND<0.01	0.066	0.14	7
	Dam Deep	31.3	0.03	ND<0.01	0.028	0.23	10
8/5/2020	Dam Surface	42.5	0.07	0.04	0.030	0.15	17
	Dam Deep	39.6	0.04	0.04	0.031	0.15	11
10/1/2020	Dam Surface	36.3	0.27	0.22	0.174	0.13	16
	Dam Deep	43.9	0.21	0.21	0.039	0.17	23
10/28/2020	Dam Surface	78.7	0.07	0.22	0.002	0.31	10.4
	Dam Deep	73.4	0.07	0.22	0.005	0.32	10.8
"ND" = Non-detect (Below the minimum detectable range)							

Appendix V:

Phytoplankton and Zooplankton Sample Results

Phytoplankton and Zooplankton Community Composition Analysis								
Sampling Location: Tibbetts Pond			**Sampling Date: 5/28/2020**					
Site 1: Dam								
Phytoplankton								
Bacillariphyta (Diatoms)	**1**		**Chlorophya (Green Algae)**	**1**		**Cyanophyta (Blue-Green Algae)**	**1**	
Asterionella	R		*Pediastrum*	R				
Fragilaria	R							
Melosira	P							
Tabellaria	P							
Chrysophyta (Golden Algae)						**Pyrrhophyta (Dinoflagellates)**		
Zooplankton								
Cladocera (Water Fleas)	**1**		**Copecoda (Copepods)**	**1**		**Rotifera (Rotifers)**	**1**	
Ceriodaphnia	P		*Microcyclops sp*	C		*Keratella sp.*	P	
			Nauplii	C		*Brachionus*	C	
						Arthropoda (Arthropods)		
						Chironomidae	R	
Sites:	**1**		**Comments: 1m tow with 19.4 cm opening. Zooplankton-dominated. Single larval-stage fish present in tow**					
Total Phytoplankton Genera	5							
Total Zooplankton Genera	6							
			Phytoplankton Key: Bloom (B), Common (C), Present (P), and Rare (R)					
			Zooplankton Key: Dominant (D), Abundant (A), Present (P), and Rare (R);					

Phytoplankton and Zooplankton Community Composition Analysis

Sampling Location: Tibbetts Pond			Sampling Date: 6/30/2020					
Site 1: Dam								
Phytoplankton								
Bacillariphyta (Diatoms)	**1**		**Chlorophya (Green Algae)**	**1**		**Cyanophyta (Blue-Green Algae)**	**1**	
Cyclotella	R		*Chlorella*	P				
Fragilaria	P		*Golenkinia*	A				
Melosira	A		*Oocystis*	R				
Surirella	R		*Scenedesmus*	C				
Chrysophyta (Golden Algae)			*Pediastrum*	P		**Euglenophyta (Euglenoids)**		
Dinobryon	A							
						Pyrrhophyta (Dinoflagellates)		
						Ceratium	C	
Zooplankton								
Cladocera (Water Fleas)	**1**		**Copecoda (Copepods)**	**1**		**Rotifera (Rotifers)**	**1**	
			Nauplii	A		*Keratella sp.*	C	
			Microcyclops sp	P		*Filinia*	P	
						Asplanchna	P	
						Brachionus	A	
						Arthropoda (Arthropods)		
Sites:	**1**		**Comments:**					
Total Phytoplankton Genera	11							
Total Zooplankton Genera	6							
			Phytoplankton Key: Bloom (B), Common (C), Present (P), and Rare (R)					
			Zooplankton Key: Dominant (D), Abundant (A), Present (P), and Rare (R);					

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Phytoplankton and Zooplankton Community Composition Analysis

Sampling Location: Tibbetts Pond		**Sampling Date: 7/20/20**			
Site 1: Dam					
Phytoplankton					
Bacillariphyta (Diatoms)	**1**	**Chlorophyta (Green Algae)**	**1**	**Cyanophyta (Blue-Green Algae)**	**1**
Fragilaria	P	*Gonium*	P		
		Selenastrum	C		
		Micratinium	C		
		Ankistrodesmus	C		
		Gloeotilla	P		
		Actinastrum	C		
		Golenkinia	P	**Euglenophyta (Euglenoids)**	
		Scenedesmus	P		
		Chlorella	A		
		Pandorina	C		
		Radiococcus	P		
Chrysophyta (Golden Algae)				**Pyrrhophyta (Dinoflagellates)**	
		Cryptomonads		*Ceratium*	P
Zooplankton					
Cladocera (Water Fleas)	**1**	**Copecoda (Copepods)**	**1**	**Rotifera (Rotifers)**	**1**
		nauplii	A	*Kellicottia*	C
		Cyclops	C		
		Mesocyclops	P		
Sites:	**1**	**Comments:**			
Phytoplankton Genera	12				
Zooplankton Genera	4				
		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)			

Princeton Hydro LLC

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Phytoplankton and Zooplankton Community Composition Analysis

Sampling Location: Tibbetts Pond | **Sampling Date: 8/5/20**

Site 1: Dam

Phytoplankton

Bacillariphyta (Diatoms)	**1**	**Chlorophyta (Green Algae)**	**1**	**Cyanophyta (Blue-Green Algae)**	**1**
Cyclotella	P	*Haematococcus*	P	*Dolichospermum*	C
Melosira	C	*Eudorina*	C	*Coelosphaerium*	P
		Pediastrum	R	*Microcystis*	R
		Ankistrodesmus	R	*Oscillatoria*	R
		Treubaria	C		
		Actinastrum	A		
		Closterium	R	**Euglenophyta (Euglenoids)**	
		Scenedesmus	C	*Phacus*	P
				Euglena	A
Chrysophyta (Golden Algae)				**Pyrrhophyta (Dinoflagellates)**	
Dinobryon	A	**Cryptomonads**			
		Cryptomonas	P		

Zooplankton

Cladocera (Water Fleas)	**1**	**Copecoda (Copepods)**	**1**	**Rotifera (Rotifers)**	**1**
Chydorus	R	nauplii	C	*Filinia*	A
Bosmina	R	*Microcyclops*	A	*Asplanchna*	P
				Polyarthra	R
				Keratella	P
				Brachionus	P
				Monostyla	P
				Tricocerca	R
				Platyias	R

Sites:	**1**
Phytoplankton Genera	18
Zooplankton Genera	12

Comments:

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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203 Exton Commons, Exton, PA 19341 : (610) 524-4220

Phytoplankton and Zooplankton Community Composition Analysis

Sampling Location: Tibbetts Pond			Sampling Date: 10/1/2020					
Site 1: Dam								
Phytoplankton								
Bacillariphyta (Diatoms)	**1**		**Chlorophya (Green Algae)**	**1**		**Cyanophyta (Blue-Green Algae)**	**1**	
Eunotia	P		*Chlamydomonas*	C				
Melosira	P		*Gloeotila*					
Rhizosolenia	P		*Pediastrum*	P				
			Scenedesmus	C				
Chrysophyta (Golden Algae)			*Sphareocystis*	P		**Euglenophyta (Euglenoids)**		
			Staurastrum	P		*Euglena*	P	
						Pyrrhophyta (Dinoflagellates)		
Zooplankton								
Cladocera (Water Fleas)	**1**		**Copecoda (Copepods)**	**1**		**Rotifera (Rotifers)**	**1**	
Bosmina sp.	R		*Nauplii*	P		*Keratella sp.*	P	
						Brachionus	C	
						Arthropoda (Arthropods)		
Sites:	**1**		**Comments:**					
Total Phytoplankton Genera	10							
Total Zooplankton Genera	4							
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					

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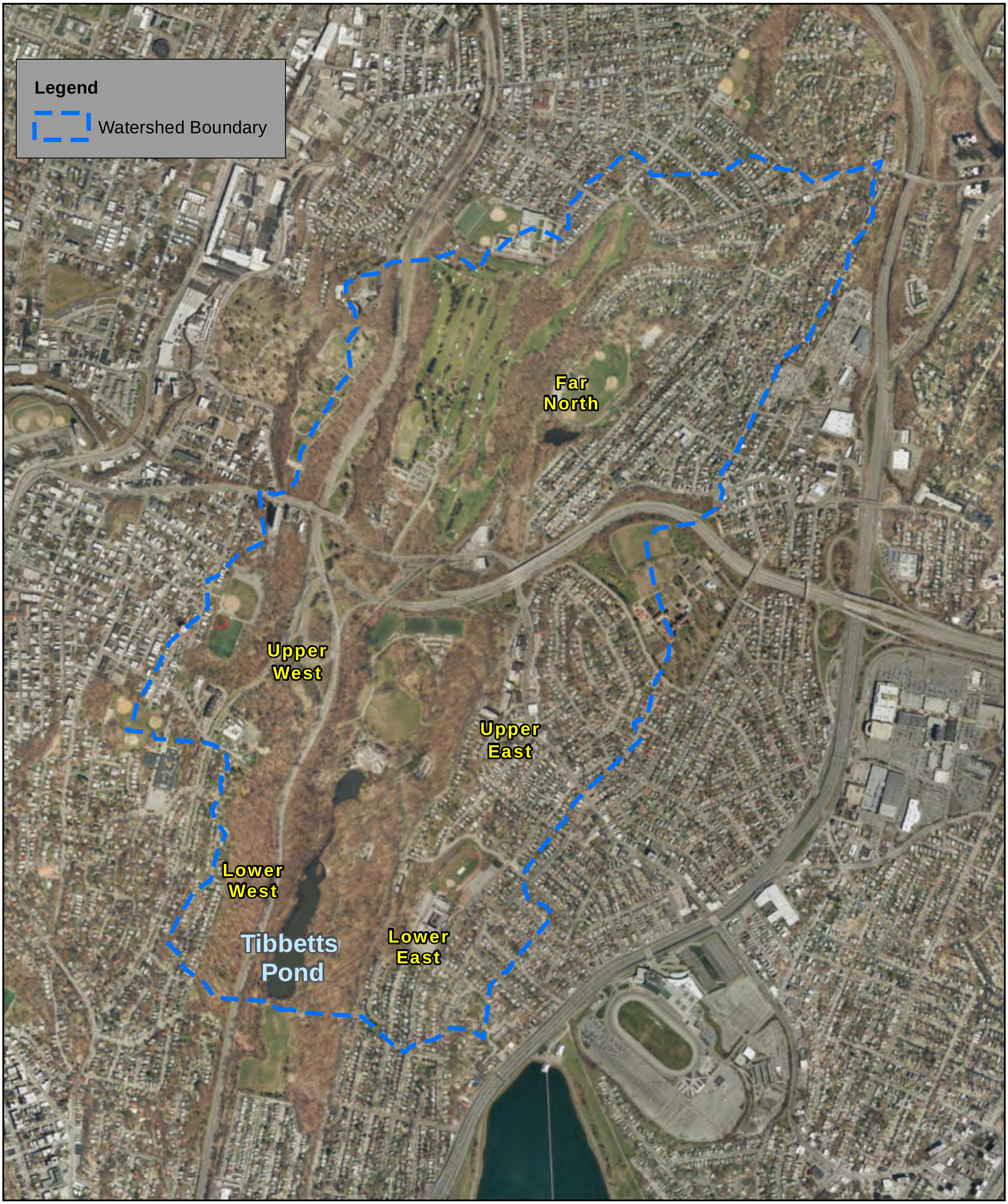
Phytoplankton and Zooplankton Community Composition Analysis

Sampling Location: Tibbetts Pond			**Sampling Date: 10/26/2020**					
Site 1: Dam								
Phytoplankton								
Bacillariphyta (Diatoms)	**1**		**Chlorophya (Green Algae)**	**1**		**Cyanophyta (Blue-Green Algae)**	**1**	
Melosira	C		*Actinastrum*	P		*Dolichospermum*	P	
			Chlorella	C				
			Coelastrum	R				
			Didymocystis	R				
Chrysophyta (Golden Algae)			*Pediastrum*	P		**Euglenophyta (Euglenoids)**		
			Scenedesmus	P		*Euglena*		
			Sphareocystis	P				
			Staurastrum	P		**Pyrrhophyta (Dinoflagellates)**		
			Tetradesmus	P		*Ceratium*		
Zooplankton								
Cladocera (Water Fleas)	**1**		**Copecoda (Copepods)**	**1**		**Rotifera (Rotifers)**	**1**	
						Asplanchna	R	
						Keratella sp.	P	
						Brachionus	A	
						Collotheca	R	
						Polyartha	C	
						Arthropoda (Arthropods)		
Sites:	**1**		**Comments:**					
Total Phytoplankton Genera	11							
Total Zooplankton Genera	5							
			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					

Appendix VI:
Tibbetts Pond Watershed Map



File: P:\1924\Projects\1924001\GIS\MXD\Subwatershed_Map.mxd, 3/3/2021, Drawn by jsmith, Copyright Princeton Hydro, LLC.

NOTES:
1. Watersheds were delineated by Princeton Hydro using 2012 DEM data obtained from the USGS National Elevation Dataset.
2. Aerial imagery obtained from ESRI World Imagery.

0 750 1,500 Feet

Map Projection: NAD 1983 2011 StatePlane New York East FIPS 3101 Ft US

WATERSHED MAP

TIBBETTS POND RESTORATION AND MANAGEMENT PLAN
WESTCHESTER PARKS FOUNDATION
CITY OF YONKERS
WESTCHESTER COUNTY, NEW YORK

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