TWILIGHT LAKE WATERSHED IMPLEMENTATION PLAN

BOROUGH OF BAY HEAD, OCEAN COUNTY, NEW JERSEY

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INTRODUCTION

The Borough of Bay Head (Bay Head) is a municipality in Ocean County, NJ that lies within the Barnegat Bay watershed and adjacent to the nearby Metedeconk River sub-watershed, both of which are impaired as evidenced by Total Maximum Daily Loads (TMDLs) established to address pathogen and phosphorus loading among other water quality impairments including dissolved oxygen, temperature, TSS, phosphorus, arsenic, and mercury (BUA, Smit, and Truhan, 2013). Twilight Lake is a focal point for this community in terms of aesthetics, ecological richness, and recreation. The lake, though without its own TMDL, still suffers a variety of water quality problems, including high densities of submerged vegetation, nuisance algal blooms (some of which could be harmful algal blooms (HABs), low dissolved oxygen (DO) and high amounts of sedimentation/turbidity.

The community and Bayhead Environmental Commission (BHEC) are very active in maintaining the health of Twilight Lake and the surrounding watershed and eagerly seek to address concerns about this waterbody. Bay Head submitted an application and was awarded funding through NJDEP's 319(h)-grant program for the development of a Watershed Based Management Plan (WBP) for Twilight Lake. The goal of the Management Plan is to identify the sources of water quality impairments and, through the USEPA nine-element approach, provide realistic and achievable management solutions to address these problems.

This WBP document addresses the nine (9) elements of a Watershed Plan as defined by the EPA (USEPA, 2008). These nine elements are meant to address all phases of a WBP from characterization to conceptual mitigation and practical design, cost, implementation, and evaluation. The following list represents a summarized and abbreviated description of the nine elements as outlined in the Handbook for Developing Watershed Plans to Restore and Protect Our Waters (USEPA, 2008).

1. Identification of causes and sources of pollution
2. An estimate of load reductions expected from management measures
3. A description of NPS management measures and implementation sites
4. Estimate the amount of technical and financial assistance to implement
5. Information and education component
6. Schedule for implementing the NPS management measures
7. A description of interim measurable milestones for implementation
8. Developing criteria to measure progress
9. Develop a monitoring component

Of particular concern is the load of phosphorus, nitrogen, and sediments to the lake through stormwater and through Barnegat Bay during tidal exchange and flooding events. The WBP identifies prioritized locations where potential stormwater treatment measures, also known as Best Management Practices (BMPs), could be installed. While not a flood focused plan, where possible, management measures to address flooding are also included. The Plan also provides recommendations for technical and financial assistance, educational/public outreach material, and the establishment of milestones and post-implementation monitoring protocol.

1.0 DESCRIPTION OF TWILIGHT LAKE

Twilight Lake is a tidal, brackish-water lake which is hydrologically connected to Barnegat Bay on the south by Scow Ditch. The lake is further characterized with the Surface Water Quality Standards (NJAC 7:9B) designation of FW2-NT/SE1 meaning it displays Freshwater, non-trout production (FW2-NT) and saline estuarine (SE1) traits. Twilight Lake is approximately 27.2 acres in area composed of two rectangular basins oriented north to south that are bisected by a peninsula on the north end and a 0.7-acre island in the middle (Kellogg Memorial Island, KMI), on the south. The two basins are connected by two narrow channels north and south of KMI. The area to the northwest is considered to be a modified tidal marsh with several sinuous fingers extending into the marsh.

The total watershed area encompasses 255 acres based on maps provided by the Bay Head Environmental Commission (BHEC) and includes Scow Ditch. Most stormwater runoff is from north and west of the lake. Another major input to the lake is Barnegat Bay, which is tidally connected through Scow Ditch, which connects the lake with Bay Head Harbor and subsequently to Point Pleasant Canal and the northern most reach of Barnegat Bay.

From the 1880s to 1980, Twilight Lake was divided into two main parts with areas north and south of KMI allowing for water circulation between the east and west. A train track existed since the 1880s on the strip of land passing north-south through the middle of the lake (KMI) and a train trestle bridging the gap between the north and south ends of the island and land on either side of the island. In the 1980s, hydraulic pumping removed sediment from the bottom of the lake on the north end which was pumped onto KMI to cover the railroad tracks on the island thereby raising the island to the current height.

Scow Ditch is Twilight Lake's connection to Barnegat Bay and tidal influences. Scow Ditch and Twilight Lake are tidal waters affected by the water quality of Barnegat Bay. This provides the basis for declaring Scow Ditch and Twilight Lake as New Jersey protected waters. New Jersey waters are protected from any measurable change in existing water quality because of their exceptional ecological significance. As tidal waters flow through Scow Ditch, Twilight Lake provides an ecological link between the environmentally sensitive wetlands and marsh lands at the north end of Twilight Lake with Barnegat Bay.

A study conducted by Princeton Hydro in June of 2012 analyzed Twilight Lake prior to Superstorm Sandy. The work consisted of three primary activities: bathymetric study and sediment probing, sediment sampling, and water quality sampling. The study concluded that the shallowness of the lake was due in part to the original basin morphometry as well as sediment infilling with sands and highly organic silts. Increases in sedimentation have deleterious impacts on the recreational and ecological aspects of Twilight Lake including:

- Promotion of the proliferation of aquatic plants and algae through increased nutrient loading
- Fishery impacts through infilling which results in loss of site complexity and spawning habitat
- Reduction in navigable areas for recreational boats

The outer rims of the Lake are moderately sloped with the area adjacent to the island having steeper slopes. A large portion of the western basin is just over three feet in depth. The eastern basin is very similar, although there is a sizable area adjacent to the island where depths exceed four feet. Two small depressions have formed at the mouth of the northwestern channel and at the head of Scow Ditch through the discharge of water at these points. These are the deepest points in the respective basins. In the western basin, the northern and southern areas are gently sloping towards the dominant basin depth and the fingers extending into the marsh are generally less than two feet deep. The northern third of the eastern basin is also gently sloping, but the southern shore of the eastern basin is relatively steep and is hardened to maintain these slopes. A shallow sandy flat is also evident along the eastern shoreline between North Street and Twilight Road near the pumped outfall.

Twilight Lake was dredged in 2014 following Superstorm Sandy. The project included the removal of approximately 17,000 cubic yards from the northeast portion of the lake and 12,000 cubic yards from the southeast portion of the lake. A bathymetric survey of Twilight Lake was completed in 2015 following the dredging. The 2015 bathymetry indicated that Twilight Lake had experienced shifts in sediment resulting in sediment loss along the outer shoreline of the lake and center island, and sediment accumulation in the middle of the body of water. This WBP includes an updated bathymetric study and comparison to the past studies; a summary is provided below.

2.0 SUMMARY OF PAST STUDIES

A number of studies and projects have been conducted in and around the Twilight Lake watershed in an effort to improve water quality conditions and comply with the State's phosphorus TMDL. For convenience these studies and projects are summarized below:

METEDECONK RIVER WATERSHED PROTECTION AND RESTORATION PLAN, 2013

The Metedeconk River Watershed Protection and Restoration Plan dated April 2013 was completed as part of the 319 (h) grant #RP09-058 by Brick Township Municipal Utilities Authority, CDM Smith and John S. Truhan Consulting Engineers in consultation with the Metedeconk Stakeholder Advisory Committee and Steering Committee. The plan compiles a comprehensive watershed characterization and a watershed plan with emphasis on nonpoint source control and stormwater management to address water quality focused on nutrients, pathogens and suspended solids reduction for the Metedeconk River, a tributary to the Barnegat Bay.

This plan was reviewed as the Metedeconk River is immediately upstream of the section of Barnegat Bay that feeds Twilight Lake. Further, it was approved by NJ DEP and determined to adequately identify and prioritize specific stormwater-related implementation projects to address water quality and quantity that are needed in order to improve water quality and address water quality impairments.

The stormwater mitigation measures recommended in this plan were used as reference in evaluating pollutant removals of similar best management practices (BMPs).

TWILIGHT LAKE NEIGHBORHOOD PLAN, 2017

The Twilight Lake Neighborhood Plan was included in as part of a series of Phase II Post-Sandy Planning Studies and Reports and was intended to look at a number of factors which will affect the future of the area, from the present state of the infrastructure and the ongoing rebuilding efforts to methods of providing a sense of unity and community. The Twilight Lake Neighborhood Plan Area is composed of the northern and central portion of the Borough that includes Twilight Lake and its watershed, as well as the area around Scow Ditch. The Neighborhood Plan was prepared to complement the Master Plan Reexamination, Zoning Ordinance Update prepared by Maser Consulting, as well as the Hazardous Mitigation Plan being prepared by the firm of Remington Vernick & Vena Engineers.

This plan provides an overview of the existing development patterns within the Twilight Lake Neighborhood Plan Area and provided recommendations to make the neighborhood more resilient to flooding and to future storm events. Some of these recommended measures included swales, bioretention curb extensions and sidewalk planters, permeable pavement, sidewalk trees and tree boxes. A number of overlooks and floating walkways were proposed along with incorporation of green infrastructure improvements.

HAZARD MITIGATION PLAN FOR THE BOROUGH OF BAY HEAD, MAY 2017

The purpose of this plan was to evaluate the impacts of potential future storms and reduce vulnerabilities throughout the Borough. The plan discusses the planning goals, strategies, and actions that are most urgently needed to improve public safety, increase resiliency, and stimulate recovery. Detailed descriptions of previous storms, current regulations, and proposed projects are discussed in the plan. The document identifies hazards, including flooding and climate change, and areas of concern. Some major mitigation measures considered including diversion of water being pumped from the Point Pleasant Pump Station into Twilight Lake, installing flood gates at Scow Ditch, and installation of Tide Flex Valves.

BAY HEAD ENVIRONMENTAL COMMISSION – ENVIRONMENTAL RESOURCE INVENTORY, 2021

The Bay Head Environmental Commission completed an Environmental Resource Inventory (ERI) in February 2021. The ERI is a compilation of the natural resource characteristics and environmental features in the Borough of Bay Head including the infrastructure and man-made physical features of the Borough. The ERI provides baseline documentation for measuring and evaluating resource maintenance and protection issues in Bay Head, now and in the future.

This particular document notes the various severe storms experienced by Bay Head over time, the geographic characteristics of the Atlantic shoreline as well as Twilight Lake, the soils, wetlands, the general climate and flood prone areas, and biological resources such as extant plant and animal species in different habitats and communities around the municipality. To give a more comprehensive perspective of these resources, the ERI also documents the anthropogenic impacts to the Township's resources such as population, land use, and municipal infrastructure.

BAY HEAD MASTER PLAN UPDATE, 2021

Approved and published December 15, 2021, this version of the municipality's master includes a *Reexamination Report and Update* from 2017 and revisions from the interim 4 years. This was updated to address items of concern for the community presented by Superstorm Sandy and subsequently the shift in community use during the COVID lockdown. In addition to many socioeconomic items addressed in this document, there is a full chapter on Climate Change-Related Hazard Vulnerability Assessment (Chapter 6). Much of this involves sea level rise and impacts thereof, but does address flooding and impacts to Twilight Lake, though does not include impacts to water quality.

Chapter 6 catalogues on-going and completed projects that address flood mitigation, including storm drain cleaning, street sweeping, storm drain system check valves, raising street levels, and a series of planned projects to direct stormwater flow from flood prone areas to pump stations to be pumped out to the ocean or Scow Ditch/Barnegat Bay; dredging Twilight Lake was also mentioned. Development of a Twilight Lake Protection and Watershed Plan to enhance water quality and the environment around the Lake was outlined in this chapter. Future Mitigation Efforts were detailed that included raising the shoreline of Twilight Lake, installing Water Flow controls in Scow Ditch, and adoption of policies to promote and implement green infrastructure initiatives when possible.

BAY HEAD ENVIRONMENTAL COMMISSION STATUS OF FLOODING STUDY PRESENTATIONS 2021 & 2022

Bay Head Environmental Commission (BHEC) conducted a study to assess the extent of flooding within the community and presented its findings relating to frequency, severity, and location of various flood impacted areas. An inventory of over 200 storm drains and 60 outfalls in the municipality was compiled, including 16 outfalls around Twilight Lake and 11 along Scow Ditch. BHEC also documented a total of 12 check valves with 2 in the Lake and 3 along Scow Ditch.

BHEC also catalogued locations of nuisance, major, and catastrophic flooding and further prioritized the locations based on mitigation needs. These may be areas that would require more detailed consideration relative to infrastructure needs. Major historic flooding events were logged. The presentation also highlighted shoreline overflow areas, locations of erosion where stabilization BMPs like a living shoreline and associated berm may be useful for controlling floods and their impact to water quality. The study was presented to the Borough in November of 2021. In July 2022 an update to the flooding study was presented in a public meeting which provided a discussion of completed actions and outlined a long-term Action Plan to address flooding hazard in Bay Head.

TWILIGHT LAKE WATER QUALITY STUDY, 2013

A water quality study was performed on Twilight Lake in 2013 which took water and soil samples as well as performed a bathymetric survey. The survey is reported below. The water quality sampling focused on eutrophication indicators.

PAST BATHYMETRIC STUDIES

Twilight Lake has been subject to a number of bathymetric studies in the past 10 years. Princeton Hydro had previously conducted two bathymetric surveys at Twilight Lake. The first was the early fall of 2012 and the second was in early 2013. The 2012 survey was conducted as part of a larger scale project regarding the entire lake, similar to this current 2021 project. The 2013 survey was conducted a few months after Hurricane Sandy severely impacted the area and provided insight to sediment deposition patterns and volumes of sediment imported from the superstorm. As a result of that storm and study, a portion of the lake was dredged in 2015. For this project, the post dredging As-Built top-of-sediment contours were obtained from the engineering firm that completed the dredging project. These contours were compared to the top of sediment contours from this 2021 project's bathymetric survey to conduct a sediment gain/loss analysis and reveal how much sediment has entered the lake since the finalization of the dredging project in 2015. The most recent bathymetry was performed on October 19, 2021 and is detailed in Section 3.

3.0 LAKE CHARACTERIZATION & IDENTIFICATION OF SOURCES OF POLLUTION

The following section corresponds with the first of the nine watershed plan elements and provides information related to the determination of the sources of pollution entering Twilight Lake. This section includes characterization related components including water quality monitoring and bathymetric survey results. In addition, watershed assessments and historical knowledge of non-point source pollution problem areas are provided as a diagnostic component of this section.

3.0 BATHYMETRIC STUDY

As mentioned in Section 2, Twilight Lake has been the subject of a number of bathymetric surveys over the past ten (10) years. Princeton Hydro conducted two bathymetric surveys at Twilight Lake, one in 2012 and another in 2013. The 2012 survey was conducted as part of a larger scale project regarding the entire lake and the 2013 survey was conducted to assess Hurricane Sandy sediment deposition patterns and volumes of sediment imported from the superstorm. A portion of the lake was subsequently dredged in 2015, which entailed having post dredge, as-built bathymetric contours recorded. A sediment gain/loss analysis was conducted using top of sediment data and contours from the 2012 and 2015 each with the data collected from the 2021 bathymetry. The most recent bathymetry was performed on October 19, 2021 and is detailed below.

METHODOLOGY

The bathymetric survey was conducted using two (2) distinct techniques that were combined to create a complete assessment of the project area. These techniques included the use of a calibrated sounding rod and a dual frequency sounder. The calibrated sounding rod was used to survey shallow areas (12 inches of water or less) and areas where the sediment composition is not conducive for echo sounding. Locations and elevations of the sounding rod samples were recorded with a Leica GS14 GPS unit. The rod was lowered into the water until it reached the top of the sediment. The location of the rod and the depth to top of sediment was recorded with the GPS unit. The dual frequency sounder (Knudsen 1612 Echosounder) method uses a high frequency and low frequency to discern the top of sediment from the bottom of sediment. The sounder was calibrated throughout the course of the survey with the calibrated sounding pole to ensure accurate water and sediment depth readings. Locations of sounding data were recorded with the Leica GS14 GPS unit. Data was collected along predetermined transects that ran from shoreline to shoreline at 150-foot intervals. Bottom of Sediment (BoS) elevations were collected.

To allow for this survey's information to be compared to past or future surveys, or for the data to be used for permitting purposes, the water depth data must be reported in real elevations (North American Vertical Datum of 1988 - NAVD88) and not relative depths (surface water elevation equal to zero). This required setting a benchmark on the project site. A drop inlet grate along the curb line was selected for use as a benchmark; more specifically, the drop inlet located on the West side of Lake Avenue, just across from the intersection of Lake Avenue and Harris Street. Multiple data point recordings of the inlet grate were taken with a Leica GS14 survey grade GPS unit. Then a site level and Philadelphia rod were utilized to record both the benchmark and the edge of water locations. Knowing the elevation of the benchmark, along with the site level data, allows for the calculation of the water surface elevation (WSEL). The benchmark was not set by a certified Professional Land Surveyor (PLS). If this survey's information is to be utilized for permitting purposes, a PLS may be required to certify the benchmark set by Princeton Hydro.

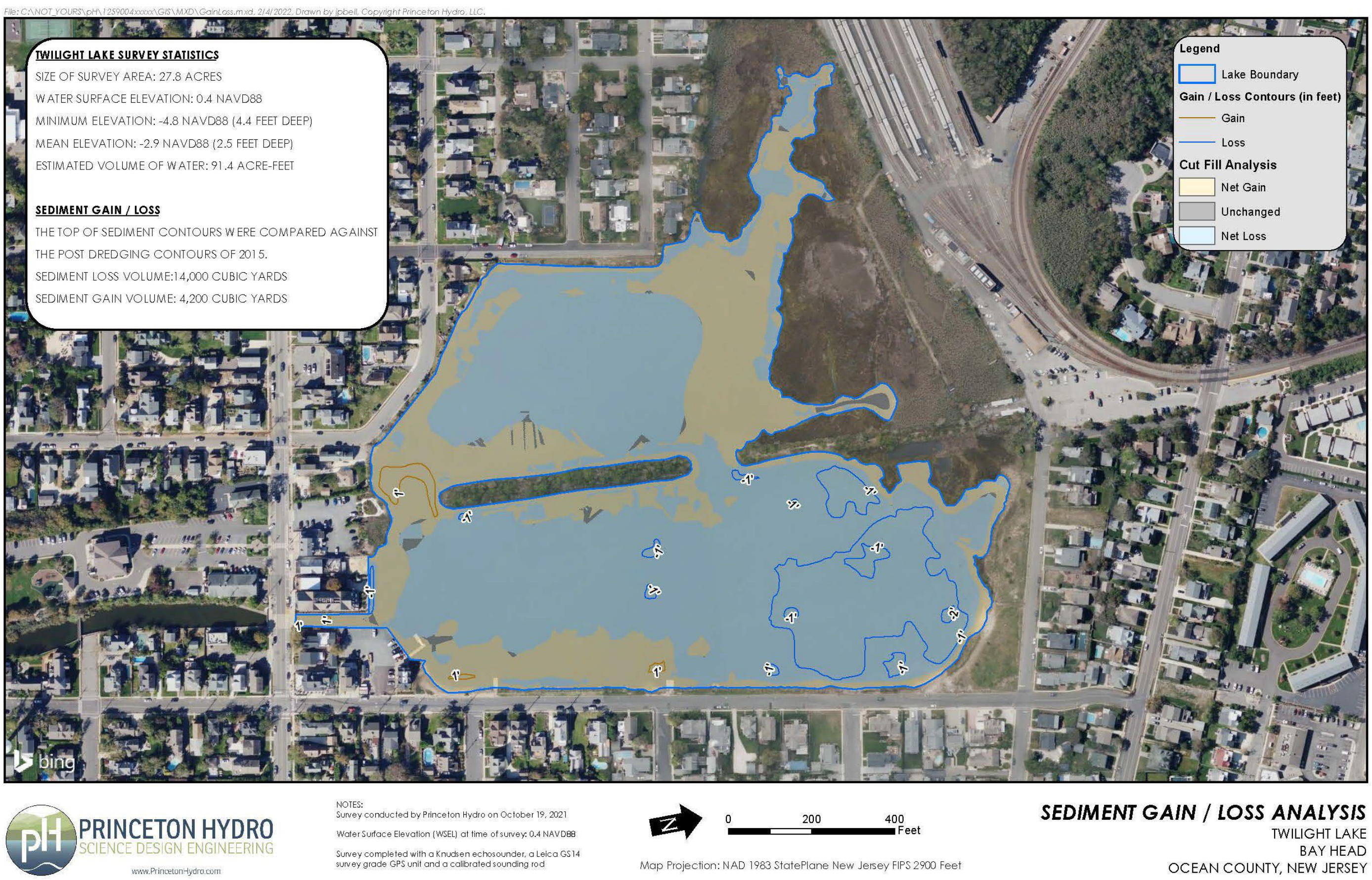
Once data collection was completed, all sounder data was downloaded to Hypack Max, a sounding software program that allows for the visual inspection of all the raw sounding data. Here, any noise or sounding anomalies were edited out. All data was then imported into a Geographic Information System program (GIS). Once in GIS, all top of sediment depths were converted into NAVD88 elevations utilizing the WSEL information collected before the survey began. A 3D model was created of the top of sediment elevations and contours representing these elevations were generated. The 2012 survey bottom of sediment elevations were compared with the current bottom of sediment elevations and found to be consistent; these 2012 elevations were then used in the 3D modeling as it has not changed from past studies or dredging efforts (since dredging would not alter compacted, consolidated bottom of sediment).

Prior to the actual survey itself, Princeton Hydro obtained the 2014 dredging as-built AutoCAD files from Munoz Engineering of Denville, New Jersey. These contours and spot elevation shots were utilized to create another 3D model within GIS. The current survey model was compared against the post-dredging model to produce the sediment gain/loss analysis. This analysis, and the resulting map, reveal where sediment deposition or loss occurred and estimated quantities of both features.

RESULTS

Figure 1 below displays the gain and loss analysis conducted by Princeton Hydro. Sediment deposition appears to be occurring in several areas of the lake as indicated in the tan coloration below. Again, this sediment gain-loss analysis was completed by comparing the 2021 top of sediment model against post dredging data provided by Munoz Engineering.

Figure 2



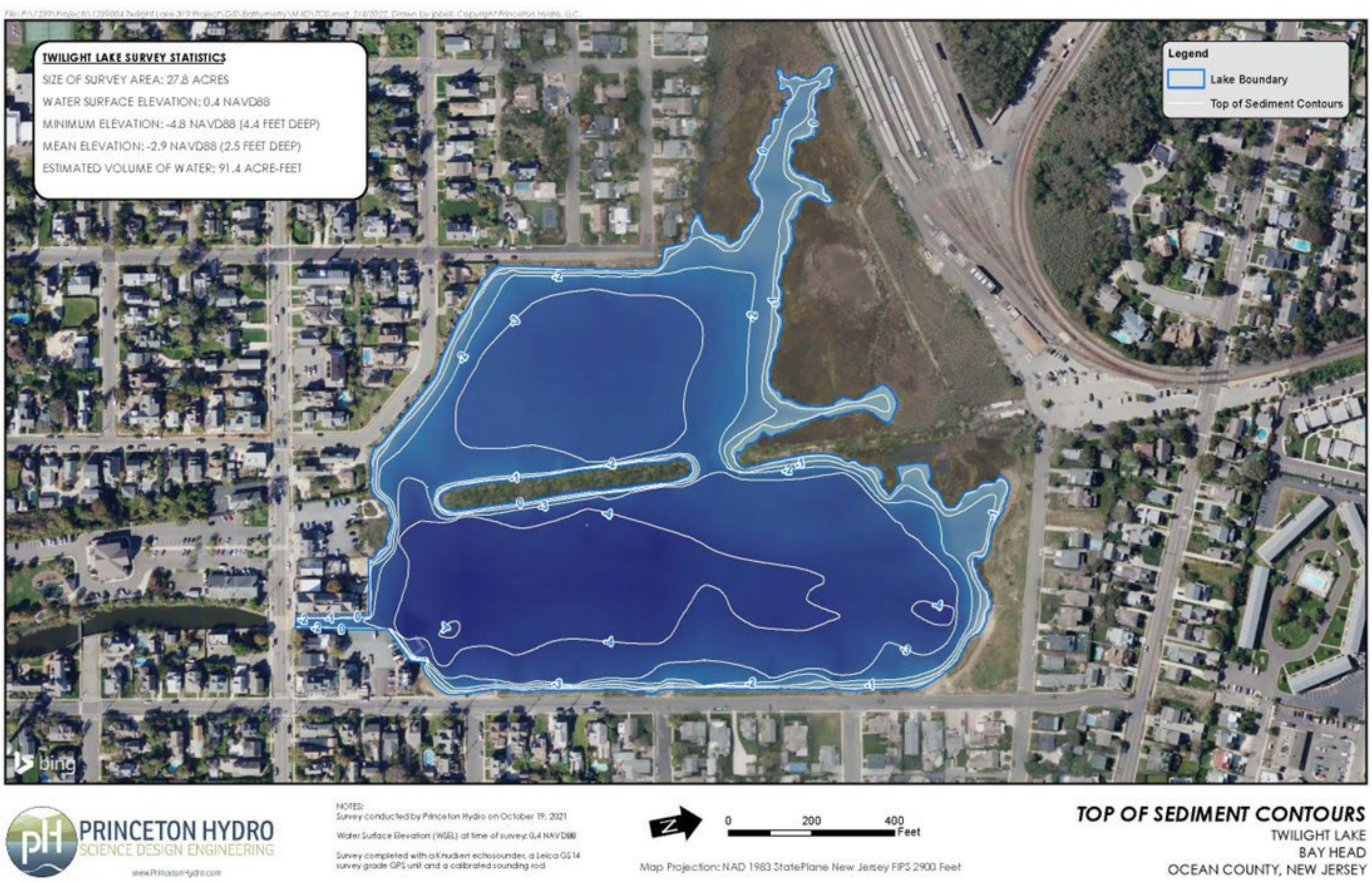
The gain/loss analysis calculated a loss of 14,200 yd^3 and gain of 4,200 yd^3 for a *net sediment loss* of 9,800 yd^3.

The inlet area in the west side of the lake displays accumulated sediment since the 2015 dredging event. Stream input from the area to the west feeds the lake from a culvert under the railroad tracks. There are two areas of sediment loss in the upper reaches of that western arm, which may be due to higher stormwater velocities during bigger storm events scouring out the bottom as it enters the lake. As inflow velocity decreases, sediment suspended in water likely deposited in the western arm and the northwest portion of the lake.

Deposition is also occurring along the southern edge of the lake (Park Avenue/Bridge Avenue) and the eastern edge of the lake (Lake Avenue from Harris Street up to the intersection of Karge Street). This is due in part to the outfalls along the lake's edge transporting stormwater from the streets into the lake and also repeated attempts at replenishment of the beach along Lake Ave at Harris Street; replenishment happened over the past four (4) years at approximately three (3) cubic yards per year. Deposition in this southern area may be slightly influenced by rising tide entering the lake through Scow Ditch. But as exhibited by the gain/loss map, less than a foot of sediment has accumulated at the mouth of Scow Ditch since the 2015 dredging - most likely due to tidal movements. Finally, small pockets of deposition appear to be forming around Kellogg Memorial Island in the middle of Twilight Lake.

In general, the depth of the water in the western half of the lake is consistently shallower than in the eastern side of the lake. This is to be expected since the dredging that occurred in the past was performed in the eastern half of Twilight Lake. The characteristics of depth across the two halves influence the flow of water into and through the Lake and Kellogg Memorial Island.

Figure 3



The middle, main body of the lake, on both the east and west sides of the island, show signs of sediment loss. Sediment was lost in the southeast portion of the lake, as that is where the 2015 dredging occurred. Still, other areas of the lake that were not dredged showed a loss of sediment which may be misleading.

Much of the gain/loss can be explained by examining the overall patterns. This sediment loss area covers a large majority of the main body of the lake and the analysis yielded an estimated sediment loss of 14,000 cubic yards. This large amount of sediment loss is spread out over 17.3 acres (65% of the lake). The average sediment loss in this large area is 0.4 feet. (~5 in). Princeton Hydro believes this area of sediment loss is actually an area of no change or possibly a small amount of deposition which has occurred in the past seven years since dredging occurred. This discrepancy is likely due to one of two things. First, there were different data collection methods between Princeton Hydro and Munoz Engineering. Princeton Hydro's larger data set was collected with an echo sounder, while the Munoz data – a smaller collection of scattered spot elevations – was collected with a survey rod or calibrated pole. The sounder may have penetrated the loose top layer of sediment a bit, resulting in top of sediment elevations slightly lower than what they should be. The most refined resolution that is expected is approximately 6 inches, and since the displayed sediment loss falls within that range it may not be an actual loss. The second issue could be due to errors in model extrapolation of depth contours. Unless data have been collected over 100% of the study area, all models are extrapolations of the existing condition and inherently less than fully accurate. A model is created by taking a smaller subset of data and allowing the computer to make a model of the entire project area, interpolating top of sediment elevations in areas where no data exists. Data interpolation varies depending on the volume of data utilized, as well as the computer program used to create the model. Munoz Engineering employs AutoCAD software while Princeton Hydro used ESRI's ArcGIS software for analyses. Each program uses different methods and algorithms to create a model, which would introduce a slightly higher error factor when comparing the two different data sets. These issues are most likely the result of the sediment loss discrepancy.

Nonetheless, the sediment gain of 4,200 cubic yards (tan areas of the map) over the past seven years yields an estimated yearly sedimentation rate of 600 cubic yards per year, an estimate that is more in line with other similar sized lakes in a developed setting and validates the conclusion of overall accumulation. It is also reasonable to consider that tides likely have had some influence on the distribution of sediments around the Lake, shifting areas of net loss and net gain.

3.1 WATER QUALITY MONITORING

Princeton Hydro, LLC conducted general water quality monitoring of Twilight Lake during the 2022 growing season (May through October) to provide an up-to-date water quality and ecological assessment of conditions within Twilight Lake. Twilight Lake has not been monitored under a State-approved Quality Assurance Protection Plan (QAPP). As such, it was absolutely critical that a set of growing season water quality sampling events were conducted so any changes or shifts in either in-lake or watershed (e.g. the tributaries) water quality conditions are documented. This task included development of a State-approved QAPP (Appendix B) and an up-to-date water quality and ecological assessment of conditions in Twilight Lake.

The current water quality monitoring program is valuable in terms of assessing the overall "health" of the lake, beginning to identify long-term trends or changes in water quality, and quantifying and objectively assessing the success and potential impacts of restoration efforts. In addition, the in-lake water quality monitoring program will be an important component in the evaluation of the long-term success of the implementation of this Watershed Based Plan. Finally, the monitoring program provides the data necessary to support the Commission's requests for grant funding to implement both watershed-based and in-lake projects to improve the water quality of Twilight Lake and potentially also for flood mitigation measures, which also impact water quality entering the lake.

MATERIALS AND METHODS

In-lake water quality monitoring was conducted at the following five (5) locations in Twilight Lake (represented in Appendix A):

Station Number	Description
Station 1 (ST-1)	West Cove
Station 2 (ST-2)	East Cove
Station 3 (ST-3)	Railyard Stream
Station 4 (ST-4)	Residential Stream
Station 5 (ST-5)	Scow Ditch

The 2022 sampling dates were 2 May, 30 May, 15 June, 13 July, 17 August, and 14 September. A Eureka Amphibian Personal Digital Assistant (PDA) with AquaTroll multi-probe unit was used to monitor the *in-situ* parameters: temperature, dissolved oxygen (DO), pH, and specific conductance during each sampling event. Data were recorded at 0.5 m increments starting at 0.1 m below the water's surface and continued to within 0.5 m of 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* data can be found in Appendix B.

At three stations (West Cove, East Cove, and Scow Ditch), discrete whole water samples were collected at a depth halfway down the water column. Discrete water quality samples were collected with a Van Dorn sampling device at 0.5 m below the lake surface. Discrete water samples were appropriately preserved, stored on ice, and transported to a State-certified laboratory for the analysis of the following parameters:

- total phosphorus-P (TP)
- soluble reactive phosphorus-P (SRP)
- ammonia-N (NH_3-N)
- nitrate-N (NO_3-N)
- total suspended solids (TSS)
- chlorophyll-*a*

At these stations, zooplankton and phytoplankton samples were collected from 0.5 m below the surface and analyzed for species composition, dominant organism, and relative density.

Monitoring at the Railyard and Residential Stream Stations (Stations 3 and 4) consisted of collecting *in-situ* and Secchi disk data; discrete water samples were collected from these stations for laboratory analyses on all the parameters except chlorophyll-*a*, ammonia-N, and plankton. Discrete data can be found in Appendix C, and Plankton data can be found in Appendix D.

Finally, during each of the six (6) sampling events, a general survey of aquatic vegetation and/or algae growth (planktonic or filamentous) was conducted.

RESULTS

IN SITU

A full summary of all in situ data can be found in Appendix C.

Water Clarity (as measured with a Secchi disk)

Transparency in lakes is generally determined through the use of a Secchi disk. The Secchi disk is a contrasting white and black disk that is lowered into the lake until no longer visible then retrieved until visible again. The average of those two lengths is defined as the Secchi depth. This depth may be influenced by algal density, suspended inorganic particles, organic acid staining of the water or more commonly a combination of all three. This parameter is often times used to calculate the trophic status (level of productivity) of a lake, which is a critical tool in lake evaluation and assessment. Based on Princeton Hydro's in-house, long-term database of lakes in New Jersey, water clarity is considered acceptable for recreational activities when the Secchi depth is equal to or greater than 1.0 m (3.3 ft).

Total water depth and Secchi depth of each station did vary slightly across sampling events due to natural processes of sedimentation and sediment transport with tidal flux. Secchi depths at Stations 1 and 2 were at least 1 m for the first half of the growing season, with shallower depths ranging from 0.8 m to 0.5 m from July to September. When water depth was greater than 1.0 m, Secchi depth at these two stations reached to the bottom sediments. Stations 3 and 4 had shallower total depths which physically limited Secchi readings with only a single instance of visibility not reaching the sediment (August at ST 4). Station 5 had the greatest total maximum depth and exhibited Secchi depths of 1 m or greater through July, with depths of only 0.5 m in August and 0.8 in September.

Temperature

Temperature is one of the most important water quality parameters since it controls the rate of all chemical and biological reactions. As the air temperature increases through the growing season, the temperature of the surface waters increases. This results in the surface waters being warmer relative to the bottom waters which results in thermal stratification.

Thermal stratification is a condition in which the warmer surface waters (called the epilimnion) are separated from the cooler bottom waters (called the hypolimnion) through differences in density. 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 example, in productive waterbodies, once the hypolimnion is cut off from the epilimnion, atmospheric oxygen cannot enter the deeper waters. This can result in a depletion of DO in the bottom waters, a condition termed anoxia. Such conditions result in an increase in the internal loading of phosphorus from lake sediments and reduce the overall habitat availability for the lake's fishery.

Temperatures were relatively consistent across stations at each sampling event, with any variation occurring at the shallower stations (ST 3 and 4) which typically were warmer than the rest of the lake or ST 3 in early May which was cooler than the rest. Temperatures recorded across all stations on 2 May ranged from 13.96-15.72°C. For the rest of the growing season, temperatures ranged from 21.23-28.31°C. Peak temperature for each station was recorded on 13 July followed by 31 May. The water column was relatively well mixed, with only one instance of thermal stratification at ST 5 in June between 1.0-1.5 m.

Dissolved Oxygen

Dissolved oxygen (DO) is crucial to most biochemical reactions occurring in freshwater ecosystems. Primary sources of DO are diffusion from the atmosphere and photosynthesis, while sinks are biological respiration and bacterial decomposition of organic matter. The abundance and distribution of DO in a lake system is based on the relative rates of producers (photosynthetic organisms) versus consumers (metabolic respiration). Again, as noted above, the general distribution of DO through a lake is also strongly influenced by the thermal properties of the water column. This affects DO concentrations not only as a result of stratification, but also in terms of the extent of DO saturation. Warmer water has a lower capacity to hold DO in solution relative to cooler water. Thus, the concentration of DO, as well as its % saturation, tends to be higher in cooler waters relative to warmer waters.

As aquatic plants and algae (both planktonic and benthic forms) photosynthesize, they take up water and carbon dioxide and through the use of light energy convert those reactants into oxygen and glucose. This serves to increase the net concentration of DO in lakes during the day in the epilimnion where there is ample sunlight to support photosynthesis; termed the photic zone. Thus, DO concentrations are generally higher in the upper water layers and lower in the deeper water layers due to a lack of photosynthetic activity in conjunction with aquatic animal / bacterial respiration.

As emphasized above, relative concentrations of DO are also due to temperature and density differences throughout the water column. When lakes thermally stratify there is generally a correlated stratification of DO concentrations as well. Deeper water layers (hypolimnion) usually contain less DO as they cannot mix with upper water layers where DO would be replenished from atmospheric sources. In highly productive lakes the hypolimnion may become devoid of DO due to bacterial decomposition of excessive inputs of organic material. The source of this material may either be from excessive phytoplankton production in the upper water layers that then sink to the bottom where they die (autochthonous) and/or from excessive watershed-derived pollutant loading (allochthonous). Also, since DO concentrations are typically measured during the daylight hours, when concentrations are their highest, there will be lower DO concentrations at night when photosynthesis ceases and diffusion is the sole input of DO to the lake.

An important consequence of anoxic conditions (DO < 1 mg/L) in the hypolimnion includes both reduced fish habitat and the release of metals and phosphorus from the sediments, a process termed internal loading. Internal loading occurs when tightly bound iron and phosphate sediment complexes are reduced thereby dissociating phosphorus from iron and making it available for diffusion into the water column. This process has been documented to contribute to the overall eutrophication of many lakes as this internal source of phosphorus is pulsed into the photic zone during strong storm events where it can fuel excessive algal growth. Such internal loading can generate persistent nuisance algal blooms over the summer season, even during drought conditions when stormwater inputs are minimal.

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 5.0 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, the NJDEP State criteria for DO concentrations in surface waters (FW2-NT and SE1 waters) is a 24-hour average of not less than 5 mg/L but not less than 4 mg/L at any time.

Dissolved oxygen was almost never below the 4.0 mg /L NJDEP threshold, though low DO conditions were recorded at 1.5m and below at ST 5 in June of DO concentrations of 4.61 mg/L and 4.19 mg/L. There were also instances of low DO saturation in the water column near ST 3 in early May and July. There was evidence of hypoxic layers at ST 5 in June (60.2% or less below 1.5m), ST 1 and ST 5 August (76.2% at 1m and 68.3% at 1.5m) and ST 2 in September (78% at 1m). Supersaturated conditions (DO>100%) were noted Throughout ST 2 on 2 May, ST 3 on 31 May, and ST 3 and 4 on 15 June. This is typically indicative of high productivity by aquatic vegetation and phytoplankton photosynthetic activity.

pH

pH is a unit-less measurement of the hydrogen ion concentration in water. Expressed on a negative logarithmic scale from 0 to 14, every change of 1 pH unit represents a 10-fold increase or decrease in hydrogen ion concentration. The pH of pure water is 7 and is termed neutral. Any value less than 7 is termed acidic, while any value greater than 7 is termed basic.

Baseline pH values are primarily determined by the ionic constituency of surrounding geology. Watersheds draining soils of easily erodible anionic constituents are generally well buffered and as such have runoff waters with basic pH values (pH above 7).

Spatial variations in pH throughout the water column are largely due to relative rates of photosynthesis versus respiration. As plants and algae photosynthesize, they release anions while collectively taking up acidic compounds related to carbon dioxide species. This results in a net increase in pH. Conversely, respiration releases carbon dioxide which results in a reduction in pH. Given these relationships, pH values may differ substantially between the surface and bottom water layers in lakes with a high amount of productivity and respiration. The optimal range of pH for most freshwater organisms is between 6.0 and 9.0. However, the NJDEP State water quality standard for pH in FW2 and SE waters is for an optimal range between 6.5 and 8.5.

pH was relatively consistent within and among ST 1, 2, and 5 through the growing season, while ST 3 varied the most. ST 4 only varied from the other stations significantly on 2 May and 17 August. Overall, pH ranged from 7.16 – 7.90. Since Twilight Lake is tidally influenced and experiences flushing from Barnegat Bay, it is expected to have relatively stable pH.

Specific Conductivity

Specific conductance or SpC, while technically measuring electrical conductance, reflects the amount of dissolved solids in the water. This value is also normalized for temperature effects. These dissolved substances derive primarily from runoff and groundwater but can also reflect other additives as would be expected in treated waters. A certain quantity of dissolved substances is important in lakes and streams to support growth of plants and algae and other metabolic processes including bone and shell development. Excessive numbers can indicate pollution or even saline intrusion; since the Barnegat Bay is the major input to Twilight Lake, these concentrations are relatively high as compared to other freshwater lakes.

Specific Conductivity generally ranged from 30,999 µS/cm to 44,560 µS/cm. There were 2 outliers recorded on 2 May: 5,670 µS/cm at ST 4 and 6,790 µS/cm at ST 3.

DISCRETE DATA

A full summary of all discrete data can be found in Appendix D.

Total Phosphorus (TP)

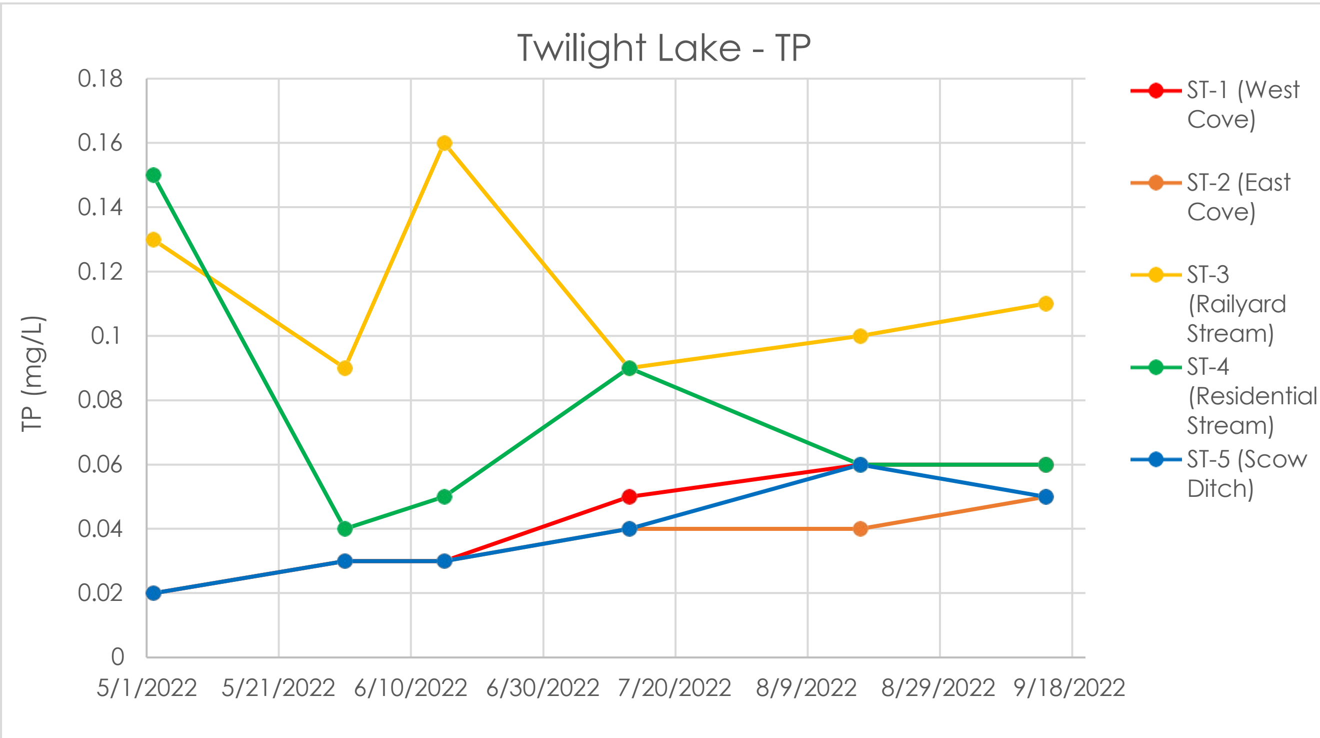
In lake ecosystems, phosphorus is often the limiting nutrient, one whose abundance is lowest relative to demand. As a result, phosphorus is often the primary nutrient driving excessive plant and algal growth. Given this nutrient limitation only relatively small increases in phosphorus concentration can fuel algal blooms and excessive macrophyte production. By monitoring total phosphorus concentrations, the current trophic status of the lake can be determined and future trends in productivity may be predicted.

It is important to note that total phosphorus concentrations account for all species of phosphorus, organic and inorganic, soluble and insoluble. Therefore, this measure accounts not only for those dissolved, inorganic species of phosphorus that are readily available for algal assimilation, but also for those species of phosphorus either tightly bound to soil particles or contained as cellular constituents of aquatic organisms which are generally unavailable for algal assimilation.

Based on Princeton Hydro's in-house database on northern New Jersey lakes, TP concentrations equal to or greater than 0.03 mg/L will typically result in the development of algal blooms / mats. The State's Surface Water Quality Standard (SWQS, N.J.A.C. 7:9B – 1.14(c) 5) for TP in the surface waters of a freshwater lake or impoundment is 0.05 mg/L. This established TP concentration is for any freshwater lake or impoundment in New Jersey that does not have an established TMDL.

TP concentrations, shown in Figure 3, started low and increased over the growing season for the main part of Twilight Lake, represented by ST 1, 2, and 5; TP at the peripheral stream inputs at ST 3 and ST 4 was more variable but were both were above the 0.05 mg/L concentration threshold for the entire season. Concentrations of TP at ST 1, 2, and 5 did not exceed this threshold until July.

Figure 3

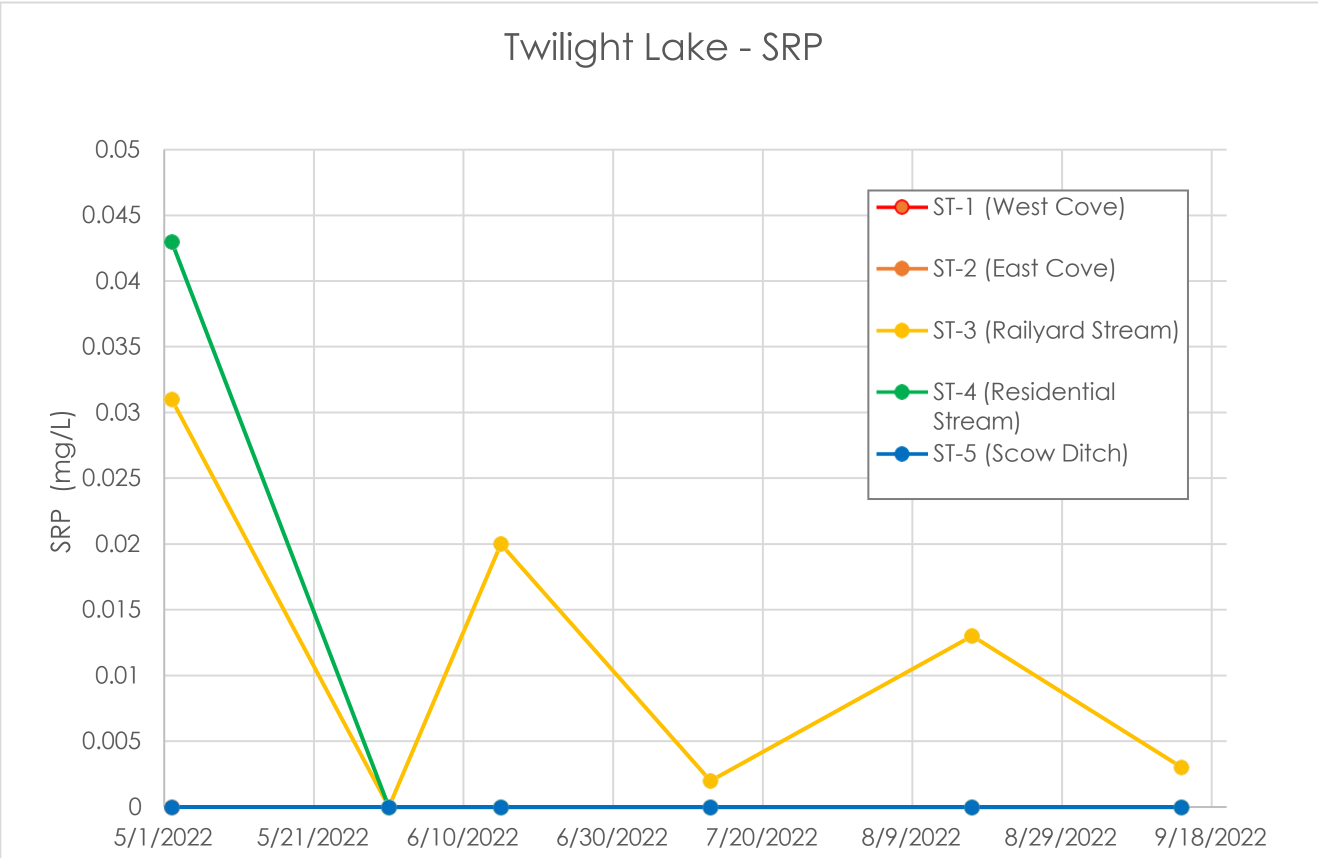


Soluble Reactive Phosphorus (SRP)

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.

SRP, depicted in Figure 4 below, was only detectable at ST 3 and 4 in early May and then undetectable after May at all stations except ST-3 (the Railyard). SRP concentrations at ST 3 and 4 on 2 May were 0.031 and 0.043, respectively, exceeding the 0.005 mg/L threshold. The remaining detectable concentrations of SRP were at ST 3 and variable going from 0.020 in June down to 0.002 in July, back up to 0.013 in August and below threshold in September to 0.003 mg/L.

Figure 4



Ammonia-Nitrogen (NH3-N)

In lakes, ammonia is naturally produced and broken down by bacterial processes while also serving as an important nutrient in plant growth. In a process termed ammonification, bacteria break down organically bound nitrogen to form NH4+. In aerobic systems bacteria then break down excess ammonia in a process termed nitrification to nitrate (NO3-). These processes provide fuel for bacteria and are generally kept in balance as to prevent accumulation of any one nitrogen compound.

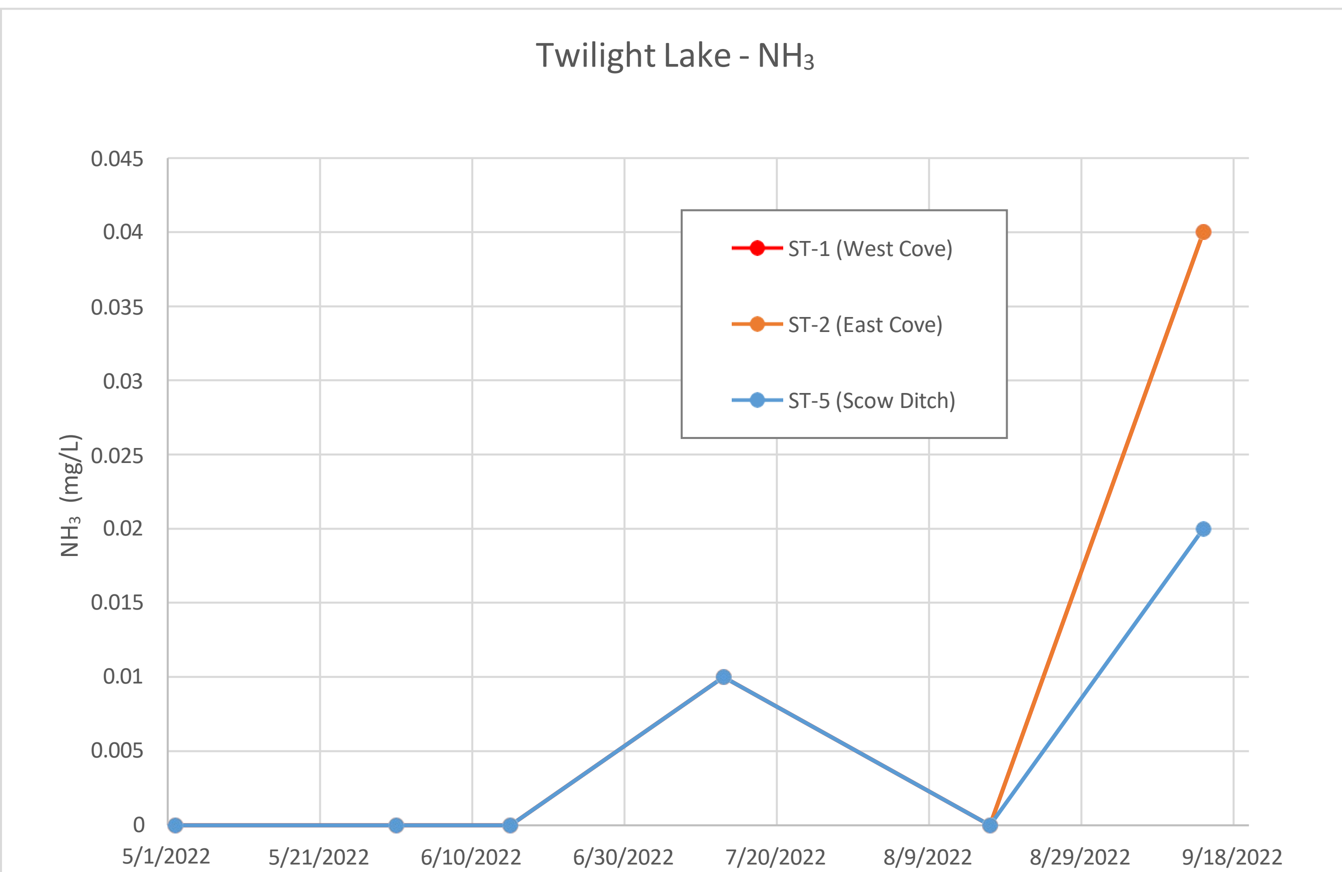
Ammonia is generally present in low concentrations in oxygenated epilimnetic layers of lakes due to the rapid conversion of the ammonium ion to nitrate. In addition, most plants and algae prefer the reduced ammonium ion to the oxidized nitrate ion for growth and therefore further contribute to reduced concentrations of ammonia in the upper water layer. In the anoxic hypolimnion of lakes ammonia tends to accumulate due to increased bacterial decomposition of organic material and lack of oxygen which would otherwise serve to oxidize this molecule to nitrate.

Increased surface water concentrations of ammonia may be indicative of excessive non-point source pollution from the associated watershed. The ammonium ion, unlike that of nitrate, may easily bind to soil particles whereby it may be transported to the lake during storm events. Another likely source of excessive ammonia in suburban watersheds is runoff from lawn fertilizer which is often highly rich in nitrogenous species. Increases in ammonia concentrations in the hypolimnion of lakes are generally associated with thermal stratification and subsequent dissolved oxygen depletion. Once stratification breaks down a pulse of ammonia rich water may be mixed throughout the entire water column whereby it will cause undue stress to aquatic organisms.

Toxicity of ammonia to aquatic species generally increases with increasing pH (>8.5) and decreasing temperature (<5°C). The general guideline issued by the EPA is that ammonia should not exceed a range of 0.02 mg/L to 2.0 mg/L, dependent upon water temperature and pH, to preclude toxicity to aquatic organisms. Surface water NH3-N concentrations above 0.05 mg/L tend to stimulate elevated rates of algal growth.

Ammonia (NH_3-N) concentrations were only measured at the in lake stations - ST 1, 2, and 5 (Figure 5). NH_3 was only detected in July and September. All stations had concentrations of 0.01 in July while concentrations at ST 1 and 2 in September were 0.04 mg/L and ST 5 was 0.02. All detectable concentrations of NH3 in Twilight Lake in 2022 were below the 2.0 mg/L threshold.

Figure 5



Nitrate-Nitrogen (NO3-N)

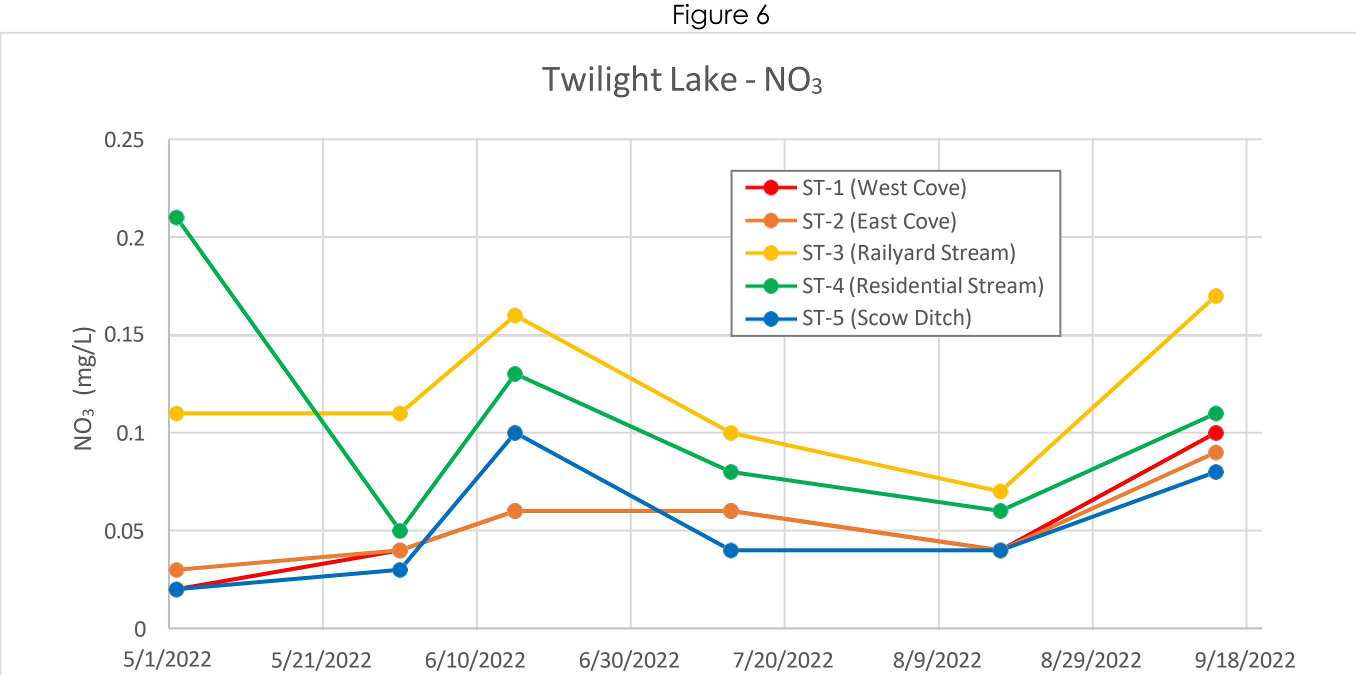
Nitrate is the most abundant form of inorganic nitrogen in freshwater ecosystems. Common sources of nitrate in freshwater ecosystems are derived from bacterial facilitated oxidation of ammonia and through groundwater inputs. The molecular structure of nitrate lends it poor ability to bind to soil particles but excellent mobility in groundwater.

Nitrate is often utilized by algae, although to a lesser extent than ammonia, for growth. Nitrate distribution is highly dependent on algal abundance and the spatial distribution of dissolved oxygen concentrations. In many eutrophic lake systems nitrate concentrations show temporal and spatial variability due to algal productivity and relative concentrations of dissolved oxygen.

Nitrate-N concentrations greater than 0.10 mg/L are considered excessive relative to algal and aquatic plant growth. Typically, lakes with concentrations above 0.30 mg/L indicates nitrogen-loading, however, concentrations below 0.50 mg/L are still considered acceptable water quality. Overall, the State and Federal drinking water standard is 10.0 mg/L.

Nitrates (NO_3-N) were tested for at all stations. The main in-lake stations remained below the 0.1 mg/L threshold until June when it rose to 0.06 mg/L at ST 1 and ST 2 through July and decreased to 0.04 mg/L in August before increasing again to 0.09 mg/L and 0.1 mg/L in September, respectively. ST 5 demonstrated a similar pattern with a spike in June to 0.1 mg/L, a drop to 0.04 mg/L through August and an increase to 0.08 mg/L in September. ST 3 at the Railyard remained above the threshold for the entire season with nitrate concentration ranging from 0.1 mg/L in July to 0.17 in September. ST 4 had the highest concentration of all the sites with 0.21 mg/L on 2 May 2022 but decreasing to 0.05 mg/L at the end of May and following a similar pattern to the rest of the stations throughout the remainder of the growing season (Figure 6).

Figure 6



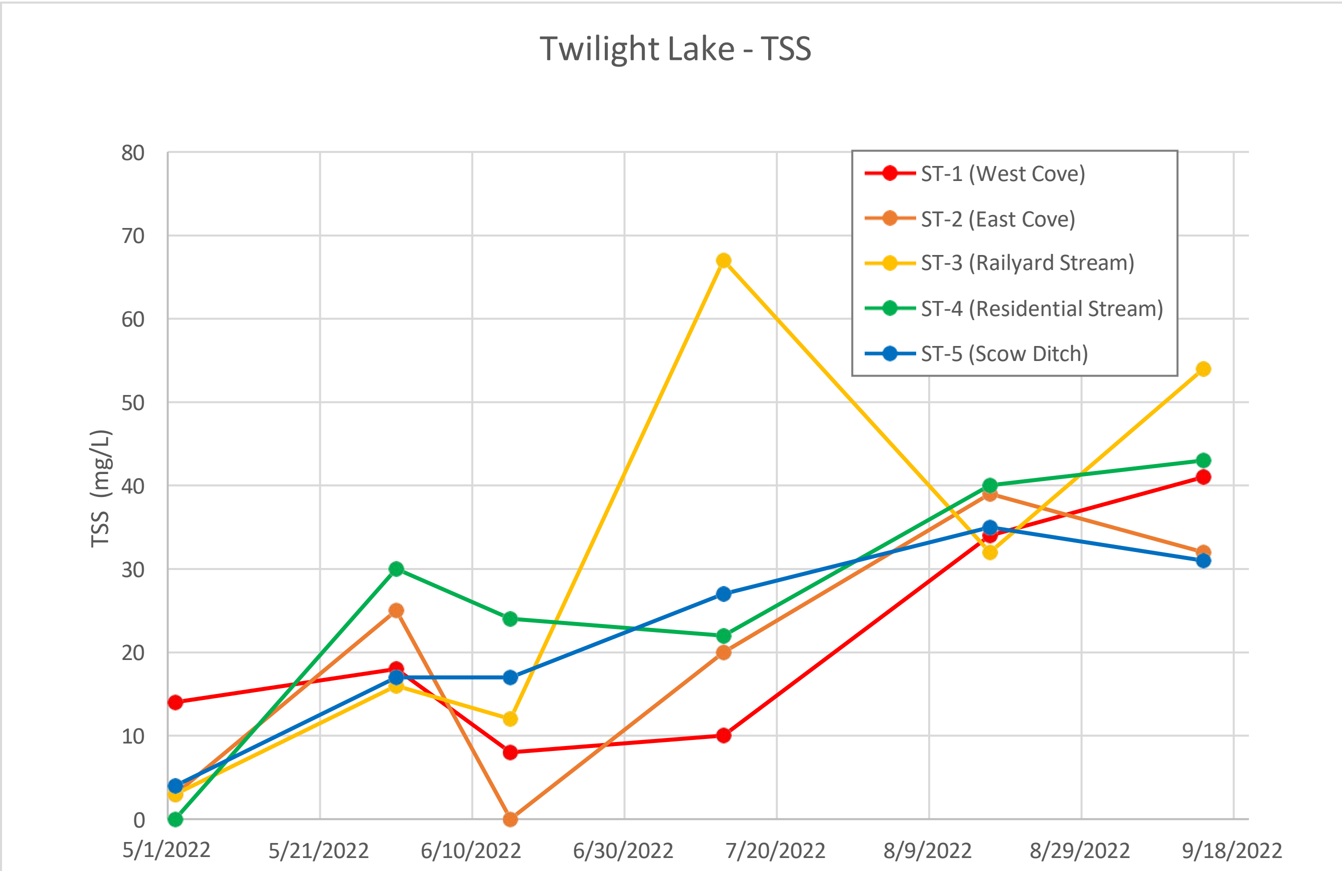
Total Suspended Solids

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 (though non-trout streams is 40 mg/L). Total suspended solids measures include suspended inorganic sediment, algal particles, and zooplankton particles.

In addition, as phosphorus molecules are often times tightly bound to soil particles, elevated total suspend solids measures may serve as indicators of not only excessive sediment inputs but also excessive phosphorus inputs to a waterbody.

Concentrations of TSS, shown in Figure 7 below, were relatively low in early May for all stations, increased with ST 3 and 4 at or above the 25 mg/L threshold by the end of the month, and all decreased below threshold by June. TSS increased slightly at sites in July, with spike to 67 mg/L at ST 3. All stations came to concentrations that ranged from 32 mg/L (ST 3) to 40 mg/L (ST 4) in August and remained high in September ranging from 31 mg/L (ST 5) to 54 mg/L (ST 3). This seemed to correspond with Secchi depth in that material in the water column increased through the season and contributed to a decrease in clarity over time.

Figure 7

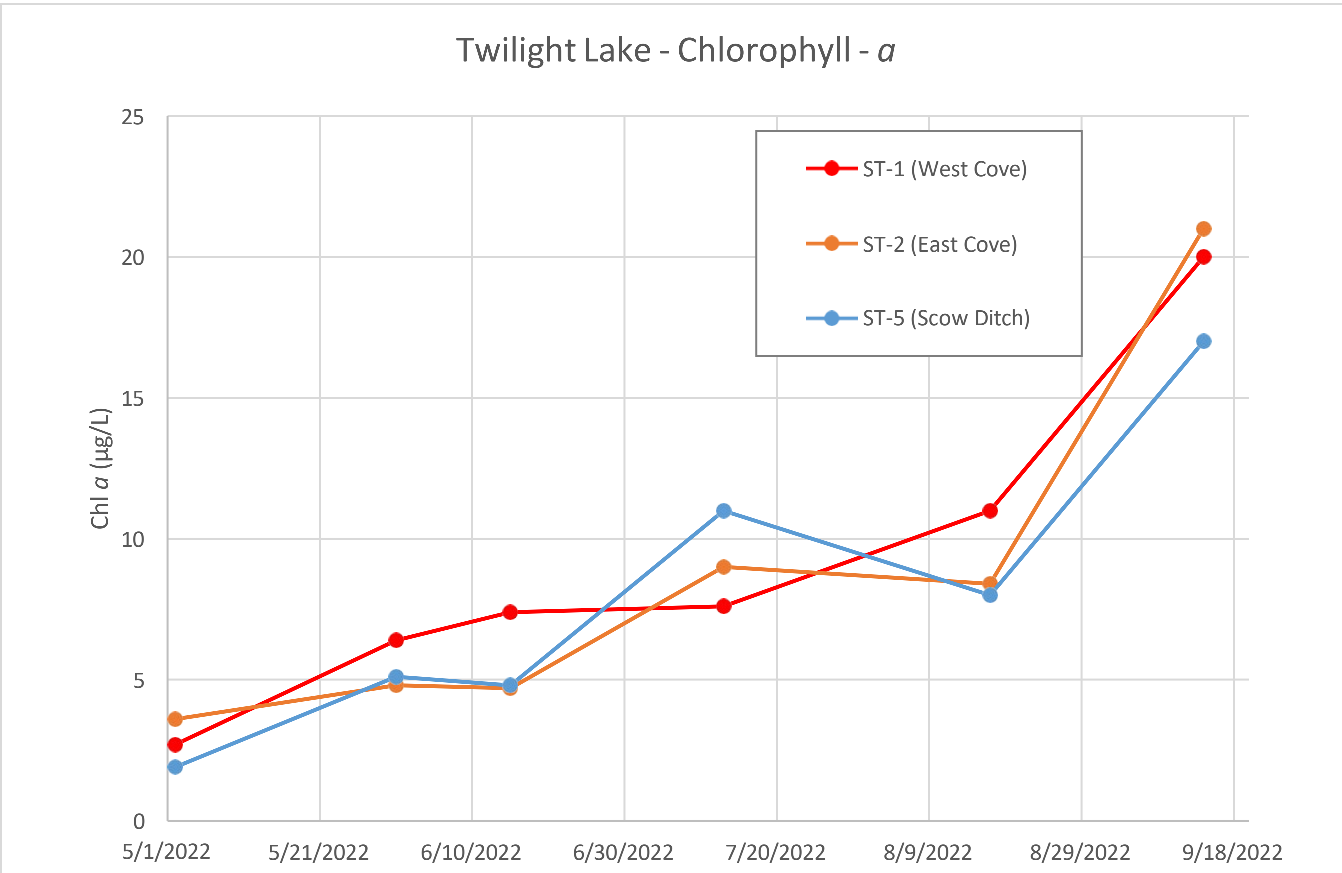


Chlorophyll-a

Chlorophyll-*a* (Chl-*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* concentrations 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.

Chlorophyll-*a* (Figure 8) was only collected at ST 1, 2, and 5 and shown in Figure 2.6. Concentrations for all 3 stations were all very low starting in May, all were below 4 µg/L. Concentrations of Chl-a for ST 2 and 5 remained around 5 µg/L through June while Chl-a at ST 1 steadily increased up to 7.4 µg/L. Concentrations at ST 1 remained about the same in July while those at ST 2 and 5 increased significantly (9 and 11 µg/L, respectively). Those values decreased slightly on August to ~8 µg/L, while Chl-a at ST 1 increased to 11 µg/L. In September, all Chl-a concentrations increased considerably, ranging from 17 (ST 5) to 21 (ST 2); ST 1 and 2 in September were the only values to reach the 20 µg/L threshold. Again, this appears to correspond with an increase in particulate matter, possibly phytoplankton, in the water column over time.

Figure 8



PLANKTON

A full summary of all plankton data can be found in Appendix E.

Phytoplankton

Phytoplankton are the base of the trophic web in any lake system and largely determine the quality of the waterbody from ecological, recreational, and aesthetic perspectives. Phytoplankton are described herein as single celled and colonial algae, forming surface and benthic (bottom) colonies that act as primary producers through photosynthesis within the lake. Phytoplankton growth is largely a function of nutrient concentrations, specifically phosphorus and nitrogen as discussed above, and available light intensity. Excessive nutrient levels can cause undesirable phytoplankton blooms that negatively impact water clarity and may form dense, floating surface mats. In addition to limiting phytoplankton biomass, nutrient levels can directly affect the phytoplankton assemblage, most notably low N:P (nitrogen to phosphorus) environments favor the growth of the undesirable

Cyanobacteria division (blue-green algae). These are the algae which commonly form surface scums that are not only aesthetically unpleasant but typically produce strong, obnoxious odors.

Phytoplankton community at ST 1 consisted of mostly dinoflagellates in May with some diatoms present. A proliferation of green algae occurred in June, the month with the greatest species richness (n=20), which displaced some of the diatoms but dinoflagellates remained common; *Aphanizomenon*, a cyanobacteria, was also common in June. Diatoms dominated the community in July with the cyanobacteria *Aphanacapsa* and two species of dinoflagellate being present. Richness decreased to n=18 in July and continued to decrease through the rest of the season, with only one species of cyanobacteria and one species of dinoflagellate being common each month, with a diatom species and a cryptomonad species common in September. ST2 had an abundance of the dinoflagellate *Ceratium* in May shifting to a number of diatom species present at the end of May and *Fragillaria* common through June. *Aphanizomenon* was common at the end of May and a number of other cyanobacteria were counted but rare through July, the most species rich month for ST 2. There were also a number of diatom species and dinoflagellates common and present in July. *Aphanacapsa* was common in September with diatoms dominating the community late in the season, with an abundance of *Melosira*. Three species of cyanobacteria were present in ST 5 at the beginning of May: *Anabaena, Lyngbya,* and *Oscillatoria*; two species of diatom and 1 species of dinoflagellate were common. Diatoms and a species of dinoflagellate, *Ceratium*, were the dominant species through June. July was the most species rich month for ST 5 (n=24), with the most common species *Aphanacapsa, Cylindrotheca, Gyrosigma,* and *Navicula*. Richness generally decreased overall in August but shifted to cyanobacteria (*Lyngbya, Microcystis*) and green algae (*Pediastrum*) being the most common. September phytoplankton populations were dominated by an abundance of the dinoflagellate *Ceratium* with the diatom *Melosira* being commonly found as well.

The NJDEP has established cell count-based criteria for the relative probability of acute health effects of these HABs. NJDEP has a Health Watch level of 20,000 cells/mL and an Advisory Guidance Level of 80,000 cells/mL. These cell counts will become more important for future monitoring and if a bloom should occur.

Zooplankton

Zooplankters are the micro-animals that inhabit the water column of an aquatic ecosystem. The zooplankton of freshwater ecosystems is represented primarily by four major groups: the protozoa, the rotifers, and two (2) subclasses of Crustacea, the cladocerans and the copepods. The cladocerans are a particularly important taxon within an aquatic ecosystem, and factor importantly in lake management. Cladocerans are typically characterized as large, highly herbivorous zooplankters capable of keeping algal densities naturally in check through predation pressure. Many species of copepods are herbivorous and can also help maintain algal densities. Aside from algae, many copepods also feed on other small aquatic animals and organic debris. Rotifers display a diversity of feeding habits. A portion of omnivorous rotifers feed on any organic material including bacteria and algae, while predaceous rotifers feed primarily on algae and other rotifer species. Protozoa feed either through ingestion or photosynthesis.

Zooplankton community at ST 1 was composed of an abundance of polychaete worm larvae, the rotifer *Tylotrocha* being common, and various stages of *Microcyclops* copepods being present. Overall richness increased through the end of May (n=13) and peaking in June (n=16) with polychaeta larvae still being common, *Microcyclops* nauplii dominating in abundance with the rotifer *Keratella*, and the cladoceran *Bosmina* being common as well. Species richness then decreased through the rest of the season, with the only common species being the rotifer *Notholca* in July, *Microcyclops* nauplii in August, and a few species only present or rare in September. Species richness at ST 2 was greatest in May (n=14), dominated by the common *Microcyclops* nauplii, polychaete worm larvae, and the rotifer *Tylotrocha*. *Microcyclops* naupliia were common through July and present through September. Rotifers, specifically *Notholca* and *Keratella* were dominant as common or present from July through September. Similar to the other stations, ST5 was dominated by *Microcyclops* nauplii, being abundant through June, present in July and common for the rest of the season. Rotifers were also dominant in the community with an abundance of *Tylotrocha* in May, *Keratella* abundant and *Kellicotia* common in June, and *Polyartha* common in July and August. Some cladocerans were present late in the season as were some rotifer species, with ostracods being the only other common organism in September at ST 5.

TSI

Carlson's Trophic State index is a commonly used tool by lake managers to assess lake productivity and to track changes in eutrophication over time. Carlson's Trophic Index is a log based, single variable trophic index that uses chlorophyll a concentration, total phosphorus concentration, or Secchi depth to calculate an index value, from 0 to 100, to designate the productivity status of a lake.

The index was calculated by Dr. Robert Carlson through the use of regression equations on a robust dataset of North American lakes. The basic assumptions of this index are that suspended particulate matter is the primary determinant of Secchi depth and that algal particles are the sole source of this suspended matter. Given these assumptions, TSI values calculated for chlorophyll a, total phosphorus, and Secchi disk should all be equal. Frequently they are not and systematic differences in productivity may therefore be determined through residuals analysis.

Index values greater than 50 are generally associated with eutrophic conditions and are correlated with a chlorophyll-a concentration of 7.3 µg/L and greater. Tracking TSI values over time may provide great insight as to the rate of lake eutrophication and the benefits of management measures which serve to reduce excessive algal growth. Twilight Lake's various TSI scores are summarized in Table 1.

Table 1

Twilight Lake - TSI						
	Station 1 - West Cove			Station 2 - East Cove		
Date	Secchi	TP	Chlorophyll-a	Secchi	TP	Chlorophyll-a
5/2/2022	56	47	40	56	47	43
5/31/2022	60	53	49	59	53	46
6/15/2022	56	53	50	56	53	46
7/13/2022	63	61	50	63	57	52
8/17/2022	56	63	54	56	57	51
9/14/2022	70	63	60	63	61	60

Both Stations 1 and 2 have relatively consistent Secchi TSI values, with the West Cove being slightly higher if there was any variation. In either case, the TSI values are higher than 50, highest in July and September at 63 and 70 respectively. The case remained the same for TSI values based on TP, consistent throughout the season with any variation being higher values in the West Cove. Again, in both cases, TSI values increased through the growing season from 47 on May 2 to 63 and 61 on September 14 at Station 1 and 2, respectively. TSI values from Chl-*a* were more variable between stations but increased within a station through the growing season from 40 in May to 60 in September at Station 1 and 43 in May to 60 at Station 2.

Overall, TSI values above the level associated with eutrophic conditions (TSI = 50) for most of the growing. The exceptions to these eutrophic TSI values include for TP TSI values in May, Chl-*a* TSI values through May in the West Cove, and Chl-*a* into June in the East Cove. Though not specifically listed as impaired, Twilight Lake typically exhibits characteristics of a eutrophic waterbody through the major part of the growing season based on these indices.

SUMMARY

Twilight Lake is relatively well mixed with only a few instances of stratification exhibited by temperature and DO in some deeper waters late in the summer. Within most stations, pH is also relatively consistent. TP in the main body of the lake, starts low and increases through the season while concentrations of TP and SRP in the northwestern wetland areas (ST 3 and 4, including near the Railyard) start out rather high in the beginning of the season. Ammonia levels do not exceed thresholds until the end of the season;

nitrates are variable but highest coming from ST 3 and 4. TSS also starts low and increases through the growing season, with a spike at ST 3, but high values from all stations by August. Chl-*a* concentrations also tend to increase in the main portion of the lake as the season progresses, with exceedances of thresholds on in September. Phytoplankton communities are most diatoms and dinoflagellates, with some green algae and cyanobacteria; no bloom levels were experienced in 2022. Zooplankton observed most were copepod nauplii, polychaeta larvae and some estuarine rotifers.

Though Twilight Lake is not specifically list as impaired by the NJDEP, data does indicate some eutrophic conditions, which is further supported by Carlson's Trophic State Indices for Secchi Depth, TP, and Chl-*a*. Reduction of these indicators to mesotrophic levels would serve as a valid benchmark for restoration.

2.3 POLLUTANT LOAD AND HYDROLOGY MODELING

Environmental models are powerful and widely used tools that fulfill many different functions and are used in a variety of capacities and at different scales. At their most basic, models are mathematical relationships that transform user inputs from various sources to yield a set of output data that can be numeric, categorical, indices, dimensionless variables, graphics, or other formats. The primary use of modeling is to increase understanding of system characteristics, dynamics, and function.

MapShed and its online variant Model My Watershed, will serve as the primary model for the project, which is based on the Generalized Watershed Loading Function (GWLF) model. This is described as a good mid-level model and is recommended by the USEPA for the development of WBPs. This model uses inputs such as watershed areas, soil characteristics, topography, and land use/land cover data to project pollutant loads for the parameters described above. The output is on a monthly and annual basis further broken down by various sources. The results on a monthly scale can be quite variable, and much of this is due to the seasonal differences of the water budget as pollutant loading and hydrology elements are inextricably linked as water is the prime vector of almost all loading. Therefore, the model calculates hydrology in parallel with pollutant loading.

Modeling is used here to provide a context of observed conditions; how various aspects of the watershed affect the observed water quality and biology of the system. It can also highlight which features of the pollutant loads merit mitigation.

The hydrology and pollutant loading dynamics of Twilight Lake are complex. While the total watershed area is modest, stormwater routing has effectively changed the watershed boundary. The system is tidal, connected to Bay Head Harbor, itself a part of Barnegat Bay, via Scow Ditch. As a result, Twilight Lake experiences regular tidal cycling, which impacts not only the hydrology of the system, but the pollutant loading. Additionally, the Scow Ditch watershed must also be considered a contributor to Twilight Lake. The remainder of this section will discuss the modelling methodology and the results.

WATERSHED STATISTICS AND LAND USE/LAND COVER COMPOSITION

Land Use/Land Cover (LU/LC) is one of the major determinants of watershed hydrology and pollutant loading. LU/LC can be used to infer the behavior of precipitation on the landscape, essentially the rates at which it infiltrates or forms runoff, the relative rates of evapotranspiration based on vegetative cover, the development of pollutants, and ultimately their transport through the watershed. Tables 2 and 3 summarize the land use statistics for each of the watershed areas, reporting areas in acres and hectares. For this modelling exercise, three primary areas were considered, including the Twilight Lake watershed or main catchment excluding the lake, Twilight Lake proper, and the Scow Ditch subwatershed.

Table 2

Land Use/Land Cover (hectares)			
LU/LC	**Twilight Lake Watershed**	**Twilight Lake**	**Scow Ditch Subwatershed**
Forest	0.2	0.0	0.0
Wetland	13.8	0.0	0.0
Bare_Rock	0.5	0.0	0.4
Ld_Mixed	18.0	0.0	2.5
Md_Mixed	35.1	0.0	13.9
Hd_Mixed	8.2	0.0	4.7
Ld_Open_Space	4.6	0.0	0.1
Open_Water	0.0	11.0	1.1
Total	80.4	11.0	22.7

Table 3

Land Use/Land Cover (acres)			
LU/LC	**Twilight Lake Watershed**	**Twilight Lake**	**Scow Ditch Subwatershed**
Forest	0.5	0.0	0.0
Wetland	34.1	0.0	0.0
Bare_Rock	1.2	0.0	1.0
Ld_Mixed	44.5	0.0	6.2
Md_Mixed	86.7	0.0	34.3
Hd_Mixed	20.3	0.0	11.6
Ld_Open_Space	11.4	0.0	0.2
Open_Water	0.0	27.2	2.7
Total	198.7	27.2	56.1

The Twilight Lake watershed is the direct catchment to the lake, excluding the open water areas of the lake proper. The delineation is based on that provided by the Bay Head Environmental Commission, which in turn is based on the routing of the stormwater management system. It should be noted that this effective watershed is smaller than that indicated by a topographic delineation, and large swaths of the topographic watershed, particularly those areas to the west of Bay Avenue, south of Bridge

Avenue, and north of Osborne Avenue are all routed away from Twilight Lake and discharge elsewhere. The total area of the Twilight Lake watershed, excluding the lake, is approximately 80.4 hectares (ha) or 198.7 acres. Over 76% of the watershed falls within three land use types: low-, medium-, and high-density mixed land use types, consistent with a developed town. Most of the remainder consists of wetlands and low-density open space.

Twilight Lake proper consists of a delineation of the open water areas of the lake, here determined to be 11.3 ha or 27.2 acres.

The Scow Ditch subwatershed is 22.7 ha or 56.1 acres. Like the main catchment, it is predominantly urban and dominated by medium-density mixed uses. It also includes the open waters of Scow Ditch, approximately 1.1 ha. In non-tidal systems, the Scow Ditch catchment would be considered to be downstream of the lake's outlet, and therefore outside of the drainage area. Scow Ditch is tidal however, with bi-directional flow and discharges to Twilight Lake on the incoming tide, and therefore direct loading to Scow Ditch contributes to the pollutant and hydrologic loads of Twilight Lake. For this modelling exercise, half of both the hydrologic and pollutant loads generated within the Scow Ditch watershed were considered to be transported to Twilight Lake coincident with the incoming tide. On the outgoing tides, those loads would be discharged to Bay Head Harbor.

WATERSHED HYDROLOGY

For the purposes of this study, watershed hydrology is used primarily as a way to understand system function as it relates to flows from the watershed, tidal flows, and for the context of the transport and delivery of pollutant loads. It is not a hydraulic study and does not model flooding. The hydrology examines several important components of the water budget, including precipitation, evapotranspiration (ET) which represents a seasonal loss of water from the system, runoff, groundwater flux, and a net term. The net term metric is essentially the sum of runoff and groundwater flux; groundwater flux is generally subsurface but can also be expressed as stream baseflow.

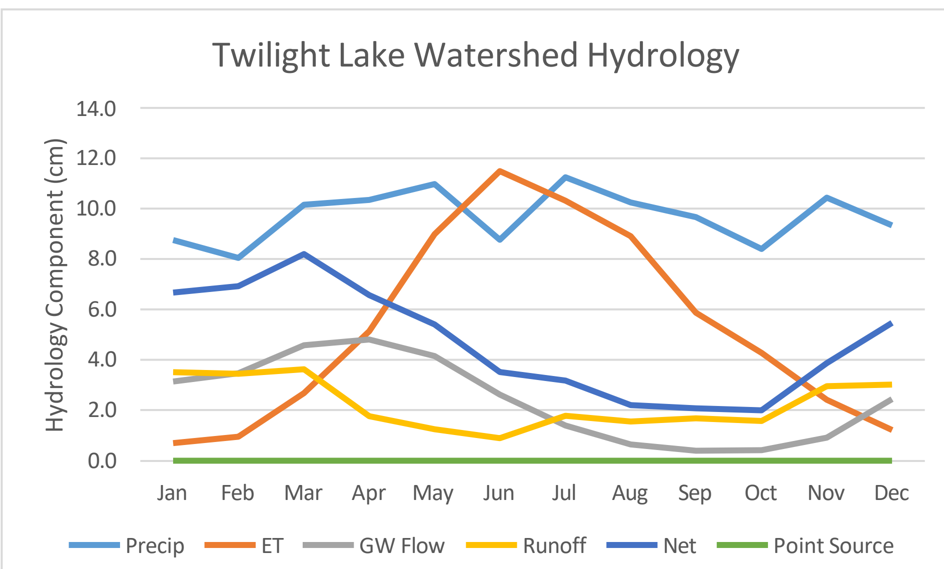
The hydrology data was examined at several scales and using several different formats for the various hydrologic units. For the main Twilight Lake watershed, the data is presented in an interesting, but intuitive format. Precipitation is considered the base of the hydrologic cycle and is typically reported as a one-dimensional unit, in this case as centimeters (cm). Each of the other elements are reported in the same way (Table 4). This fosters easier comparisons across each of the budget terms and how it is related back to precipitation. Values are also developed for each component during each month of the year. The data is also plotted in Figure 9.

Table 4

Twilight Lake Watershed Hydrology Components (cm)					
Month	Precip cm	ET cm	GW cm	Runoff cm	Net cm
Jan	8.75	0.69	3.14	3.52	6.66
Feb	8.04	0.95	3.47	3.45	6.92
Mar	10.16	2.68	4.58	3.63	8.20
Apr	10.35	5.13	4.81	1.77	6.57
May	10.98	8.98	4.15	1.25	5.40
Jun	8.76	11.48	2.62	0.90	3.52
Jul	11.24	10.31	1.39	1.79	3.18
Aug	10.24	8.90	0.65	1.55	2.20
Sep	9.66	5.87	0.39	1.68	2.07
Oct	8.40	4.27	0.42	1.58	2.00
Nov	10.44	2.41	0.91	2.96	3.87
Dec	9.34	1.22	2.44	3.02	5.46
Total	116.36	62.89	28.97	27.10	56.05

Note, the precipitation values for the Watershed do not include precipitation entering Twilight Lake directly.

Figure 9



Overall, precipitation in the region tends to be relatively steady through most of the year. The other components, however, vary widely. This is primarily due to the influence of ET which is dependent on ambient temperature and solar radiation, increases rapidly through the spring, peaks through the summer, and begins to seriously decline through the autumn. In fact, ET is generally similar to precipitation during the summer months, on average, and may exceed total rainfall at times. Both the groundwater and runoff terms tend to follow the difference between precipitation and ET terms. Groundwater flux is very low during the late summer and into early autumn while groundwater remains depressed even while ET rates are falling.

While this presentation is useful to contextualize the budget terms in relation to precipitation, comparisons across the different hydrologic units are facilitated by using volumes; this study uses cubic meters (m^3) which is equivalent to 1,000 liters (1 L). The hydrology for the Twilight Lake watershed is reported in m^3 in Table 5 below.

Table 5

Twilight Lake Watershed Hydrology Components					
Month	**Precip** m^3	**ET** m^3	**GW** m^3	**Runoff** m^3	**Net** m^3
Jan	7.04E+04	5.55E+03	2.52E+04	2.83E+04	5.35E+04
Feb	6.46E+04	7.64E+03	2.79E+04	2.77E+04	5.56E+04
Mar	8.17E+04	2.15E+04	3.68E+04	2.92E+04	6.59E+04
Apr	8.32E+04	4.12E+04	3.87E+04	1.42E+04	5.28E+04
May	8.83E+04	7.22E+04	3.34E+04	1.01E+04	4.34E+04
Jun	7.04E+04	9.23E+04	2.11E+04	7.24E+03	2.83E+04
Jul	9.04E+04	8.29E+04	1.12E+04	1.44E+04	2.56E+04
Aug	8.23E+04	7.16E+04	5.23E+03	1.25E+04	1.77E+04
Sep	7.77E+04	4.72E+04	3.14E+03	1.35E+04	1.66E+04
Oct	6.75E+04	3.43E+04	3.38E+03	1.27E+04	1.61E+04
Nov	8.39E+04	1.94E+04	7.32E+03	2.38E+04	3.11E+04
Dec	7.51E+04	9.81E+03	1.96E+04	2.43E+04	4.39E+04
Total	9.36E+05	5.06E+05	2.33E+05	2.18E+05	4.51E+05

The Twilight Lake watershed hydrology only represents one component of the total hydrology for the lake. There are three other primary components, including tidal hydrology, Scow Ditch subwatershed, and direct net precipitation on Twilight Lake. Each of these components will be described in more detail below.

Tidal hydrology was estimated by examining the United States Geological Survey (USGS) tidal data for the Barnegat Bay at Mantaloking station for 2021 to 2022. In general, the average monthly tidal spectrum or tidal range for this station was fairly small, ranging from 0.50 ft to approximately 1.25 ft during the period of record. Using this data, in combination with observations made at Twilight Lake during sampling events and factoring in tidal lag, an estimate for daily tidal range was developed for each month. To calculate the monthly tidal exchange, this tidal range was multiplied by the number of high tides per month (somewhat less than 2 per day) and multiplying that by the area of the lake. This calculation yielded monthly tidal exchange.

The next component was the Scow Ditch subwatershed. This was calculated in the same manner described for the Twilight Lake watershed, but the quantities were divided in two to reflect that only half of that hydrologic load originating in that subwatershed would be discharged to Twilight Lake via Scow Ditch on the incoming tides.

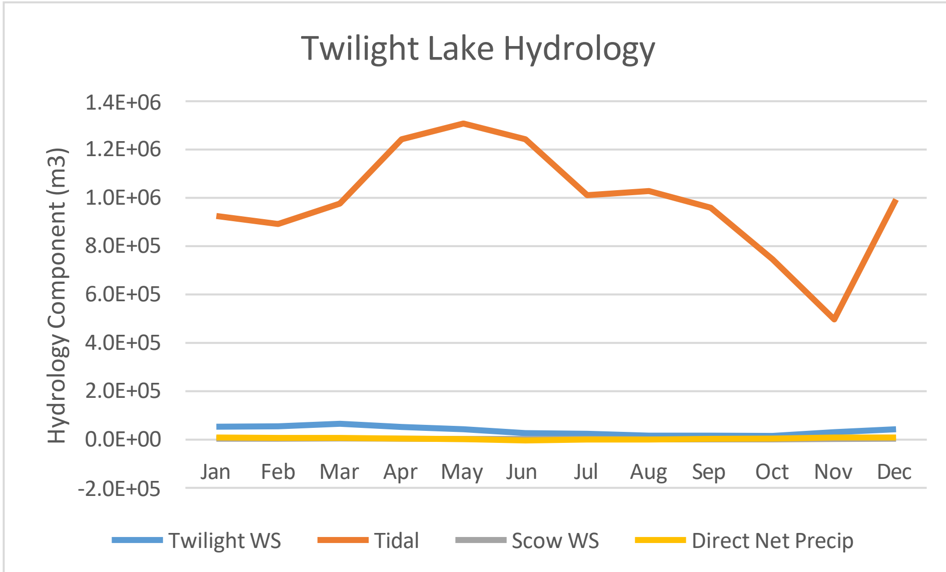
Lastly, a direct net precipitation term was calculated for Twilight Lake. This represents the direct precipitation falling on Twilight Lake minus evaporative losses.

These four components, the Twilight Lake watershed, tidal flux, Scow Ditch subwatershed, and direct net precipitation were then added to calculate total system hydrology. The total term represents all water inputs to Twilight Lake. Furthermore, the total inputs are equivalent to the total outputs; any difference in the two would be reflected in either a gain or loss of stage in the lake. The summary table of these components is provided below in Table 6 and plotted in Figure 10.

Table 6

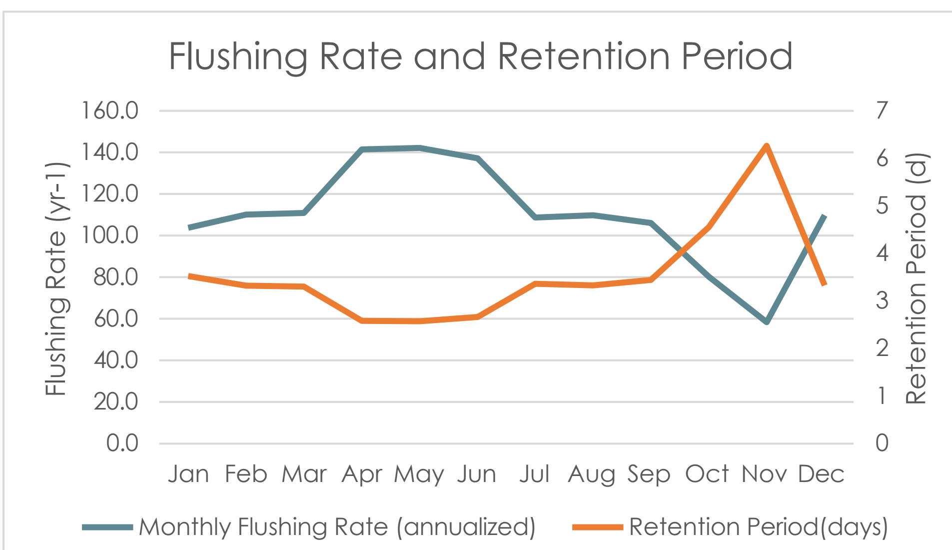
Twilight Lake Hydrology Components					
Month	Twilight WS m^3	Tidal m^3	Scow WS m^3	Direct Net Precip m^3	Total m^3
Jan	5.35E+04	9.26E+05	4.13E+03	8.87E+03	9.92E+05
Feb	5.56E+04	8.92E+05	4.12E+03	7.80E+03	9.59E+05
Mar	6.59E+04	9.77E+05	4.81E+03	8.23E+03	1.06E+06
Apr	5.28E+04	1.24E+06	3.70E+03	5.74E+03	1.31E+06
May	4.34E+04	1.31E+06	3.09E+03	2.20E+03	1.36E+06
Jun	2.83E+04	1.24E+06	2.14E+03	-2.99E+03	1.27E+06
Jul	2.56E+04	1.01E+06	2.04E+03	1.02E+03	1.04E+06
Aug	1.77E+04	1.03E+06	1.39E+03	1.47E+03	1.05E+06
Sep	1.66E+04	9.60E+05	1.36E+03	4.17E+03	9.82E+05
Oct	1.61E+04	7.46E+05	1.45E+03	4.54E+03	7.68E+05
Nov	3.11E+04	4.97E+05	2.71E+03	8.83E+03	5.40E+05
Dec	4.39E+04	9.94E+05	3.62E+03	8.93E+03	1.05E+06
Total	4.51E+05	1.18E+07	3.46E+04	5.88E+04	1.24E+07

Figure 10



The hydrology of Twilight Lake, even utilizing a relatively conservative tidal exchange estimate, is completely dominated by tidal flow. Tidal flux accounts for approximately 95.6% of the total water budget. Tidal exchange alone is 12.6 times higher than the total rainfall received by the main watershed. Conceptually, this does make sense. Even if tidal range in Twilight Lake is only several inches, a storm event to drive a similar response may only occur once every several weeks, a much lower rate. As such, this tidal dominance is a strong control on the pollutant loading of the system, and also indicates that the lake has a very rapid flushing rate (Figure 11).

Figure 11



The flushing rate of Twilight Lake is very high throughout the year, though does vary based on season; rates are based on an average total lake water volume estimated from the 2021 Bathymetric Survey of 91.4 acre feet or 112,740 m^3. Flushing in winter is characterized by a replacement of the full volume of the Lake at an approximate rate of 110 times/year which then increases to 140 times/year when winter precipitation causes greater runoff. The high rate of flushing drops back 110 times per year in the summer and then further in the Autumn down to 60 times/year in November but then quickly returns to 110 times/year in December. Retention period, also known as residence time, is reciprocal to flushing rate and is very short relative to other lakes. The water volume of Twilight Lake is retained from as low as three (3) days in spring to as much as 6 days in November. These patterns are strongly influenced by the tidal flux but should be considered carefully when thinking about nutrient loading since N or P retention is also linked to sediment and water conditions. Nonetheless, this indicates that control of flow through Scow Ditch would be a major management strategy to be considered.

POLLUTANT LOADING

Pollutant loading here is focused on those elements that have the largest impact to environmental function, namely the nutrient pollutants and solids loading. The model was therefore used to develop pollutant loads for Total Nitrogen (TN), Total Phosphorus (TP), and Total Solids (TSS). These are further broken down by their source load and by percentage.

Total nitrogen is an important macronutrient for plants and algae. Nitrogen pollution is often associated with dissolved forms, although not always. Solids may include eroded materials like topsoils, stream bank materials, or resuspended bed material in energetic systems like estuaries. However, groundwater sources tend to be quite important, including septic systems. Fortunately, the Twilight Lake watershed is serviced by sanitary sewer, thereby eliminating that potential source of loading from septic systems. In addition to groundwater loading, impervious surface runoff can be important in contributing to pollutant loads in urbanized watersheds. This would include fertilizers, animal waste, and other contributions; this holds true for phosphorus as well.

The effects of excessive phosphorus loading are well documented in both estuaries and freshwater ecosystems. In freshwaters, it is particularly well correlated to eutrophication, and while less important than nitrogen in estuaries, it is also problematic. As described above, the bulk of the phosphorus is usually in particulate form and is therefore most often associated with eroded particles and organic matter. Dissolved forms account for a much smaller fraction of the load, but because of their high biological reactivity can be especially important. Sediment loading is also an important element of the pollutant load in the ecology of these waterbody. Sedimentation has been a significant issue in the past, especially those events resulting from major coastal storms. Infilling due to sedimentation can cause a significant loss of depth, and while there are recreational impacts associated with this, there are a number of ecological impacts. Shallower depths lead to more rapid warming and allow more of the pond bottom to support photosynthesis. Due to both of these effects, shallower depths are often associated with increased, often nuisance, growth of plants and algae.

Like the hydrology calculations, pollutant loads consider several different primary loads - namely those originating in the Twilight Lake watershed, from the Scow Ditch subwatershed, and within the tidal flow. Loads from the two watershed areas were calculated using the model directly. Few changes were required to the input files, although population using septic systems was set to 0. Farm animal and livestock populations were set to 0, the initial estimates are generally based on a county-level-per-unit-area density applied to the appropriate land cover types within the watershed (this was not used though since the county-level livestock density does not apply in Bay Head). Goose loading was added using an estimate of the population based on numbers provided by the Environmental Commission. Using these settings, the model provides loading estimates, broken down into runoff from each of the LU/LC types, as well as associated loads including in this case geese, stream bank erosion which includes erosion in both defined and undefined channels, groundwater, and septic systems (here all of those inputs providing no loads as described above). For the Scow Ditch subwatershed, all the calculated loads were halved to replicate loading only on the incoming tidal cycle.

Tidal loads were calculated outside of the model. Concentrations for TP, TN, and total suspended solids (TSS) were calculated from a dataset published by USGS collected within Point Pleasant Canal. Monthly average concentrations were calculated for each of the three parameters and multiplied by the average monthly tidal flux as discussed in the hydrology to develop loads in kilograms (kg).

An effort to model the effects of flood derived loads was also attempted. Generally, the MapShed derived model is not equipped to perform such a task. Nonetheless, An attempt was made to calculate flood derived loads using defined flood prone areas and depth of flooding supplied by the Environmental Commission. The concentration of the contaminants entering Twilight Lake during flooding used in the calculation is the same as used for tidal flow, which came from USGS Point Pleasant Canal published values. (Reference: https://nwis.waterdata.usgs.gov/nwis/qwdata/?site_no=01408043.) The results show that flood derived loads were significant as discussed in Appendix F. Controlling this source of pollutant loading by limiting or blocking flow of flood waters during flood conditions would contribute to the reduction in contaminant loading.

The loads for each of the primary parameters were then summed. A summary of the sources is provided in Table 7 below.

Table 7

Twilight Lake Pollutant Loading							
Category	**Description**	**TN**		**TP**		**TSS**	
		kg	**%**	**kg**	**%**	**1000 kg**	**%**
Twilight WS Runoff	Forest	0.0	0.0	0.0	0.0	0.0	0.0
	Wetland	4.9	0.1	0.3	0.1	0.0	0.0
	Bare_Rock	0.3	0.0	0.0	0.0	0.0	0.0
	Ld_Mixed	8.9	0.2	0.9	0.2	0.3	0.1
	Md_Mixed	53.2	1.0	5.4	1.1	2.7	0.9
	Hd_Mixed	12.4	0.2	1.3	0.3	0.6	0.2
	Ld_Open_Space	2.3	0.0	0.2	0.0	0.1	0.0
	Open_Water	0.0	0.0	0.0	0.0	0.0	0.0
Twilight WS Other Sources	Geese	1.2	0.0	0.4	0.1	0.0	0.0
	Stream Bank	0.0	0.0	11.0	2.3	48.6	15.9
	Groundwater	79.2	1.5	2.3	0.5	0.0	0.0
	Septic Systems	0.0	0.0	0.0	0.0	0.0	0.0
Tidal	Tidal	4937.4	96.3	464.2	95.0	251.7	82.1
Scow Ditch WS	Scow WS	27.0	0.5	2.5	0.5	2.4	0.8
Total		5126.6	100.0	488.6	100.0	306.4	100.0

Tidal loads accounted for the vast majority of the pollutants loads, in excess of 80% for each of the parameters. It was particularly high for nitrogen and phosphorus, both over 95%. This corresponds well to the total hydrology of the system. A greater percentage of the solids load is generated directly in the watershed, a consequence of runoff and stream bank erosion (please note that solids loads are reported as 1000 kg or metric tons). While runoff accounted for relatively little solids load, stream bank erosion was fairly high. This is likely a consequence of the sandy soils in the watershed. Stream bank erosion is reported as total solids, this would include both a suspended solids component as well as settleable solids and bed loads. The settleable solids and bed load either quickly fall out of suspension or never enter suspension but continue to be mobile along the sediment interface depending on the energetics of the flow. The tidal solids calculation was based on suspended solids only and does not capture those coarser particles.

Across the board, all of these loads are extremely high. However, a significant factor that needs to be considered is the retention of these loads. While there is undoubtedly high loads of nutrients and solids entering the lake, there is also a very high load that departs. Recall, in this model, hydrologic inputs and outputs are essentially balanced. The bulk of this load is therefore caught in a tidal oscillation, moving in and out daily. Generally, limnology considers retention of nutrients to be inversely proportion to flushing. Because Twilight Lake has a high flushing rate, it likely has a low retention capacity. The retention of solids may be somewhat more variable and depends on both particle size and the hydrodynamics of the system.

It may be more appropriate to consider the these loads not in absolute terms of mass, but as concentrations accounting for both pollutant mass and hydrology, which is reflected in the concentrations measured in the analyzed water quality samples. Certainly, the measured and calculated concentrations are also relatively high.

The pollutant loads were also calculated on a monthly basis, which is provided in Table 8 below. There is considerable seasonal variation amongst the three parameters, especially the two nutrient parameters. In all cases, the growing season (roughly April through September) tends to show higher loading rates. This is likely due to biological activity in the estuary at this time. Certainly, a fair amount of the nitrogen, phosphorus, and to a lesser extent solids loads are bound in phytoplankton cells during the growing season, and the increased biomass at this point would be reflected in the loads of those parameters in Twilight Lake. Solids loading tends to be highest in the spring months, coincident with peak hydrologic loading, both in the estuary and the watersheds, reflecting elevated rainfall, low ET, and saturated soils.

Table 8

Twilight Lake Pollutant Loading by Month			
Month	**TN** kg	**TP** kg	**TSS** 1000 kg
Jan	368.6	29.3	21.5
Feb	299.7	23.7	20.5
Mar	319.8	26.7	24.6
Apr	430.9	56.9	28.9
May	442.3	45.2	41.7
Jun	640.5	41.6	22.8
Jul	456.4	47.9	24.8
Aug	561.8	63.5	29.7
Sep	441.5	44.1	24.6
Oct	464.0	36.7	21.3
Nov	342.9	35.7	17.6
Dec	357.9	37.4	28.3
Total	5126.1	488.5	306.4

Model validation was also performed. This was accomplished by calculating concentrations for TP and TSS, by dividing monthly calculated pollutant loads by monthly calculated hydrologic loads and comparing this to measured concentrations averaged across the west cove, east cove and Scow Ditch stations. These three stations represent the bulk of the water in Twilight Lake and provide a more representative concentration to compare against numbers derived by the model than using pollutant load concentrations from all five sample locations. Note that this was not performed for TN as the two nitrogen species measured in the field do not equate to TN, missing crucial components such as solids and organic nitrogen species. The agreement was quite good, accounting for differences between projected monthly values and grab samples, as well as the vagaries of weather and other antecedents at a particular point in time. In particular, the TP data exhibited increasing concentrations moving through the season. This comparison is summarized in Table 9 below.

Table 9

Comparison of Model and Measured Values					
Model Average (mg/L)			Measured Average (mg/L)		
Month	TP	TSS	Date	TP	TSS
Apr	0.043	22.2	2-May	0.020	7.0
May	0.033	30.8	31-May	0.030	20.0
Jun	0.033	17.9	11-Jun	0.030	12.5
Jul	0.046	23.8	13-Jul	0.043	19.0
Aug	0.060	28.3	17-Aug	0.053	36.0
Sep	0.045	25.1	14-Sep	0.053	34.7
Oct	0.048	27.8			

3.4 FIELD BASED WATERSHED ASSESSMENT

An initial assessment of the Twilight Lake watershed (Appendix A) was conducted by one scientist and one engineer from Princeton Hydro on 10 February 2022. Tom Charlton and Rick McGoey from Bay Head were present during the assessment to point out areas of concern and provide information regarding completed and upcoming projects, site history, etc. The goal of this visual field assessment was to identify and document channel conditions and bank/shoreline stability, general ecological conditions, and the presence of stormwater infrastructure. The information documented during this site visit was used to identify candidate sites for watershed best management practices (BMPs) most well suited for immediate or long-term implementation. These BMP recommendations can then be used for future potential grant opportunities as detailed proposed projects. Due to the history of flooding in the Twilight Lake watershed, best efforts were be made to incorporate green infrastructure into watershed restoration measures. 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. However, like many lake communities, there is not a lot of space for larger, more conventional BMPs, such as wetland treatment facilities, so candidates that involve the retrofitting of exiting stormwater structure were also be included.

Most of the sites that were visited during the watershed assessment were located around the shoreline of Twilight Lake and Scow Ditch or in very close proximity. The two main concerns expressed by the Bay Head representatives were related to pollutants originating from the NJ Transit Railyard yard and tidally influenced flooding. Shoreline erosion around Twilight Lake was also expressed as a major concern, which appears to be largely a result of the flooding. Some of the specific areas that were visited and documented during the site visit and the specific concerns at these locations include:

- Locations along Lake Avenue that are prone to flooding and shoreline erosion
- Lake Avenue and Twilight Road which is prone to flooding; this location also has a previously installed manufactured treatment device (MTD)
- Drainage Ditch on Twilight Road that is prone to flooding; the curbside storm drain here has a check valve to prevent backflow flooding
- Where Twilight Road meets the train station parking lot which is prone to flooding; concerns were also raised about potential pollutants originating from the train station

- The peninsula/island (old train rail) that is subject to severe erosion
- Municipal parking lot / park located along Scow Ditch; this location lacks any subsurface stormwater infrastructure
- Club Drive curbside storm drain, which is prone to flooding, especially where Club Drive meets Bridge Avenue
- W Lake Avenue and Oak Drive curbside storm drain; the shoreline above the outfall appeared to be eroding here
- W Lake and Cranberry Avenue which is a major flood area

Some general watershed restoration measures that were originally discussed during the site visit included:

- A living shoreline around much of the Twilight Lake Shoreline, where practicable
- Green infrastructure, such as vegetated swales
- Installation of additional manufactured treatment devices (MTDs)
- Retrofit of existing BMPs or stormwater infrastructure to enhance nutrient removal capacity, such as the installation of nutrient filtration media
- Potential for rain gardens or other green infrastructure in some of the grassy areas around the lake, although this will require further investigations into the existing stormwater structure in those locations as well as the general suitability of the sites for green infrastructure practices

More detailed BMP recommendations can be found in Section 4: Management Measures.

SEDIMENTATION

Outfall pipes from storm drains are often found to be buried in sedimentation at the bottom of Twilight Lake. This greatly restricts storm water drainage flow. Outfall pipes must enter Twilight Lake near or at the bottom of the Lake to achieve gravity drain from the catch basins. With a buildup of silt in Twilight Lake several catch basin outfall pipes are now partially to fully buried. Attachment 1 provides locations and pictures of this sedimentation problem. Outfall pipes numbered one and three show only one inch of open pipe of 12-inch diameter pipes. Outfall pipes numbered five and eight are partially buried. It is interesting to note that pipes installed more recently around 2014-2015 are reasonably clear. Pipes installed years ago (1960s-1970s) are fully buried in silt (outfall pipes one and three). Recognizing dredging occurred in 2015 shows that it was effective in reducing sedimentation levels in the lake.

FLOODING

Excessive water encroaching on Bay Head lands is a consistent problem experienced by the community. The BHEC has investigated this phenomenon and monitors it regularly. There are a number of locations that are prone to flooding including:

- Osborne Ave and Lake Ave
- Twilight Rd and Lake Ave
- North St and Lake Ave

- Karge St and Lake Ave
- Harris St and Lake Ave
- Mount St and Lake Ave
- Bridge Ave and Club Dr
- West Lake Ave and Club Dr
- West Lake Ave and Cranberry Ave
- Note 1: During the February 22, 2022 Site Visit, flooding was still occurring on Osborne Ave at the intersection with Lake Avenue. In June 2022 Ocean County modified the drainage of Osborne Avenue. Storm water is now directed from Osborne Avenue to Point Pleasant Beach Brick Municipal pumping station. This change has successful mitigated flooding along Osborne Avenue. Since completion, there has been no flooding on Osborne Avenue.

As flood event intensity increases, some of these locations merge to form larger flooded areas. Flooding appears to coincide with regular tidal flux and is further impacted by weather conditions. Additional runoff from floods can introduce additional nutrients from the watershed into Twilight Lake. As such, various flood conditions from the BHEC Flooding Study were included in the nutrient load modeling to determine its effect on Twilight Lake.

EROSION

Significant erosion is occurring on the west shoreline of Twilight Lake opposite North Street on the peninsula. Two beach fronts were established in the northeast and southeast corners of Twilight Lake. These two areas experience erosion and sand is added to these areas approximately once a year. Kellogg Memorial Island also experiences some erosion as reported by the Public Works Department and evidenced by the visual Field Based Watershed Assessment conducted by Princeton Hydro (outlined below).

TURBIDITY

Turbidity has been noted but there are no specific recurring locations. Some cloudiness to the water in Twilight Lake has been noted at outfalls, but not of any notable intensity.

CANADA GEESE POPULATION

Waterfowl can be a major source of nutrients to a waterbody. The geese population at Twilight Lake has been observed by residents and has been summarized by the BHEC in two ways:

1. Transient Geese which seem to come and go. They will fly in for a day or two and then fly to another location. These typically come in a large flock of 70 -100 during the summer and 50-100 during the winter. Public Works has counted over 100 geese around Twilight Lake at times, but they reportedly only stayed for less than one day.
2. "Resident" or "Non-Transient" Geese which remain around Twilight Lake for long periods of time, and possibly the entire summer. Since Canada geese egg control was limited prior to 2019, there will continue to be geese returning to Twilight Lake for years to come. The resident

geese population ranges from 20-40 most of the summer starting in April and then thins out around November when it is around 10 to 20.

Though geese remain a source of nutrient loading for Twilight Lake, these observations do not entail quantitative measurements or formal tracking; therefore, determinations about which geese stay and leave are subjective. Data included about waterfowl populations in the modeling are based on local observations but were conservative estimates from those reports.

4.0 ESTIMATE OF LOAD REDUCTIONS

This section corresponds to the second US EPA element, an estimate of load reductions expected from management measures. At the watershed-scale it is important to quantify total loads and reduction targets to achieve a water quality outcome consistent with the Surface Water Quality Standard (SWQS) or other regulations. At the site-specific scale, identifying these reductions in comparison to targeted reduction is of less utility because nutrient concentrations in the lake will still largely be determined by watershed-wide processes.

Twilight Lake has an estimated annual TP load of 488.6 kg while the average in-lake TP concentration, at all stations and during all events in 2021, was 0.06 mg/L. The 0.06 mg/L concentrations was determined by calculating the mean concentration of all samples taken all five sample locations. This concentration is greater than the concentrations reported in Table 9 since Table 9 used sample values from three locations which is an appropriate approach when comparing sample results to model calculated values. The 0.06 mg/L value is a more represented value of the pollutant loading throughout the lake when comparing it to the NJ Surface Water Quality Standard of 0.05 mg/L, the maximum concentration for surface water quality. (N.J.A.C. 7:9B). The 0.06 mg/L properly characterizes the high level of pollutant loading in Twilight Lake exceeding the maximum quality concentration NJ specifies for the ecological health of surface waters. In a simplified sense, the load reduction needed to bring the average TP concentration to the SWQS of 0.05 mg/L is 81.4 kg/yr. Please note, this method is simplified as the hydrodynamic modeling needed to compute P retention in a tidal environment is complex and not included in this scope of work. Refinement of P-retention utilizing 3-d hydrodynamic modeling may potentially be one component of a more detailed analysis built into the evaluation of the flood control gate in the future.

To date, the Borough of Bay Head has conducted a number of measures to minimize and reduce nutrient loading to Twilight Lake. Many of the mitigation measures were to address flooding but also help to decrease nutrient and sediment loading as well.

STORMWATER PROJECTS IMPLEMENTED SINCE 2011

a. Check valves installed in 6 stormwater outfalls (Two at West Lake Avenue near the intersection with Metcalf Street, One each at Oak Drive, Johnson Street, Twilight Lake Road and Club Drive).

b. Storm Drain and Road Upgrade Project at West Lake Avenue and Metcalf Street - Bay Head completed a storm drain and road upgrade project at the south end of West Lake Avenue and Metcalf Street. This included adding storm drain catch basins, rerouting piping, installing additional storm drain piping, and installing two check valves in two outfalls (as mentioned above)

c. Storm Drain Upgrade Project near the intersection of Lake and Strickland Avenues – adding catch basins

d. Pumping Stations

   The New Jersey Department of Transportation installed a major storm water infrastructure along the entire Route 35 which drains to two storm drain pumping stations in Bay Head in 2014-2015. One pumping station is at the western road end of

Mount Street and one at the western road end of Goetze Street. These were installed to pump down Route 35 storm water, known as Main Street in Bay Head. Storm drain catch basins near these pumping stations along Lake Avenue drain to these pumping stations. One pumping station at Goetze Street works well in mitigating flooding on Lake Avenue and Goetze Street. The pumping station at Mount Street and Lake Avenue does not work as well since the pumping system discharges into Scow Ditch. Scow Ditch is physically constrained so the discharge does not disperse quickly coupled with the fact that the bulkhead at this location has a low spot. The result is

that Scow Ditch waters flow back onto Mount Street during flood conditions causing the pumping station to work excessively in removing flood waters from Lake Avenue and Mount Street and heavy water flow from Scow Ditch at the point of pump discharge back onto Mount Street.

e. Non-leak manhole covers – five (5) along West Lake Ave and Metcalf St; four (4) along Club Drive

f. Dredging –conducted in summer 2015 to remove debris from Superstorm Sandy. The area east of KMI along the full north-south length of the lake was dredged along with Scow Ditch north of Bridge Avenue. The goal of dredging was to remove sediment and debris which entered Twilight Lake from Superstorm Sandy, not to deepen the Lake.

g. Ocean County completed a redesign of the storm drain system along Osborne Avenue in May 2022. Storm water gravity drains to Point Pleasant Brick Municipal pumping station where it is further pumped to the ocean. This project has mitigated flooding on Osborne Avenue.

STORM DRAINS

Storm drain outfall pipes are located in Twilight Lake that require periodic sedimentation cleaning to clear the pipe outfalls. This is performed but reported to only last a few tide cycles before the outfall pipes are buried in sediment again.

Cleanout of storm drains was performed on all basins (approximately 126 basins) in 2017, 2018 and 2019. (Before 2017 storm drain basins were only cleaned when severe blockage occurred.) In 2020 and 2021 a reduced number of basins were cleaned due to COVID concerns during close proximity clean out operations. 40 were cleaned in the fall of 2020 and 40 were cleaned in the fall of 2021. In addition, basins were cleaned when clogging or blocking is found. It is expected annual cleanout of all basins will recommence in 2023 as COVID limitations have been lifted.

STREET SWEEPING

Bay Head is 1.25 miles long at the greatest north-south distance and 0.78 miles wide at its greatest east-west dimension. It has approximately 7 miles of roads. All roads are swept on a monthly basis. Roads with the greatest amount of sand and debris accumulation (low areas) are swept an average of three times a month. Bay Head records an average of sweeping 12 miles of roadways a month; annually it's ~144 miles. Seven (7) miles of the 12 miles is for each road surface and 5 miles is for additional cleaning which, for some roads, involves two or three sweepings.

Some streets are swept twice a month, especially in low areas that collect sand and debris and those in close proximity to the ocean front. The streets are also swept on an as-needed basis. For example, following the major flooding on 27-31 October 2021, some streets were swept twice during a single event due to the large amount of accumulated debris.

CANADA GEESE

Bay Head has taken two steps to help reduce the Geese population. One is placing threatening figures of predators like coyotes along the lake shoreline. These were located along the northern shoreline have only had minimal success. They do not effectively scare the geese since the birds are seen comfortably walking around and eating around the figures. These were removed after two years in place.

Bay Head also has an active project to seek out and find geese nests and addle geese eggs. Over the past three years, the Borough of Bay Head has addled and average of 50 eggs from 10 nests each year. This is done two to three times annually during nesting season. This method is considered to be 100% effective in controlling the "resident" population down.

GENERAL APPROACH TO ADDRESS STORMWATER NUTRIENT LOADS ENTERING TWILIGHT LAKE

Since there is no official TMDL for Twilight Lake, there is no previously identified pollutant load target rate. However, based on a combination of water quality monitoring and simplified modeling, it was determined that the current baseline annual TP load is estimated at 488.6 kg Which correlates with an in-lake mean TP concentration of 0.06 mg/L. A reduction of 81.4 kg/yr of TP is therefore recommended to meet the SWQS target of 0.05 mg/L.

Scow Ditch input contributes a significant load, compounding on the complex nature of nutrient loading.

Reduction of nutrients would be most effective by treating water coming in from Scow Ditch or controlling flow through this input more actively. Water quality data showed the northwestern wetlands to also have a fair amount of nutrient input indicating that this would be a good area for in-lake management measures, like adsorbents, to reduce nutrients. In order to address stormwater entering the Lake, measures should be focused on catch basins and outfalls since stormwater loading comes from medium development areas. It is also apparent that sediment is introduced by erosion along various parts of the lakeshore, which should be stabilized as well.

5.0 MANAGEMENT MEASURES

This section corresponds to the third of the EPA elements and consists of a description of the management measures necessary to achieve the desired 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 further reduce the TP and other pollutants loads entering the lake. Thus, time was spent in the field identifying potential project sites, with a focus on sites that have the capacity to accommodate green infrastructure. 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.

There were three main strategies associated with the field site assessments.

1. The first strategy is focused on addressing the major and most significant source of pollutant loading entering Twilight Lake, tidal flow through Scow Ditch.

2. The second strategy focused on identifying sites suited to enhancing, modifying, or upgrading the existing stormwater infrastructure throughout the watershed. Thus, site assessments were conducted throughout the watershed and focused on locations that receive a large volume of stormwater runoff. Wherever possible, green infrastructure was integrated into any proposed project.

3. The third strategy focused on conducting lake shore assessments along the shoreline of Twilight Lake (including the peninsula, Kellogg Memorial Island, and the wetlands bordered by the NJ Transit Railyard). Again, where feasible, green infrastructure was integrated into any recommended designs.

As mentioned in Section 2, an initial assessment of the Twilight Lake watershed was conducted by Princeton Hydro accompanied by BHEC on 10 February 2022. The information documented during this site visit was used to identify pollutant sources but also candidate sites for watershed best management practices (BMPs) most well suited for immediate or long-term implementation which can then be used for future potential grant opportunities. With information from the water quality monitoring through the 2022 growing season and associated watershed modeling, a number of sites and BMPs have been recommended to assist in the nutrient load reductions to Twilight Lake.

However, like many lake communities, there is not a lot of space for larger, more conventional BMPs, such as wetland treatment facilities, so candidates that involve the retrofitting of exiting stormwater structures and underground manufactured treatment devices (MTDs) are also included.

This watershed is relatively small and is highly developed with mostly residential properties. Any recommended BMPs will have to be carefully designed with space constraints in mind. Further, the municipality is impacted by flooding issues so consideration must be made with BMPs that address water quantity as well as quality.

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

- **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 is initiated. Without such information results could be extremely costs and even disastrous.
- **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.
- **Permit Requirements** – Depending on some of the factors listed above, as well as the location of the site relative to the lake and associated waterways, permitting can vary from none to minimal to substantial. Thus, the potential required permitting must be determined in order to quantify the total costs associated with the design phase. While general permitting costs were estimated in the proposed cost for each project, these do not include permits specific to the Bay Head area.
- **Access and Ownership** – Issues such as right-of-ways and easements need to be seriously considered in the selection of specific BMPs, MTDS and/or green infrastructure projects. Additionally, the source of the funding for implementation may limit where a project can be implemented. For example, typically if a project is being covered through an NPS 319-grant, the project site 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 may 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.

Site 1: Lake Ave and Harris (40.0715, -74.0448)

This area is prone to flooding and erosion and has been subject to beach replenishment in the past. Twilight Lake spills over the low-lying sandy shoreline during flooding events. There are three (3) outfalls here that are partially clogged but are proposed to be replaced within the next year. Bay Head is also considering raising the shoreline in this location and incorporating a living shoreline, while still preserving the small “beach” area behind the raised shoreline. No emergent vegetation exists in this immediate area but there is phragmites growing around much of the shoreline on this street.

Bay Head is planning on an upgrade to Lake Avenue roadway and storm drain infrastructure. At the Lake Avenue/Harris Street intersection, three new catch basins are planned to be installed which will be connected. One outfall will be installed to one catch basin and the outfall will have an inline check valve installed to prevent backflow.

Recommended Restoration Measures: Site 1 would benefit from the installation of slightly elevated living shoreline structures which would provide a buffer against flooding, reduce nutrient in the water and stabilize the bank to decrease erosion potential. The current existing storm drains can be converted to have catch basin filter inserts to address water quality issues which are recommended. The use of treeboxes at this location would be preferred but treebox designs need a minimum of 5 by 7 feet surface area and 5 to 6 feet elevation from the top of the treebox to a bottom drain/overflow drain pipe which connects to a gravity storm drain infrastructure. At Site 1, a vertical difference of 5 to 6 feet above the existing storm drain infrastructure does not exist. A treebox is not a viable solution at this Site

Estimated Costs The cost to design, permit and install a living shoreline varies between $1,000 to $5,000 per linear feet. Variations in the details of the design and existing topography and interferences causes variation in the cost. At Site 1 along Lake Ave near the intersection with Harris Street, approximately 300 linear feet would benefit from a Living Shoreline which would involve grading changes, soft structure like coir logs and vegetation. The cost would range from $300,000 up to $450,000. The annual maintenance cost of a Living Shoreline typically costs less than $100 per linear foot. At Site 1, this would be a cost of approximately $30,000 per year.

An insert in a storm drain costs approximately $1,000 per insert not including media, plants or labor. With three storm drains at Site 1, this is a cost of $3,000. There is an annual maintenance cost to remove and install new media in the inserts. This costs approximately $500 per box, so at Site 1 this is an annual maintenance cost of $1,500. Catch basin retrofits may be subject to limitation depending on the depth of infrastructure.

Estimated P Reduction: With a length of 300’ of shoreline and recession rate of 4” per year there would be an estimated annual P reduction of 0.54 kg/yr as based on an average sediment bulk density of 34 kg/ft^3, average sediment P content of .000621 kg TP/kg sediment, and P reduction efficiency of 85%. These values are based on a P reduction tool for shoreline restoration developed by Vermont DEC.

Estimated P reduction from three (3) catch basin inserts is 1,2 kg/yr as based on a loading rate of 1.6 kg/ha/yr for the contributing drainage area with an estimated removal percentage of 25%.

Site 2: Lake Ave and North St (40.0741, -74.0441)

This shoreline area along Lake Avenue in the area of North Street lacks a shoreline buffer beyond the rip rap along Lake Ave. There are two (2) outfalls/curbside storm drains along the Lake that are proposed to be replaced within the next year. North Street floods with water at this point.

Bay Head is planning on an upgrade to Lake Avenue roadway and storm drain infrastructure. At the Lake Avenue/North Street intersection, two new outfall pipes are planned to be installed to existing catch basins and both will have inline check valves installed to prevent backflow.

Recommended Restoration Measures: Site 2 would benefit from the installation of slightly elevated living shoreline structures which would provide a buffer against flooding, reduce nutrient in the water and stabilize the bank to decrease erosion potential. The current existing storm drains can be converted to have catch basin filter inserts to address water quality issues which are recommended. The use of treeboxes at this location would be preferred but are not feasible due to lack of depth for installation.

Estimated Costs The cost to design, permit and install a living shoreline varies between $1,000 to $5,000 per linear feet. Variations in the details of the design and existing topography and interferences causes variation in the cost. At Site 2 along Lake Ave near the intersection with North Street, approximately 200 linear feet would benefit from a Living Shoreline which would involve grading changes, soft structure like coir logs and vegetation. The cost would range from $200,000 up to $300,000. The annual maintenance cost of a Living Shoreline typically costs less than $100 per linear foot. At Site 2, this would be a cost of approximately $20,000 per year.

An insert in a storm drain costs approximately $1,000 per insert. There is an annual maintenance cost to remove and install new media in the inserts. This costs approximately $500 per box, so at Site 2 this is an annual maintenance cost of $1,000. Catch basin retrofits may be subject to limitation depending on the depth of infrastructure.

Estimated P Reduction: With a length of 200’ of shoreline and recession rate of 4” per year there would be an estimated annual P reduction of 0.36 kg/yr as based on an average sediment bulk density of 34 kg/ft^3, average sediment P content of .000621 kg TP/kg sediment, and P reduction efficiency of 85%. These values are based on a P reduction tool for shoreline restoration developed by Vermont DEC.

Estimated P reduction from the catch basin inserts as based on a removal rate of 25% is 0.48 kg/P/yr.

SITE 3: LAKE AVE AND TWILIGHT ROAD (40.0748, -74.0439)

The northeastern corner of Twilight Lake runs along the north end of Lake Avenue and running west along Twilight Road. The Twilight Road area has a couple of sandy beach sections of shoreline with a grass area extending along much of Twilight Road. Between and adjacent to the sandy beaches there are phragmites patches. There is a relatively large MTD that drains water from the north end of Lake Ave which can be identified by the manhole maintenance covers. MTD was originally installed to treat overflow water from Lake of the Lillies but the lake no longer receives water from Lake of the Lillies. This is an area where flooding is a concern.

Recommended Restoration Measures: Site 3 would benefit from the installation of slightly elevated living shoreline structures which would provide a buffer against flooding, reduce nutrient in the water and stabilize the bank to decrease erosion potential. The current existing storm drains catch basins can be converted to install filter inserts to address water quality issues which are recommended. The use of treeboxes at this location would be preferred but treebox designs need a minimum of 5 by 7 feet surface area and 5 to 6 feet elevation from the top of the treebox to a bottom drain/overflow drain pipe which connects to a gravity storm drain infrastructure. At Site 3, a vertical difference of 5 to 6 feet above the existing storm drain infrastructure does not exist. A treebox is not a viable solution at this Site. In addition, Bio Retention Basin is a possible option but basins also require a larger settling area with a bottom gravity drain 5 to 6 feet below the top of the basin. The topography at Site 3 does not support a Bio Retention Basin.

Estimated Costs The cost to design, permit and install a living shoreline varies between $1,000 to $5,000 per linear feet. Variations in the details of the design and existing topography and interferences causes variation in the cost. At Site 3 along the north end of Lake Avenue and Twilight Lake as well as along Twilight Road is about 650 linear feet would benefit from a Living Shoreline which would involve grading changes, soft structure like coir logs and vegetation. The cost would range from $650,000 up to $800,000. The annual maintenance cost of a Living Shoreline typically costs less than $100 per linear foot. At Site 3, this would be a cost of approximately $65,000 per year.

An insert in a storm drain costs approximately$1,000 per insert. With two storm drains at Site 3, the total all-inclusive cost is approximately $2,000. There is an annual maintenance cost to remove and install new media in the inserts. This costs approximately $500 per box, so at Site 3 this is an annual maintenance cost of $1,000. Catch basin retrofits may be subject to limitation depending on the depth of infrastructure.

Estimated P Reduction: With a length of 650' of shoreline and recession rate of 4" per year there would be an estimated annual P reduction of 1.17 kg/yr as based on an average sediment bulk density of 34 kg/ft^3, average sediment P content of .000621 kg TP/kg sediment, and P reduction efficiency of 85%. These values are based on a P reduction tool for shoreline restoration developed by Vermont DEC.

Estimated P reduction from catch basin inserts is 0.29 kg/P/yr.



SITE 4: TWILIGHT ROAD DRAINAGE DITCH (40.0753, -74.0445)

The drainage Ditch from Twilight Road is lined with phragmites and receives runoff from the road. The drainage Ditch has open grassy areas along each side. The Borough recently installed a check valve in the curbside storm drain to try and prevent backflow flooding.

Recommended Restoration Measures: This Ditch should be enhanced to better handle backflow and better filter nutrient loads from Twilight Road. This can be accomplished by converting this Ditch into a vegetated bioswale. The Ditch could also be reconfigured to be less of a straight line to the Lake and be more sinusoidal (and have more length of the Ditch for a similar area) as more of a manufactured wetland area.

The current existing storm drains catch basins can be converted to install filter inserts to address water quality issues which are recommended. The use of treeboxes at this location would be preferred but treebox designs need a minimum of 5 by 7 feet surface area and 5 to 6 feet elevation from the top of the treebox to a bottom drain/overflow drain pipe which connects to a gravity storm drain infrastructure. At Site 3, a vertical difference of 5 to 6 feet above the existing storm drain infrastructure does not exist. A treebox is not a viable solution at this Site. In addition, Bio Retention Basin is a possible option but basins also require a larger settling area with a bottom gravity drain 5 to 6 feet below the top of the basin. The topography at Site 3 does not support a Bio Retention Basin.

Estimated Costs: Any recommended enhancement to the Ditch would involve design, permitting, and grading changes as well as plantings. Installation costs could range from $30,000 - $75,000.

An insert in a storm drain costs approximately$1,000 per insert. With two storm drains at Site 4, the total all-inclusive cost is approximately $2,000. There is an annual maintenance cost to remove and install new media in the inserts. This costs approximately $500 per box, so at Site 4 this is an annual maintenance cost of $1,000. Catch basin retrofits may be subject to limitation depending on the depth of infrastructure.

Estimated P Reduction: Estimated P reduction from the bioswale is 0.48 kg/P/yr while estimated P reduction from the catch basin inserts is 0.24 kg/P/yr.

SITE 5: TWILIGHT ROAD AND TRAIN STATION (40.0757, -74.0459)

Immediately south of Birch Place at the entrance to the NJ Transit Railyard lies a large wetland area that is likely mostly underwater during high tide. A pipe that receives runoff from the surrounding street and likely part of the train station parking lot discharges into the wetland area that could be improved through the installation of a vegetated filter strip

Recommended Restoration Measures: Discharge from the pipe should be routed through a vegetated filter strip to enhance pollutant removal prior to discharge in the wetland.

Estimated Costs: A vegetated filter strip to treat discharge from the stormwater pipe would involve design, permitting, and installation with planting and should be estimated at approximately $30,000 to $75,000.

Estimated P reduction: Estimated P reduction is 0.42 kg/P/yr from a vegetated filter strip.

SITE 6: ISLAND / PENINSULA (40.0738, -74.0463)

The train used to run across the lake on a strip of land and train trestle separating the East and West halves of Twilight Lake. Today, Kellogg Memorial Island and the peninsula are separated and the trestle has been removed allowing for more flow. The shorelines of the peninsula and Kellogg Memorial Island exhibit severe, active erosion. Stabilization of these shorelines would decrease this as a source of sedimentation to Twilight Lake and total solid's introduction, which would, in turn, allowing the Lake to maintain (and not lose) volume for flood storage. Further, sediment from the island/peninsula are vehicles for sequestered nutrients and stabilization would reduce nutrient loading to the Lake.

Recommended Restoration Measures: Nutrient and sedimentation reduction would be best addressed by shoreline stabilization with a living shoreline. Both sides of the Island would need stabilization while just the eastern side of the peninsula needs to be addressed (the western side is wetland area. Kellogg Memorial Island's east side has rip rap that would need to be removed as well.

Estimated Costs The cost to design, permit and install a living shoreline varies between $1,000 to $5,000 per linear feet. Variations in the details of the design and existing topography and interferences causes variation in the cost. At Site 6 along the Kellogg Memorial Island, there is approximately 1,200 linear feet would benefit from a Living Shoreline which would involve grading changes, soft structure like coir logs and vegetation. The cost would range from $1,200,000 up to $6,000,000. The annual maintenance cost of a Living Shoreline typically costs less than $100 per linear foot. At Site 6, this would be a cost of approximately $120,000 per year.

Since the peninsula is adjacent to wetlands, there is approximately 300 linear feet to stabilize costing at minimum $300,000. Maintenance of living shorelines typically costs less than $100 per linear foot annually, resulting in an annual cost of approximately $30,000. **Estimated P Reduction:** With a length of 1,500' of shoreline and recession rate of 4" per year there would be an estimated annual P reduction of 2.69 kg/yr as based on an average sediment bulk density of 34 kg/ft^3, average sediment P content of .000621 kg TP/kg sediment, and P reduction efficiency of 85%. These values are based on a P reduction tool for shoreline restoration developed by Vermont DEC.

SITE 7: MUNICIPAL LOT / PARK NEXT TO SCOW DITCH (40.0692, -74.0461)

Approximately 700 feet south of Twilight Lake on the western side of Scow Ditch is the municipally owned Centennial Park. Near the footbridge that travers Scow Ditch there is a pipe that receives runoff from surrounding municipal lot/park and discharges into Scow Ditch. There are no storm drains in this lot so this pipe may receive a large volume of stormwater during a storm event. Municipally owned properties like this are ideal for BMPs.

Recommended Restoration Measures: Since this specific area where the pipe is located is limited in space, a vegetated bioswale is recommended to address nutrient and sediment load carried in runoff to the pipe and discharged to Scow Ditch. This is also an area of high public visibility which elevates this area in terms of priority and outreach value. The green infrastructure BMP installed here would be optimal to be accompanied by an educational sign. There are other areas along Scow Ditch in this park that could serve as rain garden style BMPs, as well; this park should be considered for other pollinator/rain garden style BMP installations along the Scow Ditch path as well.

Estimated Costs: Design, permitting, and installation of a vegetated bioswale in this area would range in cost from $30,000 to $75,000. Educational signage specific to this BMP would cost $2,500. Costs for additional rain gardens along the path would vary depending on the style and size but would likely range from $30,000 to $65,000.

Estimated P Reduction: Estimated P reduction from this project would be 0.24 kg/P/yr.

SITE 8: CLUB DRIVE CURBSIDE STORM DRAIN (40.0712, -74.0470)

There is a curbside storm drain that receives runoff from Club Drive as it curves from going SE to S away from Twilight Lake. This is a major flood area and should be considered for stormwater treatment. The curbside storm drain on the east side of the road closest to Twilight Lake collects water from the street and the surrounding drainage area and discharges to the Lake. However, the outfall is partially submerged and filled in with sediment. This provides evidence of a fair amount of sediment transport from this drainage of the watershed. There is also a fair amount of phragmites growth along the shoreline.

Recommended Restoration Measures: There are a number of treatments that could be proposed for this location. Starting at the street as pretreatment, the storm drain can be retrofit with a catch basin insert. Finally, approximately 30-50 linear feet of shoreline should be stabilized with a living shoreline or at least restoration by removing the phragmites.

Estimated Costs The cost to design, permit and install a living shoreline varies between $1,000 to $5,000 per linear feet. Variations in the details of the design and existing topography and interferences causes variation in the cost. At Site 8 along Club Drive there is approximately 50 linear feet would benefit from a Living Shoreline which would involve grading changes, soft structure like coir logs and vegetation. The cost would range from $50,000 and $250,000. The annual maintenance cost of a Living Shoreline typically costs less than $100 per linear foot. At Site 8, this would be a cost of approximately $5,000 per year.

An insert in a storm drain costs approximately$1,000 per insert. There are six storm drains at Site 8. The total all-inclusive cost is approximately $8,000. There is an annual maintenance cost to remove and install new media in the inserts. This costs approximately $500 per box. At Site 8 this is an annual maintenance cost of $3,000. Catch basin retrofits may be subject to limitation depending on the depth of infrastructure.

Estimated P Reduction: With a length of 50' of shoreline and recession rate of 4" per year there would be an estimated annual P reduction of 0.09 kg/yr as based on an average sediment bulk density of 34 kg/ft^3, average sediment P content of .000621 kg TP/kg sediment, and P reduction efficiency of 85%. These values are based on a P reduction tool for shoreline restoration developed by Vermont DEC.

Estimated P reduction from a basin insert is approximately 0.08 kg/P/yr.

Site 9: West Lake Ave and Oak Drive Curbside Storm Drain (40.0724, -74.0484)

Due east of Oak Drive, there is a curbside storm drain that receives runoff from West Lake Ave and Oak Dr. The shoreline at and around the outfall is eroding backwards toward the street; this may be due to a combination of water movement in the lake and overland runoff.

Recommended Restoration Measures: The eroding shoreline could be stabilized to reduce sediment loading to the Lake by installation of a small section of living shoreline. As discussed with the Borough, there is limited depth in this area to accommodate a tree box or trench.

Estimated Costs: The cost to design, permit and install a living shoreline varies between $1,000 to $5,000 per linear feet. Variations in the details of the design and existing topography and interferences causes variation in the cost. At Site 9 along West Lake in the area of Oak Drive there is approximately 30 linear feet would benefit from a Living Shoreline which would involve grading changes, soft structure like coir logs and vegetation. The cost would range from $30,000 and $50,000. The annual maintenance cost of a Living Shoreline typically costs less than $100 per linear foot. At Site 9, this would be a cost of approximately $3,000 per year.

Estimated P Reduction: With a length of 30' of shoreline and recession rate of 4" per year there would be an estimated annual P reduction of 0.05 kg/yr as based on an average sediment bulk density of 34 kg/ft^3, average sediment P content of .000621 kg TP/kg sediment, and P reduction efficiency of 85%. These values are based on a P reduction tool for shoreline restoration developed by Vermont DEC.

SITE 10: WEST LAKE AVE AND CRANBERRY AVE (40.0734, -74.0482)

The corner of West Lake Ave and Cranberry Ave is a major area of flooding concern. Flood water usually comes up from Twilight Lake at the surface concrete “drainage ditch” in the top right photo. The immediate infrastructure appears to be in a state of disrepair. There is also a stand of grass along the shoreline on West Lake Ave.

Recommended Restoration Measures: The drainage Ditch here should at least be reinforced or relocated and can be improved to include a green infrastructure BMP such as a vegetated bioswale or small treatment wetland. The shoreline can be treated to remove phragmites and could have a living shoreline could be installed here.

Estimated Costs: Drainage relocation costs can be highly variable and are dependent on the distance and reconfiguration upon installation; conservative estimates on costs including design, permitting, and installation would start at $50,000. A vegetated bioswale could cost at least $30,000 and living shorelines installed here would cost approximately $50,000.

Estimated P Reduction: Estimated phosphorus reduction from the utilization of a vegetated bioswale is 0.16 kg/P/yr and shoreline restoration (50’) is 0.09 kg/P/yr.




SITE 11: WOODWARD AVE AND WESTERN AVE (40.0733, -74.0514)

There is a drainage ditch/stream that originates at the municipal recycling center and travels underground to this location and is then conveyed in a pipe to Twilight Lake under Woodward Ave.

Recommended Restoration Measures There is potential for an underground MTD here, but the pollutant load at this location may not be high since it originates in a wetland area and flows through a vegetated stream. Some of the ditch/stream may be able to be renovated into a vegetated swale with a more stable conveyance for stormwater as it approaches and enters an MTD.

Estimated Costs A vegetated bioswale could cost at least $30,000 including design, permitting, and installation. MTDs for this space are estimated to cost $20,000-$30,000 each and are estimated to be as much as $50,000-70,000 with design, permitting and installation.

Estimated P Reduction: The estimated contributory drainage area to this proposed BMP is 1.4 Ha (3.5 Ac) with an estimated annual P load of 2.24 kg/TP/yr. Utilizing an estimated P reduction of 50% (From PA BMP manual) produces an estimated reduction of 1.12 kg/yr.

A vegetated swale is necessary to provide a stable, piped conveyance into the MTD. A vegetated swale will reduce the annual P load of 0.42 kg/TP/yr.

SITE 12: SCOW DITCH

In addition to the specific management measures previously recommended in this section, it was made clear by the modeling and direct observation by the community that pollutant loading from Barnegat Bay entering Twilight Lake through Scow Ditch play a dominant role in adding pollutants to the Lake. The ability to more directly control flow into and out of Twilight Lake through Scow Ditch would provide the community with the greatest level of management of water quality from the largest loading source. Other municipalities along the coast have implemented managing the influence of tidal water on coastal lake to prevent detrimental flooding with a fair degree of success. This includes controls at Stockton Lake, Glimmer Glass Lake, Lake Louise, and Wreck Pond.

Recommended Restoration Measures There are a number of management measures that have already begun to be investigated by the Bay Head Environmental Commission, with the main purpose of mitigating flooding. These measures will also help mitigate pollutant loading. One such measure is a tide gate on Scow Ditch. Since Scow Ditch is the main source of pollutant loading to Twilight Lake, such a management measure should be considered as a means of pollutant control in addition to flood control and should be further investigated for proper design, cost, and implementation. Specifically, Installation of flow control gates to limit/stop tidal water flow from Barnegat Bay to Twilight Lake during flood conditions was thoroughly considered by BHEC. The concepts explored were the installation of either swing gates or lift gates. As a subjective case study, flow through Scow Ditch was blocked in June of 2013 for approximately 8 weeks while a new sewer line was installed crossing Scow Ditch. Two dams were installed to block the flow and the space between the two dams was dewatered.. As a result, hide tide from June 8 and 28 storms were blocked and no flooding was observed around Twilight Lake when it was expected.

Estimated Costs Part of the process to assess the value and impact of installing tide gates will first be a detailed study of the hydraulic and hydrologic properties of the tidal flow through Scow Ditch into Twilight Lake. This study may potentially incorporate 3-dimensional hydrodynamic modeling which can be expanded to further evaluate contaminant loading dynamics as they relate to flushing and retention. An estimate of the cost of this analysis is $100,000. The cost of designing, permitting and constructing a tidal flow control gate requires further investigation.

Estimated P Reduction: The benefit of installing a tidal flood control gate are further discussed in Appendix F. It is estimated up to 46% (409.1 kg / 897.7 kg) of the phosphates entering Twilight Lake on a yearly basis can be prevented from entering the Lake by closing the tidal flow control gate prior to Major Storms.

MORE GENERALIZED WATERSHED MANAGEMENT MEASURES

BIOCHAR

A nutrient adsorbent like biochar is a mitigation measure appropriate for some locations around the Lake, including the wetlands to the northwest. Since Scow Ditch is modeled to contribute more than 80% of Twilight Lakes nutrient load it would provide an ideal candidate for nutrient capture and inactivation. The strategy of using a nutrient adsorbent would need to be carefully considered since it would be located in an area of high nutrient loading but also high flushing, with tidal shifts almost twice daily. Frequent replacement of the media may be needed depending on the current rate of tidal flow.

PUMP SYSTEM

Since flooding is a concern to the community, utilizing a pump system during periods of rapid volume increase to Twilight Lake may also be an effective method of removing volume and associated nutrients. The Borough of Bay Head has begun investigating what it would entail to pump Twilight Lake out to Atlantic Ocean during severe flood events. Use of existing piping infrastructure through the Brick Township Municipal Utilities Authority (BTMUA) Pumping Station or install new pumping system would be considered. A pipe was installed in 2006 in the northeast corner of Twilight Lake to receive pumping from BTMUA Pumping station. BTMUA pump station now pumps Lake of Lilies to the Atlantic Ocean to two 48" diameter pipes that were installed at the ocean release point in 2018 for pumping to ocean. Tying Twilight Lake's connection to the BTMUA pump station into this outfall to the Atlantic Ocean should be further investigated.

6.0 TECHNICAL AND FINANCIAL ASSISTANCE

Implementation of plan elements and project concepts is dependent on securing the funding and technical assistance to support those goals. Costs for the design, installation, and maintenance of most proposed stormwater structure are provided in this report and its associated appendices. As a crucial element of a WBP, this section addresses the fourth of the EPA nine elements.

FINANCIAL ASSISTANCE

From a practical perspective, one of the major limitations on successfully managing NPS pollution, meeting water quality standards and designated uses, and controlling stormwater is funding. The expense of these items is three-pronged: first, the management of NPS pollution requires action on a broad front because the loading by definition is diffuse and effective management requires the implementation of many projects; second, while the management measures are often simple from a conceptual perspective, the permitting, design, materials, labor, and monitoring, not to mention land acquisition and easements, all incur real and significant costs. These costs are further amplified because implementation is typically sponsored at a local level, be it municipality, landowner, or NGO, where ready access to capital may be difficult. Finally, funding and/or the infrastructure needs to be in place for the long-term management and maintenance of any BMP or green-implementation project.

Despite the costs of implementing individual projects or enacting a watershed management plan such as this document, there are a wide array of funding resources available to help offset the costs. Grants are typically the primary source of these funds, but other streams are available including the issuance of bonds, typical governmental budgeting and appropriations, and low-interest loans. These funds help defer the costs of such projects and typically carry a number of conditions to both maximize the funding and ensure the delivery of a high-quality product often requiring matching funds, in-kind contributions, and strict reporting and monitoring requirements. The availability of these funds is predicated on meeting the goals of the grantor which can range from simple environmental restoration and conservation, more focused efforts to meet the objectives of a program, regulation, or law such as the Clean Water Act, or targeted efforts to meet the needs of a specific requirement such as satisfying a TMDL. Often, these grants operate on all three levels. In addition, many of the programs provide not only financial assistance, but technical assistance. The following sections will explore some of the available funding opportunities.

STATE FUNDING

SECTION 319 NON-POINT SOURCE MANAGEMENT PROGRAM

One of the best known, widely utilized, and powerful programs developed to manage NPS pollution throughout the nation is the Section 319 Nonpoint Source Management Program. This program was established in 1987 under amendments to the Clean Water Act and created a funding mechanism in which monies were allocated to the States, territories, and tribal authorities that award and administer grants for State and local level projects. According to the EPA website, billions of dollars have been allocated over the life cycle of the program, and from 2000 through 2017 (the last posted update) at least $150 million has been made available annually. While this funding covers an array of activities, the 319 grants are recognized by the EPA as particularly important in implementing TMDLs.

There are a number of requirements under federal statute and governing technical regulations. Thematically, the grants are to cover projects that provide for the management of nonpoint source pollution. There is a continued focus on WBPs that meet the EPA Nine Elements; this WIP adheres to these requirements. There are a number of reporting and tracking requirements to ensure and document the success of the projects. Implementation of Non-Structural Best Management Practices will also be considered, but is of a lower priority. Those elements will include:

- Monitoring, Assessment, and Trackdown Projects – These elements are important in describing the focal points for implementation projects using a targeted approach.
- Watershed or Statewide Education and Outreach Projects – These types of projects are focused on increasing awareness, educating the public about the needs for these types of actions, and developing the base support and political will to implement pollutant control strategies. Some of the topics to be addressed would include pet waste, lawncare, and runoff management.
- Land Use Management Projects – These types of projects would support municipal or governmental management efforts and would include items such as land use evaluations, modification of regulatory programs to support green infrastructure and low impact development (LID), educating public officials, incorporating integrated pest management (IPM) and nutrient management, and other similar activities.

These priorities evolve over time and are subject to change in response to emerging issues or completion of historical objectives. The grant process is competitive and therefore those grant submissions that best address the priorities, demonstrate project understanding, and have a sound technical approach have the best chance of successful award. One of the benefits of preparing a WBP that adheres to the EPA Nine Elements is that the management measures and implementation projects identified within the document often conform to priority action items thus increasing the likelihood of successful award. 319 Grants are likely to play a major role in meeting the funding requirements for this WBP.

NJDEP FUNDED GRANTS IN 2022

The most recent round of 319 funding was released by NJDEP on December 30, 2021 for eligible nonpoint source (NPS) pollution control projects to be considered for funding under the Water Quality Restoration Grant Program. There was up to $9.4 million in grants available for watershed restoration and enhancement measures with a request for proposals through February 2022. NJDEP currently uses a rotating basin approach for the five water regions of New Jersey, with this round focused on the Upper Delaware River Watershed and the Northeast; the next round will be focused on the Atlantic Coastal region in 2024. Shovel ready projects are often prioritized, giving Bay Head ample time to develop designs for BMPs prior to the next 319 RFP release targeting Twilight Lake's watershed.

Additionally, NJDEP released RFPs for their Stormwater Competitive Grants and Resilience/Stormwater Utility programs in August 2022. As part of its comprehensive efforts to improve water quality and mitigate the worsening impacts of flooding caused by climate change, the New Jersey Department of Environmental Protection (NJDEP) announced it was seeking applications for $10 million in grants to

modernize stormwater management systems and to provide technical assistance to municipal, county and utility authorities to plan to become more resilient, including conducting feasibility Studies for forming stormwater utilities and resilience planning for local governments impacted by Tropical Storm Ida, that will focus on strategies to better manage the impacts of stormwater.
The general breakdown is as follows:

- $2 million is for Technical Assistance for SW Utility Feasibility study
- $1 million for Technical Assistance for Resilience Planning
- $7 million is for SW Demonstration Projects and Planning such as construction of Green Infrastructure projects, removal and restoration of impervious areas, SW Basin retrofits and planning for stormwater Implementation

Bay Head has submitted applications for both and should continue to seek funding from sources like these.

OTHER FUNDING SOURCES

In addition to the 319 Grants, the federal government has enacted a host of additional programs and grants designed to address broad environmental protection goals. The origin, statutory authority, responsible agency, and objectives of these programs are variable, as are year-to-year to funding which can be Congressional appropriation, environmental damages settlements, excise taxes, or other sources. A summary table is provided below that identifies the responsible agency, the name of the grant or program, and URLs to the program web page (Table 10). A brief summary of the highlights is discussed below.

The EPA maintains a broad portfolio of programs and responsibilities, as well as providing technical guidance to the States and other actors. As such, EPA programs run the gamut from community health initiatives to straight environmental conservation efforts and many programs in between. As such, some programs deal with meeting water quality or air quality criteria, targeting specific geographic locations or sensitive environmental features, outreach and education, and habitat improvements. As with all of the grants, while each program and grant has specific requirements to meet the stated objectives, environmental restoration, protection, and NPS pollution management broadly overlap and one project can fulfill many different goals. For instance, the creation of a stormwater wetland may be constructed to meet water quality goals but may also be viewed as habitat creation. This type of approach allows various funding avenues to be explored.

The United States Fish and Wildlife Service (USFWS) also is a major federal grantor. Unlike EPA, USFWS programs tend to have a tighter focus on habitat-oriented projects. These can include many different habitat types such as wetlands and uplands, and may foster habitat improvements for various species like migratory fishes, shorebirds, or imperiled species. The United States Forest Service also has a more singular focus and implemented primarily at a landscape level.

The National Fish and Wildlife Foundation's National Coastal Resilience Fund restores, increases and strengthens natural infrastructure to protect coastal communities while also enhancing habitats for fish and wildlife. Established in 2018, the National Coastal Resilience Fund invests in conservation projects that restore or expand natural features such as coastal marshes and wetlands, dune and beach systems, oyster and coral reefs, forests, coastal rivers and floodplains, and barrier islands that minimize the impacts of storms and other naturally occurring events on nearby communities. The National Coastal Resilience Fund supports the implementation of nature-based solutions to enhance the resilience of coastal communities and ecosystems to these threats. National Fish and Wildlife Foundation strategically invests in projects that construct or restore coastal habitats that increase the capacity of communities and habitats to withstand and recover from disruptions and adapt to changing environmental conditions. Nature-based solutions include natural and hybrid ("green-gray") solutions, such as restoring coastal marshes, reconnecting floodplains, rebuilding dunes or other natural buffers, and installing living shorelines. Additionally, NFWF prioritizes investments that address the disproportionate risks faced by underserved communities and projects that are community led or incorporate direct community outreach and engagement.

The Federal Emergency Management Agency provides a number of grants that are becoming increasingly relevant in light of the impacts of climate change. Of interest to Bay Head and the Twilight Lake Watershed are those related to flooding and resilience, particularly as a coastal area.

Table 10

Entity	Program	Link
EPA	Urban Waters Small Grants	https://www.epa.gov/urbanwaters/urban-waters-small-grants
	Healthy Communities Grant Program	https://www3.epa.gov/region1/eco/uep/hcgp.html
	Five Star Restoration Grant Program	https://www.epa.gov/urbanwaterspartners/five-star-and-urban-waters-restoration-grant-program-2018
USFWS	North American Wetlands Conservation Act	https://www.fws.gov/birds/grants/north-american-wetland-conservation-act.php
NFWF	National Coastal Resilience Fund	https://www.nfwf.org/programs/national-coastal-resilience-fund
FEMA	Hazard Mitigation Grants	https://www.fema.gov/grants/mitigation
	Flood Mitigation Assistance Grant	https://www.fema.gov/grants/mitigation/floods
	Building Resilient Infrastructure & Communities	https://www.fema.gov/grants/mitigation/building-resilient-infrastructure-communities
	Pre-disaster Mitigation Program	https://www.fema.gov/grants/mitigation/pre-disaster
NRCS	Conservation Stewardship Program	https://www.nrcs.usda.gov/wps/portal/nrcs/main/national/programs/financial/csp/
	Emergency Watershed Protection Program	https://www.nrcs.usda.gov/wps/portal/nrcs/main/national/programs/landscape/ewpp/

TECHNICAL ASSISTANCE

As much as funding is necessary to implement management programs and projects technical assistance is required to properly design and oversee implementation of management measures be it structural or cultural BMPs, outreach, training, or a related course of action. The following section will discuss project roles, key players, and sources of technical information and assistance.

- **Project Sponsor** – The project sponsor serves as the hub of project implementation. For many of the projects identified, the Commission will serve as the project sponsor, although non-profits and even landowners may also serve this role. They are responsible for all project activities, usually starting with identifying the need for a project in response to a regulatory requirement, identified problem, emergency need, or general policy. They subsequently interface with the landowner or manager, and identify stakeholders to move the project forward. This is followed by securing funding or submitting grant applications. If awarded they hire consultants, contractors, and vendors, interface with regulators, oversee the financials, and ensure all steps are followed. Experience is of great benefit in navigating the complexity of the process.
- **Landowner/Manager** – Landowners or managers have a vested interest in project success, and grant permission to proceed. In some cases, they may serve as project sponsor, but more typically either approach the project sponsor to correct a problem or are approached by the project sponsor after having identified their holding to have some significance.
- **Stakeholders** – Stakeholders consist of many people, but a large component would include the community that are directly or indirectly affected by the project, but regulators, public officials, and others may all have real interests. Identifying stakeholders early in the project and soliciting their input is very important. In watershed projects, there is a strong link between project success and those located downstream and therefore stand to gain the most by its success. While technical contributions may be limited, this is not always the case, and stakeholders and residents often have the best understanding of system deficiencies, a resource that needs to be utilized.
- **Grantor** – The grantor at the most basic level is responsible for financial assistance and project awards. As noted above, financial assistance is usually not offered in a vacuum and grant awards are often associated with programs that offer technical assistance. In addition, the grantor usually imposes strict reporting requirements as a condition of the grant award that would include technical reporting, design, and financial management.
- **Regulators** – A major function of regulatory agencies is to ensure that projects, whether implementation projects, planning, or other, meet the technical regulations. In particular, implementation projects are often subject to various land use and other permitting requirements although exceptions and waivers may be offered depending on the scope and objective of the project. Besides overseeing the regulatory matters, regulators may function as the grantors or project sponsors. They typically act as contributing partners in these types of projects.
- **Professionals and Consultants** – This class includes ecologists, hydrologists, engineers, planners, geologists and related professions that are typically hired by the project sponsor at the onset of the project. They serve multiple roles, but core functions may include monitoring, project design, preparation of permit applications, construction oversight, and reporting and interface with all other project roles. Coordinating the varied project components is a fundamental responsibility of consultants. In particular, consultants offer their project experience to navigate

the various of demands of the project and thus must demonstrate technical, regulatory, outreach, and project management knowledge and the ability to identify sources of assistance.

- **Contractors and Vendors** – Contractors and vendors both offer deep technical knowledge of project implementation and necessary materials. The best contractors are also well-versed in the regulations to ensure project success.

7.0 EDUCATION AND OUTREACH

This section reviews the education and outreach(E/O) aspect of the WBP. Specifically, it deals with identifying and building stakeholder involvement, developing educational and outreach programs and materials, and encouraging the adoption of measures and practices to protect the watershed and water quality. This section corresponds to the fifth of the EPA nine elements.

7.0 OUTREACH DEVELOPMENT

The protection and preservation of water quality and the ability to address the existing water quality impairments in the Twilight Lake watershed is contingent upon the education of the target audience including public officials, residents, landowners, businesses, and other stakeholders in the watershed. Goals of E/O programs should include:

- Improving communication, training, and coordination among local, County, and State governments and environmental and stakeholder organizations. Improve public education and raise awareness to promote stewardship of watershed resources, improve water quality, and reduce NPS pollutants, particularly indicator bacteria.
- Celebrating successes to recognize continuing and noteworthy efforts, encourage participation, and continue the implementation of the WMP.
- Focusing on development of ordinances that impact water quality and impacts to the watershed, including development

One of the best and most comprehensive sources for the development of outreach programs is the EPA's *Getting in Step: A Guide for Conducting Watershed Outreach Programs,* 3rd ed.:

https://cfpub.epa.gov/npstbx/files/getnstepguide.pdf.

This document discusses outreach program development and implementation. The EPA also maintains the *Nonpoint Source Outreach Digital Toolbox* (https://cfpub.epa.gov/npstbx/index.html), a clearinghouse for various educational materials including surveys, evaluations, and media campaigns.

Some of the key outreach methods include:

- Demonstration projects
- Watershed tours and hikes
- Workshops and staff training seminars
- Volunteer opportunities for cleanups, planting, and monitoring
- Planning efforts and local ordinance

The Programs and Institutions identified in the financial and technical assistance section should be consulted, as appropriate. Other groups or sources that may provide appropriate materials are:

- The Groundwater Foundation: https://www.groundwater.org/
- The River Network: https://www.rivernetwork.org/
- Green Values Stormwater Toolbox: http://greenvalues.cnt.org/
- Center for Invasive Species and Ecosystem Health: https://www.invasive.org/

Continuing to identify stakeholders is also an important component of this project. Specifically, efforts need to be made to engage not only the community at large, but a targeted pro-active effort is necessary to include property owners or managers that own land that contains and/or is adjacent to waterways, ponds, wetlands, and floodplains.

7.1 ONGOING OUTREACH EFFORTS

Through this project there are current and active outreach programs. The WBP has already successfully identified project partners and stakeholder groups that have the ability and capacity to promote the goals of the plan and disseminate educational materials. In addition to the grantee, the following project partners have been identified:

- NJDEP
- Borough of Bay Head
- Bay Head Environmental Commission
- Conserve NJ

To date, the following outreach has been conducted.

- Borough of Bay Head Environmental Commission Flood Hazard Study
- Updates of WBP development to BHEC monthly meetings
- Partnering with Bay Head School science classes on water quality monitoring and presentation of WQ information in June and September 2022

Flood mitigation and its role in WQ improvement are a core component of BHEC outreach. Flooding does introduce nutrients into the system. Though it is modeled to be a minor source of nutrient and sediment load, it is still a source and can also be seen as a source of erosion. BHEC will continue to make this one of their highest priorities and should include its impact on water quality when presenting their investigations and findings to the public.

8.0 IMPLEMENTATION SCHEDULE

As required by the sixth EPA element, this document contains an implementation schedule. Step 6 is intended to provide a timeline such that measurable actions are implemented in a reasonably expeditious way. From a practical perspective, one of the major limiters on successfully managing NPS pollution, meeting water quality standards and designated uses, and simply implementing a comprehensive watershed management plan is funding. Without question, project implementation is not an inexpensive proposition. As such, there will likely be a heavy reliance on grants and other financial vehicles. In turn, securing such funding is difficult for a number of reasons. Assistance programs are subject to changing appropriations from year to year and may be entirely defunded. Grant programs often have relatively low levels of funding relative to demand, and as a consequence the process tends to be quite competitive. Further, funding and management priorities change over time.

The remainder of this section will explore the implementation schedule.

YEARS 1 TO 2

In the short term, local non-profits and watershed stakeholders should form partnerships with land-owners of properties identified in the BMP section above. As some potential projects are on private property, these partnerships will be critical to securing buy-in from those landowners. Focus should also be on addressing the highest priority projects that have a strong likelihood of being approved and implemented on municipal land as well since access and installation of recommended BMPs is much easier with town-owned lands.

The focus, especially in the early phase, should also be to research grant availability, prepare grant submissions, and initiate the projects when funding becomes available. Realistically, all grant applications will not be awarded and therefore it is recommended that multiple applications are submitted. If a grant application is denied a different source of funding should be investigated or the project should be resubmitted in the next funding cycle. When possible and capacity allows, it is recommended that multiple projects be worked on concurrently. The life cycle of each project will naturally vary, but the cradle to grave duration of each individual project is likely to span two to three years from grant award to post-construction monitoring, even if the construction phase is brief.

Projects with the highest probability to be implemented, due to property ownership, are associated with municipal land and other public properties. One of the primary reasons these projects are most likely to be implemented is that grant applications typically look for non-profit or municipal applicants which coincide with the tax status of these organizations. Furthermore, buy-in on projects at these sites is typically streamlined as stormwater projects may be used as an educational opportunity for the community. These projects include catch basin retrofits, vegetated bioswales, and the nutrient adsorbent (BioChar) BMPs.

In addition to the highest priority project sites with a strong likelihood of being approved and implemented, some of the lower priority items should also be initiated at this time. This would include measures that include low-cost solutions like community outreach efforts and promotion of projects, procedures, and BMPs that should be adopted by homeowners and land managers. These are the types of projects that have lower technical requirements, but also keep the community engaged and harness their efforts to meet pollution abatement goals.

YEARS 3 TO 5

This phase of project implementation is primarily focused on the development of projects which have been identified as a high priority of those that have the greatest chance of funding and implementation. This phase is focused on securing funding and implementation for BMP projects like the pipe at Centennial Park (BMP 7) and the smaller living shoreline stabilizations. This is also the period of time when serious development of the Scow Ditch flood gates design would be advanced.

There is an expectation that project implementation rates should accelerate in this phase of the project, in part building off the project experience gained in the first phase. As such, much of the focus will be on initiating the remaining highest priority sites. At the same time, many of the projects initiated in years 1 and 2 are anticipated to be nearing completion, have been completed, or have been constructed but have continuing monitoring and reporting requirements. Realistically, some of the initial projects forwarded, those with conceptual designs, likely have not been started and these will continue to hold priority in this phase of the project. As always, funding will be a major control in the execution of these projects.

YEARS 6 TO 10

This phase is focused on the implementation of the longer-term projects. These projects may include areas owned by private entities or more complex projects from a logistical and stakeholder standpoint. This would include the larger living shoreline stabilization projects and implementation of the Scow Ditch gates.

POST YEAR 10

This phase is focused on much longer-term projects that would likely require considerable coordination between property owners and regulatory authorities as well as long term monitoring. Scow Ditch measures may fall under this category.

9.0 INTERIM MEASURABLE MILESTONES

In order to track implementation progress and assess how implementation compares with the schedule a set of interim milestones needs to be developed. These milestones are distinct from water quality monitoring, load reductions, and performance metrics. This corresponds to seventh of the nine US EPA plan elements.

Milestone metrics are meant to function as tracking tools or program indicators. In most cases, individual projects will be subject to a number of reporting requirements often involving various monitoring programs. These milestones can be used to encapsulate individual project data within the framework of the larger WBP program. Some of the milestones that should be tracked include:

- Number of grant application packages developed and submitted
- Successful grant awards
- Funding secured
- Outreach programs implemented
- Number of project demonstrations, watershed walks, cleanup events and similar
- Mailers sent, attendance at events, volunteers recruited
- Number of stormwater projects in-progress and completed
- Acres of runoff managed, number of retrofits, number of BMPs installed
- Bank stabilization and riparian buffer enhancement projects in-progress and completed
- Number of shoreline feet stabilized, acres of buffer improved, trees and shrubs installed, and other related metrics
- Pet waste and wildlife management projects in-progress and completed.
- Signage erected, waste receptacles installed, waste bags provided, and similar items
- Changes to land use regulations, adoption of new ordinance, dedication of funds, modification of operations, and similar initiatives enacted at the local government scale
- Attainment of designated uses, de-listing of impaired waters, and similar compliance with environmental quality standards

10.0 EVALUATION CRITERIA

While the milestones serve as programmatic indicators, evaluation criteria are performance metrics used to ascertain load reductions, concentrations, flows, and similar evaluations. This corresponds to the eighth US EPA element. A specific indicator of success is nutrient load reduction, such as the amount TN, TP, and TSS removed through each implemented stormwater BMP or watershed actions. Typically, with each completed project, the amount of TN, TP, and TSS removed through that project is quantified on an annual basis. The resulting removed amount of those nutrients can then be deducted from the lake's modelled total load. The project-based, estimated nutrient removal rates are usually based on the collection of water quality data and/or the implementation of some relatively simple pollutant loading models.

In addition to the specific indicators listed above, additional metrics may be monitored and quantified based on the requirements of specific grants. These evaluation criteria can be applied to three basic levels regarding watershed management: project specific criteria, field measurements of surface waters, and regulatory requirements including water quality standards. The following section discusses these three elements.

PROJECT SPECIFIC CRITERIA

At a project specific level evaluation criterion will be formulated to address the objectives of that individual project. Therefore, evaluation criteria cannot be uniformly applied across project types. Criteria are likely to also be dictated by the technical assistance program if employed, conditions of the funding source, and regulatory and permit conditions. A list of some of the likely evaluation criteria are provided for each of the generalized management measures. Most of the criteria are anticipated to be directly measured, although modeling will likely play an important role as well due to the scope of the project or difficulty in obtaining measurements.

STORMWATER MANAGEMENT CRITERIA

Stormwater management projects encompass a wide range of project types, but generally address either stormwater quality or stormwater quantity with wide overlap between the two as addressing hydrology and hydraulics often results in quality improvements. Many of the commonly measured or modeled stormwater quality metrics include:

- Solids, particularly total suspended solids, total solids, or total settleable solids
- Nutrient pollutants including various phosphorus species such as total phosphorus, orthophosphates, and nitrogen species including total nitrogen, nitrate, total Kjeldahl nitrogen
- In urbanized settings or associations with transportation infrastructure hydrocarbons are often measured as these are associated with fuels
- In the same areas and industrial facilities metals, particularly the RCRA metals like chromium, lead, mercury, may be explored Because the TMDL for each river is based on TP concentrations, TP will be the stormwater quality metric that is most heavily relied upon.

Stormwater quantity criteria focus on the hydrology and hydraulics of the catchment and project and include:

- Peak flows
- Average flow
- Volume reduction
- Recharge
- Storage volumes

A subset of the hydrology and hydraulics metrics would include projects that address instability in which metrics like channel geometry and channel protections would be evaluated.

SHORELINE STABILIZATION AND BUFFER ENAHNCEMENTS

This class of management measures includes shoreline and buffer area projects to address instability, erosion and sedimentation, hydraulics, and habitat quality.

Substrate and solids characterization include:

- Particle size metrics such as D50 and D84
- Bed load
- Solids metrics including total suspended solids and total solids

Buffer area enhancements have many benefits including cooling of surface water, improved habitat quality, enhanced pollutant and nutrient trapping, and soil stability. Criteria to evaluate these benefits include:

- Vegetative cover
- Water temperature
- Canopy cover/insolation
- Infiltration

Measuring localized nutrient and solids loads can be difficult because runoff is not necessarily concentrated in these areas. Biological surveys can be useful indicators for both these projects and may include:

- Fishery composition and related community metrics
- Macroinvertebrate community metrics
- Mussel surveys
- Plant and periphyton metrics

PET WASTES AND WILDLIFE MANAGEMENT CRITERIA

These types of management measures are designed to specifically reduce bacterial and pollutant loading, accomplished through behavioral modification and other techniques. The following criteria can be used to evaluate these programs:

- Bacteria concentrations
- Nutrient concentrations
- Waste density
- Wildlife use metrics including frequency, density, and duration

SURFACE WATERS EVALUATION CRITERIA

Monitoring surface waters is where the cumulative effect of the various management measure and implemented projects is best expressed and consequently measured. The Twilight Lake WBP is primarily focused on recreation impairments TP. However, it also touches upon aquatic life use impairments which may be related to many factors including NPS pollution caused by excess nutrients and sediments and also secondarily addresses flooding.

Of course, concerns regarding pollutants and their generation within the watershed, as well as their impact on the environment demand evaluation through a broad suite of criteria. Many of these criteria are already employed throughout the watershed, although, some additional criteria may be added as necessary.

Regarding water quality sampling, there are field measured parameters collected in-situ and the collection of water quality samples for discrete laboratory analysis. In-situ criteria should include:

- Water temperature
- Dissolved oxygen
- Specific conductance
- pH
- Clarity or Secchi depth where appropriate
- Chlorophyll-*a* and phycocyanin (a pigment only cyanobacteria produce)

Discrete water quality criteria would include:

- Phosphorus species including total phosphorus, soluble reactive phosphorus, organic phosphorus, etc.
- Nitrogen species including total nitrogen, nitrate, nitrate, ammonia, total Kjeldahl nitrogen
- Solids including total solids, total dissolved solids, total suspended solids, and total settleable solids
- Standard limnological parameters such as alkalinity and hardness
- Additional discrete analytes as necessary including hydrocarbons, metals, semi-volatile organic compounds

Hydrology is a key concern regarding the functions of rivers, as well as an important factor in pollutant loading. It is therefore important to monitor:

- Discharge
- Precipitation

Biological sampling, within both lakes and their contributing tributaries, can be important in evaluating system function. This may include:

- Fishery community metrics
- Submerged aquatic vegetation composition
- Chlorophyll-a, a proxy measure of algal biomass
- Phytoplankton and zooplankton metrics
- Cyanotoxin concentrations produced by cyanobacteria or blue-green algae
- Wetland plant composition
- Vegetative coverage

REGULATORY CRITERIA

The regulatory criteria provide not only a statutory standard, but a means to evaluate the field sampling and modeling activities. Here, the *New Jersey Surface Water Quality Standards N.J.A.C. 7:9B* are of primary concern. These include classifications of surface and groundwaters with accompanying designated uses. There are also assigned water quality standards, both numerical and narrative. For Twilight Lake the following criteria are especially important:

- Dissolved oxygen
- Turbidity
- pH
- Nutrients
- Biological Condition

11.0 MONITORING

Monitoring is used to supply the data necessary to evaluate pollution reduction goals. Following the criteria cited above, monitoring occurs at two levels, project specific and larger watershed-scale surface water monitoring efforts. This section corresponds to the last of the US EPA nine elements.

PROJECT SITE MONITORING

Monitoring at project sites is often a condition of project funding. There are several basic monitoring program designs that can be employed at the site level. All of these varying monitoring program designs may require the preparation of a quality assurance project plan or QAPP to ensure the correct criteria are being evaluated, the proper methods employed, and the program is consistent with quality assurance standards. This has already been done for this WBP and can be readily modified to fit any situations required by each specific site's monitoring needs.

INFLUENT AND EFFLUENT

The most basic site monitoring program, particularly those for stormwater management designs, consists of monitoring the influent and effluent streams. This allows direct comparisons of concentrations to determine removal rates. If paired with flow data, concentrations can be integrated to determine load removals. The criteria monitored will depend on the objectives of the project, as well as the dictates of funding and regulatory requirements.

PRE- AND POST-MONITORING

Another common method of determining reductions and adherence to water quality or other standards is to conduct monitoring prior to project implementation and again after completion. This may be a particularly useful methodology in situations where influent concentrations are hard to measure because they are not neatly concentrated or where there was no influent concentration prior to project implementation. In any case, monitoring prior to construction or other implementation, and again afterward provides an effective means of determining concentration and load reductions specific to the project.

LONGITUDINAL MONITORING

Monitoring over time can also be important in assessing design performance. This is particularly true where the project contains an element of site evolution. This would be especially true in situations where there is a biological element, such as increasing vegetative coverage over time or the development of the macroinvertebrate community for stream grade controls. There may also be a reason for event-based sampling, such as assessing erosion after a channel forming flow event or a flood. These sampling programs may rely on quarterly sampling or some other set frequency, or by a triggering environmental condition or event.

CONTROL-IMPACT

Comparative monitoring can also be useful, by monitoring within a control area and an impact area corresponding to the project site. Monitoring of reference conditions can also be useful in the design phase. When paired with a time element this type of sampling design is called BACI (before, after, control, impact) and is especially powerful from a statistical perspective in determining project efficacy.

MODELING

Modeling is also a valid way to ascertain site specific function. Simple models like STEPL are endorsed by the US EPA for use in determining BMP removal rates. Certainly, a host of other models of varying complexity exist that are used in a similar role. Modeling presents an alternative to in-field sampling, can reduce costs, and is useful for projects where measurable changes in water quality are difficult to sample, such as when infiltration is enhanced.

An innovative method of obtaining frequent water column profiles, even on daily or hourly scales, is through the use of monitoring buoys. While expensive, these monitoring buoys provide invaluable data that go above and beyond the capabilities of the standard boat-based water column profiles that are obtained by a field scientist once or twice a month, depending on the monitoring schedule. Regardless of the method that is used to obtain this important data, it is imperative that the internal phosphorus load of Twilight Lake be addressed accordingly in order to combat harmful algal blooms in the most effective manner.

WATERSHED SCALE SURFACE WATER MONITORING

In-lake monitoring should also be conducted to gauge how Twilight Lake is responding to the reductions in pollutant loads. In-lake and watershed-based monitoring should continue in the future, using a similar monitoring program as was established for the creation of the WBP. This will provide an ever-increasing inter-annual database to identify long-term trends in water quality. Five (5) in-lake monitoring stations have been monitored in Twilight Lake for a variety of physical, chemical, and biological parameters.

12.0 WATERSHED BASED PLAN SUMMARY

Though Twilight Lake is not listed as impaired by the NJDEP, it does experience water quality impairments to some degree. Past studies have documented various aspects of the lake and its watershed, including bathymetric profile and sedimentation. Water quality monitoring in 2022 and watershed modeling further support Twilight Lake's status as being slightly eutrophic through the growing season and helped to develop nutrient load reduction targets. Visual, field-based watershed assessments helped to identify areas around the watershed that would be suitable for prospective best management practices (BMPs) to be implemented to mitigate water quality issues; nutrient load reduction is the intended purpose of the recommended BMPs but flood mitigation was also taken into consideration during this process.

Wetland areas in the northwest of the lake seem to be areas where in-lake nutrient load reduction may be most effective, while modeling shows Scow Ditch to be the main source of loading to Twilight Lake, making this area a priority for consideration of BMP implementation as well.

Elements of EPA's watershed plan guidelines are covered by those aforementioned activities and analyses, while the remaining elements included the outlining of sources of Financial and Technical Support (Section 6), Education and Outreach opportunities (Section 7), an implementation schedule (section 8), Milestone and Evaluation Criteria (Sections 9 and 10, respectively), and how the progress of the plan will be monitored (Section 11).

REFERENCES

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Bay Head Planning Board and Colliers Engineering and Design. 2021. Master Plan, Reexamination Report and Update.

Brick Utilities Authority, C.D. Smith, and John S. Truhan Consulting Engineers Inc. 2013. Metedeconk River Watershed Protection and Restoration Plan.

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Remington, Venick, and Vena Engineers. 2017. Hazard Mitigation Plan for The Borough of Bay Head.

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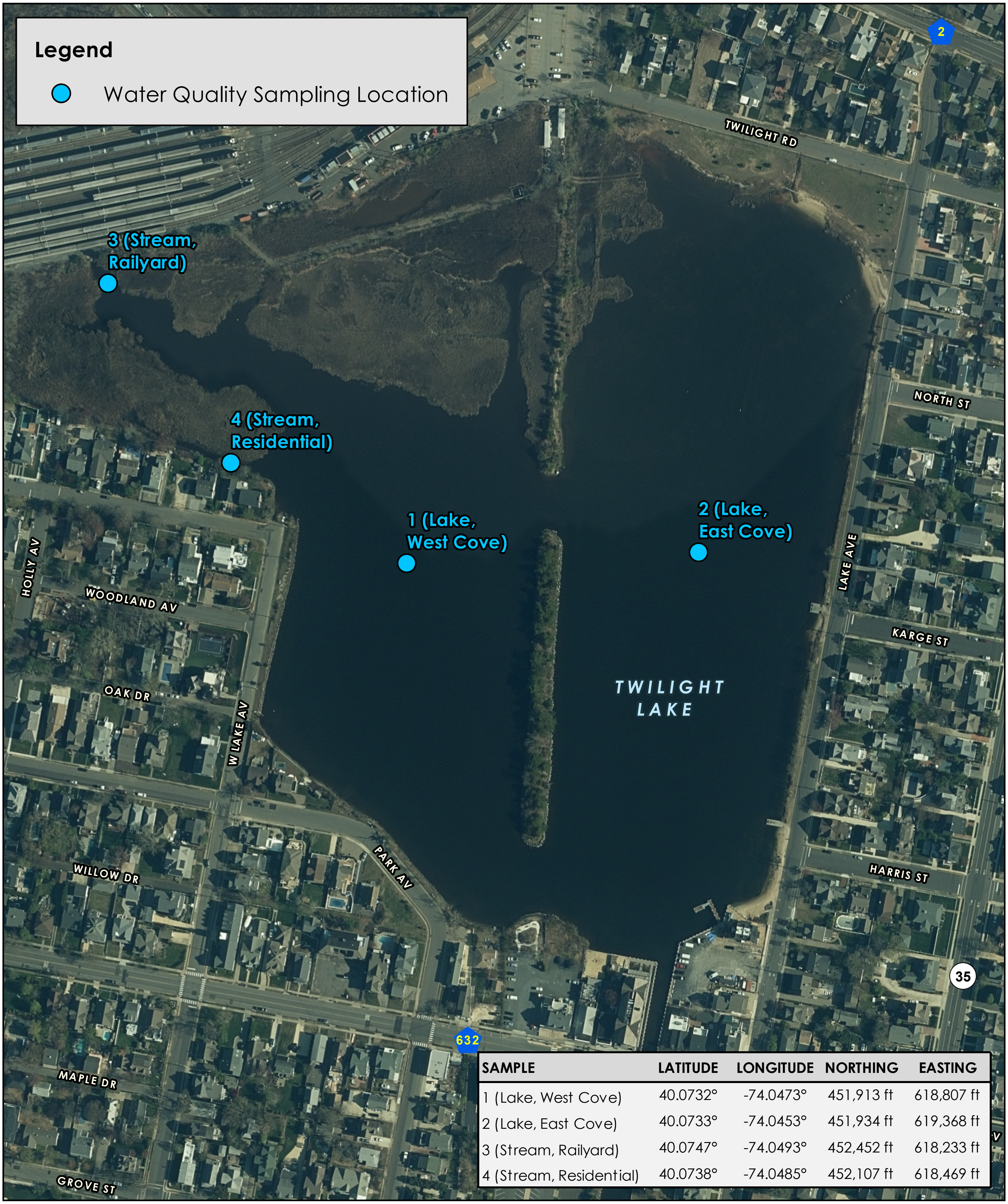
Vermont DEC. 2022. Bioengineered Lake Shoreline Stabilization Estimated Phosphorus Reduction Calculator.

APPENDIX A

MAPS



SAMPLE	LATITUDE	LONGITUDE	NORTHING	EASTING
1 (Lake, West Cove)	40.0732°	-74.0473°	451,913 ft	618,807 ft
2 (Lake, East Cove)	40.0733°	-74.0453°	451,934 ft	619,368 ft
3 (Stream, Railyard)	40.0747°	-74.0493°	452,452 ft	618,233 ft
4 (Stream, Residential)	40.0738°	-74.0485°	452,107 ft	618,469 ft

NOTES:
1. Water quality sampling locations are approximate.
2. 2020 orthoimagery obtained from NJ Office of Information Technology (NJOIT), Office of Geographic Information Systems (OGIS).

0 125 250 Feet

Map Projection: NAD 1983 2011 StatePlane New Jersey FIPS 2900 Ft US

WATER QUALITY SAMPLING LOCATION MAP

QUALITY ASSURANCE PROJECT PLAN
TWILIGHT LAKE
BOROUGH OF BAY HEAD
OCEAN COUNTY, NEW JERSEY

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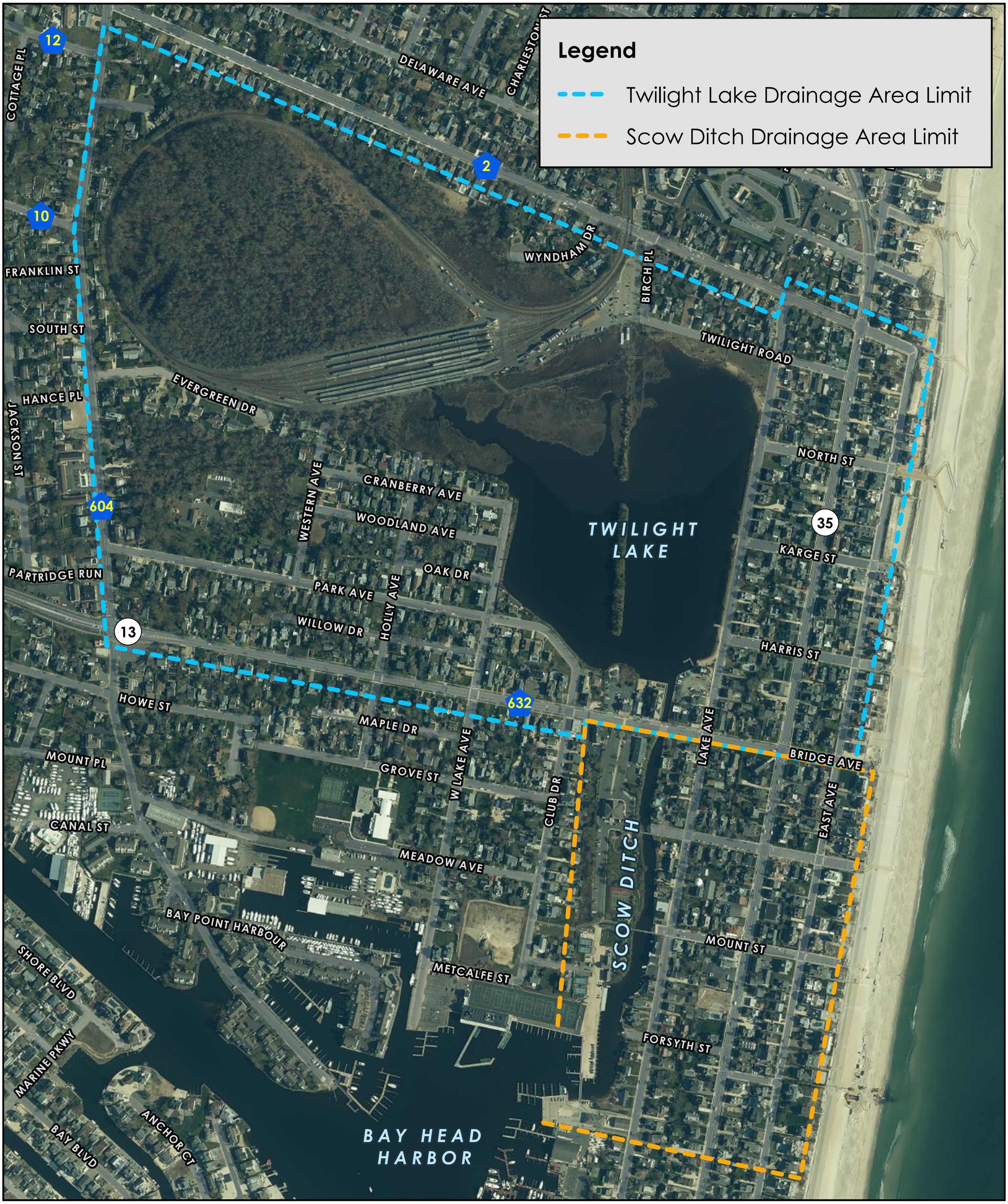

File: P:\1259\Projects\1259004 Twilight Lake 319 Project\GIS\APRX\Twilight Lake WIP Maps\Twilight Lake WIP Maps.aprx, 10/20/2022, Drawn by tsrinivasan, Copyright Princeton Hydro, LLC.

NOTES:
1. Drainage area limits are approximate.
2. 2020 orthoimagery and roads obtained from the NJ Geographic Information Network (NJGIN) Open Data portal: https://njgin.nj.gov/

0 300 600 Feet

Map Projection: NAD 1983 2011 StatePlane New Jersey FIPS 2900 Ft US

DRAINAGE AREA MAP

TWILIGHT LAKE
BOROUGH OF BAY HEAD
OCEAN COUNTY, NEW JERSEY

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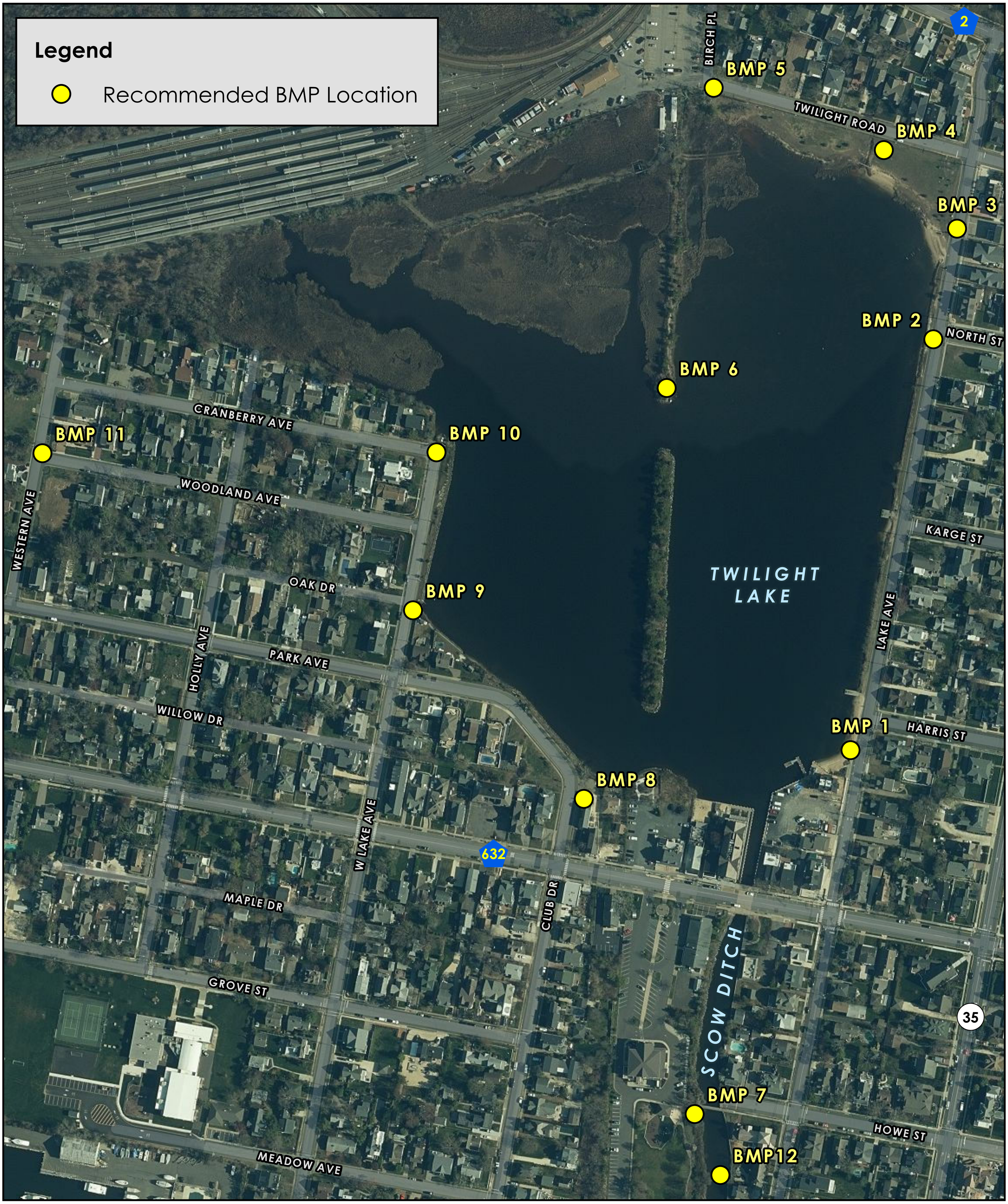

File: P:\1259\Projects\1259004 Twilight Lake 319 Project\GIS\APRX\Twilight Lake WIP Maps\Twilight Lake WIP Maps.aprx, 4/25/2023, Drawn by jpbell, Copyright Princeton Hydro, LLC.

NOTES:
1. Recommended BMP locations are approximate.
2. 2020 orthoimagery and roads obtained from the NJ Geographic Information Network (NJGIN) Open Data portal: https://njgin.nj.gov/

0 150 300 Feet

Map Projection: NAD 1983 2011 StatePlane New Jersey FIPS 2900 Ft US

RECOMMENDED BMP LOCATION MAP

TWILIGHT LAKE
BOROUGH OF BAY HEAD
OCEAN COUNTY, NEW JERSEY

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SCIENCE DESIGN ENGINEERING
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APPENDIX B

Water Quality Data Collection
Quality Assurance Protection Plan
(QAPP)

QUALITY ASSURANCE PROJECT PLAN (QAPP)

Twilight Lake and Watershed Management Plan
Ocean County, NJ

Grant Identifier #
WQR-2019-Bay Head-00172

Lead Organization:
Borough of Bay Head
Frank Pannucci, Borough Administrator 83
Bridge Avenue
Bay Head, NJ 08742
Office: 732-892-0574
Email: fpannucci@bayheadnj.us

Principal Investigator:
Dr. Fred Lubnow Director of
Aquatic Programs
Princeton Hydro, LLC,
1108 Old York Road, PO Box 720, Ringoes, NJ 08551 908-
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VERSION 2: PREPARED NOVEMBER 2021

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Appendix A – Sample Chain of Custody Form
Appendix B –Sampling Site Map – Proposed Sampling Stations
Appendix C – Standard Operating Procedures
Appendix D – NJDEP Approved Scope of Work

TITLE AND APPROVAL PAGE - QUALITY ASSURANCE PROJECT PLAN (QAPP)

Twilight Lake and Watershed Management Plan

Prepared by: Fred S. Lubnow Date: Sept 17, 2021
Fred Lubnow, Ph.D., Principal Investigator
Princeton Hydro, LLC

Reviewed by: Date: Sept 17, 2021
Chris Mikolajczyk, QA/QC Officer
Princeton Hydro, LLC

Reviewed by: Date: 3/17/22
Frank Parnucci, Adminstrator
Grantee: Borough of Bay Head

Reviewed by: Lynette Lurig Date: 12/06/21
Lynette Lurig
NJDEP Bureau of Environmental Assessment,
Restoration and Standards

Reviewed by: Deborah Kratzer Date: 11/16/2021
Deborah Kratzer
NJDEP Bureau of Environmental Assessment,
Restoration and Standards

Approved by: Jenna Majchrzak (In place of MH) Date: 4/5/2022
Melissa Hornsby, Quality Assurance Protection Plan Reviewer
NJDEP, Office of Quality Assurance

Approved by: Cathryn Schaffer Date: April 1, 2022
Cathryn Schaffer ~~Larry Torok~~, Manager, Bureau of Watershed Management

QAPP Approval Date ______________________________

1.0 TITLE PAGE

Twilight Lake and Watershed Management Plan

Grant Identifier #: **WQR-2019-Bay Head-00172**

HUC 14 Name/Number: #02040301040030 Barnegat Bay

Anticipated Sampling Dates: Project Months 9 - 15

Project Requested By: Borough of Bay Head

Date Project Initiated: 2021

Grant Administrator: Frank Pannucci, Administrator
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Project Manager: Frank Pannucci, Administrator
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2.0 Distribution List

Frank Pannucci, Administrator Borough of Bay Head 83 Bridge Avenue Bay Head, New Jersey 08742 732-892-0574 fpannucci@bayheadnj.us	Fred Lubnow, Ph.D. Princeton Hydro, LLC Suite 1, 1108 Old York Rd. P.O. Box 720 Ringoes, NJ 08551 908-237-5660 flubnow@princetonhydro.com
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	Larry Torok NJDEP - Bureau of Watershed Management 401 East State Street PO Box 420 Trenton, New Jersey 08625-0420 (609) 984-9488 larry.torok@dep.nj.gov

3.0 PROJECT ORGANIZATION

The following identifies the key Borough of Bay Head staff and contractors involved in this project. This information is summarized in Figure 1, Communication Flow Chart. The role and responsibility of each key team member are discussed further in Section 5. Contact information for key project and personnel is provided in Sections 1 and 2 above.

Grant Administrator:	Frank Pannucci, Administrator
Address:	Borough of Bay Head 83 Bridge Avenue Bay Head, New Jersey 08742
Phone:	732-892-0574
Email:	fpannucci@bayheadnj.us

Principal Investigator:	Fred Lubnow, Ph.D.
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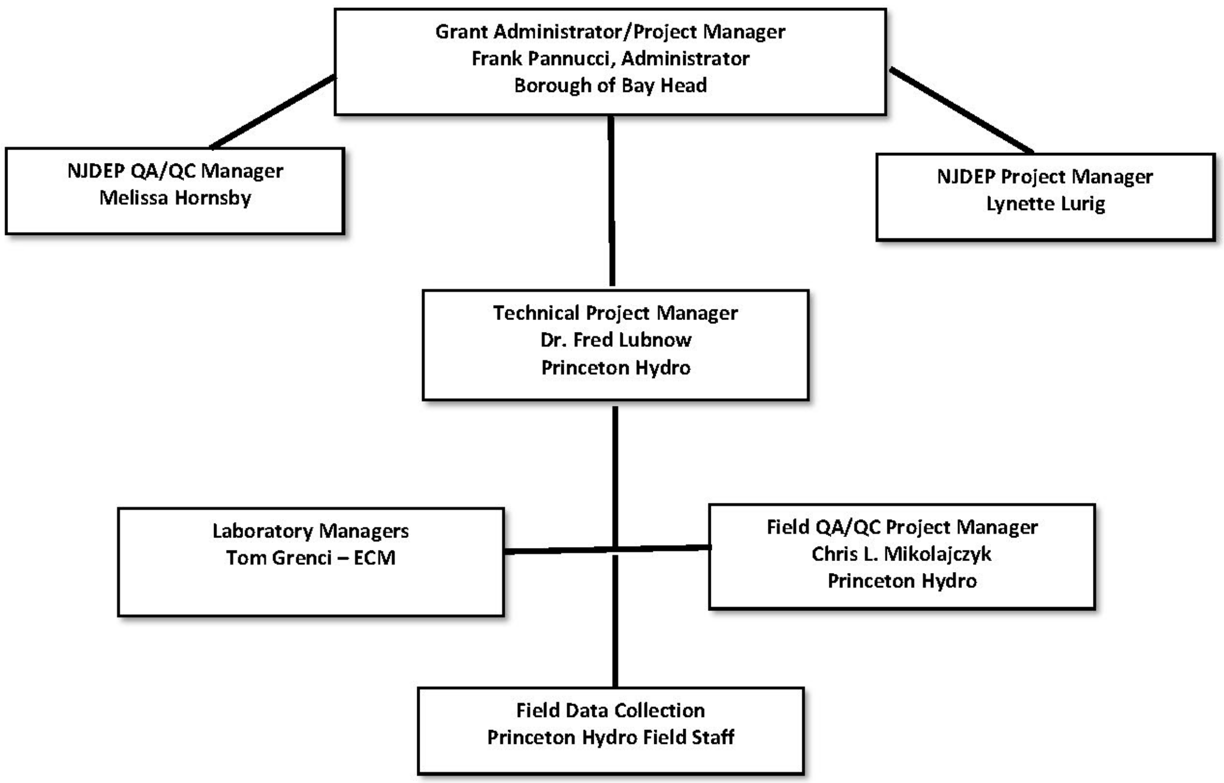
Phone:	(908) 237-5660
Email:	flubnow@princetonhydro.com

Project Manager:	Frank Pannucci, Administrator
Address:	Borough of Bay Head 83 Bridge Avenue Bay Head, New Jersey 08742
Phone:	732-892-0574
Email:	fpannucci@bayheadnj.us

QA/QC Officer:	Chris Mikolajczyk
Address:	Princeton Hydro, LLC (#10006) P.O. Box 720 1108 Old York Road, Suite 1 Ringoes, New Jersey 08551
Phone:	(908) 237-5660
Email:	cmiko@princetonhydro.com

NJDEP Certified Lab	Environmental Compliance Monitoring (#18630)
Lab Manager	Mr. Thomas Grenci
Address	349 US Highway 206 Hillsborough, NJ 08844
Phone	908-874-0990
Email	ecm-inc@att.net

Figure 1 – Communication Flowchart



The above organizational/communication chart (Figure 1) illustrates the overall program management structure of this project. As noted, the entire project will be under the direction of the New Jersey Department of Environmental Protection and Lynette Lurig will serve as the Contract Manager. Mr. Frank Pannucci of the Borough of Bay Head will serve as grant administrator and project manager. Mr. Pannucci will ensure the project will be completed as per the specifications of the approved work plan, on time and on budget.

Dr. Fred Lubnow will serve as the Principal Investigator, and in that capacity will oversee all technical aspects of this project. It will be his responsibility to coordinate all the field sampling efforts and subsequent data analysis. Dr. Lubnow will also be both directly involved and supervise the activities of those engaged in the field sampling aspects of this project. Finally, he will be primary author of the project's final report and prepare the technical components of the quarterly reports.

Mr. Mikolajczyk will function as the QA/QC Officer, a role he routinely fulfills as part of his job responsibilities at Princeton Hydro. He will work independently to retain his ability to identify and require action taken on any QA or QC issues that may arise. It should be noted that Mr. Mikolajczyk brings to this project well over 20-years of experience in QAQC, having served as QA Officer for numerous NJDEP as well as USEPA sponsored projects of a nature and scope similar to this project. This includes QA/QC experience in an analytical lab setting. He is also especially knowledgeable of the deployment and operation of automated sampling equipment and as such will be in a position to assure that the sampling conducted using such equipment has been designed and implemented correctly. Overall, it will be his job to ensure that all elements of this project involving the collection of data, whether in the field or through a contract analytical lab, meets the QA standards set forth in this document.

Mr. Grenci of ECM Inc. will be responsible for the QA/QC associated with the lab analyses conducted on the discrete water quality samples for nutrients concentrations. He has worked extensively in a similar capacity on other Princeton Hydro projects including New Jersey Department of Environmental Protection (NJDEP), United States Army Corps of Engineers (USACOE), United States Geological Survey (USGS) and United States Environmental Protection Agency (USEPA) commissioned sampling efforts.

4.0 SPECIAL TRAINING NEEDS/CERTIFICATIONS

None of the proposed water quality sampling requires any special training or certification. However, it will all be conducted under the supervision of Fred Lubnow, Ph.D. who has extensive expertise in the collection and analysis of water quality samples. Additionally, both Princeton Hydro (#10006) and ECM (#18630) are certified by the NJDEP for their respective parameters (see Section 7.0 below for further detail).

5.0 PROBLEM DEFINITION / BACKGROUND

The Borough of Bay Head (Bay Head) submitted an application and was awarded funding through NJDEP's 319(h)-grant program. These funds will be used to develop a Lake/Watershed Management Plan for Twilight Lake, Ocean County, NJ. The lake suffers a variety of water quality problems, including high densities of submerged vegetation, nuisance algal blooms (some of which can be harmful), low dissolved oxygen (DO) concentrations and high amounts of sedimentation / turbidity. Since Twilight Lake is a focus point for the public relative to the enjoyment of local natural resources, the goal of the Management Plan is to develop a strategy to cost effectively address these impacts through both in-lake and watershed-based management activities.

Princeton Hydro will conduct a 1-year detailed sampling of the lake for the purpose of collecting the data needed to assess the lake and design the lake and watershed management plan.

6.0 PROJECT DESCRIPTION

A. Scope Statement and Project Objectives

The Borough of Bay Head, incorporated in 1886, is located in northeast Ocean County and falls under watershed management area 13 (Barnegat Bay) and subwatershed BarnegatBay01 – Point Pleasant Canal and Bay Head Harbor. On land, Bay Head is bordered by Point Pleasant Beach to the north and Mantoloking to the south. The Borough is approximately 0.60 square miles consisting of mostly historic age residential housing.

Located at the center of Bay Head is a body of water that has become a center piece of life in the Borough, that body of water is Twilight Lake. Twilight Lake is a saltwater lake that connects to the Barnegat Bay by a small delta named Scow Ditch. This lake is a great spot for residents to fish, paddle board, or perform other aquatic activities. Not only is this lake important to the residents of Bay Head but it is important to the environmental needs of the Barnegat Bay.

The Borough of Bay Head intends to develop a Lake/Watershed Management Plan for Twilight Lake. Such a plan will address a number of water quality issues, including high densities of submerged vegetation, nuisance algal blooms (some of which can be HABs), low dissolved oxygen (DO) concentration and high amounts of sedimentation/turbidity. Since Twilight Lake is a focus point for the community relative to the outdoor recreation, the goal of the Management Plan is to develop a strategy to cost effectively address these impacts through both in-lake and watershed-based management activities.

B. Scope of Work

Baseline water quality monitoring will be conducted over the 2022 growing season (May - October). This would entail monthly water quality sampling at the lake for a total of six (6) sampling events. Samples will be collected at a minimum of two (2) stations, with at least one (1) sampling station in each cove. During each event and at each station, *in-situ* water quality data will be collected at profile from surface to bottom for dissolved oxygen, temperature, pH, and specific conductivity. Princeton Hydro is field certified by NJDEP (#10006) in these in-situ parameters. The lake's clarity (Secchi disk transparency) will also be measured.

At a station established in the approximate center of the east and west coves, discrete whole water samples will be collected at a depth halfway down the water column. All of these samples will be submitted to a NJDEP certified lab, ECM (#18630), for the analysis of total phosphorus (TP), soluble reactive phosphorus (SRP), nitrate nitrogen (NO3-N), NH3 nitrogen (N as ammonia), Chlorophyll a, and total suspended solids (TSS). At the same two stations, zooplankton and phytoplankton samples will be collected and analyzed for species composition, dominant organism, and relative density. Additionally, during each of the six (6) sampling events, a general survey of aquatic vegetation and/or algae growth (planktonic or filamentous) will be conducted.

As part of a detailed, field-based survey of the watershed to ground truth the pollutant load modeling, 3 watershed-based baseflow (no rain in the previous 72 hours) stream monitoring events will be conducted at the two streams that enter the lake from the western end. During these monitoring events, both *in-sit*u and discrete water quality data will be collected. Discrete water quality samples will be collected at each site and analyzed for TP, SRP, NO3-N and TSS at ECM, as with the lake samples.

All attempts will be made to sample during dry conditions and storm conditions will be avoided. Overall, the data collected through this sampling effort will be used as part of the analyses and the preparation of the deliverables associated with the Lake and Watershed Management Plan.

Table 1 – Testing Summary

Sample Location	Coordinates		Parameters to be Tested
	X	Y	
1 (Lake, West Cove)	451,851	618,814	*In-Situ*, TP, SRP, TSS, NH3-N, NO3-N, Chl a and Phyto/Zoop ID
2 (Lake, East Cove)	451,953	619,360	*In-Situ*, TP, SRP, TDP, NH3-N, NO3-N, Chl a and Phyto/Zoop ID
3 (Stream, Railyard)	452,452	618,233	*In-Situ*, TP, SRP, TSS, NO3-N
4 (Stream, Residential)	452,107	618,469	*In-Situ*, TP, SRP, TSS, NO3-N
5 (Lake, Scow Ditch Input)	451,210	619,304	*In-Situ*, TP, SRP, TSS, NO3-N

Mr. Frank Pannucci the Borough of Bay Head administrator will function as the current Project Manager. All field work will be conducted under the direct supervision of Dr. Fred Lubnow of Princeton Hydro, the project's Principal Investigator.

7.0 QUALITY OBJECTIVES AND CRITERIA FOR MEASUREMENT DATA

Within Section 7 of this QAPP the criteria for deciding to accept, reject, or qualify the data generated through both field and lab testing is outlined below. The procedures that will be followed and the criteria used to assess the validity and usability of the data have been established in a manner consistent with both NJDEP and USEPA quality assurance guidance plans.

A. Experience and Expertise in Conducting Proposed Scope of Work

Princeton Hydro, LLC will provide the technical support needed to complete the field sampling component of this project, which is the subject of this QAPP. Princeton Hydro is extremely experienced and familiar with the entire field sampling program proposed for this project having both prepared QAPPs for numerous similar projects, as well as having successfully implemented the associated sampling efforts.

B. Data Usage

The data collected during this study will be utilized to assess the current state of the lake and watershed and will be used to formulate the Lake and Watershed Management Plan. The specific nutrient parameters that will be lab measured within the lake are TP, SRP, TSS, NH3-N, NO3-N and chlorophyll *a.* This testing will be conducted by the NJDEP certified analytical laboratory ECM (#18630). *In-situ* data collection will entail the measurement of pH, dissolved oxygen (DO), specific conductivity and temperature. Princeton Hydro is certified by the NJDEP for the collection of *in-situ* data (NJDEP Lab Certification #10006). Princeton Hydro will also conduct cyanobacteria related analysis, specifically phytoplankton and zooplankton identification.

C. Sampling Procedures

All sampling procedures shall be conducted in conformance with standard practices and procedures listed in *Standard Methods for the Analysis of Water and Wastewater, 22nd Edition* (American Public Health Association, 2011), State Field Sampling Procedures Manual (NJDEP, 2005) and/or any applicable USEPA guidance document.

D. Water Quality Monitoring Parameters and Frequency

1. This QAPP specifically covers the sampling period beginning upon the initiation of growing season monitoring and continuing for approximately six (6) months (April-September). Grab samples will be collected in the lake once monthly from May to October.

2. All water quality grab samples will be collected following procedures found in the "NJDEP Field Sampling Procedures manual, August 2005."

3. The sample locations will be marked and verified with GPS, reported in decimal degrees NAD83, as well as state plane coordinates. In addition, sampling staff, in consultation with NJDEP, will use detailed site sketches to locate the sampling location on the first and subsequent visits.

4. Samples will be collected at a depth equaling the mid-water level of the total depth. All samples will be collected directly into laboratory-supplied containers.

5. New, pre-cleaned, sterile sample containers provided by the laboratory will be used for the project. Any required preservatives will be added to the bottles by the laboratory prior to sampling. All samples will be transported on ice in coolers to maintain sample temperatures greater than freezing but below 4°C.

6. All signatories of this QAPP shall be notified in writing anytime a deviation in the final approved QAPP is performed.

E. Sample Labels

A sample label will be affixed to each sample container at the time the samples are collected in the field. The following will be recorded on each label with waterproof ink:

- Sample station location and identification number
- Client/project name
- Date of sample collection
- Time of sample collection
- Name of sample collector
- Type of preservative (if used)

F. Field Data Sheets

Field data sheets will be used to fully document all data and sample collection results or activities. Field personnel will prepare the field data sheets at the time of sample collection. The field data sheets will provide opportunity for the recording of all activities associated with the collection of the samples.

G. Parameter Table

The water quality parameters to be measured and associated analytical methods are presented in Tables 2 and 3 – Proposed Field Sample Parameters and Laboratory Sample Parameters, respectively. This table was developed in coordination with the independent analytical laboratory Environmental Compliance Monitoring, Inc. (ECM; #18630). ECM will conduct the nutrient-based chemical laboratory analysis of TP, SRP, TSS, NH3-N, NO3-N and chlorophyll *a,* Princeton Hydro will conduct the *in-situ* and zooplankton/phytoplankton-based analysis following the methods and protocols also listed in Table 2 – Field Sample Parameters.

Information on project required parameter detection limits (sensitivity), reporting levels, levels of interest, precision and accuracy for parameters of interest is listed in Table 4. This table was developed in conjunction with Mr. Thomas Grenci of ECM, Inc. and indicates the laboratory data quality that is expected for this study. Dr. Fred Lubnow and Mr. Chris Mikolajczyk also contributed to this table for the algal/microcystin specific parameters.

Table 2 - Proposed Field Sample Parameters

Parameter	Analytical Method Reference* (Standard Methods)	Sample Container and Preservation Method	Holding Time (Max)	Performed By
pH	SM 4500-H B-2011	Analyzed *In-situ*	Analyze Immediately	Princeton Hydro
Specific Conductivity	SM 2550 B-2011	Analyzed *In-situ*	Analyze Immediately	Princeton Hydro
Temperature	SM 2550 B-00	Analyzed *In-situ*	Analyze Immediately	Princeton Hydro
Dissolved Oxygen	"Other In Situ Method" *Luminescent Dissolved Oxygen* 1002-8-2009	Analyzed *In-Situ*	Analyze Immediately	Princeton Hydro

Table 3 - Proposed Laboratory Sample Parameters				
Parameter	**Analytical Method Reference * (Standard**	**Sample Container and Preservation Method**	**Holding Time (Max)**	**Performed By**
Total Phosphorus	4500-P B-5 and 4500-P E	1 Pint plastic, H_2SO_4 added to pH <2, cool to 4°C	28 days	ECM Inc
Soluble Reactive Phosphorus	4500-P E	1 Pint plastic, cool to 4°C	48 hours	ECM Inc
Total Suspended Solids	2540 D	1 Pint plastic, cool to 4°C	7 days	ECM Inc
Ammonia-Nitrogen	4500-NH3 B&D	1 Pint plastic, H_2SO_4 added to pH <2, cool to 4°C	28 days	ECM Inc
Nitrate-Nitrogen	352.1	1 Pint plastic, cool to 4°C	48 hours	ECM Inc
Chlorophyll *a*	10200H 1 & 2	1000 mL opaque plastic bottle, cool to 4°C	ASAP – filter within 48 hours	ECM Inc
Phytoplankton ID**	10200 F 1 & 2	100 mL plastic bottle, Lugols solution added, cool to 4°C	ASAP	Princeton Hydro
Zooplankton ID**	10200 F 1 & 2	100 mL plastic bottle, Lugols solution added, cool to 4°C	ASAP	Princeton Hydro

**** - For Informational Purposes Only**

H. Data Comparability

Analytical data comparability will be achieved by following the analytical methodology, preservation practices and holding times described in Tables 2 and 3. Each parameter will be analyzed using the referenced methodology and changes in analytical procedures will not take place from sample to sample. The same holds true for sample preservation, holding times and QA/QC practices. The methods used are standard analytical methods that will also allow comparisons with data from any earlier projects.

I. Data Completeness

Data will be considered complete and usable for decision-making when all results have been completed and submitted to the NJDEP, in accordance with the sampling and analytical methodology and the required QA/QC practices listed in this project plan. However, it is recognized that some data loss may occur as a result of factors such as sampling equipment malfunction, losses during sample handling, or analysis outside of laboratory acceptance limits. Samples will be re-analyzed if results are outside of laboratory acceptance limits, providing that sufficient sample volume is available and that holding times for the affected parameters(s) have not been exceeded. If sample volume is not sufficient, a new sample will be collected for a complete new set of analyses.

All project data, including any data rejected as outliers, laboratory results flagged for not meeting quality control acceptance criteria or any other scientifically-based reason, even if the data is not used in the final research analysis will be submitted to the Department.

J. Spiking Protocol

ECM, the State certified laboratory that will conduct the chemical analyses, identified the frequency of spiking of the samples is one per twenty samples (Table 4).

Table 4 - Information on Laboratory Detection Limits, Precision and Accuracy for Discrete Water Quality Parameters							
Parameter	**Sample Matrix**	**Project Required Detection Limit**	**Reporting Level**	**Level of Interest**	**Relative Percent Difference***	**Percent Recovery***	**Performed By**
Total Phosphorus	Water	0.02 mg/L	0.03 mg/L	0.03 mg/L	-9 to 9	86 - 128	ECM Inc
Soluble Reactive Phosphorus	Water	0.002 mg/L	0.003 mg/L	0.005 mg/L	-9 to 9	81 - 129	ECM Inc
Total Suspended Solids	Water	2 mg/L	2 mg/L	5 mg/L	-6 to 6	N/A	ECM Inc
Ammonia-Nitrogen	Water	0.01 mg/L	0.01 mg/L	0.10 mg/L	-21 to 21	0 - 148	ECM Inc
Nitrate-Nitrogen	Water	0.02 mg/L	0.03 mg/L	0.10 mg/L	-21 to 21	56 - 158	ECM Inc
Chlorophyll *a*	Water	0.3 mg/M^3	0.4 mg/L	5 mg/M^3	-66 to 66	N/A	ECM Inc
pH	Water	0.05	0.10	0.5	N/A	N/A	Princeton Hydro
Specific Conductivity	Water	1 µmhos/cm	5 µmhos/cm	10 µmhos/cm	N/A	N/A	Princeton Hydro
Temperature	Water	0.5°C	1.0°C	1.0°C	N/A	N/A	Princeton Hydro
Dissolved Oxygen	Water	0.2 mg/L	0.5 mg/L	0.5 mg/L	N/A	N/A	Princeton Hydro

*** As supplied by ECM**

Table 5 - Information on Field-Based Instrument Detection Limits, Precision and Accuracy for Discrete Water Quality Parameters							
Parameter	**Sample Matrix**	**Project Required Detection Limit**	**Reporting Level**	**Level of Interest**	**Relative Percent Difference***	**Percent Recovery***	**Performed By**
Phytoplankton ID**	Water	100 cells/ml	200 cells/ml	1,000 cells/ml	N/A	N/A	Princeton Hydro
Zooplankton ID**	Water	N/A	N/A	N/A	N/A	N/A	Princeton Hydro

***** = For Informational Purposes Only and to Inform Advisories***

K. Precision

Precision is defined as the ability to provide agreement among repeated measurements. Overall, the precision of the data collection will be accomplished by using the same set of field scientists with extensive experience in such sampling charged with the execution of the field monitoring element of the project.

Given the overall aeration assessment nature of this project, no blanks will be collected. A field duplicate will be collected during each sampling event. Field duplicates will be collected for a different water quality parameter during each individual sampling event. As per the USEPA:

> "A field duplicate is a duplicate sample collected by the same team or by another sampler or team at the same place, at the same time. It is used to estimate sampling and laboratory analysis precision. Field duplicate samples may be collected and analyzed as an indication of overall precision. These analyses measure both sampling and laboratory precision; therefore, the results may have more variability than laboratory duplicates which measure laboratory performance."

Field duplicates will typically show some nominal degree of difference between values. As long as all data quality objectives for both samples are met, the original data point only will be considered an approved data point and thus will be used for final reports and for all data analyses. Should this data point fail on the data quality objectives (see Table 4), the utilization of the data point will be determined as follows. First, all reports of raw data will include the questioned field duplicate. However, the report will identify those data points which did not meet all data quality objectives. Second, for derivative analyses and statistics based on the raw data, those duplicates that do not meet data quality objectives will be handled in one of two ways. If the primary sample and field duplicate sample data values fall outside the relative percent difference for field replicates range of the specific parameter (Table 4), both values will be discarded and will not be used in subsequent analyses, data summaries, or reports. However, if the values for the field duplicate samples fall within the parameter specific range for the relative percent difference for replicates as observed in Table 4, the original value will be used for all analyses and included in all reports.

Precision of the nutrient data generated from the labs will be insured by the participating lab's QA/QC protocols and documentation that the results are in keeping with the precision limits established for the given testing methodology (Table 3) and that the analyses were conducted in a manner consistent with the lab's established protocols, including Chain of Custody related issues such as correct preservation and transportation techniques.

All QAPP related data and all associated raw data records (including chain of custody records, records of calibrations and calibration checks) shall reside indefinitely at the facility producing the data (in this case Princeton Hydro LLC) or the academic or research institution performing the review and compilation of the data. Additionally, the data shall be transferred for archival storage to the EPA Water Quality Portal (WQP) via the Water Quality Exchange (WQX).

L. Bias

Bias results in the systematic distortion or deviation of data in one direction. In this study this would apply to biased in-situ data or lab results. The former can be controlled and eliminated by using properly calibrated field meters and review of the data by the QA Officer immediately following its reporting. For the lab data, bias will be eliminated by the use of matrix spike samples as defined in the QA/QC procedures of ECM (refer to Table 4 and H above).

M. Representativeness

Representativeness is defined as the extent to which the collected data represents the actual condition or system that is the subject to the study or analysis. The representativeness of the data generated through this project will largely be ensured by the careful selection of sampling location and the frequency of sampling as defined in Section 7D.

Representativeness will also be assured by the project team participants who have been engaged in other similar projects involving the assessment of aeration systems and in the collection of lake samples. Princeton Hydro personnel have successfully conducted numerous tributary and lake monitoring programs all of which involved NJDEP and/or USEPA QAPP review and approval.

8.0 PROJECT ORGANIZATION, RESPONSIBILITY AND SCHEDULE

Specifics concerning project organization and responsibility are provided in Table 6. Fiscal management, administration, overall project management of the project will be the responsibility of Mr. Frank Pannucci, of the Borough of Bay Head. Dr. Fred Lubnow of Princeton Hydro will serve as the Principal Investigator. He will work directly with the Project Manager, Frank Pannucci, in the execution of the field sampling activities detailed above. The responsibilities of the Principal Investigator will include overall project coordination, data management and documentation. The Project Manager will coordinate the sampling efforts, including working with the PI and Field Team personnel to ensure sampling is scheduled, samples are collected, and samples are delivered to ECM Inc. in a manner fully consistent with this QAPP. Mr. Chris Mikolajczyk will serve as the QA/QC Officer for the project.

Table 6 - Key Project Personnel and Related Project Responsibility		
Area of Responsibility	**Name**	**Affiliation**
Overall Project Coordination	Frank Pannucci	Borough of Bay Head
NJDEP Project Review	Lynette Lurig	NJDEP
NJDEP Project Review	Deborah Kratzer	NJDEP
Principal Investigator	Dr. Fred Lubnow	Princeton Hydro, LLC
Project Manager	Frank Pannucci	Borough of Bay Head
Laboratory Analysis	Jackie Tyma	Environmental Compliance Monitoring, Inc.
Laboratory QC	Beth Fagan	Environmental Compliance Monitoring, Inc.
Performance Auditing	Thomas Grenci	Environmental Compliance Monitoring, Inc.
Data Processing	Mike Hartshorne	Princeton Hydro, LLC
QA/QC Officer	Chris Mikolajczyk	Princeton Hydro, LLC
Data Quality Review	Dr. Fred S. Lubnow	Princeton Hydro, LLC
Systems/Field Auditing	Melissa Hornsby	NJDEP

Table 7 displays the proposed sampling schedule for all field related activities associated with the tributary monitoring program. As noted, the time frame for the completion of the field sampling spans approximately 2-7 months.

Table 7 - Proposed Sampling Schedule	
Month	**Project Activity**
Project Month 1 (June 2021)	Initiate Project
Project Month 10-16 (May-Oct 2022)	Initiate and Complete Monitoring Program

9.0 Chain of Custody Procedures

Chain of Custody (COC) procedures will be utilized to track the samples from the point when water quality samples are collected, through their transport to ECM, as well as their subsequent laboratory analysis. If possible, personnel responsible for sampling operations will inform the analytical laboratory at least twenty-four (24) hours in advance of the date that water quality samples will be delivered. The sample collector will be required to record on the project field sheet the following information: sample number and/or station, date and time of collection, source, preservation technique and collector's name. The sample collector will also record pertinent field data; field observations and the analyses required on the field data sheets. The sample collector will deliver the samples to the laboratory, seals unbroken, where laboratory personnel will visually inspect all sample containers to confirm the method of transportation, date of collection and preservation technique. Samples will not be accepted and fresh samples will be requested if for any reason the holding time was exceeded, proper preservation techniques were not followed or transportation conditions were unsuitable. A lab COC form will be completed to identify the analyses requested and will be submitted to the laboratory at the time of sample delivery. A copy of the COC form is provided in Appendix A. The COC will confirm the process and procedure as well as confirm the analytes (TP, SRP, TSS, NH3-N, NO3-N and chlorophyll *a*) subsequently measured by ECM.

10.0 Calibration Procedures and Preventive Maintenance

Environmental Compliance Monitoring, Inc. (#18630) is a State-certified Analytical Testing Laboratory that maintains an active Quality Assurance/Quality Control (QA/QC) program to ensure that the collected data will meet all project requirements and that laboratory instruments are properly calibrated as per their NJDEP approved Standard Operating Procedures (SOPs). Standards will be analyzed with each batch of samples to ensure that instruments are operating properly. These procedures are in accordance with New Jersey Laboratory Certification Program regulations.

In addition, Princeton Hydro LLC (#10006) is a State-certified Laboratory that maintains an active Quality Assurance/Quality Control (QA/QC) program to ensure that the collected data will meet all project requirements and that field instruments are properly calibrated as per their NJDEP approved SOPs. These procedures are in accordance with all applicable New Jersey Laboratory Certification Program regulations and are included with Princeton Hydro's Standard Operating Procedures previously approved by the NJDEP-OQA as part of their NJDEP Certified Laboratory operation. As can be found in the SOPs found in Appendix C, the specific conductivity meter is calibrated each day of use, the dissolved oxygen meter is calibrated weekly or before each use (whichever is less frequent), the pH meter is calibrated each day of use, with a check standard run after 3-hours of meter use and the temperature probe is calibrated quarterly.

All sampling and decontamination procedures shall be in conformance with standard practices and procedures listed in Standard Methods for the Analysis of Water and Wastewater, 22nd Edition (American Public Health Association, 2011), NJDEP State protocol (Field Sampling Procedures Manual, 2005) and/or any applicable US EPA guidance document. Princeton Hydro will properly decontaminate all field sampling equipment in between sample locations and the collection of samples in accordance with all NJDEP protocol, specifically the Field Sampling Procedures Manual (2005) as well as the Princeton Hydro boat-based sampling SOP. Specifically, the field equipment should be rinsed with a non-phosphorus detergent, a generous tap water rinse (minimum of three (3) rinses) and finally followed by a distilled and deionized water rinse. This will also be done with the unpreserved sample containers in the field with sample water, to ensure that no residues or contaminants are left in the sample containers.

11.0 NON-DIRECT MEASUREMENT (SECONDARY DATA)

Secondary data use will be limited to maps and GIS data obtained from the NJDEP and other possible municipal sources. The project does not propose or plan to make use in any capacity of existing water quality data or similar data available through State or County sources as part of this effort.

12.0 DOCUMENTATION, DATA REDUCTION, AND REPORTING

All QA/QC data and project information will be collected according to applicable State and Federal regulations. For a minimum of five years, Princeton Hydro and the Borough of Bay Head will keep all data in a digital format on file. These data will be transferred to the NJDEP and USEPA in the form of a final report in hard copy and digital formats at the close of the project.

All project data, including any data rejected as outliers, laboratory results flagged for not meeting quality control acceptance criteria or any other scientifically-based reason, even if the data is not used in the final research analysis will be submitted to the Department.

13.0 PERFORMANCE AND SYSTEMS AUDITS

A. Performance Auditing

ECM (#18630) is a State of NJ certified laboratory. The laboratory participates in Proficiency Testing (PT) Studies for each category of certification and accreditation and is required to pass each of these PE studies in order to maintain certification. The NJDEP conducts performance audits of each laboratory that is certified or accredited. ECM also participates in several additional programs to ensure data accuracy. The laboratories participate in New Jersey Laboratory Certification Program Performance Evaluation Program water pollution (WP) and water supply (WS) studies and the discharge monitoring report (DMR-QA/QC) program.

B. Systems Auditing

The NJDEP Office of Quality Assurance conducts Bi-annual (for TNI laboratories) or tri-annual (ECPL) laboratory certification assessment audits and on-site Technical Systems Audits (TSA) of each certified laboratory. The findings of these audits, together with the New Jersey Laboratory Certification Program Performance Evaluation Program results, are used to update each laboratories certification status.

C. Data Review and Validation

The project QA/QC Officer will ensure that all data for the project are generated in accordance with all procedures outlined in this QA/QC Project Plan. If the proposed field sampling process is not performed as outlined within this QAPP, the field event shall be redone. Quality control samples will be analyzed with each sample batch and results will be provided with the data reports. If a QC sample provides unacceptable results during any given day, the sample analysis must be repeated for those parameters affected. QA/QC requirements (spikes & duplicates) are required by the laboratory. Generally, spikes and duplicates are run 1 for every 20 samples, or once every 30 days, whichever is more frequent. The laboratory supplied Relative Percent Differences and Recovery Percentage values found in Table 4 will be utilized for this purpose. All project participants will immediately report any deficiencies to the QA/QC Officer. The QA/QC Officer will recommend appropriate corrective action and determine the acceptability of affected data when deficiencies are noted. The QA/QC Officer will notify the Project Officer of any unacceptable data to ensure that it is not included in evaluations of water quality for reporting purposes. The QA/QC Officer shall notify the Project Officer in writing anytime a deviation from the approved plan occurs.

Results of all corrective actions will then be documented. Data validation will be performed by Princeton Hydro, LLC and will be provided with the final report.

All QAPP related data and all associated raw data records (including chain of custody records, records of calibrations and calibration checks) shall reside indefinitely at the facility producing the data (in this case Princeton Hydro LLC) or the academic or research institution performing the review and compilation of the data. Additionally, the data shall be transferred for archival storage to the EPA Water Quality Portal via the Water Quality Exchange (WQX).

D. Field Auditing

The NJDEP will be notified prior to any field sampling event so that they may conduct on on-site audit of the field sampling procedures.

E. Correction Action

Any time changes to the approved QAPP are required; all signatories of the QAPP will review the changes and sign-off on the changes. The changed QAPP will then be sent to all the signatories. Additionally, Section 13.0 C above describes corrective actions with regards to both field collected and laboratory supplied data.

F. Reports

All data collected, will be compiled and summarized by Princeton Hydro and provided to the Borough of Bay Head for subsequent distribution to the NJDEP. Princeton Hydro will provide the analysis of the data, as well as formal project / data documentation within 90 days of the close of the grant.

In addition, as per Attachment D-1 of the contract, all data collected through the course of the project must be submitted in the format requested by the Department, which is usually EPA's WQX database, or another suitable database approved by the grant manager. Information regarding using WQX is located at:

https://www.epa.gov/waterdata/water-quality-data-upload-wqx

14.0 REFERENCES

American Public Health Association. 2011. *Standard Methods for the Analysis of Water and Wastewater, 22nd Edition*. Washington, D.C.

New Jersey Department of Environmental Protection and Energy. 2005. *Field Sampling Procedures Manual*. Trenton, New Jersey.

APPENDIX A

Sample Chain of Custody

ECM 349 US Highway 206, Hillsborough NJ 08844 (908) 874-0990

COC NO:

CHAIN OF CUSTODY RECORD

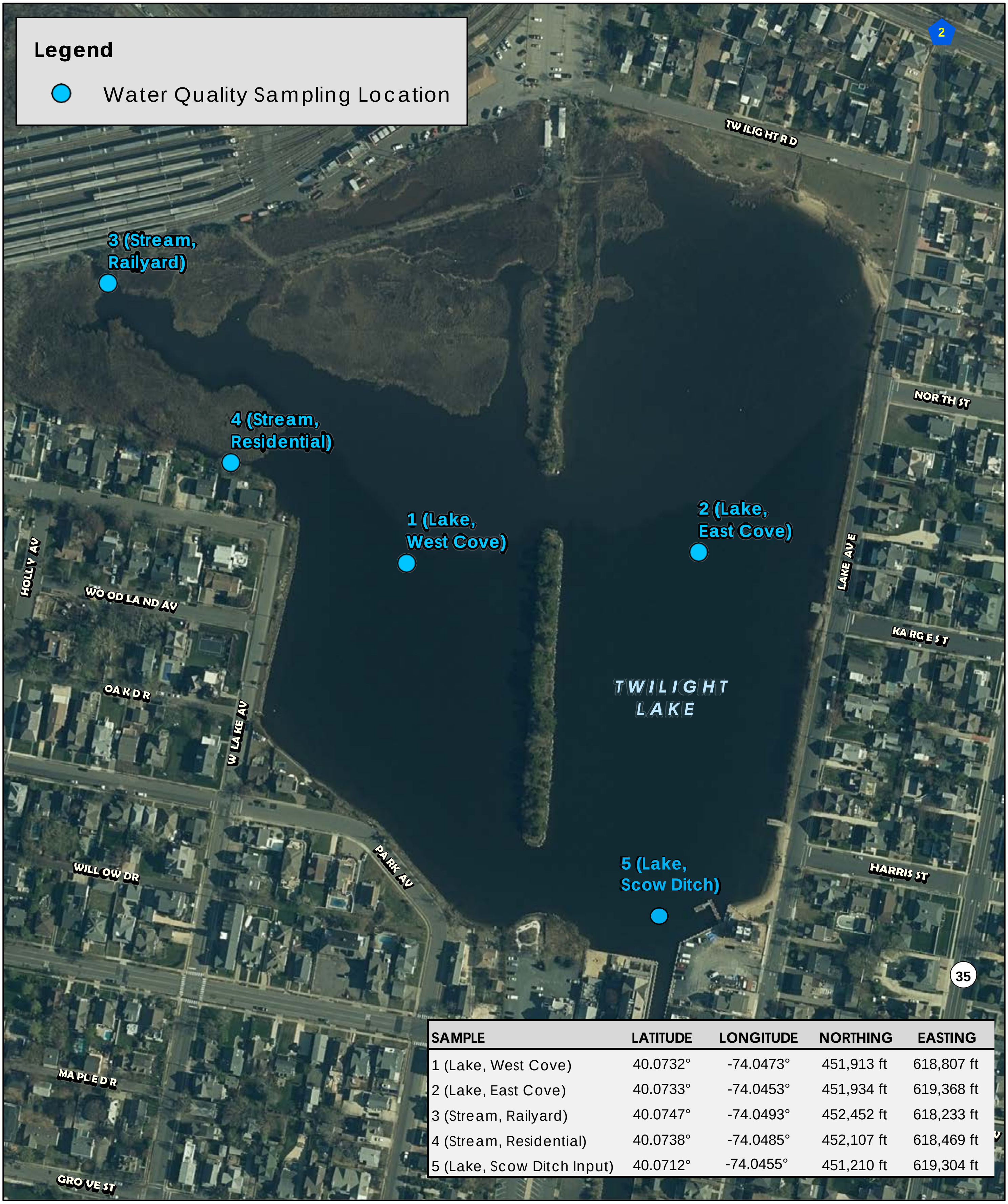
PROJECT NO.	PROJECT NAME			NO. OF CONTAINERS	pH (For Nitrate/Nitrite Analysis)	NO PRESERVATIVE	SULFURIC ACID	NITRIC ACID	HYDROCHLORIC ACID	OTHER	LAB USE ONLY
	REGULATORY? ____ YES ____ NO										JOB NO: ______
DATE	SAMPLERS NAME										LOT NO: ______
SAMPLE DATE	TIME	COMP OR GRAB	STATION LOCATION								SAMPLE NUMBERS

COOLER TEMP: DATE & TIME: INITIALS:	pH<2 Y N N/A pH>10 Y N N/A	COMMENTS:	
RELINQUISHED BY: (Signature)	DATE/TIME	RECEIVED BY: (Signature)	DATE/TIME
RELINQUISHED BY: (Signature)	DATE/TIME	RECEIVED BY: (Signature)	DATE/TIME
RELINQUISHED BY: (Signature)	DATE/TIME	RECEIVED BY: (Signature)	DATE/TIME

NOTE: The Chain of Custody Form is used to ensure and document compliance with sampling and laboratory protocol for regulatory programs. All information should be completed on the form

APPENDIX B

Sampling Site Map



SAMPLE	LATITUDE	LONGITUDE	NORTHING	EASTING
1 (Lake, West Cove)	40.0732°	-74.0473°	451,913 ft	618,807 ft
2 (Lake, East Cove)	40.0733°	-74.0453°	451,934 ft	619,368 ft
3 (Stream, Railyard)	40.0747°	-74.0493°	452,452 ft	618,233 ft
4 (Stream, Residential)	40.0738°	-74.0485°	452,107 ft	618,469 ft
5 (Lake, Scow Ditch Input)	40.0712°	-74.0455°	451,210 ft	619,304 ft

File: P:\1259\Projects\1259004 Twilight Lake 319 Project\GIS\MXD\Water_Qual_Sampling.mxd, 11/12/2021, Drawn by thopper, Copyright Princeton Hydro, LLC.

NOTES:
1. Water quality sampling locations are approximate.
2. 2020 orthoimagery obtained from NJ Office of Information Technology (NJOIT), Office of Geographic Information Systems (OGIS).

0 125 250 Feet

Map Projection: NAD 1983 2011 StatePlane New Jersey FIPS 2900 Ft US

WATER QUALITY SAMPLING LOCATION MAP

QUALITY ASSURANCE PROJECT PLAN
TWILIGHT LAKE
BOROUGH OF BAY HEAD
OCEAN COUNTY, NEW JERSEY

PRINCETON HYDRO
SCIENCE DESIGN ENGINEERING
www.PrincetonHydro.com

APPENDIX C

Standard Operating Procedures

LAKE SAMPLING

APPROVED: ______________________ REVISION DATE: March 1, 2018

Scope and Application

This standard operating procedure (SOP) is applicable to the collection of water samples from lakes, shallow lakes, and reservoirs for the purpose of condition monitoring. It is applicable to samples taken from the surface and at any depth along a vertical column between the surface and bottom. It is limited to samples collected for physical, chemical, and biological (phytoplankton/zooplankton) analysis.

Summary of Method

No single sampling procedure can be applicable to all sampling situations; therefore, no single procedure is recommended. Water samples from surface waters are generally done in one of the following ways:

> **Hand-collected sample –** bottle in hand for collection of surface sample on shallow lakes
> **Integrated sampler –** composite sample collected over the top 2 meters of the water column
> **Depth sample -** sample collected at depth (Kemmerer)

Health and Safety

Field staff will use chemicals in the preservation of samples. Material Safety Data Sheets should be consulted for proper handling of these preservatives (sulfuric acid, nitric acid, Lugol's solution, and methanol) to avoid inhalation and eye/skin irritation problems.

Field staff should not sample during adverse conditions (presence of lightning, swift current/flooding, gusts/waves greater than the boat can safely navigate). If lightning is present, staff should return to the vehicle (get boat off of lake) and wait a minimum of 20 minutes from the last visible lightning flash before returning to the water.

All state project location boating safety rules and regulations must be followed. By law, personal flotation devices (PFDs) must be easily accessible (not in storage) when the boat is on the water, including throwable (Type IV) PFDs.

Cautions and Interferences

Contamination of the sample can occur if the sampling device is not properly rinsed prior to sample collection. For standard sampling equipment (i.e. integrated samplers) the sample device should be rinsed three times from the opposite side of the boat from where the sample will be collected. For depth samplers, the lowering of the device through the water column provides the necessary rinsing.

Sample contamination can also occur if the bottom sediments are disturbed during the sample collection. Should this occur, the sampling device should be emptied, rinsed, and sample collection should be attempted again at a lesser depth to avoid this contact. For depth samples, the sample may need to be taken from a different location on the boat to avoid already disturbed bottom sediments.

Personnel Qualifications/Responsibilities

Field staff must be familiar with proper sampling techniques, sample handling, safety procedures, and record keeping. New staff and interns must be trained and accompanied in the field by experienced staff until competence is assured.

Equipment and Supplies

A variety of sampling equipment is needed for surface water sample collection. The general equipment needed for lake trips is listed below:

- Key West Boat/Jon Boat/PFDs
- Anchor
- Paddles
- Integrated sampler
- Plankton Tow Nets
- Depth Sampler
- Secchi Disk
- Coolers
- Ice
- Sample bottles
- Preservatives (acid, methanol, Lugol's)
- Permanent Markers
- Field Notebooks
- Water Quality Meter (WQM)
- Camera
- GPS Unit (If using the Key West, GPS is built in to boat controls)

Procedures

<u>Pre-trip requirements</u>

Water Quality Meter (WQM) calibration

WQM calibration is required for pH, specific conductivity, temperature and dissolved oxygen. These calibrations should occur a minimum of weekly with the exception of pH, which should be done at the beginning of each sampling day. All manufacturers recommended calibration instructions should be followed. All SOPs for calibration of the water quality meters are located in the field office laboratory and should be referenced when calibrating the meters.

Boat preparation

Boats used in sampling should have sufficient tire pressure and bearing grease for the trailer and sufficient synthetic oil for the outboard (where applicable) and battery charge to complete the trip. In addition, sufficient PFDs, paddles, anchors, and rope are required. Gunnel and winch straps should be in good working order (no frays). Ensure trailer lights are functional prior to leaving the Field Office. Inoperable lights must be repaired prior to taking the boat/trailer on the road. Extra boat motor oil should be on board the boat; fuel levels should be checked prior to the first launch of the trip.

Equipment preparation

Equipment should be prepared to complete sampling trip. Ensure the correct number of bottles and preservative necessary to complete all regular and duplicate sampling. On multi-day trips, sufficient pH bufer is necessary to conduct daily pH calibration. Coolers, ice, bottles, preservative(s), lake kit (plankton tow, Secchi disk, and Kemmerer), integrated sampler, field notebooks, camera, GPS/maps, and WQM should be loaded into the trip vehicle.

<u>On shore requirements</u>

Equipment preparation

Bottles and field sheets for the sampling location should be labeled (see example below). Bottles and preservative should be loaded into the small boat cooler. WQM, GPS/maps, camera, and field sheets/field notebook should be loaded into the boat. Ensure the lake kit and integrated samplers are in the boat.

Boat preparation

Remove gunnel straps/tie downs from the boat and trailer. Ensure the plug is in the boat and raise the motor up. Trailer lights should be unplugged from the vehicle. Leave the boat safety chain and winch strap connected to the trailer until it is safely backed into the water. At this point, the vehicle should be moved to the boat launch and backed in. The emergency brake must be on prior to attempting a launch. Care must be taken with the winch, so that the crank arm/handle does not slip loose and cause potential injury to field staff. The winch should be unlocked only when the boat launch rope is tied to the boat and held securely by field staff. Remove the winch strap and safety chain and push the boat into the water. Once off the trailer, one staff member should remain with the boat at the dock/launch while the other moves the vehicle and trailer to the appropriate parking area.

Sampling requirements

Travel to sampling location

From the dock, travel to the sample location(s) predetermined for the lake via the handheld or boat mounted GPS units. Stop the boat and drop the anchor, ensuring the boat is not drifting. If windy conditions prevail, a second anchor may be necessary to hold the boat in place.

Sample collection

These next steps should occur simultaneously. One staff member will conduct profile sampling and field sheet recording while the other conducts the ‘wet’ sampling.

WQM Measurements (Profile)

1. Replace the WQM travel cover with the weighted sonde guard.
2. Turn on the WQM.
3. Lower WQM until the probes are just in the water. Allow the numbers to stabilize.
4. Record these readings, either manually in the field notebook, or in the meter electronic storage.
5.Lower the WQM 1.0 meter, and repeat steps 3 through 5 until the bottom has been reached.

Field Notebook Completion

1. Visually assess the condition at the sampling site.
2. On the field notebook, determine the condition and suitability of recreation of the lake at the sampling site.
3. Assess other uses occurring on the lake – fishing, swimming, etc. Note these in the notebook.
4. Note any macrophyte problems that are limiting lake use (curly leaf pondweed, Eurasian milfoil, etc.) on the sheet.
5. Note weather conditions on the field sheet.

Photo

1. Take a photo of the lake at the sampling location.
2. Optional photos include algal blooms, macrophyte conditions, or visible scums at the sampling site.
3. Mark in the field notebook that a photo has been taken.

Surface Sample – for lakes 2 meters or deeper

1. Remove caps from the integrated sampler.
2. Lower into water, cap, remove from water and release cap
3. Repeat two more times.
4. On the other side of the boat, lower the unstoppered tube into the water column until the top is at the water surface. Be sure to keep hands on the outside of the tube and stopper only.
5. Place the stopper in the tube.
6. Slowly raise the tube to just below the water surface.
7. As the tube breaks the surface, either quickly cap, or allow contents to pour into a clean, open 2 L plastic sample bottle. Again, ensure that hands to do not touch the inside of the bottle or cap.
8. Cap and invert the bottle. Pour contents into 1 L and 250 mL plastic sample bottles.
9. If necessary, preserve the 250 mL nutrient bottle with a vial of $H2SO4$.

10. Repeat steps 4 through 7 to collect a second sample for chlorophyll-a and algae analysis. Pour into 2 L bottle.
11. Place all bottles in a cooler with ice.

Surface Sample – for lakes less than 2 meters deep
1. Uncap the 2L bottle
2. Tip the bottle upside down and lower it into the water column until the sampler's elbow is at the water surface. Be sure the inside of the bottle and cap are not touched by the sampler.
3. Invert the bottle and allow it to fill.
4. Bring the bottle to the surface, taking care to avoid any surface scum/material.
5. Cap and invert the bottle. Pour contents into 1 L and 250 mL plastic sample bottles.
6. If necessary, preserve the 250 mL nutrient bottle with a vial of H_2SO_4.
7. Repeat steps 1 through 4 to collect a second sample for chlorophyll-a and algae analysis
8. Place all bottles in a cooler with ice.

Depth Sample – for lakes deeper than 3 meters only
1. Open Kemmerer sampler by pulling the two caps outwards until they lock.
2. Slowly lower the Kemmerer over the side of the boat to the desired depth.
3. Release the messenger down the taut rope to trip the closing mechanism. (If it is a deep lake, it may require two messengers).
4. Raise the Kemmerer to the water surface. There may or may not be a stop valve on the sampler – be sure you have your bottle ready (uncapped).
5. Ensure there is no sediment in the sample. If there is, discard the sample and repeat steps 1 through 4 from the opposite side of the boat, going to a lesser depth to avoid bottom sediments.
6. Drain the contents of the Kemmerer into a 250 mL sample bottle.
7. If necessary, preserve the sample with a vial of H_2SO_4.
8. Place sample in cooler.

Phytozooplankton/Zooplankton Sample
1. Check zooplankton net to ensure the stop valve, basket, and lowering rope are all securely attached.
2. Open valve and rinse the zooplankton tow.
3. Close the valve after draining the basket.
4. On the opposite side of the boat, lower the zooplankton net to a depth that is 0.5 meters off the bottom.
5. Slowly raise the tow at a constant rate of 1 foot per second until it breaks the water surface.
6. Rinse the net, without allowing new lake water to enter the top of the net, prior to putting it in the boat.
7. If the basket is full (water still in the net), swirl the contents so that water is able to drain through the basket.
8. Drain the contents of the basket into the sample container.
9. Separate the basket from the net.
10. Rinse the basket with deionized water to free any remaining zooplankton.
11. Add this remaining sample to the original bottle.
12. View the quantity and relative size of the zooplankton.
13. Note in field notebook.
14. If necessary, preserve the sample with Lugols solution.
15. Place sample in coller for delivery to in-house biological laboratory.

Secchi Transparency
1. Remove sunglasses and move to the shady side of the boat.
2. Lower the Secchi disk over the side of the boat.
3. When the disk just disappears from view, stop and note this depth.
4. Slowly raise the disk until it reappears, stop and note this depth.
5. Average the two depths and record this value on the field sheet to the nearest 0.1 meter.

Return to launch and trailer boat
Upon completion of sampling, return the boat to the dock/launch. Be sure to raise the motor prior to loading the boat onto the trailer. All switches should be shut off and if any water was taken on, the bilge should be run to empty the boat. One field staff stays at the dock with the boat while the other backs the vehicle into the water. Load the boat onto the trailer; walk on the trailer only if decking is in place, otherwise use waders to assist with the loading of the boat. Once the winch strap is attached to the boat, lock the winch prior to cranking in the boat to avoid injury from a free-spinning crank handle. Secure the safety strap and pull the boat away from the launch area.

On shore –invasive species field decontamination
1. Once trailered, move vehicle/boat away from access.
2. Visible aquatic plants and animals should be removed from the boat, motor, and trailer.
5. Water should be drained from the boat and the motor after each lake.
6. Sampling equipment and boats should be sprayed with a pressure washer if plant residue remains after initial cleaning.
7. If the lake to be sampled is known to have invasive species, this should be sampled at the end of a trip and/or should be sampled with separate equipment (i.e. for spiny water flea). If necessary, stop at a car wash and spray down the boat to minimize the possibility of transferring species between lakes.
8. Gunnel straps should be secured to the boat.
9. The motor should be returned to the travel position (varies by manufacturer).
10. Trailer lights should be plugged back into the vehicle.

<u>Post-trip requirements</u>

End of trip sample processing
1. Proceed to laboratory.
2. Unload all samples from vehicle – transfer to wet lab.
3. Organize bottles and field sheets by lake.
4. Fill out lab COC.

Equipment removal
Remove all equipment from vehicle with the exception of the roadside repair kit. The digital camera, GPS, and field notebooks should return to the main office for processing. If applicable, the WQM may be downloaded at the office. Used bottles should be placed in the used bottle bin for return to the laboratory. Unused, clean bottles should be returned to the appropriate clean bottle shelves. Coolers should be drained and placed upside down to dry. Dry coolers should be returned to the shelves. Rain gear, and any other personal items should be removed from the vehicle and returned to their normal storage locations (locker, desk, etc.). Once vehicle is cleaned, return vehicle to field office parking area.

Boat Clean Up
Remove life jackets from stow away compartments and lay over the edge of the boat/seats to dry. Inflatable life jackets should be stored in a secure location (i.e. locker). Open up lake kit and lay out ropes and the plankton tow so they will dry between trips. Boats and trailers should be sprayed down weekly to remove excess dirt, any remaining plant/algae residue, etc. Ensure that all the switches are in the 'off' position so the battery is not drained for the next staff person. If any problems arose with the boat or trailer during the trip, alert other aquatics staff of the problem immediately, so the boat/trailer is not taken out until fixed. Take appropriate steps to fix/correct the problem with the boat or trailer.

Processing Photos
At the end of each trip, photos should be downloaded and labeled in the office. The following steps should be taken to ensure that the name format and storage locations are the same for all lakes sampled.

1. Download the photos to the appropriate P drive folder.
2. Rename the photos with the appropriate name.
3.Delete the photos off the camera and charge batteries if necessary.

References

SOP has been adopted and modified from the Minnesota Department of Natural Resources Lake Sampling Guide. Specifically, this document can be found at:

http://www.pca.state.mn.us/publications/wq-s1-16.pdf

CONDUCTIVITY
(SM 2510 B-11)

APPROVED: ______________________ REVISION DATE: DECEMBER 14, 2017

Summary

Conductivity is a measure of the ability of an aqueous solution to carry an electric current. This ability depends on the presence of ions; on their total concentration, mobility, and valence; and on the temperature of measurement.

Solutions of most inorganic compounds are relatively good conductors. Conversely, molecules of organic compounds that do not disassociate in aqueous solution conduct a current very poorly, if at all.

Sample size and Preservation

A minimum of 250 ml sample size is used. The sample may be collected in either plastic or glass and should not be preserved. The holding time for a sample is 28 days. In the field, the individual meters will measure the Conductivity of the water column ***in-situ***.

APPARATUS

Princeton Hydro currently possesses three (3) water quality meters that measure Conductivity.
Specifically, these are:

- Hydrolab Quanta with 5 meter cable (Serial nos. QT00648 and QD00732)
- Hydrolab Quanta with 15 meter cable (Serial nos. QT00646 and QD00667)
- Eureka Amphibian with 30 meter Manta (Serial nos. SN00018 and MM12110855)

beakers (for samples measured in laboratory)

Reagents

Conductivity Standard Solutions: 1,413 µmhos/cm, commercially available.

STANDARD SOLUTION IS TO BE DISCARDED UPON EXPIRING.

STANDARD SOLUTION IS TO BE DATED UPON RECEIPT INTO THE LABORATORY AND DATED UPON OPENING. IN ADDITION THE CERTIFICATE OF ANALYSIS MUST BE ACQUIRED FOR EACH NEW BOTTLE OF STANDARD.

PROCEDURE

An initial five point calibration curve shall be established using standard solutions of various concentrations to cover the necessary range typically observed during field measurements. Each separate instrument curve is to be kept in the conductivity calibration log book.

A cell constant must be determined <u>annually</u> for each instrument, and all calculations recorded dated and signed by the analyst in the *Conductivity Calibration Record* notebook. Cell constant is calculated as follows:

$C, cm^{-1} = (0.001412)(R_{KCl})[1 + 0.0191(t-25)]$

R_{KCl} = measured resistance, ohms
t = observed temperature, ˚C (Meters compensate for temperature automatically)

Calibrate the Conductivity meter <u>each day of use</u>.

- ✓ Immerse the meter into the commercially prepared 1,413 µmhos/cm standard. Record this reading, in addition to date, instrument and initials into the *Conductivity Calibration Record* notebook. (Most conductivity meters, especially those for field use, indicate conductivity directly and possess a temperature sensor for automatic temperature adjustment).

- ✓ If the reading is outside the required +/- 1% window, that is, outside 1399 µmhos/cm – 1427 µmhos/cm, adjust the meter to read 1,413 µmhos/cm and then record the adjusted measurement (1,413 µmhos/cm) to the *Conductivity Calibration Record* notebook.

- ✓ After this adjustment switch the meter back to measurement mode and read the standards as a check. Verify result is within 1% of the true value.

NOTE: Discard calibration aliquot after each use.

- ✓ Rinse off the electrode with DI and place it into the sample. The *in-situ* stirrer will operate while waiting for reading to stabilize.

- ✓ The conductivity is read directly from the meter and automatically temperature compensated for 25°C.

- ✓ Duplicate conductivity reading must be taken every day or every twenty sample measurements, whichever is more frequent. Duplicate results should agree within 20% relative percent difference (RPD).

DISSOLVED OXYGEN
(SM 4500-O G-11)

APPROVED: ______________________ REVISION DATE: DECEMBER 14, 2017

Summary

Dissolved Oxygen (DO) levels in natural and wastewaters depend on the physical, chemical, and biochemical activities in the water body. The analysis for DO is a key test in water pollution and waste treatment process control.

Sample size and Preservation

A minimum of 300 ml sample size is used for the calibration procedure. The calibration sample should be collected directly into a glass stopper BOD bottle and immediately prepared for Winkler titration. This titrated sample can then be used as a comparison value for the calibration of the field DO meters. In the field, the individual meters measure the DO of the water column ***in-situ*** utilizing a membrane electrode. However, if samples are collected separately they must be analyzed within 15 minutes of collection time. Sample collection and analysis time must be recorded in the field notebooks.

APPARATUS

Princeton Hydro currently possesses three (3) water quality meters that measure dissolved oxygen. Specifically, these are:

- Hydrolab Quanta with 5-meter cable (Serial nos. QT00648 and QD00732)
- Hydrolab Quanta with 15-meter cable (Serial nos. QT00646 and QD00667)
- Eureka Amphibian with 30-meter Manta (Serial nos. SN00018 and MM12110855)

Meters shall be calibrated weekly or before each use, whichever is less frequent, in addition, the meter should be calibrated against air saturated water (utilizing the individual meter manufacturers instructions) weekly or before each use.

- BOD bottle
- Large beaker
- Class A buret – 25 ml
- Grade A pipets – various sizes

- 500 ml Erlenmeyer flask
- 250 ml graduate cylinder

Reagents

ALL REAGENTS ARE TO BE DATED UPON RECEIPT INTO THE LABORATORY AND DATED UPON OPENING

Manganous sulfate solution – commercially prepared
Alkali-iodide-azide reagent – commercially prepared
Starch solution – commercially prepared
Sulfuric Acid – commercially available

Standardized sodium thiosulfate titrant – commercially prepared (Replaced commercially on a quarterly basis, be sure to acquire the lot-specific certificate of analysis for sodium thiosulfate and sulfuric acid when ordering)

DISCARD ANY REAGENTS WHICH ARE EXPIRED

PROCEDURE FOR CALIBRATING AGAINST AIR-SATURATED WATER

Prepare an oxygenated tap water sample, which can be split into separate aliquots, by shaking rapidly in a large container, such as a plastic gallon jug.

Split the oxygenated sample into aliquots. Fill a 300 ml BOD bottle with one aliquot, this aliquot will be utilized for the Winkler titration.

Place another aliquot into a container adequate enough for the field DO meter to read. This aliquot will then be utilized for the calibration of the field DO meter.

WINKLER TITRATION

To the sample collected in the 300 ml BOD bottle, add 1 ml of Manganous Sulfate solution, followed by 1 ml of alkali-azide reagent. If pipets are dipped into sample, rinse them before returning to reagent bottles. Alternatively, hold pipet tips just above liquid surface when adding reagents. Stopper carefully to exclude air bubbles and mix by inverting bottle a few times. When precipitate has settled sufficiently (approximately ½ the bottle volume) to leave clear supernate above the manganese hydroxide floc, add 1.0 ml of concentrated sulfuric acid. Restopper and mix by inverting several times until dissolution is complete. Titrate a volume corresponding to 200 mls of original sample after correction for sample loss by displacement by reagents. Thus, for a total of 2 ml of Manganous sulfate and alkali-azide reagents added to a 300 ml bottle, titrate 200 x 300/(300-2) = 201 mls.

Titrate with 0.025M sodium thiosulfate solution to a pale straw color. Add a few drops of starch solution and continue titration to first disappearance of blue color. If end point is overrun, back titrate with 0.0021M bi-iodate solution added dropwise, or by adding a measured volume of treated sample. Correct for amount of bi-iodate solution or sample added. Disregard subsequent recolorations due to the catalytic effect of nitrite or to traces of ferric salts that have not been complexed with fluoride.

For the titration of a 200 ml sample, 1 ml of sodium thiosulfate solution = 1 mg DO/L.

Once a DO value of the tap water sample has been determined, compare this value to the reading that the field meter displays. The results of the Winkler titration and the value determined using the meter must agree within +/- 0.3 mg/L. (If they do not, the lab must take corrective action such as cleaning the probe, checking the integrity of the membrane, etc. until acceptable agreement is achieved). Record the results of this calibration, instrument type and date of calibration into the *Dissolved Oxygen Calibration Record* notebook.

Finally, a zero DO standard must be checked prior to field use. This zero DO standard is created as per the 22^{nd} edition of Standard Methods; "Add excess sodium sulfite, $Na_2S_2O_3$, and a trace of cobalt chloride, $CoCl_2$, to bring DO to zero". The zero-standard result must be ≤ 0.3 mg/L or else corrective action must be taken. Finally, record this zero DO reading onto the calibration sheet found in the *Dissolved Oxygen Calibration Record* notebook.

pH

(SM 4500 H B-11)

APPROVED: ______________________ REVISION DATE: DECEMBER 17, 2017

Summary

Measurement of pH is one of the most important and frequently used tests in water chemistry. At a given temperature, the intensity of the acidic or basic character of a solution is determined by pH or hydrogen ion activity. The basic principle of electrometric pH is determination of the activity of the hydrogen ions by potentiometric measurements using a glass electrode.

Sample size and Preservation

A minimum of 250 ml sample size is used, if measured in the laboratory. The sample may be collected in either plastic or glass and should not be preserved. The holding time for a sample is 15 minutes. In the field, the individual meters measure the pH of the water column ***in-situ***.

APPARATUS

Princeton Hydro currently possesses three (3) water quality meters that measure pH. Specifically, these are:

- Hydrolab Quanta with 5 meter cable (Serial nos. QT00648 and QD00732)
- Hydrolab Quanta with 15 meter cable (Serial nos. QT00646 and QD00667)
- Eureka Amphibian with 30 meter Manta (Serial nos. SN00018 and MM12110855)

beakers (for samples measured in laboratory)

Reagents

Buffer Solutions: pH 4, 7 and 10, commercially available.

ALL BUFFER SOULTIONS ARE TO BE DATED UPON RECEIPT INTO THE LABORATORY AND DATED UPON OPENING. IN ADDITION, HIGLIGHT THE LOT NUMBER AND DATE OF EXPIRATION UPON RECEIPT INTO THE LABORATORY. BUFFER SOLUTIONS ARE TO BE DISCARDED UPON EXPIRING

PROCEDURE

Calibrate the pH meter each day of use.

- ✓ Calibrate the meter with three standard pH buffers. This will involve pH buffer solutions of 4.0, 7.0 and 10.0.

- ✓ Fill an appropriate vessel with each buffer solution of interest.

- ✓ Rinse the probe with DI water and gently place it in the beaker containing the pH 7.0 buffer. Let the meter settle on a reading. Record this reading in the *pH Calibration Record* notebook. If necessary, adjust the meter to the true value of the buffer at the calibration temperature and record pH and buffer temperature data, including date, time, instrument and initials into the *pH Calibration Record* notebook. Rinse the probe with DI water.

- ✓ Repeat this step for the remaining buffers, pH 4.0 and pH 10.0. Be sure to rinse the probe between each step. Record these readings into the *pH Calibration Record* notebook. Buffer values must be recorded to two decimal places during calibration.

- ✓ After rinsing, place the probe back in the pH 7.0 buffer. The meter should return to 7.0 ± 0.1 pH units. Record this value into the calibration record book. Record the buffer temperature during the calibration procedure.

- ✓ A check pH buffer is required when the pH meter is in use for longer than a 3 hour period. Every 3 hours check the meter with a buffer in the range of interest. If the pH differs by more than ± 0.2 pH units from the 7.0 standard buffer value, the meter shall be recalibrated. Record pH buffer re-check data, including date, time, instrument and initials in the *pH Calibration Record* notebook, as well as the associated field personnel notebook.

NOTE: Discard pH buffer calibration aliquots after each use.

- ✓ Rinse off the electrode with DI and place it into the sample. The *in-situ* stirrer will operate while waiting for reading to stabilize.

- ✓ The pH unit is read directly from the meter, and placed into a field sampling log book. Be sure to include time of the sample reading to ensure, if necessary, the 3 hour check buffer requirement for the pH meter.

- ✓ Duplicate pH reading must be taken daily or every twenty (20) sample measurements, whichever is more frequent. Duplicate results must agree within +/- 0.1 pH units.

TEMPERATURE

(SM 2550 B-00)

APPROVED: ______________________ REVISION DATE: DECEMBER 14, 2017

Summary

Temperature readings are used in the calculation of various forms of alkalinity, in studies of saturation and stability with respect to calcium carbonate, in the calculation of salinity, and in general laboratory operations.

In limnological studies, water temperatures as a function of depth often are required. Elevated temperatures resulting from discharges of heated water may have significant ecological impact. Identification of source of water supply, such as deep wells, often is possible by temperature measurements alone.

Sample size and Preservation

In the field, the thermometers will measure the Temperature of the water column *in-situ*. If necessary, the sample may be collected in either plastic or glass and should not be preserved. There is a 15 minute holding time for temperature, and is to be analyzed immediately. Although most of the field measurements are conducted *in-situ*, the sample time and analysis time must be recorded into the field notebooks upon analysis.

APPARATUS NEEDED

Princeton Hydro currently possesses three (3) water quality meters that measure temperature.

Specifically, these are:

- Hydrolab Quanta with 5 meter cable (Serial nos. QT00648 and QD00732)
- Hydrolab Quanta with 15 meter cable (Serial nos. QT00646 and QD00667)
- Eureka Amphibian with 30 meter Manta (Serial nos. SN00018 and MM12110855)

NIST Certified thermometer

Reagents

No reagents are required for this analysis.

PROCEDURE

Calibrate the metal field thermometers vs. the NIST Certified thermometer quarterly and any laboratory glass thermometers annually as follows:

- ✓ Place both the NIST Certified thermometer and the field meter thermometer in a vessel of solution, such as tap water.

- ✓ Record the identification number of the NIST Certified thermometer and the identification number of the field instrument thermometer into the temperature Calibration Record Notebook when taking the measurements.

- ✓ Compare the readings of the two thermometers and then calculate the difference, if any, between the two thermometers. Record this difference into the *Temperature Calibration Record* notebook and be sure to label each individual field meter with this correction difference.

- ✓ Readings then taken with the field meter thermometer should then have this correction factor accounted for in final field data recordings.

APPROVED: ________________ REVISION DATE: 01/31/06

1.0 Summary

Chlorophyll is a common indicator of phytoplankton biomass. The following method is used to determine chlorophyll-a, b, c, and pheophytin-a. Always work in subdued light to avoid degradation.

2.0 Sample Size and Preservation

A 1000 ml sample is used, or if high content of phytoplankton is present, a smaller portion of sample may be used. Sample containers must be opaque (i.e. amber) or covered in aluminum foil. Samples should be kept in the dark (i.e. cooler or refrigerator) at all times when not being analyzed. Samples should be preserved with magnesium carbonate as soon as possible; but, no later than 48 hours and filtered through a 4.7 cm, 1.5 µm porosity glass microfibre filter. Samples once filtered, should be frozen, dessicated, and analyzed within 28 days.

3.0 Apparatus

3.1 Filtration Equipment

3.2 Spectrophotometer

3.3 Cuvettes

3.4 Tissue Grinder

3.5 Centrifuge, and centrifuge tubes

3.6 Scissors

3.7 4.7 cm, 1.5 um glass fibre filter

4.0 Reagents

4.1 **Powdered magnesium carbonate**

4.2 **Saturated magnesium carbonate solution** – Add 1.0 g finely powdered $MgCO_3$ to 100 ml distilled water.

4.3 **Aqueous Acetone Solution** – Mix 90 parts acetone with ten parts saturated magnesium carbonate solution.

4.4 **0.1N HCL** – Add 8.3mL concentrated hydrochloric acid to DI water for a final volume of 1 Liter.

5.0 Procedure: Chlorophyll-a, b, c

5.1 Add small scoop powdered magnesium carbonate to sample to be preserved and filtered. Measure volume of sample and record in log book.

5.2 Filter sample through the glass fiber filter, fold in half, wrap in a larger piece of filter paper and label filter paper with pencil. Place in a container containing dessicant and freeze until ready for analysis (no longer than 28 days)

5.3 Cut filter paper with sample in small pieces and place in tissue grinder with 5 mls 90% acetone solution.

5.4 Macerate at 500 rpm for at least two minutes.

5.5 Transfer sample to disposable centrifuge tube and cover.

5.6 Bring to 5 mls with acetone solution record final volume in lab note book.

5.7 Steep samples for at least 2 hours at 4°C in darkness..

5.8 Clarify by centrifuging for five minutes.

5.9 Decant clarified sample into a 1-cm cuvette and read at wavelengths 750, 664, 645, and 630 nm.

5.10 Analyze a DI water blank through entire process.

5.11 Coordinate with sampling personnel, prior to a sampling event, to ensure sufficient sample is collected to perform a replicate analysis as needed (minimally 1 in 20 samples or one per month).

6.0 Calculations for Chlorophyll a,b,c

Abs 750nm = A1

Abs 664nm = B1

Abs 647nm = C1

Abs 630nm = D1

Extract Volume (L) = E1

Sample Volume Filtered (L) = F1

Chl a = ((11.85 (B1 – A1)) – (1.54 (D1 – A1)) - (0.08 (D1 – A1)))(E1/(F1x0.001)

Chl b = ((21.03 (B1 – C1)) – (5.43 (D1 – B1)) - (2.66 (D1 – D1)))(E1/(F1x0.001)

Chl c= ((24.53 (B1 – D1)) – (7.60 (D1 – C1)) - (1.67 (D1 – B1)))(E1/(F1x0.001)

7.0 Determination of Pheophytin

Pheophytin analysis CANNOT be done before Chlorophyll analysis

7.1 Transfer 3ml of clarified extract to a 1-cm cuvette and read optical density (OD) at 750 and 664 nm.

7.2 Acidify extract in the cuvette with 0.1 ml of 0.1N HCL and gently agitate.

7.3 Read the OD at 750 and 665 nm 90 seconds after acidification. The volumes of extract and acid and the time after acidification are critical for accurate, consistent results.

8.0 Calculations for pheophytin

Subtract the 750-nm OD value from the readings at 664nm and 665 nm. Using the corrected values, calculate the chlorophyll-a and pheophytin-a per cubic meter as follows:

$$\text{Chlorophyll-a, mg/m}^3 = \frac{26.7\,(664_b - 665_a)\,(V_1)}{V_2\,(0.001)}$$

$$\text{Pheophytin-a, mg/m}^3 = \frac{26.7((1.7(665_a)) - 664_b)\,(V_1)}{V_2\,(0.001)}$$

where:

V_1 = volume of extract, L

V_2 = volume of sample, L

664_b, 665_a = optical densities of extract before and after acidification, respectively.

All of the above calculations can be found in excel

9.0 Quality Control

A blank must be analyzed with every batch. A replicate must be analyzed every 20 samples or once per month, which ever is most frequent.

10.0 Comments and Deviations

ECM adds additional magnesium carbonate before filtration to insure chlorophyll a is not converted to pheophytin.

1.0 Scope and Application

This method is applicable to the determination of nitrate in drinking, surface and saline waters and domestic and industrial wastes. **This procedure is applicable to water pollution samples with concentrations greater than 0.02 mg/L.**

2.0 Summary of Method

The reaction between nitrate and brucine produces a yellow color. The intensity of the color is dependent on the amount of nitrate in the sample. Since this reaction is heat dependent, precise heat control and incubation time is imperative. Photometric measurement is made at 410nm using a 1 cm cell path. The method is suitable for measurements as low as 0.02 mg/l nitrate as nitrogen.

3.0 Sample Size and Preservation

Sample should be received in a plastic bottle and kept cool at 4 degrees C. Samples have a holding time of 48 hours. If samples are received and analyzed within 24 hours of collection, no preservative is necessary. If samples are received and analyzed more than 24 hours after collection, sample must be preserved with Sulfuric Acid (H_2SO_4).

4.0 Apparatus

4.1 Spectrophotometer equipped with 1 cm or larger cells for use at 410nm.

4.2 30 ml test tubes

4.3 10 ml, 5 ml and 1 ml pipettes

5.0 Reagents

5.1 Nitrate stock solution: (1ml = 0.1 mg N) Dissolve 721.8 mg anhydrous potassium nitrate, KNO3, in distilled water and dilute to 1,000 ml. Add 2 ml of chloroform per liter of solution as a preservative. This standard is stable for 6 months.

5.2 Nitrate working standard: 10 mg/L NO3-N. Dilute 10 ml of stock to 100 ml with DI water.

5.3 Calibration standards: Dilute 0.2, 0.4, 0.6, 0.8 and 1.0 ml of working standard to 10 mls. This will result in a series of 0.2, 0.4, 0.6, 0.8, and 1.0 mg/l standards, respectively.

5.4 Bruce Sulfanilic Acid Solution: Dissolve 1 g brucine sulfate and 0.1 g sulfanilic acid in approximately 70 mls hot DI water. Add 3 ml concentrated HCL and dilute to 100 mls. Refrigerate between usage. CAUTION: Brucine is a poison. Alternatively, brucine sulfanilic acid can be purchased.

5.5 4:1 Sulfuric Acid Solution: Add 500 ml concentrated sulfuric acid to 125 mls of DI water. Prepare under hood using caution, highly exothermic. Use ice water bath to cool.

5.6 Sodium Chloride Solution: Dissolve 300 g sodium chloride in DI and dilute to 1,000 ml.

6.0 Procedure

6.1 Place metal heating block on the center of the hot plate under hood. Turn heat to the fourth bar on knob. The temperature of the metal heating block must reach 100°C before placing samples in block.

6.2 Use 10 ml of sample or an aliquot diluted to 10 mls. Pour into a 30 ml test tube.

6.3 Add 2 ml of sodium chloride solution, mix thoroughly by swirling.

6.4 Add 10 ml of 4:1 sulfuric acid, mix thoroughly by swirling, let cool.

6.5 Add 0.5 ml of brucine sulfanilic solution, mix thoroughly, and IMMEDIATELY place in heating block

6.6 Heat tubes between 95 and 100 degrees C by placing samples in center of heating block.

6.7 After 25 minutes, remove the samples from the heating block and immerse in an ice water bath.

6.8 When cool (20-25°C), read absorbance at 410 nm.

6.9 If it is necessary to correct for color or turbidity a duplicate sample must be analyzed with addition of all reagents except brucine sulfanilic acid.

7.0 Calculations

7.1 mg/L NO3 - N = (Sample Abs. – Blank Abs.) (F) (Dilution Factor)

7.2 mg/kg wet NO3-N (solids) = $\frac{(mg/L)(L)}{(Kg)}$

Where:
L = volume filtrate (Liters)
Kg = weight of solid filtered

To obtain mg/kg dry, divide above result by percent solids

F is obtained from the linear regression of calibration standards via Excel program.

8.0 Quality Control

8.1 A calibration curve must be analyzed once per quarter.

8.2 A blank and 0.4 mg/L standard must be analyzed with every batch.

8.3 A 0.4 mg/L quality control standard must be analyzed with every 20 samples or once per month, which ever is most frequent.

8.4 A 0.4 mg/L matrix spike and a matrix spike duplicate must be analyzed every 20 samples or once per month, which ever is most frequent.

ECM

TOTAL PHOSPHORUS
SM 18TH ED 4500-P B5, E

APPROVED: [signature] REVISION DATE: 01/25/06

1.0 Summary

Total Phosphorus includes all orthophosphates and condensed phosphates, dissolved and particulate, organic and inorganic. To release phosphorus from combination with organic matter, digest and oxidize. The rigor of digestion required depends on the type of sample. For most samples, the persulfate digestion method is sufficient. For more rigorous digestions, i.e. soils, etc. refer to Standard Methods. **This procedure is applicable for water pollution samples with concentrations greater than 0.01 mg/L.**

2.0 Sample Size and Preservation

50 mls sample in glass/plastic container preserved with H_2SO_4 to pH < 2. Sample should be kept cool at 4°C. Holding time is 28 days.

3.0 Reagents

3.1 Persulfate Digestion

a) *Sulfuric Acid Solution*: Carefully add 300 ml concentrated H_2SO_4 to approximately 600 mL deionized water and dilute to 1 L with deionized water.

b) Ammonium Persulfate (peroxydisulfate): $NH_4)_2S_2O_8$, solid, or Potassium persulfate, $K_2S_2O_8$, solid.

c) Sodium hydroxide: (NaOH) 12.5N.

3.2 Ascorbic Acid Method

a) *Sulfuric Acid: H_2SO_4, 5N*: Dilute 70 ml concentrated H_2SO_4 to 500 ml with deionized water and mix well.

b) *Potassium antimonyl tartrate solution:* Dissolve 1.3715 g $K(SbO)C_4H_4O_6 \cdot 1/2H_2O$ in 400 ml deionized water in a 500 ml volumetric flask and dilute to volume. Store in a glass-stoppered bottle.

c) *Ammonium molybdate solution:* Dissolve 20.0 g $(NH_4)_6Mo_7O_{24} \cdot 4H_2O$ in 500 mL deionized water. Store in glass-stoppered bottle.

d) *Ascorbic Acid, 0.1M:* Dissolve 1.76 g ascorbic acid in 100 ml in deionized water. The solution is stable for about 1 week at 4°C.

e) *Combined Reagent:* Mix the above reagents in the following proportions for 100 mL of the combined reagent: 50 ml 5N H_2SO_4, 5 ml potassium antimonyl tartrate solution, 15 ml ammonium molybdate solution, and 30 ml ascorbic acid solution. Mix well after the addition of each reagent. Let all reagents reach room temperature before they are mixed and mix in the order given. If turbidity forms, shake and let stand for a few minutes until turbidity disappears before proceeding. The reagent is stable for 4 hours.

f) *Standard phosphate solution:* Dissolve 219.5 mg anhydrous KH_2PO_4 in deionized water and dilute to 1000 ml in a volumetric flask. 1.00 ml = 50.0 ug PO_4 – P

4.0 Apparatus

4.1 150 ml Erlenmeyer flask

4.2 50 ml graduated cylinders

4.3 Spectrophotometer, for use at 880 nm, providing a light path of 1 cm.

5.0 Procedure

Persulfate Digestion

5.1 Pour 50 ml sample into a 125 ml Erlenmeyer flask. Add 1 drop of phenolphthalein indicator solution. If a red color develops, add H_2SO_4 solution dropwise until color just disappears. Prepare each sample like this and also, prepare a blank of deionized water with the same method.

5.2 Add 1.0 ml Digestion Reagent (H_2SO_4 solution) and 0.4 g solid Ammonium Peroxydisulfate, $(NH_4)_2S_2O_8$ or 0.5 g solid $K_2S_2O_8$.

5.3 Boil gently on a preheated hot plate for 30-40 minutes or until a final volume of 10 ml is reached. Cool and bring volume back up to 50 ml with deionized water. Continue with Ascorbic Acid Method.

Ascorbic Acid Method

NOTE: If analyzing a large batch (>20 samples) separate the batch into 2 smaller batches to avoid violating the time constraints.

5.4 Add 1 drop phenolphthalein indicator solution to the 50 ml samples prepared with the above Persulfate Digestion Method. Add 12.5N NaOH dropwise until a faint pink color is present.

5.5 Discharge the pink color by adding 5N H_2SO_4 dropwise. **NOTE: 5N H_2SO_4 must be added dropwise to avoid over-acidifying the sample. An overly acidic sample will result in a negative response.**

5.6 Prepare a series of 50 ml standards with the standard phosphate solution (2f) in the concentrations of 0.1, 0.2, 0.3, 0.4, and 0.5 ppm. Standards do not require digestion or pH adjustment.

5.7 Add 8.0 ml combined reagent to each of the standards, samples, and the blank within 20 minutes of adjusting the pH. Mix thoroughly. After at least 10 minutes, but no more than 30 minutes, measure absorbance of each sample at 880 nm.

5.8 Zero the spectrophotometer with the blank and record. Then, proceed with measurement of samples and standards at 880 nm and record.

5.9 **To correct for turbidity or interfering color in samples -** Prepare a sample blank by adding all reagents except ascorbic acid and potassium antimonyl tartrate to the sample. Subtract blank absorbance from the absorbance of the sample.

6.0 Calculation

6.1 Construct a curve from the absorbances obtained from the standards. Plot absorbance vs. phosphate concentration (mg/L) to give a straight line passing through the origin. (Use Microsoft Excel program labeled "STD-CRV")

6.2 Obtain an F factor from the curve. Multiply the F factor by each absorbance to obtain the mg P / L for each sample.

7.0 Quality Control

7.1 A blank must be carried through the entire analysis.

7.2 A curve must be analyzed once/quarter.

7.3 A minimum of two standards must be analyzed with every batch at a concentration of 0.3 mg/L. One standard must be digested and carried through the entire process, the other standard need not be digested. These standards must be analyzed every 20 samples. Therefore, if the batch contains 20 samples, 2 standards will be analyzed. If there are 21 samples, 4 standards will be analyzed. If there are 41 samples, 6 standards must be analyzed, and so forth.

7.4 A Quality Control standard at a concentration of 0.3mg/Lmust be analyzed every 20 samples or once per month, whichever is more frequent.

7.5 An MS and MSD must be analyzed every 20 samples or once per month, whichever is more frequent.

ECM

SOLUBLE REACTIVE PHOSPHATE- SRP

SM 18TH ED 4500-P, E, EPA 365.2

APPROVED: [signature]

DATE: 01/18/06

1. Scope and Application

Phosphates that respond to colorimetric tests without preliminary oxidative digestion of the sample are termed "reactive phosphorus". Reactive phosphorus occurs in both dissolved and suspended forms. Soluble Reactive Phosphate is measured in an unpreserved sample that has been filtered through a 0.45-um membrane filter. The filtration will remove any particles or detritus that may contain phosphorus. Using the 5-cm cell path the method is sensitive down to 0.003 mg/l of soluble reactive phosphate. **This procedure is applicable to water pollution samples.**

2. Method Summary

Ammonium molybdate and potassium antimonyl tartrate react in an acid medium with soluble reactive phosphate to form a heteropoly acid-phosphomolybdic acid-that is reduced to intensely colored molybdenum blue by ascorbic acid.

3. Sample Size and Preservation

50 mls unpreserved sample in glass/plastic container. Samples should be filtered immediately and kept cool at 4°C. Holding time is 48 hours.

4. Reagents

4.1 ***Sulfuric Acid, H_2SO_4, 5N:*** Dilute 70 ml concentrated H_2SO_4 to 500 ml with deionized water and mix well.

4.2 ***Potassium antimonyl tartrate solution:*** Dissolve 1.3715 g $K(SbO)C_4H_4O_6 \cdot 1/2H_2O$ in 400 ml deionized water in a 500 ml volumetric flask and dilute to volume. Store in a glass-stoppered bottle.

4.3 ***Ammonium molybdate solution:*** Dissolve 20.0 g $(NH_4)_6Mo_7O_{24} \cdot 4H_2O$ in 500 ml deionized water. Store in glass-stoppered bottle.

4.4 ***Ascorbic acid, 0.1M:*** Dissolve 1.76 g ascorbic acid in 100 ml in deionized water. The solution is stable for about 1 week at 4°C.

4.5 ***Combined Reagent:*** Mix the above reagents in the following proportions for 100 ml of the combined reagent: 50 ml 5N H_2SO_4, 5 ml potassium antimonyl tartrate solution, 15 ml ammonium molybdate solution, and 30 ml ascorbic acid solution. Mix well after the addition of each reagent. Let all reagents reach room temperature before they are mixed and mix in the order given. If turbidity forms, shake and let stand for a few minutes until turbidity disappears before proceeding. The reagent is stable for 4 hours.

4.6 ***Standard Phosphate Solution:*** Dissolve 219.5 mg anhydrous KH_2PO_4 in deionized water and dilute to 1000 ml in a volumetric flask. 1.00 ml = 50.0 ug PO_4 – P

4.7 ***Working Phosphate Standard:*** Add 1.0 ml of the standard phosphate solution to a 50 ml volumetric flask and dilute to mark with DI.

5. Procedure

Filtration

5.1 Prepare 0.45-um membrane filters by filtering several 100-ml portions of deionized water through the filters to remove any possible phosphorus.

5.2 Filter enough of each sample and a deionized water blank through the prepared 0.45-um membrane filters to produce 50 ml volumes for the test.

Ascorbic Acid Method

5.3 Add 1 drop phenolphthalein indicator solution to the 50 ml filtered samples. If a pink color develops, add 5N H_2SO_4 solution dropwise to just discharge color.

5.4 Prepare a series of calibration standards by adding 0.5, 1.0, 2.0, 3.0 and 4.0 ml of the working standard (4.7 above) to 50 ml of DI. This will result in a calibration curve with the final concentrations of 0.01, 0.02, 0.04, 0.06 and 0.08 mg/L respectively.

5.5 Add 8.0 ml combined reagent to each of the standards, samples, and the blank and mix thoroughly. After at least 10 minutes, but no more than 30 minutes, measure absorbance of each sample at 880 nm.

5.6 Using the 5-cm cell, zero the spectrophotometer with the prepared blank. Then proceed with measurement of samples and standards at 880 nm. Record all values.

5.7 To correct for turbidity or interfering color in samples – Prepare a sample blank by adding all reagents except ascorbic acid and potassium antimonyl tartrate to the sample. Subtract blank absorbance from the absorbance of the sample.

6. Calculations

6.1 Construct a curve from the absorbances obtained from the standards. Plot absorbance vs. phosphate concentration (mg/L) to give a straight line passing through the origin. (Use Microsoft Excel program labeled "STD-CRV")

6.2 Obtain an F factor from the curve. Multiply the F factor by each absorbance to obtain the mg/ L for each sample.

7. Quality Control

A blank must be analyzed with every sample. A QC standard, spike, and spike duplicate must be analyzed every 20 samples or every 30 days, which ever is most frequent.

ECM

AMMONIA – ION SELECTIVE ELECTRODE
SM 18th ED. 4500NH_3 B,F; EPA 350.3

APPROVED: [signature]   DATE: 12/21/05

Scope and Application

This method is applicable to the measurement of ammonia nitrogen in potable and surface waters and domestic and industrial wastes. Ammonia nitrogen is found naturally in surface and wastewater. Its concentration is generally low in unpolluted groundwaters since it adsorbs to soil particles and clays and is not readily leached from soils. Ammonia is produced largely by the deamination of organic nitrogen containing compounds and by hydrolysis of urea.

Summary of Method

The ammonia selective electrode uses a hydrophobic gas-permeable membrane to separate the sample solution from an electrode internal solution of ammonium chloride. Dissolved ammonia (NH3 aq and NH4+) is converted to NH3 aq by raising the pH to above 11 with a strong base. NH3 aq diffuses though the membrane and changes the internal solution pH which is sensed by a pH electrode.

This method is applicable for **wastewaters that have an ammonia concentration of 0.02 to 4.00 mg NH3-N/L**. High concentrations of dissolved ions affect the measurement, but color and turbidity do not. Sample distillation is unnecessary if it has been previously demonstrated that distillation does not effect the result. If distillation is necessary, follow the Ammonia Titration SOP for distillation, prior to electrode analysis.

Sample Size and Preservation

A 100 ml sample is used, or a portion diluted to 100 mls. The sample should be preserved with sulfuric acid to a pH of less than 2, and analyzed within 28 days.

Apparatus

a. Expanded scale or digital pH meter or ion selective meter.
b. Ammonia selective electrode
c. Magnetic stirrer with TFE coated stirring bar
d. 150 ml beakers
e. 100 ml graduated cylinder

Reagents

a. **Stock Ammonium Chloride Solution**: Purchase commercially prepared standard with a concentration of 1000 mg/l NH3 as N.
b. **Standard ammonium chloride solution (10 mg/l)**: Dilute 1 ml of 1000 mg/l stock to 100 mls with DI.

c. **Ammonia pH Adjusting ISA**: Commercially prepared (Orion 951211) or equivalent.

d. Ion Selective Electrode Internal Fill Solution: Commercially prepared Orion #951202.

Procedure

Samples will need to be distilled prior to ammonia probe determination unless the source has been demonstrated to be free of interferences. Follow the distillation procedure found in the Ammonia Titrimetric SOP substituting 0.04N sulfuric acid for the boric acid indicator in the collection beaker. A blank must be run through the entire procedure.

NOTE: Electrode operation should be checked prior to analysis by pipetting 1 ml of 1000 ppm NH3 standard in a beaker and adding 100 ml of DI. Add pH adjusting buffer and record mV reading when stable. Next, Pipet 10ml of the 1000ppm NH3 standard into the same beaker, stir thoroughly and record mV reading when stable. The difference between the first and second electrode potential is defined as the slope, and should be in the range of -54 to –60 mV/decade when the solution temperature is between 20-25 degrees C. Record the results in the Ion Selective Electrode Operation Log Book. If the slope is out of range consult the ISE manual for troubleshooting procedures.

1. Prepare standards in concentrations of 0.10, 0.20, 0.40, 0.80, and 1.0 mg/l by diluting 1.0, 2.0, 4.0, 8.0 and 10.0 mls of 10 mg/l working standard to 100 mls.

2. Use 100 mls of sample or a portion diluted to 100 mls.

3. Immerse electrode in sample and mix with a magnetic stirrer. Maintain the same stirring rate and temperature of about 25 degrees Celsius for all standards and samples. A temperature difference of 1 degree C will give rise to about 2% measurement error. To prevent air entrapment on the membrane, use the electrode holder that keeps the electrode at a 20 degree angle.

4. Add 1.0 ml ISA pH adjustment buffer solution to the sample being tested. The blue color indicates a pH of >11. If blue color disappears add additional buffer in 1ml increments recording the amount of buffer added. This additional volume must be accounted for in the calculation. If using 10N NaOH use pH paper to ensure the pH is maintained at >11.

5. Keep electrode in solution until a stable milliVolt reading can be obtained.

Quality Control

An undistilled deionized water blank must be analyzed with every batch. A calibration curve must be analyzed once per quarter or when the continuing calibration standard is not within 90-110% of its true value. A continuing calibration standard must be analyzed every 20 readings. An MS and MSD, as well as an outside source standard must be analyzed every 20 samples or once per month, whichever is more frequent.

Calculations

Follow procedure for Graphing Probe Analysis. The procedure will generate an equation in the format of $Y = Ae^{(-BX)}$. A and B are constants given by excel, X is the millivolt reading, and Y is the ammonia concentration in mg/L.

NH_3-N (mg/L) = C – D

Where:

C = Sample concentration, NH_3-N (mg/L), obtained from $Y = Ae^{(-BX)}$

D = Blank concentration, NH_3-N (mg/L), obtained from $Y = Ae^{(-BX)}$

APPENDIX D

NJDEP Approved Scope of Work

Scope of Work for the Borough of Bay Head's 319(h)-Grant (WQR-2019-Bay Head-00172)

Submitted to the Borough of Bay Head
Submitted by Princeton Hydro, LLC
25 May 2021

Project Description - The Borough of Bay Head (Bay Head) submitted an application and was awarded funding through NJDEP's 319(h)-grant program. These funds will be used to develop a Lake / Watershed Management Plan for Twilight Lake, Ocean County, NJ. The suffers a variety of water quality problems, including high densities of submerged vegetation, nuisance algal blooms (some of which can be HABs), low dissolved oxygen (DO) concentration and high amounts of sedimentation / turbidity. Since Twilight Lake is a focus point for the public relative to the enjoyment of local natural resources, the goal of the Management Plan is to develop a strategy to cost effectively address these impacts through both in-lake and watershed-based management activities. Thus, this proposed Scope of Work is for Princeton Hydro to successfully complete all of the tasks associated with the development of this Management Plan.

Task 1 - Review of all Historical Background Data. Any historical data will be obtained from the Borough, as well as any other regulatory agencies, (such as NJDEP, USACE, and the USGS). This information will be reviewed in advance of implementing the watershed assessment outlined in Tasks 4.0 and 6.0. By doing so, a capitalization on established water quality trends, problems and issues raised through any past sampling efforts, and evaluation of the relative success of any past restoration efforts, can be accomplished. All streams within the watershed that feed the lake will also include a review of all available surface water data available through NJDEP, USACE, USGS, etc. Additionally, there is a Strategic Recovery Planning Report (2016) and a Coastal Vulnerability Report (2019), which will be reviewed. These documents were developed as part of assessing Post Superstorm Sandy's impacts and develop a long-term strategy in addressing climate change through adaptive management.

The reviewed information will be used as the foundation of the watershed assessment. This is part of a standard study approach for any lake / watershed. Making use of these supplemental data collected by others to complement field efforts is beneficial, assuming that the data were collected by properly trained personnel in a manner consistent with standard NJDEP quality assurance protection plan protocols.

Task 2 - Author Quality Assurance Project Plan. As cited in the RFP and required by NJDEP, a Quality Assurance Project Plan (QAPP), will be developed. Princeton Hydro (PH) has authored numerous QAPPs that have been approved by the NJDEP Office of Quality Assurance. PH will develop the QAPP, which will outline all field sampling protocol and methodology, identify all water quality parameters that will be monitored, in-situ and discrete samples that will be collected, the NJDEP certified labs that will be used for analysis, and finally, the proposed location of all sampling.

Task 3 - Bathymetric Survey. A bathymetric survey is the mapping of water depth and the amount 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 statistics such as mean depth and volume of water and unconsolidated sediment.

For compatibility with future surveys (and possible permitting) and well as for one PH conducted in 2012 (see attachments), the water depth data must be real elevations (North American Vertical Datum of 1988 - NAVD88) and not relative depths (surface water elevation equal to zero). This will require the setting of a benchmark on the project site, preferably close to the shoreline. PH will set a benchmark adjacent to the lake with a survey grade GPS unit, and calculate the surface water elevation before the start of the survey with a site level and Philadelphia rod.

The bathymetric survey will be conducted utilizing two methods. These methods include a calibrated sounding rod and a dual frequency echo sounder with GPS. This method will be employed to survey shallow areas (12 inches of water or less) and in areas where the bottom sediment composition is not conducive for echo sounding. The dual frequency sounder (Kundsen Engineering model 1612 Echosounder) uses a high frequency and low frequency to discern the top of sediment from the bottom of sediment. The sounder will be calibrated throughout the course of the survey with the calibrated sounding pole to ensure accurate water and sediment depth readings. Locations of sounding data will be recorded with a Leica GPS unit. Data will be collected along predetermined transects that run from shoreline to shoreline in an East-West fashion in both cove areas at one hundred- and fifty-foot intervals.

Once all field work is complete, the sounder data will be edited with Hypack Max, a sounder software suite that enables the editing of the raw sounder data. It is here that the Rogers Surveying tide gauge file will be imported into the software and the raw sounding data will be converted into NAVD88 elevations. The raw data will also be checked for any apparent errors in the data, such as double reflections and/or aquatic vegetation interference. Once all raw data has been registered in NAVD88 elevations and edited for accuracy, the data will be exported from the Hypack Max software and into our Geographic Information System (GIS) program, ArcGIS.

In addition to the bathymetric assessment, a composited sediment sample will be collected from each cove for grain size analysis. This analysis will aid in making management decisions within the Plan relative to dredging and how the unconsolidated material should be handled, transported, and eventually disposed of. In addition, such data will aid in the regulatory process associated with dredging.

PH conducted a bathymetric assessment of Twilight Lake in May 2012, prior to Superstorm Sandy hitting the Mid-Atlantic States later that year. The results of this bathymetry are provided as water depth and sediment thickness maps. Prior to Sandy the lake was approximately 42% filled in with sediment. Thus, the bathymetry proposed for this study would be compared to the pre-storm condition of the lake to determine if the lake has gained or lost sediment over the last 8+ years.

Task 4 - Watershed Modeling: Hydrologic and Pollutant Loads. The objective of this task will be to develop hydrologic and pollutant budgets for the lake. The hydrologic and pollutant loading data will enable the Borough to identify and target the primary subwatersheds or stormwater discharge areas requiring the greatest load control and evaluate the feasibility of managing these loads. This will aid the Borough in selecting, prioritizing, and implementing nutrient and sediment load management efforts, thus ensuring that future restoration practices are directed to the watershed projects having the greatest overall benefit to the long-term management of surface water quality.

Watershed pollutant loading and hydrology will be modeled using a mid-level model and recommended for use by the USEPA such as MapShed / Wikiwatershed. Alternative models will be considered such as the UAL methodology and the modified TR-55. The model will be applied to describe system hydrology and pollutant loading within the watershed and associated subwatersheds. Hydrology and pollutant loading are inextricably linked and thus are calculated in parallel within the model. The pollutants to be modelled include phosphorus, nitrogen, sediment, and bacteria, while the hydrology will include estimates of precipitation, runoff, evapotranspiration, groundwater flux, and streamflow or discharge. An added layer of complexity associated with Twilight Lake is that the system is tidally influenced. Thus, this will need to be integrated into the hydrologic and pollutant modeling efforts.

The models utilize loading coefficients, essentially the quantity of a pollutant produced per unit area, to specific land cover types and land areas; the hydrology module operates similarly. A series of algorithms modifies these results according to weather data, soils, and slopes among many other factors. The models also allow for the inclusion of other potential factors such as septic systems, animal densities (i.e. farms, geese) and other factors that impact pollutant loads and hydrology.

In turn, these modeling efforts can be used to rank the sub-watersheds relative the amount of human-generated TP they produce. In turn, this information can be used to identify locations for BMP that can effectively manage the pollutant loads generated by each major sub-watershed's specific pollutant loads. Emphasis should be given to bioretention and living shoreline type systems that can be implemented on a lot-specific or regional scale. Such BMPs have a high capacity for the removal of nutrients and can mitigate issues associated with flooding. An examination and discussion of the water quality benefits of restoring and/or creating wetland buffers, riparian buffers, aquascape/ living shorelines will also be conducted. Where possible, based on available information, the report will identify examples of site-specific locations where wetland buffers, riparian buffers, and lakefront aquascaping / living shorelines could be installed. Finally, the Borough has already made a conscious effort to seek funds for some of these types of projects, such as living shorelines. The Lake / Watershed Plan will provide additional support in justifying the need for agencies to fund these types of projects within the Twilight Lake watershed.

Task 5 - Water Quality Monitoring. Following NJDEP approval of the QAPP, water quality monitoring will be conducted over the 2021 growing season (May - October). This would entail monthly water quality sampling at the lake for a total of six (6) sampling events. Samples will be collected at a minimum of two stations, with at least one sampling station in each cove. During each event and at each station, *in-situ* water quality data will be collected at profile from surface to bottom for dissolved oxygen, temperature, pH, and specific conductivity will be conducted. PH is field certified by NJDEP (#10006) in these in-situ parameters. The lake's clarity (Secchi disk transparency) will also be measured.

At a station established in the approximate center of the east and west coves, discrete whole water samples will be collected at a depth halfway down the water column. All of these samples will be submitted to an NJDEP certified lab (#18630) for the analysis of total phosphorus (TP), soluble reactive phosphorus (SRP), nitrate nitrogen (NO_3-N), NH_3 nitrogen (N as ammonia), Chlorophyll *a,* and total suspended solids (TSS). At the same two stations, zooplankton and phytoplankton samples will be collected and analyzed for species composition, dominant organism, and relative density. Additionally, during each of the six (6) sampling events, a general survey of aquatic vegetation and/or algae growth (planktonic or filamentous) will be conducted.

Task 6 - Visual Watershed Assessment and Monitoring. Watershed-based modeling efforts will be used to quantify the current existing pollutant loads; however, the model is only capable of providing pollutant loads on a sub-watershed basis. The first element of an EPA nine-point plan includes identification of the causes and sources of pollutant loading; therefore, a detailed field-based survey of the watershed will be conducted using a standardized Visual Assessment Protocol.

Visual assessments provide a more comprehensive assessment of the watershed, including channel conditions and bank / shoreline stability, general ecological conditions, and the presence of stormwater infrastructure. Additionally, these field assessments will provide information to generate maps and data on existing conditions for stakeholder education, provide specific data on problem sites for future potential grant opportunities, and aid in the prioritization of these potential project site with the aid of the subwatershed analysis.

In addition, as part of these assessments, 3 watershed-based baseflow (no rain in the previous 72 hours) stream monitoring events will be conducted at the two streams that enter the lake from the western end. During these monitoring events, both *in-sit*u and discrete water quality data will be collected. Discrete water quality samples will be collected at each site and analyzed for TP, SRP, NO3-N and TSS.

Task 7 - Fine-Tuning of Hydrologic and Pollutant Load Models. Modelling provides estimates of the hydrologic and pollutants loads, but it does not replace empirical data. After the water quality data are collected, the model will be re-visited and fine-tuned. Additionally, the empirical data can be used to assess the lake's internal phosphorus load and tidal influx. Finally, this task will analyze the hydrologic data generated in conjunction with the external and internal pollutant loads to compute the trophic state of the lake.

Task 8 - Author Final Report. Once all laboratory data have been received and processed a Lake Protection and Watershed Management Plan will be authored in accordance with the nine minimum elements of the USEPA. The report will discuss the data and observations compiled during the monitoring and compare these data to established USEPA/NJDEP trophic state standards and surface water quality threshold values. The report will also cover any water quality issues that were observed or measured, especially relative to phosphorus loading and the *in-situ* data.

The report will include a discussion of watershed management measures best suited for immediate or long-term implementation. For each recommended measure, a preliminary cost estimate for implementation will be included. Also, regulatory constraints impacting any of the recommended measures will be discussed and a list of anticipated NJDEP permits, will be included.

Tentatively, it is already known that the important components of the Plan will include dredging to reduce material that has accumulated in the lake under post-Sandy conditions, as well as the creation and establishment of living shorelines and other green infrastructure throughout the watershed. In addition to water quality management, the Plan needs to include measures that will mitigate and minimize flooding in the area and living shorelines are just one component of this strategy. Others include, but are not limited to, wetlands and additional habitat enhancement features.

Finally, it should be noted NJ Transit is proposing an expansion of its train yard near the lake in the near future. Thus, by documenting existing conditions and proposed watershed projects in the Plan, the Borough will have a strategy in discussing with NJ transit potential mitigation measures for any impacts they may have on the lake and its associated natural resources.

Summary Table of the Tasks Associated with the Scope of Work for the Twilight Lake and Watershed Management Plan

Task / Deliverable	Fixed Fee
Task 1 - Review of all Historical Background Data	$5,750.00
Task 2 - Author Quality Assurance Project Plan	$3,950.00
Task 3 - Bathymetric Survey	$10,550.00
Task 4 - Watershed Modeling: Hydrologic and Pollutant Loads	$12,980.00
Task 5 - Water Quality Monitoring	$25,100.00
Task 6 - Visual Watershed Assessment and Monitoring	$7,650.00
Task 7 - Fine-Tuning of Hydrologic and Pollutant Load Models	$6,070.00
Task 8 - Author Final Report	$12,950.00
Total for Scope of Work Tasks	**$85,000.00**

APPENDIX C

IN-SITU DATA

In-Situ Monitoring for Twilight Lake - Secchi Depth (m)							
Station	Maximum Total Depth (m)	5/2/2022	5/31/2022	6/15/2022	7/13/2022	8/17/2022	9/14/2022
ST-1 (West Cove)	1.30	1.3*	1.0*	1.3*	0.8	0.6	0.5
ST-2 (East Cove)	1.30	1.3*	1.1*	1.3*	0.8	0.7	0.8
ST-3 (Railyard Stream)	0.50	0.4*	0.3*	0.4*	0.4*	0.5*	0.4*
ST-4 (Residential Stream)	0.30	0.3*	0.2*	0.3*	0.3*	0.3	0.3*
ST-5 (Scow Ditch)	1.90	1.5	1.3*	1.6	1.0	0.5	0.8
*Secchi depth equal to sampling date's total depth and the lake bottom's sediment							

In-Situ Monitoring for Twilight Lake - Temperature (°C)							
Station	DEPTH (meters)	5/2/2022	5/31/2022	6/15/2022	7/13/2022	8/17/2022	9/14/2022
ST-1 (West Cove)	0.1	15.08	25.76	24.52	26.43	24.31	24.41
	0.5	15.14	25.72	24.52	26.49	24.29	24.43
	1.0	15.72	-	24.39	26.47	24.47	24.33
ST-2 (East Cove)	0.1	14.63	25.31	24.00	26.33	23.67	24.55
	0.5	14.74	25.26	24.00	26.30	23.68	24.55
	1.0	14.87	24.98	23.44	26.25	24.01	24.25
ST-3 (Railyard Stream)	0.1	13.96	28.10	27.37	28.31	24.70	24.93
ST-4 (Residential Stream)	0.1	14.89	26.53	26.33	28.07	25.26	24.49
ST-5 (Scow Ditch)	0.1	14.66	25.60	24.06	26.42	24.06	24.39
	0.5	14.50	25.52	24.00	26.35	24.06	24.37
	1.0	14.70	25.37	23.88	26.25	23.93	24.38
	1.5	15.03	-	21.43	-	23.97	-
	1.8	-	-	21.23	-	-	-

In-Situ Monitoring for Twilight Lake - Dissolved Oxygen													
Station	DEPTH (meters)	(mg/L)						(% Sat.)					
		5/2/2022	5/31/2022	6/15/2022	7/13/2022	8/17/2022	9/14/2022	5/2/2022	5/31/2022	6/15/2022	7/13/2022	8/17/2022	9/14/2022
ST-1 (West Cove)	0.1	8.96	6.80	7.16	6.65	7.13	6.50	99.9	94.2	95.7	91.6	98.1	91.12
	0.5	8.87	6.82	7.06	6.24	6.96	6.46	99.0	94.5	94.4	88.0	96.1	90.51
	1.0	8.41	-	6.16	6.23	5.47	6.26	96.0	-	82.7	87.8	76.2	87.43
ST-2 (East Cove)	0.1	9.14	6.69	7.45	6.49	7.37	6.67	101.1	92.1	98.0	90.7	100.3	93.71
	0.5	9.16	6.66	7.45	6.38	7.16	6.57	101.8	91.5	98.4	89.7	98.1	91.36
	1.0	8.90	6.21	7.13	6.34	6.51	5.61	101.0	85.1	94.3	89.0	90.0	78.00
ST-3 (Railyard Stream)	0.1	6.21	7.64	7.28	4.78	6.01	6.21	61.3	110.8	101.3	68.6	83.6	86.78
ST-4 (Residential Stream)	0.1	6.96	6.83	7.84	6.45	5.72	6.23	70.0	96.0	107.8	93.1	78.6	87.24
ST-5 (Scow Ditch)	0.1	8.68	6.53	7.47	6.61	7.07	5.81	95.3	90.2	98.9	92.1	97.1	81.07
	0.5	8.49	6.57	7.24	6.26	6.97	6.04	94.1	90.2	95.8	87.9	96.0	85.21
	1.0	8.46	6.52	6.83	6.15	7.01	6.09	94.7	89.8	90.2	86.3	96.4	85.07
	1.5	7.64	-	4.61	-	5.06	-	86.1	-	60.2	-	68.3	-
	1.8	-	-	4.19	-	-	-	-	-	54.5	-	-	-

In-Situ Monitoring for Twilight Lake - pH (S.U.)							
Station	DEPTH (meters)	5/2/2022	5/31/2022	6/15/2022	7/13/2022	8/17/2022	9/14/2022
ST-1 (West Cove)	0.1	7.89	7.67	7.61	7.53	7.66	7.73
	0.5	7.90	7.66	7.59	7.53	7.68	7.72
	1.0	7.80	-	7.49	7.54	7.59	7.70
ST-2 (East Cove)	0.1	7.84	7.66	7.63	7.27	7.41	7.71
	0.5	7.88	7.66	7.63	7.40	7.56	7.71
	1.0	7.88	7.60	7.63	7.46	7.57	7.64
ST-3 (Railyard Stream)	0.1	7.36	7.61	7.21	7.16	7.50	7.47
ST-4 (Residential Stream)	0.1	7.47	7.62	7.55	7.49	7.41	7.73
ST-5 (Scow Ditch)	0.1	7.90	7.65	7.66	7.51	7.66	7.69
	0.5	7.87	7.64	7.63	7.55	7.70	7.71
	1.0	7.87	7.64	7.57	7.56	7.73	7.71
	1.5	7.78	-	7.48	-	7.60	-
	1.8	-	-	7.44	-	-	-

In-Situ Monitoring for Twilight Lake - Specific Conductance (µS/cm)							
Station	DEPTH (meters)	5/2/2022	5/31/2022	6/15/2022	7/13/2022	8/17/2022	9/14/2022
ST-1 (West Cove)	0.1	30,999	34,897	32,072	35,710	40,130	43,001
	0.5	31,662	34,881	32,132	35,720	40,030	42,935
	1.0	34,814	-	34,007	35,730	41,460	42,910
ST-2 (East Cove)	0.1	31,574	34,803	31,972	35,680	40,820	42,989
	0.5	32,317	34,815	32,030	35,690	40,870	42,936
	1.0	34,480	34,902	34,631	35,690	42,730	42,916
ST-3 (Railyard Stream)	0.1	6,790	34,410	31,601	34,930	39,720	42,206
ST-4 (Residential Stream)	0.1	5,670	34,888	32,582	35,740	38,040	43,049
ST-5 (Scow Ditch)	0.1	31,814	34,564	31,831	35,600	40,250	42,813
	0.5	33,423	34,696	31,952	35,600	40,280	42,804
	1.0	34,273	34,779	32,254	35,610	40,590	42,813
	1.5	35,067	-	40,174	-	44,560	-
	1.8	-	-	40,468	-	-	-

APPENDIX D

DISCRETE DATA

Twilight Lake - 2022 Discrete Lab Data							
Metric	Station	5/2/2022	5/31/2022	6/15/2022	7/13/2022	8/17/2022	9/14/2022
TP (mg/L)	ST-1 (West Cove)	0.02	0.03	0.03	0.05	0.06	0.06
	ST-2 (East Cove)	0.02	0.03	0.03	0.04	0.04	0.05
	ST-3 (Railyard Stream)	0.13	0.09	0.16	0.09	0.1	0.11
	ST-4 (Residential Stream)	0.15	0.04	0.05	0.09	0.06	0.06
	ST-5 (Scow Ditch)	0.02	0.03	0.03	0.04	0.06	0.05
SRP (mg/L)	ST-1 (West Cove)	ND < 0.002	ND < 0.002	ND < 0.002	ND < 0.002	ND < 0.002	ND < 0.002
	ST-2 (East Cove)	ND < 0.002	ND < 0.002	ND < 0.002	ND < 0.002	ND < 0.002	ND < 0.002
	ST-3 (Railyard Stream)	0.031	ND < 0.002	0.020	0.002	0.013	0.003
	ST-4 (Residential Stream)	0.043	ND < 0.002	ND < 0.002	ND < 0.002	ND < 0.002	ND < 0.002
	ST-5 (Scow Ditch)	ND < 0.002	ND < 0.002	ND < 0.002	ND < 0.002	ND < 0.002	ND < 0.002
NH3 (mg/L)	ST-1 (West Cove)	ND < 0.01	ND < 0.01	ND < 0.01	0.01	ND < 0.01	0.04
	ST-2 (East Cove)	ND < 0.01	ND < 0.01	ND < 0.01	0.01	ND < 0.01	0.04
	ST-3 (Railyard Stream)	-	-	-	-	-	-
	ST-4 (Residential Stream)	-	-	-	-	-	-
	ST-5 (Scow Ditch)	ND < 0.01	ND < 0.01	ND < 0.01	0.01	ND < 0.01	0.02
NO3 (mg/L)	ST-1 (West Cove)	0.02	0.04	0.06	0.06	0.04	0.1
	ST-2 (East Cove)	0.03	0.04	0.06	0.06	0.04	0.09
	ST-3 (Railyard Stream)	0.11	0.11	0.16	0.1	0.07	0.17
	ST-4 (Residential Stream)	0.21	0.05	0.13	0.08	0.06	0.11
	ST-5 (Scow Ditch)	0.02	0.03	0.10	0.04	0.04	0.08
TSS (mg/L)	ST-1 (West Cove)	14	18	8	10	34	41
	ST-2 (East Cove)	3	25	ND < 2	20	39	32
	ST-3 (Railyard Stream)	3	16	12	67	32	54
	ST-4 (Residential Stream)	ND < 2	30	24	22	40	43
	ST-5 (Scow Ditch)	4	17	17	27	35	31
Chl a (µg/L)	ST-1 (West Cove)	2.7	6.4	7.4	7.6	11	20
	ST-2 (East Cove)	3.6	4.8	4.7	9	8.4	21
	ST-3 (Railyard Stream)	-	-	-	-	-	-
	ST-4 (Residential Stream)	-	-	-	-	-	-
	ST-5 (Scow Ditch)	1.9	5.1	4.8	11	8	17

APPENDIX E

PLANKTON DATA

Twilight Lake Phytoplankton Relative Abundance 2022																			
Taxa/Genus	**Habitat***	**St 1 West Cove**						**St 2 East Cove**						**St 5 Scow Ditch**					
		05.02	**5.31**	**6.15**	**7.13**	**8.17**	**9.14**	**05.02**	**5.31**	**6.15**	**7.13**	**8.17**	**9.14**	**05.02**	**5.31**	**6.15**	**7.13**	**8.17**	**9.14**
Cyanobacteria																			
Anabaena	F						P			R		R		P	R		R		
Aphanizomenon	F			C				P	C	R					R	P			
Aphanocapsa	F/E				P	R	C				R	P	C				C	R	P
Coelosphaerium	F					R				R									
Lyngbya	F/E					C				R		P		P				C	
Merismopedia	F/E						P												
Microcystis	F								R						R			C	
Oscillatoria	F/E		R			P	P				R	P		P	R			P	
Green Algae																			
Chlamydomonas	F/E	R			R						R						R	R	
Chlorella	F/E			P							R			R					
Gloeococcus	F						R										R		
Gloeomonas	F			C		R	R				R	R	P						R
Nephrocytium	F			C															
Pandorina	F			P															
Pediastrum	F/E		R	P		P					R	P					R	C	
Scenedesmus	F			P															
Staurastrum	F			R	R		R			R			R				R		R
Tetraselmis	F/E			R															
Treubaria	F			R															
Zygnema	F															R			
Diatoms																			
Amphiprora	E				C												P		
Asterionella	F/E			C					R	R	R					P	R		
Asterionellopsis	E							R											
Bacillaria	E	R			R												R	R	
Chaetoceros	E		R		R														P
Coscinodiscus	E					R	P		R								P	R	P
Cyclotella	F/E				R												R		R
Cylindrotheca	E				C				P				R		R		C		P
Ditylum	E																R		
Epithemia	E				P		R												
Fragillaria	F/E	P	C	P				P	C	C				P	C	C	R		
Gyrosigma	F/E		C	R	A	P	C		P	R	C	R	C		P		C	R	P
Leptocylindrus	E								P										
Lauderia	E												P						R
Melosira	F/E	R	C	R	P	P	P	P	R	P	R	P	A		C	R	P	C	C
Navicula	F/E	R	P	P	P	R	P	R	P	R	R				P	P	C	R	R
Nitzschia	F/E					R	R				P	P	R					R	P
Pseudonitzchia	F/E								R									R	R
Skeletonema	E	R																	
Stephanopyxis	E		R											R		P			
Striatella	E	R			R												P		
Surirella	F/E	R			P	R	P				R		R				P		R
Synedra	F/E				P		R		R		R						P	R	
Thalassionema	E									R				P		C			
Cryptomonads																			
Chroomonas	F/E			R		R	C				R	R	P				P	R	R
Dinoflagellate																			
Ceratium	F/E	C	P	R	P	R	C	A	R	P	C	P	C	C	R	C	P	R	A
Gymnodinium	F/E	R		C	P	C				R	P	P	P				R	P	
Hemidinium	F/E			C															
Mesodinium	F/E		R																
Euglenoids																			
Euglena	F/E				P				R								R		
Phacus	F						R												
Trachelomonas	F			R		R							R	R					

* F - Freshwater F/E - Freshwater/Estuarine E-Estuarine

A - Abundant C - Common P - Present R - Rare

Twilight Lake Zooplankton Relative Abundance 2022																			
Taxa/Genus	**Habitat***	**St 1 West Cove**						**St 2 East Cove**						**St 5 Scow Ditch**					
		05.02	**5.31**	**6.15**	**7.13**	**8.17**	**9.14**	**05.02**	**5.31**	**6.15**	**7.13**	**8.17**	**9.14**	**05.02**	**5.31**	**6.15**	**7.13**	**8.17**	**9.14**
Cladocerans																			
Bosmina	F/E		R	C	R	R		R	P	P	R	P	P	P	R	C	P	P	P
Ceriodaphnia	F/E				R	R				R		R	R			P		P	R
Chydorus	F/E															R			
Daphnia	F/E												R						
Diaphanosoma	F/E					R						R							
Copepods																			
Acartia	E							P	P	R	R			C	P		R	R	R
Cyclops	F/E	R	R					R								R			
Diaptomus	F					R								R	R				
Eurytemora	E							R	R						P				
Mesocyclops	F									R									
Microcyclops	F	P	P	R						R									R
Nauplii	F/E	P	C	A	P	C	P	C	C	C	C	P	P	A	A	A	P	C	C
Rotifers																			
Anuraeopsis	F/E															R			
Ascomorpha	F/E		R	P	R			R		R		P							
Asplanchna	F/E										R								R
Brachionus	F/E					R						R						R	R
Conochilus	F/E			R														R	
Filinia	F/E															R		R	
Kellicotia	F/E	R		P			R						R	R	R	C	R		R
Keratella	F/E	P	P	A	P	P	R	R	P	P	R	C	R	R	P	A	P	P	R
Lepadella	F/E						R												
Monostyla	F													R					
Notholca	F/E				C	P	P				C	C	P				C	C	P
Polyarthra	F/E			R				R	R							R			
Pompholyx	F/E	R	P	C				R	R	P	R				R	R		R	
Synchaeta	F/E			R				R							R				
Trichocerca	F/E					R				R		R				P			
Tylotrocha	F/E	C	P					C	R					A	R	P			
Other Taxa																			
Crab Zoea	E		R	R		R		P	P					P	P				
Polychaete Larva	E	A	C	C	R	R	P	C	C	P	R			A	C	P	R	P	P
Barnacle Nauplii	E		R	R	R		R	P	P	P					P	R	P		
Bivalve Larva	E		R	R			R		R							R			
Snail Larva	E		R	R	R				R		R	R	R		R	R			R
Odonata	F/E			R												R			
Isopoda	F/E								R						R				
Ostrocoda	F/E												P						C

* F - Freshwater F/E - Freshwater/Estuarine E-Estuarine

A - Abundant C - Common P - Present R - Rare

APPENDIX F

FLOOD DERIVED LOADS

Appendix F was prepared by
the Bay Head Environmental Commission

FLOOD DERIVED LOADS

Background: Nuisance and Major Floods

The Borough of Bay Head experiences flooding on a monthly basis. Most floods are termed Nuisance Floods since the water level of Barnegat Bay and Twilight Lake rise to a level that storm drain systems are not able to gravity drain. When this occurs, water backs up at storm drain catch basins and flows onto roads. This occurs at a number of low lying areas throughout the Borough. Roads are not flooded to the extent that vehicular traffic is impeded, however it is considered a nuisance when walking through town. Nuisance Floods occur, on average, once a month and involve flow from Barnegat Bay through Scow Ditch and into Twilight Lake. The amount of water flowing into Twilight Lake over normal tidal fluctuates is small compared to the amount that flows during a Major Flood.

Major floods occur, on average, four times a year. Large amounts of water overflow the shoreline of Twilight Lake and bulkheads along Scow Ditch and Barnegat Bay. When this occurs, the depth of water on streets is high enough to affect the safety of cars trying to drive through the flooded streets. This requires blockading all or a portion of the majority of roads (84% of all roads were fully or partially blockaded during the Dec 23, 2022 flood) in Bay Head. The large amount of water during Major floods has prompted a closer look at the impact such events have on pollutant loading in the Twilight Lake Watershed.

Dec 23, 2022 Major Flood Showing Bridge Avenue is flooded and blockaded which is the main business district of Bay Head and an east-west emergency evacuation route leaving the Barrier Island.

Hydrology of Major Floods

When storms cause the level of Barnegat Bay and therefore, Twilight Lake to rise, then flood water overflows onto streets, yards, sidewalks, parking areas, etc. In the past three years, water depths as great as 17 inches have been measured in the center crown of roads. This depth prompts the police to close the road to all traffic. The amount of water that flows through Scow Ditch into Twilight Lake can be estimated by measuring the rise of level of Twilight Lake and the extent (area and depth) of water flooded onto roads, sidewalks, yards, parking lots, etc. Measurements during the worst Major Flood in the past three years found that 34.7 Million gallons (4.64 E+6 cubic feet) of water traveled through Scow Ditch above normal tidal water level variation. This was the highest amount measured for the worst Major Flood. On average, 19.5M gallons (2.6E+07 cubic feet) of water typically flows through Scow Ditch and enter Twilight Lake during a Major Flood event. With an average of four Major floods each year, this equates to 78M gallons (1.04E+7 cubic feet) of water.

To show this in comparison to other water inputs into Twilight Lake, the total hydrology values of Table 6 ‘‘Twilight Lake Hydrology Components’’ are provided in Table 1 of Appendix F and a column added to include water flow into Twilight Lake from four Major Floods per year. The actual amount of water is greater if Nuisance Floods were included, but the total volume of water from nuisance floods is small compared to Major Floods and therefore, has a much smaller impact.

Table 1 of Appendix F

Twilight Lake Hydrology Components		
Source of Water	Volume of Water Entering Twilight Lake Without Flood Waters Included (m^3) (From Table 6)	Volume of Water Entering Twilight Lake With Flood Waters Included (m^3)
Twilight Lake Watershed	4.51E+05	4.51E+05
Tidal Water Flow	1.18E+07	1.18E+07
Scow Ditch Watershed	3.46E+04	3.46E+04
Direct Net Precipitation	5.88E+04	5.88E+04
Flood Water Flow	0	1.04E+07
TOTAL	**1.24E+07**	**2.28E+07**

Pollutant Loading of Major Floods

Flood waters flowing into Twilight Lake from Major Floods come from Barnegat Bay, the same as tidal water entering Twilight Lake. The model used pollutant concentrations of water at Point Pleasant Canal which is in close proximity to the entrance of Scow Ditch. (Reference: USGS Point Pleasant Canal published values. https://nwis.waterdata.usgs.gov/nwis/qwdata/?site_no=01408043)). The model calculated 464.2kg of TP entered Twilight Lake from tidal water flow (Ref. Table 7) and 1.18E+07 cubic meters of water carried the TP into the lake. (Ref. Table 6). This means the concentration at the Point Pleasant Canal was 0.039 mg/liter (464.2kg/1.18E+07 cubic meters). Using this same concentration, 1.04E+7 cubic meters of flood water will carry a total of 409.1kg of Total Phosphates into Twilight Lake on a yearly basis from the four Major Floods.

To show this in comparison to other pollutant loads entering Twilight Lake, the total load values of Table 7 ‘‘Twilight Lake Pollutant Loading’’ are provided in Table 2 of Appendix F along with pollutant loading from Major Floods.

Table 2 of Appendix F

Twilight Lake Pollutant Loading						
Category (Source of Water/Pollutant)	**TP Pollutant Loading Without Flood Waters Included (From Table 7)**			**TP Pollutant Loading With Flood Waters Included**		
	TN (kg)	**TP (kg)**	**TSS (1,000kg)**	**TN (kg)**	**TP (kg)**	**TSS (1,000kg)**
Twilight Lake Watershed	162.4	21.9	52	162.4	21.9	52
Tidal Water Flow	4,937.4	464.2	251.7	4,937.4	464.2	251.7
Scow Ditch Watershed	27	2.5	2.4	27	2.5	2.4
Flood Water Flow	0	0	0	4,351.6	409.1	221.8
TOTAL	5126.8	488.6	306.1	9,478.4	897.7	527.9

This simplified approach of determining pollutant loading follows the methodology used to calculate the loading presented in Table 7 of Section 2.3 of the main report. As previously described, this approach does not account for flushing that occurs as flood waters recede after each flood and therefore the residence time of water and pollutants in Twilight Lake and its affect are not considered.

Pollutant Concentrations – Comparison of Model to Measured Values

Section 2.3 of the main report compares the model results to measured pollutant concentrations averaged over the open water areas of Twilight Lake where samples were taken: the west cove, east cove and Scow Ditch sample locations. This same comparison adding pollutants entering Twilight Lake from Major Flood waters is provided in Table 3 of Appendix F. Average numbers are compared and are not based on monthly values for simplification.

Table 3 of Appendix F shows that including flood waters in the model provides a closer match to the sample results than not including pollutants added by flood waters.

Table 3 of Appendix F

Comparison of Model and Measured Values							
Pollutant Concentrations <u>Without Flood Waters Included</u> (From Table 9)						**Pollutant Concentrations <u>Including</u> Flood Waters**	
Model Average (mg/L)			**Measured (Sample) Average (mg/L)**			**Model Average (mg/L)**	
Month	**TP**	**TSS**	**Date**	**TP**	**TSS**	**TP**	**TSS**
Apr	0.043	22.2	May 2	0.020	7.0		
May	0.033	30.8	May 31	0.030	20.0		
Jun	0.033	17.9	Jun 11	0.030	12.5		
Jul	0.046	23.8	Jul 13	0.043	19.0		
Aug	0.060	28.3	Aug 17	0.053	36.0		
Sep	0.045	25.1	Sep 14	0.053	34.7		
Oct	0.048	27.8					
Average	**0.044**	**24.3**		**0.038**	**21.5**	**0.039**	**23.2**

Estimate of Load Reductions – Management Measure

Flood waters add 409.1kg of TP to Twilight Lake on a yearly basis. This is 46% (409.1/897.7) of the total TP entering the lake per year. Tidal Water adds 464.2 kg of TP to Twilight Lake on a yearly basis, which is 52% (464.2/897.7) of the yearly total. The installation of a tidal flood control gate on Scow Ditch will directly control the flow of water and pollutants from Barnegat Bay entering Twilight Lake. The intent is to close the gate valves before Major flood events which would eliminate 46% of the TP entering Twilight Lake. If the gate were closed during other tidal flow conditions, then a portion of the TP entering from tidal flow would be eliminated. Total flow cannot be blocked as there is inherent ecological benefit for tidal flow in and out of Twilight Lake for flushing purposes. A closer examination of the impact of flushing and pollutant residence time in Twilight Lake is recommended to understand the net benefit of a tidal flood control gate.

Image of Typical Tidal Flood Control Gate Considered for Scow Ditch, Bay Head.