GREENWOOD LAKE WATERSHED IMPLEMENTATION PLAN

WEST MILFORD TOWNSHIP, PASSAIC COUNTY, NEW JERSEY

JANUARY 2020

PREPARED FOR:

GREENWOOD LAKE COMMISSION
ATTN: PAUL ZARILLO
2019F GREENWOOD LAKE TURNPIKE
HEWITT, NJ 07421

PREPARED BY:

PRINCETON HYDRO, LLC
1108 OLD YORK ROAD, SUITE 1
P.O. BOX 720
RINGOES, NJ 08551
908-235-5660

TABLE OF CONTENTS

EXECUTIVE SUMMARY

Greenwood Lake is a 1,920-acre waterbody located in both Passaic County, New Jersey and Orange County, New York. The watershed encompasses approximately 16,036 acres and most of the development within the watershed occurs on the northern and southern ends of the lake. Belcher Creek is the main tributary of the lake and empties into the southern end of Greenwood Lake in New Jersey. The lake is a highly valued resource for both states and has a substantial impact on the local economies. Although highly valued, the lake has been documented to experience declined water quality conditions such as blue-green algal blooms. These poor water quality conditions have been attributed to elevated watershed-based pollutant loads from total phosphorus (TP).

In response to the documented water quality problems, a Total Maximum Daily Load (TMDL) analysis was developed in 2004 by the New Jersey Department of Environmental Protection (NJDEP) for the annual TP load entering Greenwood Lake. To address this issue, a Stormwater Implementation Plan (SIP) was developed for the New Jersey end of the Greenwood Lake Watershed in 2006 for the Greenwood Lake Commission (the Commission) and the Township of West Milford by Princeton Hydro, which linked the existing TP TMDL to existing and targeted loads from the New Jersey end of the watershed. The resulting SIP was an outline for a series of projects to be implemented within the New Jersey end of the Greenwood Lake watershed to comply with the regulatory requirements as detailed in the TMDL for TP. The SIP was approved by NJDEP in 2006 and was subsequently used to obtain funding for the implementation of a variety of stormwater control and watershed management projects over the past 14 years. Funding for these projects was obtained through two Clean Water Act Section 319 Non-Point Source pollution grants; one of which was the same grant (SFY2004 319-grant) that funded the SIP. To date, these projects have addressed approximately 50% of the required reduction to be in compliance with the TMDL in the New Jersey portion of the watershed.

While the original SIP for the NJ end of the Greenwood Lake watershed was extremely useful over the last decade as a guide in the implementation of projects to reduce TP loads, it has been updated in this document to better reflect current conditions and document other watershed-based improvements. Related to this is the fact that after the original plan was approved, NJDEP began to utilize the US Environmental Protection Agency (EPA) Nine Elements approach to develop a Watershed Implementation Plan (WIP). As such, this document follows the requirements for the EPA WIP that addresses nine specific elements. This type of plan then covers a wide range of topics including identification of water quality problems, determining the cause of these problems, identifying measures to correct the problems, securing the technical and financial assistance to implement the plan, and developing criteria, schedules, and a program for monitoring to track progress.

A sub-watershed analysis was conducted for the New Jersey end of the watershed during the creation of the original SIP to rank sub-watersheds from highest to lowest relative to the amount of human-generated TP. The sub-watersheds that drain directly into Belcher Creek, the main inlet to Greenwood Lake, generate the highest human-produced TP loads. These are also the highest developed sub-watersheds relative to land use and population. Thus, the majority of monitoring and sampling associated with this project focused primarily on these three sub-watersheds and Belcher Creek itself.

The early stages of this project focused on evaluating the TMDL compliance progress achieved thus far through the implementation of the watershed-based measures over the past 14 years. This evaluation was completed through a two-pronged approach both within the watershed and in Greenwood Lake. The first approach involved field assessments of each of the BMPs that have been implemented with 319 funds since the completion of the original SIP to determine their existing status and if any maintenance or clean-outs are required. Princeton Hydro coordinated with the Town of West Milford to access and inspect each project site. Stormwater samples were also taken from four (4) of these BMPs for the quantification of TP and TSS.

The second approach included general water quality monitoring of Greenwood Lake and its tributaries during the 2019 growing season (May through September) to provide an up-to-date water quality and ecological assessment of conditions within Greenwood Lake. It was critical that a set of growing season water quality sampling events, similar to those implemented back in 2005 and 2006 as part of the original SIP, were conducted so any changes or shifts in either in-lake or watershed (e.g. the tributaries) water quality conditions are documented. As such, an updated QAPP, an up-to-date water quality and ecological assessment of conditions in Greenwood Lake, and a comparison between the current (2019) and 2005 – 2006 datasets to identify any changes or shifts in water quality were completed.

After the completion of the various evaluation metrics, the focus was shifted towards determining the remaining watershed-based TP load that needs to be reduced for TMDL compliance and the various management measures necessary to achieve these reductions. This is essentially the most important component of the WIP and consists of a list of projects that could be designed and implemented to further reduce the TP, and other pollutants, loads entering Greenwood Lake. A considerable amount of time was spent in the field identifying potential project sites, with a focus on sites that have the capacity to accommodate green infrastructure.

As mentioned above, it has been previously determined that the sub-watersheds that drain directly into Belcher Creek generate the highest human-produced TP loads. Thus, the majority of the field assessments conducted were focused on these sub-watersheds. While the majority of the recommended projects are watershed-based and involve the implementation of various BMPs and/or MTDs in the areas surrounding Belcher Creek, many of the small streams that feed Greenwood Lake were also assessed for potential streambank/shoreline restoration projects. Finally, a field survey of Belcher Creek from where the Creek enters the lake up to the dam on Pinecliff Lake was conducted to identify potential problems that contribute to water quality issues in Greenwood Lake.

For each of the 22 identified locations, a proposed BMP/restoration measure is proposed along with an estimated cost for design and implementation as well as an estimated amount of TP that would be removed with the associated restoration measure. These measures include bioretention systems, constructed wetlands, pervious pavement, vegetated filters, bioengineered streambank stabilization, and MTDs that incorporate green infrastructure where possible, among others. In order to streamline the process of project acceptance and implementation, a prioritized implementation schedule is provided as well as different avenues to secure technical and financial assistance, including state and federal grants. Finally, the necessary components required to track the progress of implemented projects was provided, including interim measurable milestones such as the number of project demonstrations, evaluation criteria such as the amount of TP removed, and both project site and surface water monitoring components.

INTRODUCTION

Greenwood Lake is a 1,920-acre waterbody located in both Passaic County, New Jersey and Orange County, New York (Appendix I). The watershed encompasses approximately 16,036 acres and most of the development within the watershed occurs on the northern and southern ends of the lake. The lake is highly valued as an ecological, water quality and recreational resource for both New Jersey and New York. Given this high value, the lake has a substantially positive impact on the local economies of both States. In addition, the lake serves as a headwater supply of potable water that flows to the Monksville Reservoir and eventually into the Wanaque Reservoir, where it supplies over 2.3 million people with drinking water.

As a result of algal blooms and excessive densities of nuisance aquatic plants, a Phase I Diagnostic/ Feasibility Study was conducted of Greenwood Lake and its watershed in the early 1980's. Funds for this study were provided through the US EPA Clean Lakes Program (Section 314 of the Clean Water Act); subsequent funds were obtained through the Clean Lakes Program for a Phase II Implementation Program to eliminate point sources, conduct mechanical weed harvesting, and install several stormwater structures and retrofits to reduce the NPS pollutant load. Water quality improvements were documented in the first half of the 1990's, relative to conditions in the early 1980's. However, more recently collected water quality data documented Greenwood Lake's impaired condition, particularly in the New Jersey end of the lake.

A Stormwater Implementation Plan (SIP) was developed for the New Jersey end of the Greenwood Lake Watershed for the Greenwood Lake Commission (the Commission) and the Township of West Milford in the mid- 2000's (Princeton Hydro, 2006). Funding for the Plan was provided through the New Jersey Department of Environmental Protection's (NJDEP) Non-Point Source 319(h) Program and Princeton Hydro was hired to develop it. The watershed-based plan linked the existing total phosphorus (TP) Total Maximum Daily Load (TMDL), developed by NJDEP in 2004, to existing and targeted loads from the New Jersey end of the watershed (Appendix II). In turn, the NJ end of the watershed was divided into a series of sub-watersheds and a phosphorus loading priority analysis was conducted to rank the sub-watersheds from "high" to "low" relative to stormwater and watershed restoration needs.

The sub-watersheds that produce the highest human-related (e.g. residential, commercial, farmland, transportation, etc.) TP loads were ranked highest in terms of the prioritization of stormwater and other watershed-based projects. Not surprising, the three highest ranked sub-watersheds were those that immediately surround Belcher Creek, the main inlet of Greenwood Lake (Appendix I). Thus, this Watershed Implementation Plan (WIP) for the New Jersey side of the Greenwood Lake watershed will focus on, but not be limited to, these three sub-watersheds.

It should be noted that the original TMDL identified the targeted reductions in TP for both the New Jersey and New York ends of the Greenwood Lake watershed, in order achieve full water quality compliance. However, the 2006 SIP was funded through an NPS 319(h) grant by the NJDEP and so it focused on the New Jersey end of the watershed relative to watershed-based recommendations. Despite this, the water quality monitoring associated with the SIP did include locations in both states, although the focus was mostly the New Jersey side of the lake. As will be described in greater depth in this report, the in-lake and stream monitoring associated with this WIP mirrored that implemented back in 2005 and 2006 but is slightly expanded to include some limited monitoring associated with cyanotoxins.

Phosphorus is often the limiting nutrient in lake ecosystems, meaning the nutrient whose abundance is lowest relative to demand. This is particularly the case for freshwater systems and indeed holds for Greenwood Lake. As a result, phosphorus is often the primary nutrient responsible for excessive plant and algal growth. TP concentrations account for all species of phosphorus, including organic, inorganic, soluble and insoluble. Once the targeted TP loads for the New Jersey end of the watershed were established, the SIP identified prioritized locations where potential stormwater treatment measures, also known as Best Management Practices (BMPs), could be installed.

The resulting SIP was an outline for a series of projects to be implemented within the New Jersey end of the Greenwood Lake watershed to comply with the regulatory requirements as detailed in the TMDL for TP. The SIP was approved by NJDEP in 2006 and was subsequently used to obtain funding for the implementation of a variety of stormwater control and watershed management projects. The grants used to complete the projects around Greenwood Lake include two Clean Water Act Section 319 Non-Point Source pollution grants from NJDEP; one of these 319 grants was the same grant (SFY2004 319-grant) that funded the SIP. Additionally, the Township of West Milford received a grant under the federal Clean Water Act program 604(b) to create an "Onsite Wastewater Treatment System (OWTS) Management Plan" in 2006 for the New Jersey portion of the watershed. This OWTS Management Plan included passing an ordinance in 2008 for the mandatory pump-out of all septic system at least once every three years and have a State-certified contractor conduct a general inspection of the system at that time to obtain a license of operation from the Township.

While the original SIP for the NJ end of the Greenwood Lake watershed was extremely useful over the last decade as a guide in the implementation of projects to reduce TP loads, it should be updated to better reflect current conditions and document other watershed-based improvements. Related to this is the fact that after the original plan was approved, NJDEP began to utilize the US EPA Nine Elements approach to develop a Watershed Implementation Plan (WIP). Thus, those watersheds that have an approved WIP, including the 9 elements, have a substantially higher chance of obtaining State and Federal funding. Although some changes in land use may have occurred in the NJ end of the watershed, such changes are not expected to be substantial over the last 10 years. However, there have been a considerable number of advances in NPS pollutant reduction technology over this period of time. Additionally, the lake-wide blooms of cyanobacteria in Greenwood Lake over the summer of 2019 placed additional emphasis on the need to continue in the long-term efforts of reducing the TP loads in the lake and comply with the TMDL.

This document will address the nine (9) elements of a Watershed Implementation Plan as defined by the EPA. These nine elements are meant to address all phases of a WIP 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 (EPA, 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

SUMMARY OF THE NINE ELEMENT WATERSHED IMPLEMENTATION PLAN

This project includes a set of eight deliverables that are inter-connected but serve to develop a 9 element-based WIP for the NJ end of the Greenwood Lake watershed:

1. Conducting a detailed in-lake and watershed-based water quality monitoring program and compare the data to that collected in 2004 and 2005 to document changes or shifts in water quality
2. Meetings with the Township of West Milford, Passaic County and other stakeholders to conduct an inventory of recently completed BMPs and other watershed measures
3. Conduct a field-based evaluation of existing stormwater project that have been completed since the original Restoration Plan with 319-grant funds
4. Field site assessments to identify potential stormwater / watershed BMP projects
5. Field site assessment of Belcher Creek to identify potential projects to reduce the NPS pollutant loads that enter Greenwood Lake
6. Assembling the WIP with the 9 elements
7. Public and project meetings
8. Submission of final version of WIP and public presentation

These elements were all addressed while developing this WIP and will be presented in this document, although not necessarily in the above order.

1. IDENTIFICATION OF SOURCES OF POLLUTUON

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 Greenwood Lake, a summary of completed watershed measures, an updated pollutant loading estimate of the NJ end of the watershed, and a synopsis of water quality data in the lake. As previously stated, the TMDL developed in 2004 determined that TP was the pollutant of concern since it is recognized as the primary nutrient driving and stimulating algal and aquatic plant growth in Greenwood Lake.

A number of studies and projects have been conducted in the Greenwood Lake watershed over the last 15 years 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:

BRIEF SUMMARY OF THE TMDL AND THE STORMWATER IMPLEMENTATION PLAN

The total phosphorus TMDL for the New Jersey end of Greenwood Lake was established in September 2004 and subsequently established for the New York end of the lake by NYS DEC in 2005. TP was the primary pollutant of concern since it has been well established that Greenwood Lake is a phosphorus limited system, which means it takes very little phosphorus to stimulate substantial amounts of algal and aquatic plant growth. For example, one pound of phosphorus has the potential to generate up to 1,100 lbs of wet algae biomass. Thus, even moderate reductions in TP will have a measurable improvement in water quality. While the TMDL for Greenwood Lake focuses solely on TP, total suspended solids (TSS) was another pollutant of concern when designing and implementing the stormwater projects.

It was previously determined in 2004 that the single largest source of TP for Greenwood Lake originates from internal loading, which accounted for 42% of the annual TP load when the TMDL was created (Table 1). However, stormwater-based surface runoff and on-site wastewater treatment systems (i.e. septic systems) combined to account for over half of the lake's annual phosphorus load (Table 1). Of the surface runoff load, low density residential, high density residential, and commercial/industrial/transportation land types accounted for the highest, second, and third highest sources of stormwater-based TP, respectively. Together, these three land types accounted for approximately 64% of the total surface runoff load. The percent contribution of the various pollutant sources entering Greenwood Lake as of the TMDL creation in 2004 is presented in Table 1.

Table 1: Annual Total Phosphorus Load Entering Greenwood Lake, NJ-NY, as of 2004.

Source of Pollutant	TP Load (kg)	Percent Contribution
Surface Runoff	1,580	38
Septic Systems	710	17
Internal Loading	1,739	42
Point Sources	70	2
Atmospheric Sources	53	1
Total	**3,088**	**100**

Based on NJDEP's phosphorus TMDL analysis in 2004, the surface runoff TP load entering Greenwood Lake was 1,580 kg while the **targeted surface runoff TP load should be 1,088 kg** (NJDEP, 2004). Thus, in order to attain the targeted TP load, the required reduction was 492 kg. To assign these reductions in an objective, fair, and equitable manner, the TP load targeted for reduction was divided based on the area of land covered within each State's watershed. New Jersey accounts for 62% of the total watershed while New York accounts for 38%. Therefore, **New Jersey is responsible for reducing its existing surface runoff load by 305 kg**, while New York is responsible for reducing its existing surface runoff load by 187 kg, based off of the loading calculations in 2004. **The surface runoff TP load in the NJ end of the lake has since been reduced, and the current load and necessary reductions will be quantified and discussed at the end of this section and the beginning of the following section.**

Since addressing the surface runoff NPS pollutant load will reduce other pollutants such as TSS, NJDEP recommended that any implementation phase of the TMDL should focus on watershed management. Any serious consideration to address the internal phosphorus load will only be made after stormwater/ surface runoff pollutant contributions have been addressed.

While the TMDL quantified how much the existing TP load needs to be reduced in order to be in compliance with the TMDL targeted loads, the TMDL analysis did not describe how these reductions are to be achieved. Thus, as part of a previous 319-grant (RP04-081), a Stormwater Implementation Plan, essentially structured as a Watershed Implementation Plan, was developed for the New Jersey end of the Greenwood Lake watershed. This Plan was approved by NJDEP in April of 2006 and a similar plan was developed for the New York end of the watershed (Town of Warwick / Village of Greenwood Lake, Orange County, New York). Thus, the SIP was used as a guide in the selection of the projects that were identified for design and implementation. To briefly summarize, a sub-watershed analysis was conducted for the New Jersey end of the watershed to rank them from highest to lowest relative to the amount of human-generated TP. Obviously, sub-watersheds that have the highest amount of developed or agricultural-based lands would be ranked high, while those dominated by forested and wetlands would be ranked lower. Not surprising, sub-watersheds G, H and I, lands that drain directly into Belcher Creek the main inlet to Greenwood Lake, generate the highest human-produced TP loads (Appendix I). These are also the highest developed sub-watersheds relative to land use and population. Thus, the stormwater projects selected for design and implementation focused primarily on these three sub-watersheds. **The sub-watershed analysis and related pollutant loads will be discussed in greater detail in the following section.**

One of the first major steps in moving the SIP into the implementation phase was to request funds through the State's Nonpoint Source Pollution (NPS) 319(h) program. The 319(h) Program funds are provided by US EPA to designated state and tribal agencies to implement their approved nonpoint source management programs. The Commission has been awarded two 319-grants over the past 15 years for the implementation of watershed-based projects to reduce the TP loads entering Greenwood Lake; one in 2004 and one in 2007, as detailed below (Princeton Hydro, 2014).

NON-POINT SOURCE (319) IMPLEMENTATION PROJECTS

The Township of West Milford (Passaic County, NJ) and the Greenwood Lake Commission were awarded a Non-Point Source (NPS) (Section 319(h) of the Clean Water Act) grant by the New Jersey Department of Environmental Protection (NJDEP) to continue in their long-term efforts to reduce the non-point source (NPS) pollution entering the New Jersey-end of Greenwood Lake. The grant was awarded in SFY 2007 (RP07-052) and stormwater installation activities were completed in May of 2014. A total of six stormwater projects were designed and implemented. In addition to these six projects, two more additional projects were implemented as part of an older 319(h) grant (SFY2004; RP04-081). These projects mainly involved the installation of stormwater structures, including Manufactured Treatment Devices (MTDs), designed to aid in the reduction of TP and other pollutants of concern. MTDs are more structural means of reducing NPS pollution and frequently, but not always, include technologies that may be exclusively manufactured by one or several companies. Green infrastructure was also incorporated into these projects wherever possible.

PROJECTS INSTALLED UNDER THE 2007 319 GRANT:

- Installation of a nutrient separating baffle box (NSBB) MTD with a polisher unit within an easement off of Beaver Avenue between Greenbrook Drive and Belcher Creek. The NSBB simply allows particulate material to settle out in a series of multi-chambered basins. Thus, this BMP focuses primarily on addressing solids (TSS) and that portion of the phosphorus load adsorbed onto sediment particles. The polisher unit adds an extra step for the removal of dissolved forms of phosphorous. This MTD treats approximately 11 acres of land and the structures were installed in April of 2011.

- Installation of a 4' x 4' BaySeparator SV MTD along Birch Avenue at the intersection with Greenbrook Drive. This MTD treats approximately 7 acres of land and the structure was installed in April of 2011.

- Installation of a 4' x 4' BaySeparator SV MTD along Rutgers Avenue. This MTD treats approximately 3.4 acres of land and the structure was installed in April of 2011.

- Installation of a NSBB MTD along Adelaide Terrace near an unnamed tributary of Belcher Creek. This MTD treats approximately 6 acres of land and construction was completed in December of 2013.

- Installation of a NSBB MTD and vegetative filter along Durant Road near Belcher Creek. This MTD treats approximately 5 acres of land and construction was completed in December of 2013.

- Installation of a 6' x 6' Filterra tree box MTD at the intersection of Reidy Place and Millington Avenue. The Filterra is a smaller retrofit that can be integrated into existing stormwater infrastructure and combines a settling basin with an organic media / native vegetation mix to remove dissolved pollutants. The drainage area to this Filterra unit is approximately 0.5 acre; this project was completed in December of 2013.

In addition to these six projects, a Vortechnics MTD was installed at Greenwood Lake Turnpike and two vegetative filters were planted along Morestown Brook as part of an older 319(h) grant (SFY2004; RP04-081).

ESTIMATED ANNUAL POLLUTANT REMOVAL EFFICIENCY OF PROJECT BMPS AND MTDS

Some relatively simple modeling was used to quantify the annual pollutant TP and total suspended solids (TSS) removal rates associated with the installed BMPs / MTDs. The same NJDEP-selected, land-use, pollutant loading coefficients that were used to quantify the annual stormwater / surface runoff pollutant loads in the TMDL (NJDEP, 2004) were used in this modeling exercise. Specifically, both the land use type and the surface area of each land type were quantified for the drainage area of each installed stormwater structure. It should be noted that the two dominant land types for these structures were typically forested and medium / high residential, which are very typical of a land community in the Mid-Atlantic States. Using the land type loading coefficients and the associated land areas, the annual TP and TSS loads were calculated for each project site's drainage area, using methodology that was similar to that used by NJDEP in the TMDL. Percent loading removals were then ascribed to each MTD or BMP, based on other studies or identified in NJDEP's Stormwater Manual. These percent removals were used to calculate how much of the annual TP and TSS load was removed as a result of the installed MTDs or BMPs.

While the primary pollutant of concern for the TMDL is TP, the amount of TSS removed as a result of the installed stormwater structure was also quantified; a substantial portion of the phosphorus entering a waterbody from stormwater can be adsorbed onto sediment particles. Thus, since phosphorus does not have a gaseous phase, reducing the stormwater-based TSS load will directly contribute to reducing the TP load as well. In addition, elevated TSS loads negatively impact water quality, producing turbid, muddy conditions, reducing water depths which exacerbates rooted plant growth, and destroys spawning habitat for many desirable fish. Given the water quality and habitat impacts of TSS, reductions in TSS loads associated with the installed stormwater projects were also quantified as part of this study.

Based on information provided by the manufacturer, the BaySeparator SV MTDs have TP and TSS pollutant removal rates of 30% and 80%, respectively. The Vortechnics MTD device that was installed along Greenwood Lake Turnpike (as part of the SFY2004 319-grant) is estimated to have TP and TSS removal rates of 30% and 64%, respectively. In contrast to these other MTDs, the Filterra unit incorporates vegetation into its design, which assimilates dissolved forms of phosphorus, and TP and TSS removal rates for this MTD are reported by the manufacturer to be 65% and 85%, respectively.

For those stormwater structures that included a vegetated filter strip (Durant Road) the TP removal rate was increased by 10%. In contrast the TSS removal rate was not altered since the vegetated filter strip was composed of meadow cover and planted woody vegetation. If the filter strip was composed of an existing forested area, it would have been increased by approximately 10%. Finally, the two vegetated filter strips that were planted along Morestown Brook, again as part of the SFY2004 319-grant, were both ascribed TP and TSS removal rates of 30% and 70%, respectively.

Again, using a simplified pollutant modeling approach and the TP and TSS removal rates associated with each stormwater BMP / MTD, the amount of TP and TSS removed by each structure was calculated. The results for these TP and TSS analyses are shown below in Tables 2 and 3, respectively.

Table 2 - Summary of the Annual TP Removal Rates for West Milford, Passaic County Stormwater Projects Installed Under the Two Non-Point Source 319-grants.

Location	Source of 319(h) Funding	BMP / Action	Kg/yr	Lbs/yr
Reidy Place	SFY2007, RP07-052	Filterra Unit	0.5	1.1
Adelaide	SFY2007, RP07-052	NSBB	1.5	3.3
Durant Road	SFY2007, RP07-052	NSBB + vegetated filter strip	1.6	3.5
Rutgers Avenue	SFY2007, RP07-052	Bay Separator	0.7	1.5
Birch Avenue	SFY2007, RP07-052	Bay Separator	1.4	3.1
Beaver Avenue	SFY2007, RP07-052	NSBB + polishing unit	5.4	11.9
Greenwood Turnpike	SFY2004, RP04-081	Vortech unit	0.2	0.4
Morsetown Brook	SFY2004, RP04-081	Vegetated filter strips	0.3	0.7
Stormwater TP Removal Total Per Year			**11.6**	**25.5**

Table 3 - Summary of the Annual TSS Removal Rates for West Milford, Passaic County Stormwater Projects Installed Under the Two Non-Point Source 319-grants.

Location	Source of Funding	BMP / Action	kg/yr	lbs/yr
Reidy Place	SFY2007, RP07-052	Filterra Unit	798	1,755
Adelaide	SFY2007, RP07-052	NSBB	3,447	7,583
Durant Road	SFY2007, RP07-052	NSBB + vegetated filter strip	2,815	6,193
Rutgers Avenue	SFY2007, RP07-052	Bay Separator	2,168	4,770
Birch Avenue	SFY2007, RP07-052	Bay Separator	4,518	9,940
Beaver Avenue	SFY2007, RP07-052	NSBB + polishing unit	6,273	13,801
Greenwood Turnpike	SFY2004, RP04-081	Vortech unit	518	1,139
Morsetown Brook	SFY2004, RP04-081	Vegetated filter strips	956	2,103
Stormwater TSS Removal Total Per Year			**21,493**	**47,284**

FIELD-BASED ASSESSMENT OF EXISTING WATERSHED PROJECTS / BMPS

As mentioned above, after the New Jersey Restoration Plan for Greenwood Lake was completed, the Commission and the Township of West Milford received funds through the State's NPS, 319(h) program to design and implement a variety of watershed projects / BMPs to reduce the NPS pollutant load entering the lake, with an emphasis on TP. Princeton Hydro conducted field assessments of each of the aforementioned project sites to determine their existing status and if any maintenance or clean-outs are required. Princeton Hydro coordinated with the Town of West Milford to access and inspect each project site.

During an assessment on 10 April 2019, it was determined that all of the MTDs implemented under the 319 grants should be cleaned out, as they had not yet been cleaned this year. Princeton Hydro recommends that all the MTDs be cleaned out at least once a year to remove the accumulated sediment, organic matter, and garbage. The routine maintenance of these devices will ensure they function properly and remove the expected TP and TSS loads. Each of the MTDs exhibited different sediment and organic accumulations. It should be noted that all of the sites were inspected, although the Filterra unit on Reidy Place could not be opened and inspected due to the nature of the MTD. Also, the filter strips on Morestown Brook were visually inspected, but there is not much of a maintenance requirement with the filter strips. Princeton Hydro also conducted three storm sampling events at four MTD locations to quantify the pollutant removal efficiency of the different MTD types; **the results from the stormwater sampling will be provided in the Estimates of Load Reductions section of this report**. A brief description of the field assessments of the MTDs are included in Table 4 Below.

Table 4 – Field Based Assessments of Existing MTDs, 10 April 2019.

Location	MTD	Sediment Accumulation	Additional Notes
Adelaide Terrace	NSBB	1st Chamber: ~0.5 ft. 2nd Chamber: No accumulation	Not much sediment accumulation.
Durant Road	NSBB + vegetated filter strip	1st Chamber: ~2 ft. 2nd Chamber: ~0.5 ft.	Leaf litter accumulated in outlet.
Rutgers Avenue	Bay Separator	1st Chamber: 2 – 4 ft.	4 ft. sediment accumulation directly after pipe; 2 ft. accumulation in rest of chamber.
Birch Avenue	Bay Separator	1st Chamber: 2 – 4 ft. across 2nd Chamber: ~0.5 ft.	This MTD may have never been cleaned out since installation. Accumulation of garbage and floatables in 2nd chamber.
Beaver Avenue	NSBB + polishing unit	**First Box:** 1st Chamber: 1 – 2.5 ft. across 2nd Chamber: ~0.5 ft. **Second Box:** 1st Chamber: ~1.5 ft. 2nd Chamber: No accumulation	First chamber accumulation varied between 1" – 2.5". Garbage and floatables accumulated in 2nd chamber of first box.
Greenwood Turnpike	Vortech unit	1st Chamber: ~ 1 ft. 2nd Chamber: < 0.5 ft. 3rd Chamber: <0.5 ft.	Normally cleaned yearly. Accumulation of garbage and floatables in 2nd chamber.

ADDITIONAL WATERSHED MEASURES

Since the completion of the Restoration Plan a variety of watershed projects have been completed with State grants and other sources funding. However, other stormwater / watershed projects may have been completed since the establishment of the Restoration Plan that were not identified. It is important to identify and recognize these additional measures so that their contributing reductions for TP and TSS can be quantified and recorded toward the TMDL.

Two of these measures include the use of non-P fertilizers on residential lands and mechanical weed harvesting, both of which on the New Jersey side of the watershed and lake, which combined account for the removal of 66 kg of TP (Table 5).

Other measures include:

STREET SWEEPING

Increases in impervious cover within watersheds are often associated with increased pollutant loading due to the reduction of pervious land that naturally drains stormwater and removes pollutants. Increased populations that are often associated with increased impervious area tend to produce more trash that ends up in the streets. There are numerous street-sweeping technologies that provide varying sediment and nutrient reduction rates. West Milford Township employs the use of a mechanical broom sweeper and vacuum sweeper to clean the streets of West Milford.

Specifically, an Elgin Eagle Mechanical sweeper and an Elgin Whirlwind Vacuum sweeper are utilized to clean the streets of West Milford. The streets are swept once a year, directly after every winter season. Overall, this street sweeper cleans 120 miles of street total each run. This waste includes leaf waste, branches, road sand and garbage that has collected along the streets of West Milford.

Through the use of street sweeping as a BMP measure, nutrient and sediment loads are removed prior to entering the lake, as a watershed-based proactive measure. Street sweeping reduces approximately 1.0 kg TP and 680 kg TSS from entering the Greenwood Lake ecosystem per year (Table 5).

MANDATORY PUMP-OUTS FOR ALL ONSITE WASTEWATER TREATMENT SYSTEMS

This measure is a result of a Clean Water Act program 604(b) grant that the township of West Milford received to create an "Onsite Wastewater Treatment System (OWTS) Management Plan" in 2006 for the New Jersey portion of the watershed.

As stated in Ordinance No. 2008 – 050, the Township established a Management Program for OWTSs "in order to ensure the proper operation and maintenance of such systems." A key component of this Program is that all OWTSs be pumped out at least once every three (3) years in order to minimize future malfunction. Removing the accumulated sludge from a septic tank on a regular basis will minimize the amount of particulate material that flows into the drain field. Particulate material in the drain field severely reduces its capacity to properly treat wastewater and remove pollutants such as phosphorus. Thus, regular pump-outs of a septic tank are a very cost-effective means of maximizing an existing system's ability to remove pollutants.

While the Township's ordinance pertains to all operating OWTSs, the OWTS Management Plan focuses only on those systems within the established Zone of Influence (ZOI). Based on the Township's GIS database, there are 1,632 OWTSs within the ZOI; approximately 84% of these systems are within the Targeted Zone (sub-watersheds G, H, and I; Appendix I). It should be noted the ordinance pertains to all OWTSs since a system can still have undesirable impacts related to local health (i.e. contamination of wells).

Pumping out the OWTSs within the ZOI should contribute toward reducing the TP load entering the waterways within the New Jersey end of the Greenwood Lake watershed. In order to quantify this for the TMDL, a number of studies were reviewed. For example, it has been stated that a properly functioning septic tank retains up to 48% of the phosphorus that enters the tank (Gold, 2006). However, studies conducted in the Cannonsville Reservoir watershed, New York, have estimated that between 20 - 30% of the TP from raw wastewater is separated out as sludge, which accumulates in the bottom of the septic tank (Day, 2011). Thus, for the OWTS Management Plan, a conservative removal rate of 10% per tank was used to calculate how much TP would be removed from the annual load once all tanks are pumped out on a routine schedule of at least once every 3 years. The removal rate was lowered to 10% for two reasons. First, there are large data gaps in the OWTS database and many of the existing systems are known to be at least 35 to 50 years old. In the absence of an extensive database, it is prudent to assume that many of these systems are operating on a sub-optimal capacity and lowering the removal rate to 10% will account for some of this in the model. Second, lowering the removal rate to 10% also contributes toward accounting for an implicit margin of safety for the TMDL analysis.

Since, as per the Township's ordinance, all septic tanks are required to be pumped out at least once every three years, with subsequent proof of action through certification, it was assumed that all OWTSs within the ZOI will participate in this management action. The median TP concentration down gradient of the municipal septic leach field and estimated water consumption were used to calculate a median per tank load of 0.44 kg of TP per year. In turn, this loading rate was multiplied by the number of OWTSs within the ZOI and then by 0.1 to calculate how much TP would be removed on an annual basis once all of the residents are in compliance with the three-year mandatory pump-outs. The resulting annual removal rate was 73 kg (Table 5).

TMDL PROGRESS

Based on all of the in-lake and watershed projects completed after the TMDL was established and the original Stormwater Implementation Plan was implemented, the amount of TP removed from the NJ end of the watershed on an annual basis is estimated to be 151.6 kg. This accounts for approximately 49.7% of the amount of TP targeted for removal under the existing TMDL for Greenwood Lake. Thus, the New Jersey end of Greenwood Lake still needs to reduce the TP load by 153.4 kg to be in compliance with the TMDL. In contrast, a similar analysis has not been completed for the NY end of the watershed, and any reductions in TP loading from NY are unknown at this time. Thus, it will be assumed that the TP load entering Greenwood Lake from NY is the same as it was when the TMDL was established in 2004, and any reductions in TP loading discussed in this report will be referring to the NJ end of the watershed. Table 5 quantifies the total amount of TP removed on an annual basis from NJ.

Table 5 – Summary of the Management Activities in the NJ end of the Greenwood Lake Watershed (Passaic County, NJ) and their associated annual Total Phosphorus Removal Rates.

Location	BMP / Action	kg/yr	Lbs/yr
Reidy Place	Filterra Unit	0.5	1.1
Adelaide Terrace	NSBB	1.5	3.3
Durant Road	NSBB + vegetated filter strip	1.6	3.5
Rutgers Avenue	Bay Separator	0.7	1.5
Birch Avenue	Bay Separator	1.4	3.1
Beaver Avenue	NSBB + polishing unit	5.4	11.9
Greenwood Lake Turnpike	Vortech unit	0.2	0.4
Morsetown Brook	Vegetated filter strips	0.3	0.7
NJ end of the watershed	non-P fertilizers on residential lands	47	103.4
NJ end of the watershed	mandatory pump-outs of OWTSs	73	160.6
NJ end of the lake	mechanical weed harvesting	19	41.8
NJ end of watershed	street sweeping	1.0	2.2
Total		**151.6**	**333.5**

SYNOPSIS OF WATER QUALITY DATA

Princeton Hydro, LLC conducted general water quality monitoring of Greenwood Lake during the 2019 growing season (May through September) to provide an up-to-date water quality and ecological assessment of conditions within Greenwood Lake. Greenwood Lake had not been monitored under a State-approved Quality Assurance Protection Plan (QAPP) since 2005. Thus, it was absolutely critical that a set of growing season water quality sampling events, similar to those implemented back in 2005 and 2006, 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 an updated QAPP (Appendix III), an up-to-date water quality and ecological assessment of conditions in Greenwood Lake, and a comparison between the current (2019) and 2005 – 2006 datasets to identify any changes or shifts in water quality (Appendix IV).

The current water quality monitoring program is valuable in terms of assessing the overall "health" of the lake, identifying 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 continues to be an important component in the evaluation of the long-term success of the implementation of the phosphorus TMDL-based Restoration 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 Greenwood Lake.

This section will include the materials and methods associated with the 2019 water quality sampling, a summary of the 2019 findings, and a comparison between the 2005 – 2006 and 2019 data. The full 2019 QAPP can be found in Appendix III. Additionally, the full Greenwood Lake Water Quality Report 2019 is included in Appendix IV.

MATERIALS AND METHODS

In-lake water quality monitoring was conducted at the following five (5) locations in Greenwood Lake (represented in Figures 1 and 2, Appendix A of the full water quality report):

Station Number	Description
L1	New York, northernmost mid-lake station
L2*	New York, mid-lake station
L3	New Jersey, mid-lake station
L4	New Jersey, near-shore outlet station at mouth of Belcher Creek
L5	New Jersey, southern near-shore station

* *In-situ* monitoring only

The 2019 sampling dates were 13 May, 11 July, and 23 September. A Eureka Amphibian Personal Digital Assistant (PDA) with Manta multi-probe unit was used to monitor the *in-situ* parameters: dissolved oxygen (DO), temperature, pH, and specific conductance during each sampling event. Data were recorded at 1.0 m increments starting at 0.25 m below the water's surface and continued to within 0.5-1.0 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 the end of the full water quality report.

Discrete water quality samples were collected with a Van Dorn sampling device at 0.5 m below the lake surface, at mid-depth and 0.5 m above the sediments at the mid-lake stations L1 and L3. Discrete samples were collected from a sub-surface (0.5 m) position at the remaining two (2) shallow sampling stations (L4 and L5). Discrete water samples were appropriately preserved, stored on ice, and transported to a State-certified laboratory for the analysis of the following parameters:

- total suspended solids
- total phosphorus-P
- total dissolved phosphorus-P
- soluble reactive phosphorus-P
- nitrate-N
- ammonia-N
- chlorophyll *a*

Monitoring at station L2 consisted of collecting *in-situ* and Secchi disk data; no discrete water samples were collected from this station for laboratory analyses. Discrete data can be found in Appendix C at the end of the full water quality report.

During each sampling event, surface and mid-depth grabs well collected at stations L1 and L3 for phytoplankton quantification. A Schindler trap was also used to sample zooplankton densities at surface and mid-depths at these stations. Surface grab samples were also taken at near-shore or beach areas on both the New Jersey and New York ends for phytoplankton quantification and cyanotoxin testing. Phytoplankton data can be found in Appendix D at the end of the full water quality report.

Tributary monitoring was also conducted at eight (8) tributaries entering Greenwood Lake, with two established at the NY end and six at the NJ end. These eight stations were monitored during the 2004-2006 monitoring program. *In-situ* and discrete monitoring for TP and TSS were conducted at each stream sampling.

2019 SUMMARY

This section provides a summary of the 2019 water quality conditions observed at Greenwood Lake.

1. Thermally stratified waters were noted in the deeper waters by the first sampling event, which then persisted throughout the remainder of the growing season. The waters were well oxygenated during the first sampling event, only dropping below the recommended DO threshold at the sediments. By the July event, the deep-water stations became anoxic at 5 meters. Anoxic conditions persisted at L1 and L2 through the September sampling, while ample DO was noted at the shallower stations.

2. A TMDL was established for TP in the New Jersey end of Greenwood Lake. TP concentrations in the surface waters of Greenwood Lake varied between non-detectable concentrations and 0.05 mg/L. TP concentrations contravened the TMDL upper limits during both the May and July sampling events. Deep water concentrations consistently exceeded the TMDL target during the 2019 season. Extremely elevated TP was noted in the deep waters of L1 due to extended periods of anoxia causing internal loading of P.

3. Elevated cyanobacteria densities were noted throughout the 2019 season at Greenwood Lake. Stations L1 and L3 both yielded algal densities above the NJDEP Health Advisory Guidance Level and were characterized as Moderate or High by WHO criteria throughout the season. During the July monitoring event, both the NJ and NY beach shoreline exceeded the NJ Health Advisory Guidance Level, characterized as High and Moderate, respectively, by WHO criteria. By the final sampling, both the NY and NJ beaches were characterized as "Moderate" by WHO standards. However, overall microcystin and cylindrospermopsin levels remained below their respective NJDEP draft recreational health advisories at each station during each sampling events.

4. Stream sampling showed elevated TP throughout the season. TP contravened TMDL standards during each sampling event. T6 yielded the most elevated TP throughout the season with maximum concentrations of 1.80 mg/L.

INTERANNUAL ANALYSIS OF WATER QUALITY DATA

A similar monitoring program was conducted during the 2005 - 2006 season. Data collected during the 2005 and 2006 seasons will be utilized for comparison to those in 2019. The main focus for this interannual comparison will be placed on the 24 August 2005, 1 August 2006 and 11 July 2019 sampling data. The reason for focusing on these mid-summer dates is because this is the most consistent time of year with sampling data available from the two different timeframes. The water quality data from 2005 – 2006 has additional data from April and November, but these months are at the very beginning and end of the growing seasons and won't necessarily provide a consistent comparison to the 2019 sampling dates. Similarly, mean values taken from April, August, and November from 2005 – 2006 would not provide a consistent comparison to mean values calculated from the 2019 sampling months of May, July, and September. Nutrient concentrations, especially TP, are going to be higher during the peak growing season months, and the most accurate comparison with the available data series includes a comparison of the peak growing season months of August and July.

Thermal stratification was noted during each of these three sampling events, with strong stratification noted at the deeper stations. L3 was well-mixed during the 2005 and 2006 sampling seasons, only exhibiting slight stratification in the bottom meter of the lake during the 2019 sampling. Persistent thermal stratification in the deeper stations caused anoxic conditions starting at 5-7 meters during each of the three sampling events at L1 and L2. During the 2005 and 2006 samplings, DO declined below the 5.0 mg/L threshold above the sediments at L3. In contrast, ample DO was noted throughout the water column at L3 during the 2019 sampling. Water clarity was variable throughout the sampling period. The deep-water station L1 exceeded the 1.0 m threshold during each sampling season, with maximum Secchi depth noted in 2006 (2.4 m). The shallower L3 had Secchi depths ranging from 0.5 m during 2005 to 1.3 m during 2006. Clarity dropped below the 1.0 m threshold during both 2005 and 2019 (0.9 m).

TP concentrations at the surface of both mid-lake stations L1 and L3 declined as time progressed (Figure 1). TP dropped from 0.05 mg/L and 0.07 mg/L during the 2005 season, to 0.02 mg/L and 0.03 mg/L in 2006, down to non-detectable concentrations (ND < 0.01 mg/L) and 0.01 mg/L, respectively, during the 2019 season. Surface TP concentrations were at or below the TMDL upper limit of 0.03 mg/L at both of these stations in 2006 and 2019. Surface TP concentrations were slightly higher at the shallower near-shore stations L-4 and L-5 during each year, though 2005 concentrations were much higher than 2006 and 2019, similar to the trend observed at the mid-lake stations.

Both mid-depth and deep-water TP concentrations at L1 were very similar in each year, varying between 0.02 mg/L and 0.03 mg/L (Figure 1). Deep water TP was variable at L3 during this sampling period, ranging from a minimum of 0.04 mg/L during 2006 up to 0.07 mg/L during 2005; the 2019 deep sample was in between those values at 0.06 mg/L. Deep TP concentrations are not likely to be as affected by watershed measures as surface TP concentrations, especially in the relatively short timeframe of 14 years; growing season TP concentrations in the hypolimnion of a stratified lake are usually higher than surface TP concentrations as a result of the internal cycling of phosphorus from anoxic bottom sediments. The bottom sediment contains legacy phosphorus that has built up over time and can continue to release from the bottom sediment during periods of hypolimnetic anoxia for years to come.

Surface soluble reactive phosphorus (SRP) concentrations during each year were relatively low, only exceeding 0.002 mg/L one time at L-5 in 2019 (Figure 2). Deep SRP concentrations were much higher at L-1 but decreased with time, from 0.011 mg/L in 2005 down to 0.004 mg/L in 2019. Similarly, deep SRP at L-3 was high in 2005 with a concentration 0.009 mg/L, but low during 2006 and 2019 with a concentration of 0.001 mg/L (Figure 2). Surface total dissolved phosphorus (TDP) concentrations were below the detection limit of 0.01 mg/L at all stations in 2019; surface concentrations in the previous years were much higher, varying between 0.01 mg/L and 0.02 mg/L. Deep TDP concentrations were much higher at L-1, but decreased with time, from 0.03 mg/L in 2005 down to 0.01 mg/L in 2019 (Figure 3). Deep concentrations at L-3 followed a similar trend, from a concentration of 0.02 mg/L in 2005, down to < 0.01 mg/L in 2019.

Surface chlorophyll *a* concentrations were variable from year to year but were highest in 2005 and lowest in 2006 (Figure 4). It is not surprising that chlorophyll *a* concentrations were highest in 2005, as TP concentrations were much higher at all stations during this year. Chlorophyll *a* is a pigment possessed by all algal groups that is used in the process of photosynthesis. Chlorophyll *a* concentrations are used as a means of quantifying algal biomass in a waterbody. In general, chlorophyll *a* concentrations greater than 20 µg/L are considered unfavorable for recreational water use. Chlorophyll *a* concentrations are directly linked to algal biomass, and therefore can often be correlated with TP concentrations. Chlorophyll *a* concentrations were elevated at all stations other than L-1 during the 2019 season (Figure 4). Similar to 2005, this is not surprising as TP concentrations were also elevated at these stations in 2019. The spring of 2019 was very wet, followed by hot temperatures throughout the summer and short but intense rainstorms; these conditions are favorable for phytoplankton, and especially cyanobacteria as was witnessed in Greenwood Lake and many lakes in the northeast this past year. The heavy precipitation continually washed nutrients and other allochthonous material from the watershed into the lake, providing a source of nutrients for the cyanobacteria to feed on early in the season.

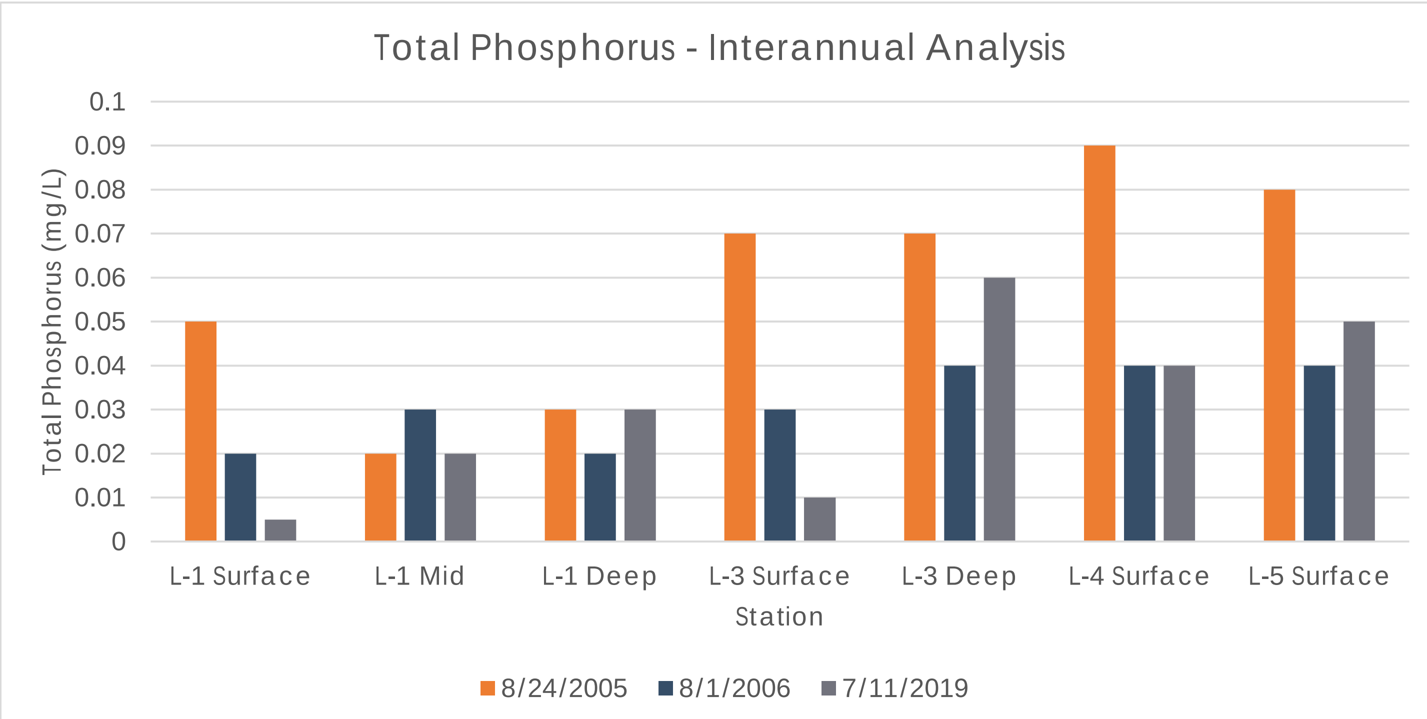


Figure 1: Total phosphorus concentrations in Greenwood Lake from 2005, 2006, and 2019.

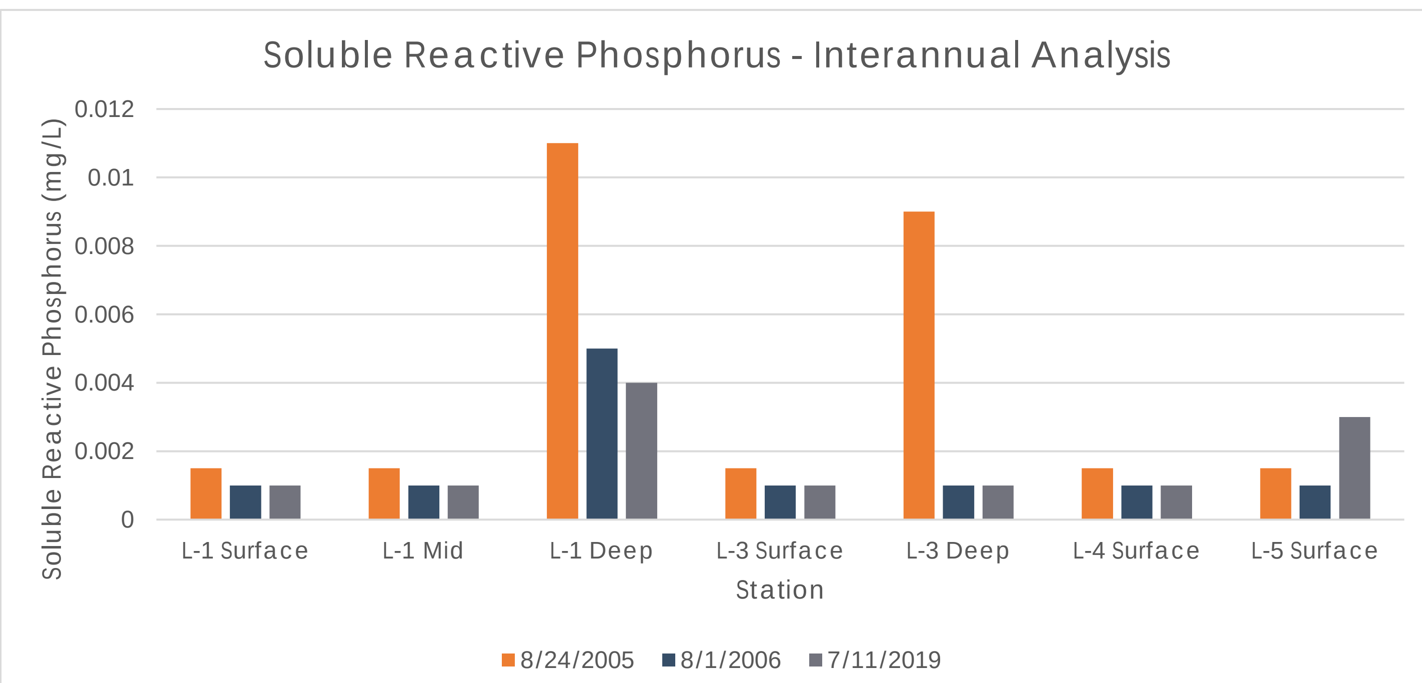


Figure 2: Soluble reactive phosphorus concentrations in Greenwood Lake from 2005, 2006, and 2019

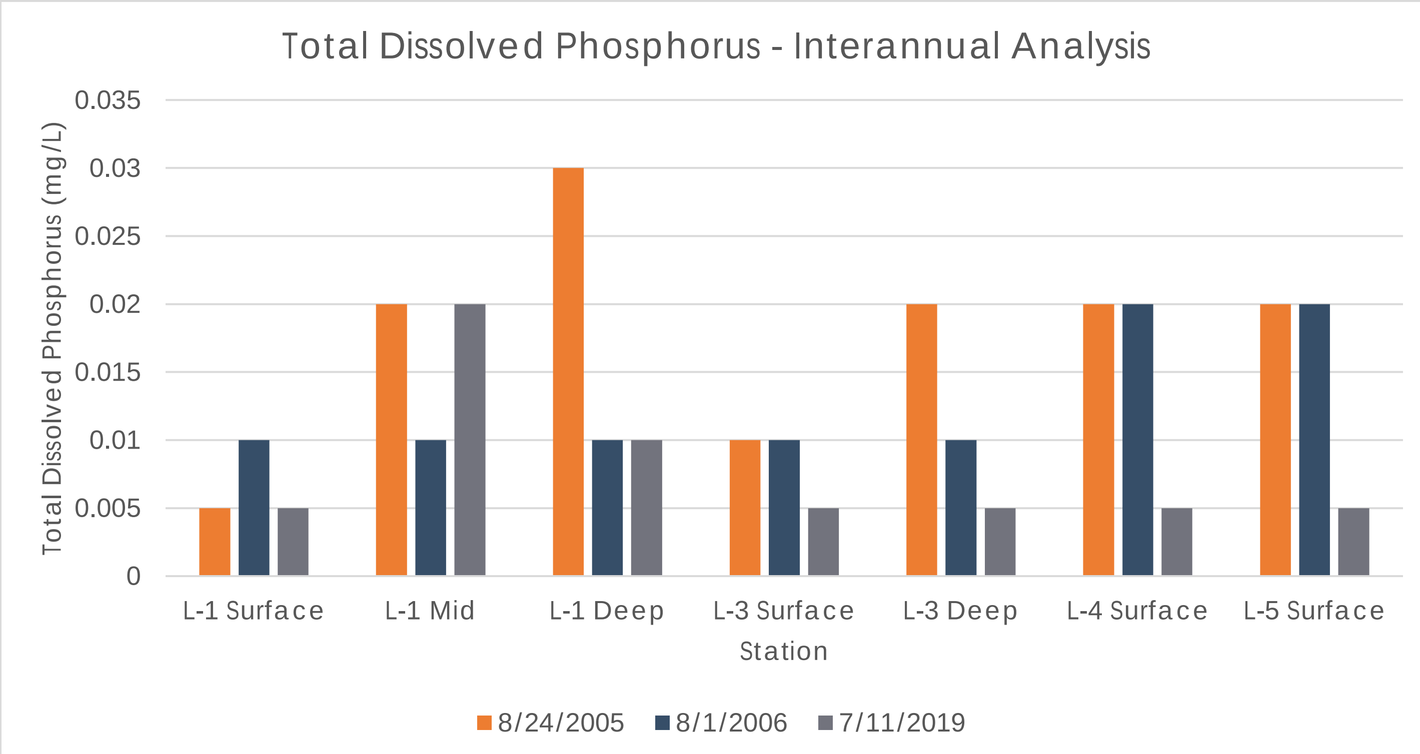


Figure 3: Total dissolved phosphorus in Greenwood Lake in 2005, 2006, and 2019.

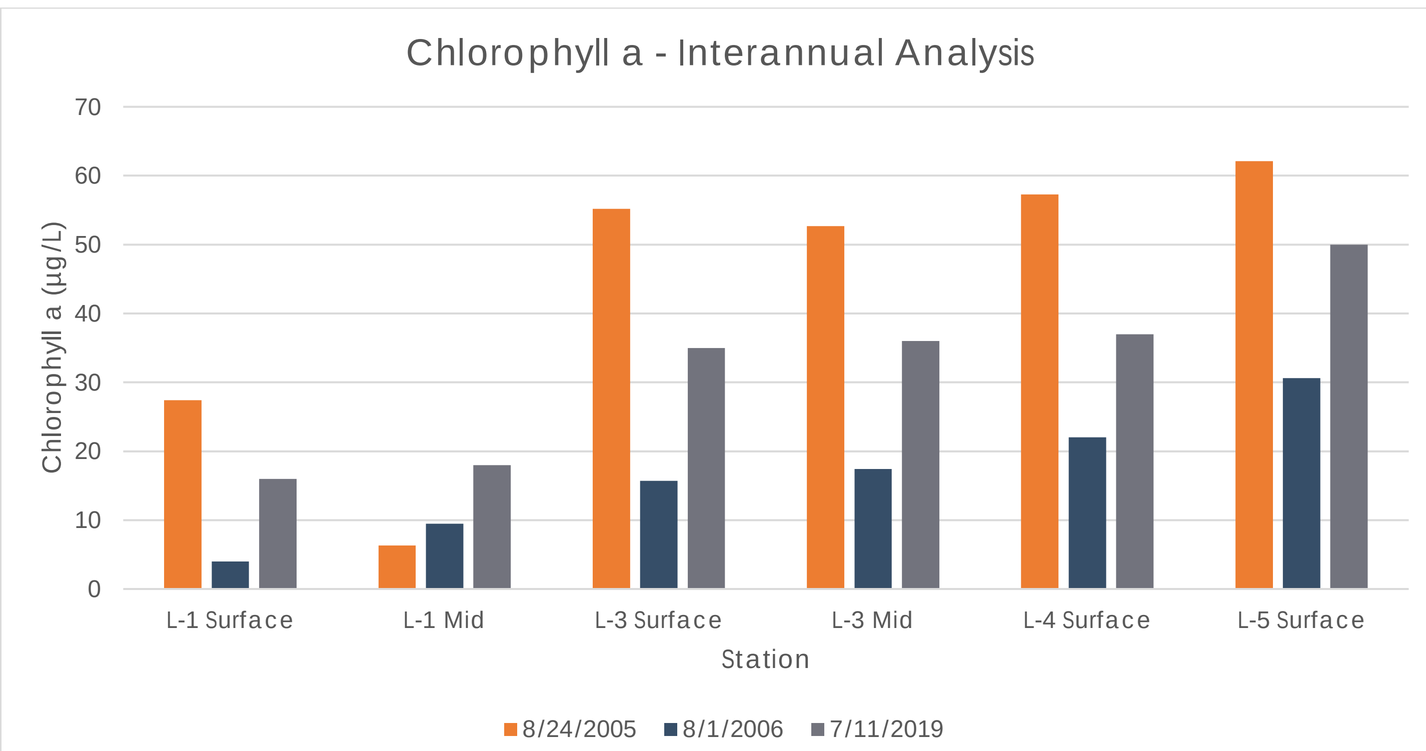


Figure 4: Chlorophyll *a* concentrations in Greenwood Lake in 2005, 2006, and 2019.

In addition to lake monitoring throughout the 2019 season, Princeton Hydro conducted sampling of various tributaries of Greenwood Lake (Appendix A at the end of the full water quality report). The purpose of this sampling was to determine sources of nutrient loading throughout the watershed in order to locate areas which may be prioritized for management efforts. Similar to the in-lake sampling, the tributary sampling in 2019 was conducted at the same sites that were sampled during the 2005 – 2006 season. Locations of all tributary sampling sites can be found in Appendices A and B at the end of the full water quality report. The tributaries were all sampled and analyzed for TP, and the results are presented in Figure 5 for 2005 – 2006 and Figure 6 for 2019.

Overall, nutrient loading in the various tributaries followed similar trends in 2019 to those observed in 2005 – 2006. For example, T-6 had the highest nutrient concentrations during both time periods, although the July and September sampling events in 2019 were much higher than those observed in 2005 – 2006; TP concentrations reached a maximum of 1.8 mg/L on 11 July 2019. Sampling site T-5 had the second highest TP concentrations during both time periods, although the July event was again much higher in 2019. All other tributaries were much lower in TP concentrations than T-5 and T-6 during both time periods, with nutrient concentrations varying between 0.005 mg/L – 0.1 mg/L. All other tributaries did not necessarily exhibit a reduction in TP concentrations between the time periods, and in many locations were often slightly higher in 2019. TP concentrations in all tributaries besides T-5 and T-6 were slightly elevated at times, although never exceeded the New Jersey Surface Water Quality Standard of 0.1 mg/L for TP in streams. It is clear that tributary locations T-5 and T-6, located at the outlet from the former West Milford Lake at Marshall Hill Road and Morestown Brook at Marshall Hill Road, respectively, are significant sources of TP loading to Greenwood Lake and are ideal locations for the implementation of BMPs.

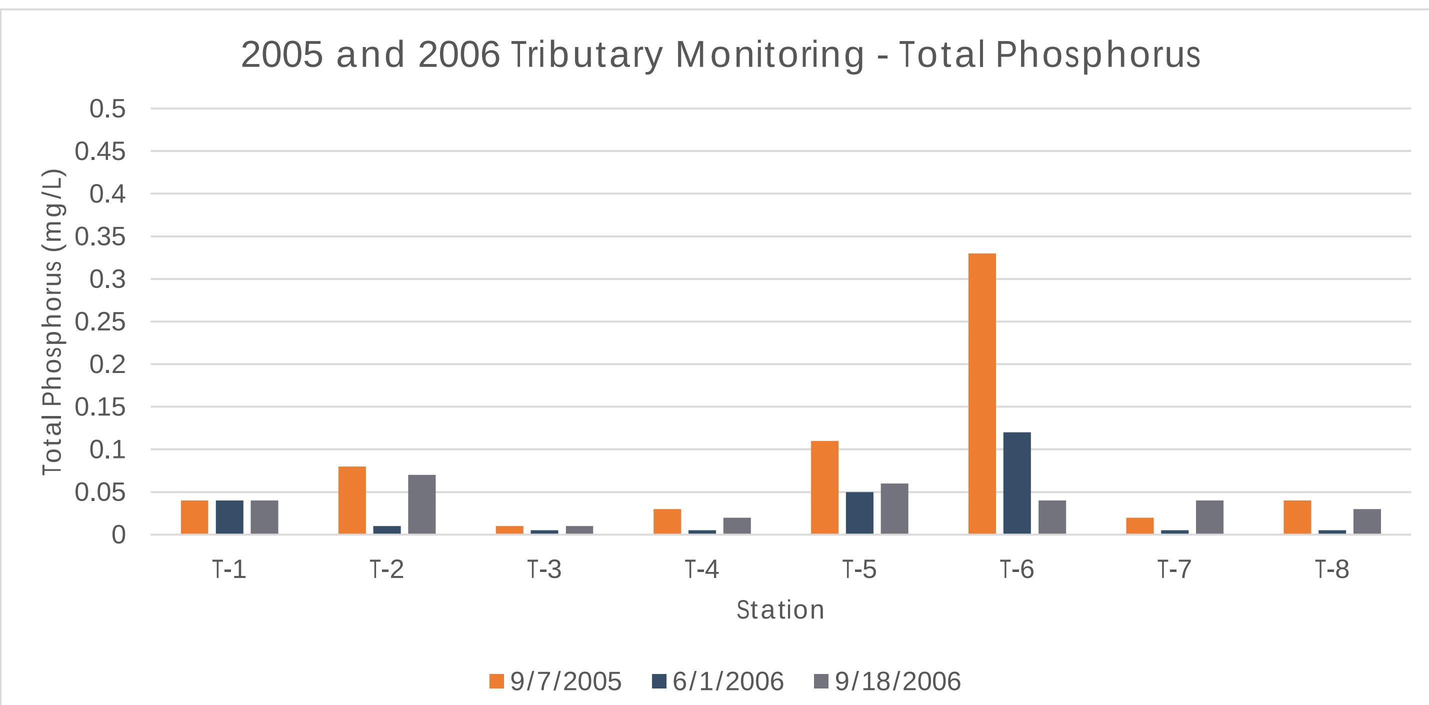


Figure 5: Total phosphorus concentrations in tributaries of Greenwood Lake on 7 September 2005, 1 June 2006, and 18 September 2006.

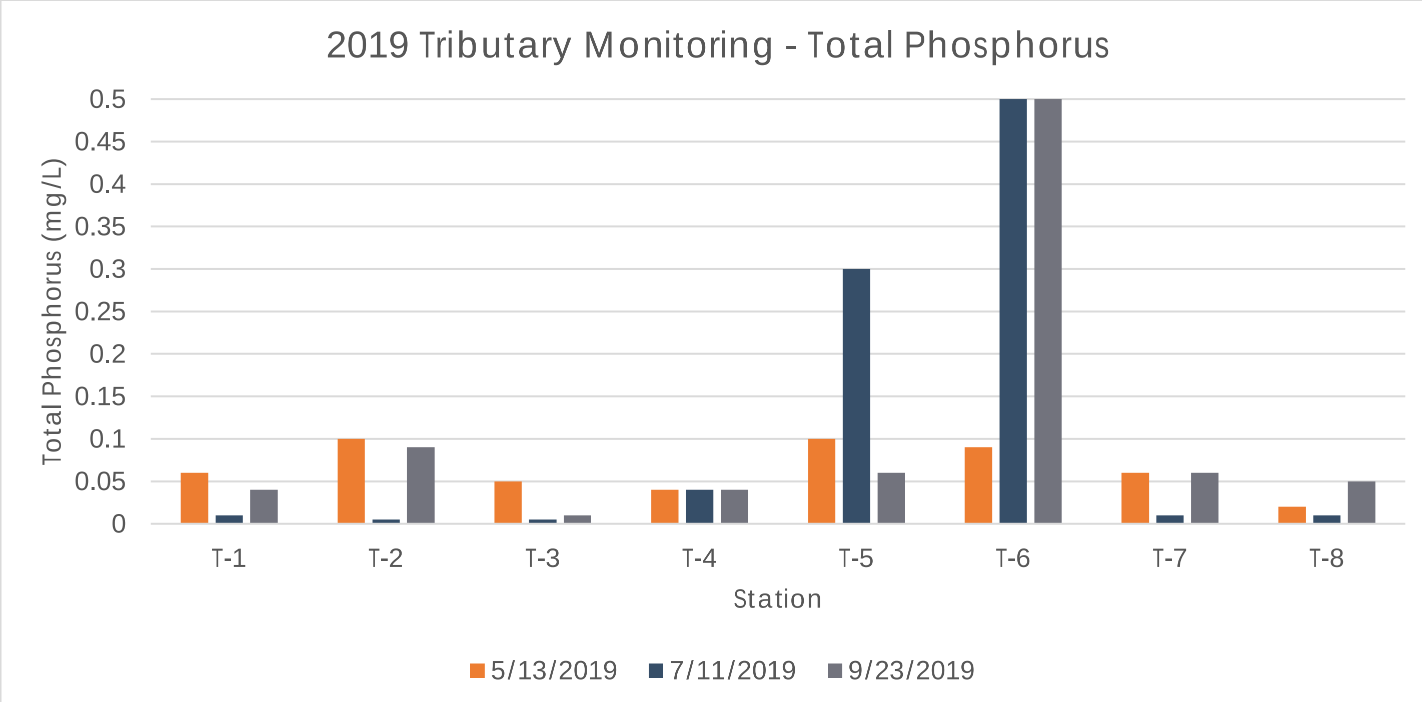


Figure 6: Total phosphorus concentrations in tributaries of Greenwood Lake on 13 May 2019, 11 July 2019, and 23 September 2019.

***Note that the actual values for 11 July 2019 and 23 September 2019 are 1.8 mg/L and 0.89 mg/L, respectively. The x-axis stops at 0.5 mg/L so all other values can be visually represented.**

INTERANNUAL TROPHIC STATE INDEX

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 chlorophyll *a* concentrations 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. Carlson's trophic state index for L1 and L3, as based on chlorophyll *a*, total phosphorus concentrations and Secchi disk depths are hereby presented in Table 6.

Table 6 - Historic TSI at Greenwood Lake				
Parameter	**Station**	**8/24/2005**	**8/1/2006**	**7/11/2019**
TP	L1	59	47	37
	L3	65	53	37
Chl *a*	L1	63	44	58
	L3	70	58	65
Secchi	L1	59	47	54
	L3	67	56	62

TSI was highest during the 2005 season, with TSI values ranging from 59 to 70 at L1 and L3. Values noted during the 2005 sampling year were indicative of eutrophic waterbodies and blue-green and macrophyte dominated communities. Chlorophyll *a* concentrations were greater than Secchi depth and TP, which is suggestive of large particulates like *Aphanizomenon* colonies. TSI declined at both L1 and L3 by 2006, ranging from 44 to 58. Mesotrophic conditions were noted at the deep station, as L1 yielded a marked decline in TSI with measures of 44 and 47 noted. Eutrophic conditions were still noted at L3 during this event. TSI was variable by the 2019 sampling season, with values ranging from 37 to 65. Overall, TP values were low, yielding a TSI of 37 at both L1 and L3. Both TSI based on Secchi and Chlorophyll *a* were indicative of eutrophic conditions, with slightly elevated TSI at L3 comparatively due to high cyanobacteria and macrophyte densities. Overall, TSI values were continuously elevated in the New Jersey end of the lake compared to the New York end during each sampling year.

SUMMARY OF INTERANNUAL DATA

Overall, 2005 had the highest values for all of the major trophic state indices, including TP, Secchi depth, and chlorophyll *a*; 2005 also had higher concentrations of SRP and TDP than 2006 and 2019. The trophic state indices for 2006 and 2019 were rather variable, although surface TP concentrations in the mid-lake stations were much lower in 2019. Conversely, chlorophyll *a* values were higher and Secchi depths lower in 2019 relative to 2005; these two indices are directly related, as increased algal densities (chlorophyll *a*) results in reduced water clarity (Secchi depth).

As far as progress between the two time periods stands, surface TP concentrations at the mid-lake stations in 2019 were clearly lower than the 2005 – 2006 values. As mentioned earlier, the increased algal densities (chlorophyll *a*) and related decreases in Secchi depths in 2019 are likely in part due to the climatic conditions experienced in northern New Jersey during the 2019 season. The spring of 2019 was very wet, followed by hot temperatures and short but intense rainstorms throughout the summer; these are considered to be favorable conditions for phytoplankton, and especially cyanobacteria, as witnessed in Greenwood Lake and many lakes in the northeast this past year. The heavy precipitation in the spring continually washed nutrients and other allochthonous material from the watershed into the lake, providing a source of nutrients for the cyanobacteria to feed on early in the season. A review of the full 2019 sampling data available in Appendix IV reveals that mid-lake TP concentrations were much higher (0.04 mg/L) at the surface stations during the wet spring, before dropping back down to levels that did not exceed 0.01 mg/L in July. Essentially, the blue-greens likely established a dominance over the algal community early in the season, and because of the climatic conditions mentioned above (short, intense summer rain storms), were able to dominate the algal community throughout the entirety of the 2019 season, even with relatively low TP concentrations; this in turn resulted in increased chlorophyll *a* concentrations and decreased Secchi depths. The TP concentrations were high enough early in the season to establish the community, and the other ‘healthy’ genera, such as the greens and diatoms, were never able to establish themselves at the same level that the blue-greens did. The intense rain storms during the summer resulted in pulses of TP loading from the watershed into the lake, which likely got assimilated rather quickly by the algae present in the surface waters.

In summary, surface TP values at the mid-lake stations during the peak summer months were lower in 2019 relative to the 2005 – 2006 values, a positive sign regarding the watershed measures that have been implemented during this time period with the intension of reducing TP loading to the lake. Unfortunately, chlorophyll *a* and Secchi depth values did not respond accordingly in 2019, but as mentioned above, this is likely in part due to the prevailing weather patterns experienced during the spring and summer. It is important to note that comparisons based on single sampling dates is limited in utility because water quality conditions fluctuate throughout the season, but as mentioned earlier in this section, the mid-summer dates of July and August provide the most consistent comparison in our database. It would be greatly beneficial to continue a monitoring program similar to that of 2019 for consecutive years in order to build a long-term database; this would make it possible to confirm that the 2019 season was indeed largely influenced by the weather and would allow for consistent seasonal means to be calculated and compared between years.

2. ESTIMATES OF LOAD REDUCTIONS

This section corresponds to the second US EPA element, an estimate of load reductions expected from management measures. As recommended by the US EPA, this section will focus on presenting the required load reductions per sub-watershed for Greenwood Lake that have been outlined in the TMDL and the original Stormwater Implementation Plan. **As previously mentioned, this section of the report will focus on the NJ end of the watershed.**

GENERAL APPROACH FOR ADDRESSING STORMWATER TOTAL PHOSPHORUS LOADS ENTERING GREENWOOD LAKE

Based on a combination of water quality monitoring/testing and simplified modeling, it was determined that all of implemented in-lake and watershed-based management measures have resulted in a reduction of the targeted TP load by 49.7% or approximately 151.6 kg per year (334 lbs / year) (Table 7). While these reductions in phosphorus have resulted in improvements in some sections of the lake and watershed, overall water quality conditions in the lake still need improvement. This was particularly obvious during the 2019 growing season when elevated TP concentrations in May 2019 resulted in cyanobacterial blooms that persisted through the summer season. Thus, efforts need to continue to reduce the lake's annual TP load in order to comply with its TMDL and attain desired water quality conditions.

Table 7: Existing and Targeted Total Phosphorus TMDL for Greenwood Lake as of 2019.

Described Scenarios	TP in kgs (lbs) per year
Annual TP load targeted for removal	305 kg (672 lbs)
Amount of TP removed between 2006 and 2018	151.6 kg (337 lbs)
Required percent reduction to attain targeted TP load	50.3 %
Amount of TP remaining to be removed	153.4 kg (335 lbs)

OBJECTIVE PRIORTIZATION OF SUB-WATERSHEDS FOR THE WATERSHED IMPLEMENTATION PLAN

As part of the creation of the original Stormwater Implementation Plan, The New Jersey end of the Greenwood Lake watershed was divided into sub-watersheds, identified as A through P (Appendix I). Again, for the sake of this analysis and this Plan, the focus is on the New Jersey end of the watershed, including sub-watersheds A through N. While sub-watersheds O and P are located in both New York and New Jersey, the majority of their land is located in New York. In addition, forested land accounts for a substantial proportion of sub-watersheds; more than 65% in sub-watershed O and almost 90% in sub-watershed P. Given these conditions, these two sub-watersheds were not included in the New Jersey sub-watershed prioritization analysis.

Using the land use / land cover database described in the New Jersey TMDL for Greenwood Lake (NJDEP, 2004) and the Unit Areal Loading (UAL) model, NJDEP calculated the annual total phosphorus (TP) loads for the Greenwood Lake watershed. GIS software was used to divide these calculated TP loads based on the sub-watershed boundaries shown in Appendix I. Sub-watersheds A through N were then ranked from the highest TP loads to the lowest.

Ranking the sub-watershed simply based on the magnitude of their TP loads can be misleading relative to the development of a Watershed Implementation Plan. For example, a large, forested sub-watershed may have a larger TP load relative to a smaller sub-watershed with a high amount of human activities (i.e. suburban development, farming). Therefore, the sub-watersheds were also ranked based on the "developed" TP loads. Essentially, for each sub-watershed the annual TP load originating from land associated with human activities was calculated. These land types included residential, industrial, transportation, commercial, and agricultural. This sub-set of each sub- watershed's complete TP load was defined as the "developed" TP load. The sub- watersheds were then ranked from the highest TP loads to the lowest.

Finally, given the size of Pinecliff Lake, its phosphorus retention coefficient was used to quantify how much of the stormwater phosphorus that enters it is retained and does not flow into Greenwood Lake. Based on an analysis conducted as part of the original Phase I Clean Lakes Diagnostic / Feasibility Study, the phosphorus retention coefficient for Pinecliff Lake is 56%. This phosphorus retention coefficient was taken into account with sub-watersheds A through F, which account for the portion of the Greenwood Lake watershed that drains directly into Pinecliff Lake (Appendix I). The concluding results of this priority ranking analysis are provided in Table 8.

As described above, Table 8 ranks the sub-watersheds of the New Jersey side of the Greenwood Lake watershed from highest to lowest in developed TP load, taking the Pinecliff Lake phosphorus retention coefficient into consideration for sub-watersheds A through F. **This sub-watershed ranking has been updated based on the nutrient reductions from the 8 watershed projects / BMPs that have been implemented with 319 funds since the creation of the original SIP. These updated rankings do not include the watershed-wide measures, such as the use of non-P fertilizers and septic pumping, as these are not specific to individual sub-watersheds and will not change their relative rankings.** Based on this analysis, sub-watershed I still has the largest developed TP load, while sub-watershed D has the smallest TP load on the New Jersey end of the Greenwood Lake watershed. These results are strongly correlated to the land use patterns within the watershed; developed land accounts for approximately 36% of the total land area in sub-watershed I, while less than 0.1% of the land is identified as developed in sub-watershed D.

As shown in Table 8, the median value of the New Jersey developed TP load dataset was 32.9 kg. In order to further rank the sub-watersheds for the prioritization of stormwater projects, those sub-watersheds that have developed TP loads below the median value of 32.9 kg, were ranked "low". That is, sites or locations targeted for stormwater projects would be low on the prioritization list.

In contrast, those sub-watersheds that had developed TP loads twice the median value, 65.9 kg, were ranked "high". Thus, potential restoration sites or locations within those sub-watersheds that have developed TP load greater than 65.9 kg would be first of the prioritization list of projects to implement. The remaining sub-watersheds that had developed TP loads greater than 32.9 kg but lower than 65.9 kg were ranked "moderate". Thus, these projects would be implemented after most of the high-ranking projects were at least considered for implementations.

It should be emphasized that the prioritization of the sub-watersheds based on their developed TP loads is a guidance tool to aid in making long-term management and planning decisions on the selection of sites of restoration. Thus, other issues such as property ownership, potential of obtaining required easements, ownership of adjacent roadways, existing environmental constraints (wetlands, steep slopes, etc.) and actual costs for design and installation need to be taken into account when making final decisions on the selection of project sites. However, the data presented here in the Watershed Implementation Plan is a site-specific and objective strategy in initiating the TMDL-based long-term management of Greenwood Lake.

Table 8: Prioritized ranking of the sub-watersheds on the New Jersey end of the Greenwood Lake watershed.

Prioritized Sub-Watershed	Developed TP Load Per Year
Sub-Watershed I	145.4 kg
Sub-Watershed G	143.9 kg
Sub-Watershed H	74.1 kg
Sub-Watershed A	59.2 kg
Sub-Watershed F	46.0 kg
Sub-Watershed C	36.4 kg
Sub-Watershed M	36.3 kg
Sub-Watershed N	29.6 kg
Sub-Watershed L	28.9 kg
Sub-Watershed J	24.1 kg
Sub-Watershed K	23.9 kg
Sub-Watershed B	14.4 kg
Sub-Watershed E	0.2 kg
Sub-Watershed D	0.1 kg
Median	**32.9 kg**

SELECTIVE STORMWATER MONITORING

A component of this revised WIP included the collection of stormwater samples, during three separate storm events, from a sub-set of the previously implemented 319(h) grant MTDs / MBPs throughout the sub-watersheds to better quantify the pollutant removal efficiency of the various structures. The goal of this component is to use the gathered data to determine if similar projects should be considered for future implementation. During each event, downgradient samples were collected for TP and TSS at four of the eight project sights:

- Reidy Place
- Durant Road
- Beaver Avenue
- Adelaide Terrace

All stormwater sampling sites were located with GPS and placed onto a map which can be found in Appendix I. Grab samples were collected during or immediately after each storm event for analysis of TP and TSS (Figures 7 & 8). A QAPP was submitted to NJDEP for review of the stormwater sampling to ensure that all sampling protocol and laboratory methodology is accepted and approved by NJDEP (Appendix III). Three stormwater events were completed after the sampling sites were chosen: 13 May 2019, 11 July 2019, and 9 December 2019. Results from all three stormwater events can be found in Figure 5 and Figure 6. It should be noted that a stormwater sample from Durant Road was not able to be collected on 9 December 2019 due to excessive snowpack throughout the filter strip where the sample would be taken from. There was no flowing water during the time of the site visit due to the snowpack and cold temperatures.

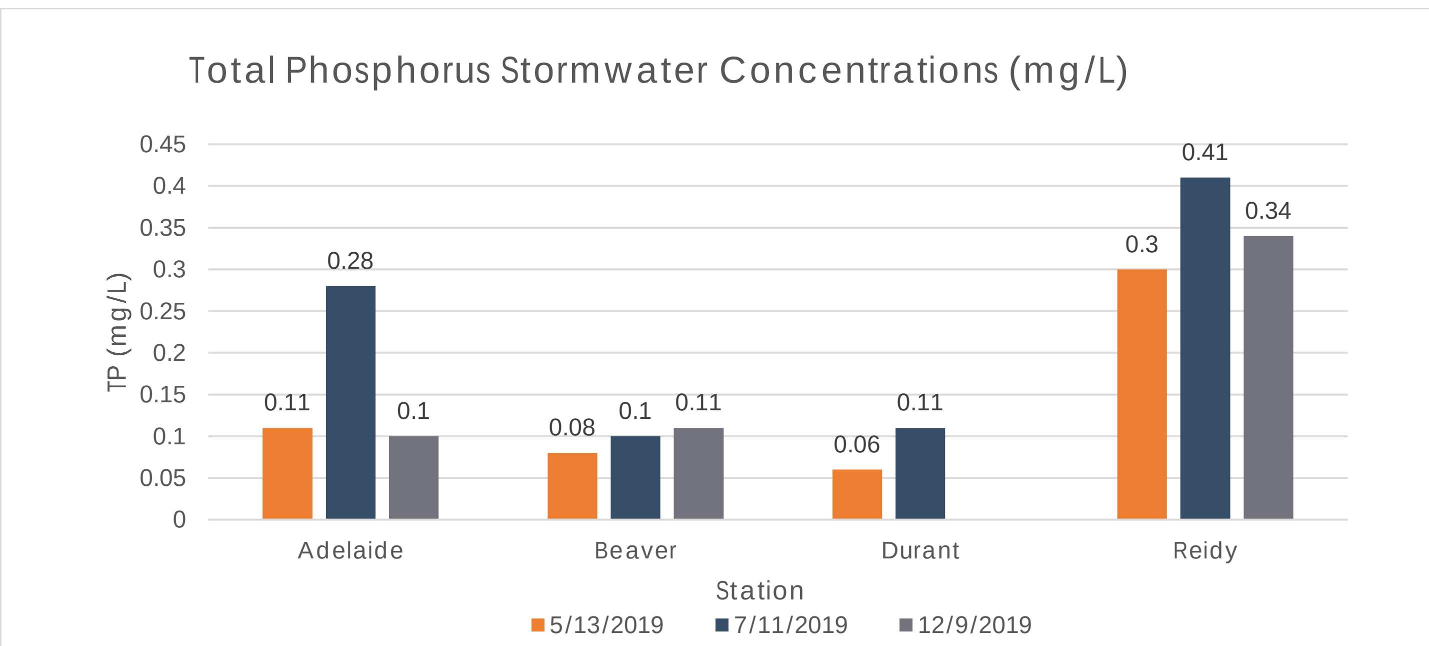


Figure 7: TP concentrations at all stormwater sampling sites on 13 May 2019, 11 July 2019, and 9 December 2019.

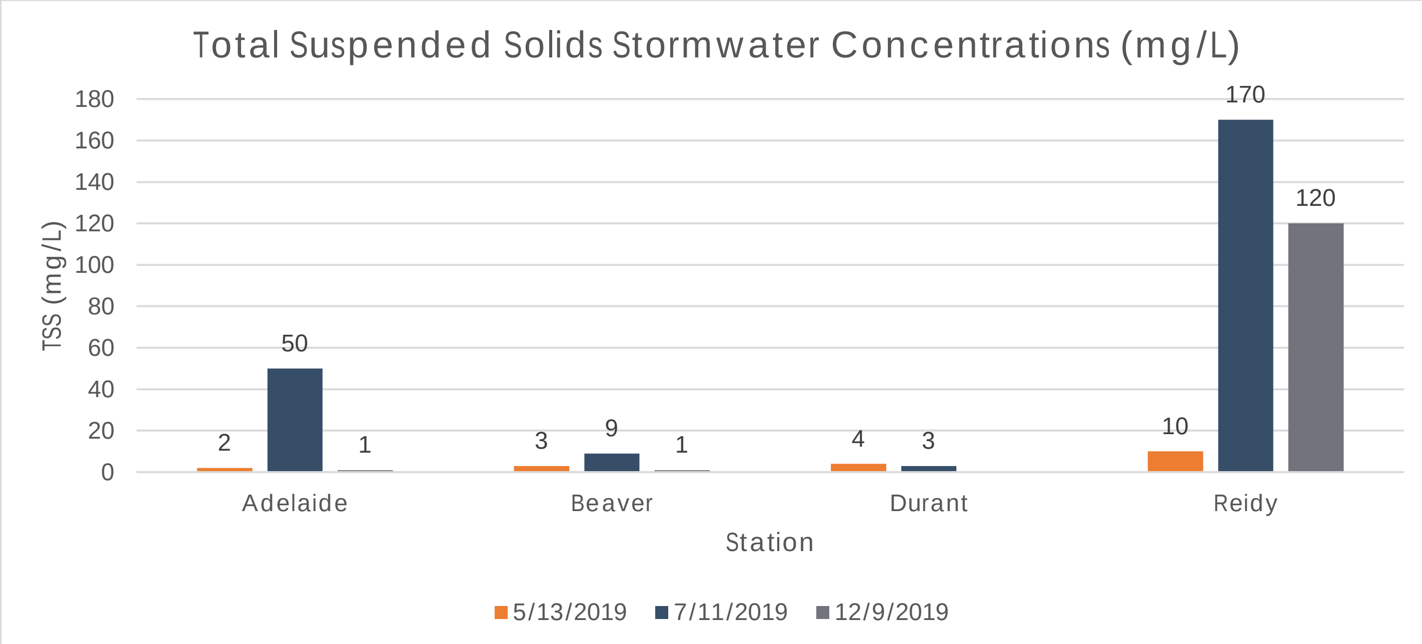


Figure 8: TSS concentrations at all stormwater sampling sites on 13 May 2019, 11 July 2019, and 9 December 2019.

DISCUSSION

Stormwater samples at Adelaide Terrace were taken directly from the outflow pipe of the nutrient separating baffle box. The samples from 11 July 2019 were elevated for both TP and TSS with concentrations of 0.28 mg/L and 50 mg/L, respectively. The other two sampling dates had similar concentrations for both parameters and were extremely low for TSS; TP concentrations remained around 0.1 mg/L. One possible explanation for the elevated concentrations in July could be that the samples were taken closer to the first flush when pollutant concentrations are expected to be the highest. TSS removals were exceptional for the other two sampling events and TP concentrations were also relatively low but would benefit from the further treatment of stormwater. As such, future recommendations for MTDs will be coupled with green infrastructure, such as bioretention systems or filter strips, wherever possible.

Stormwater samples at Beaver Avenue were taken directly from the outflow pipe of the nutrient separating baffle box at Belcher Creek. TP and TSS concentrations were similar to those at Adelaide Terrace, although concentrations during the July sampling event were not elevated to the degree that was observed at Adelaide Terrace. TP concentrations ranged from 0.08 mg/L – 0.11 mg/L and TSS concentrations ranged from 1.0 mg/L – 9.0 mg/L. Similar to what was observed at Adelaide Terrace, TSS removals in the MTD appear to be great and while TP concentrations were not extremely elevated, this site would remove more phosphorus if the MTD were coupled with green infrastructure. It is not always possible to incorporate green infrastructure, as was the case with the Adelaide Terrace and Beaver Avenue MTDs but will be incorporated wherever possible moving forward.

Samples were taken from the outflow of the filter strip at Durant Road after passing through the nutrient separating baffle box. The mean concentrations of both TP and TSS from the two sampling events at

Durant Road were the lowest of the four sites. TP concentrations ranged from 0.06 mg/L – 0.11 mg/L and TSS concentrations from 3.0 mg/L – 4.0 mg/L. The reason for the reduction in TP concentration relative to the other sites is likely due to the extra treatment that the stormwater receives when passing through the filter strip. In addition to the lower nutrient concentrations, the filter strip also reduces the quantity of stormwater that enters Belcher Creek via surface flow due to the associated infiltrative properties, further lowering the nutrient load. As such, this set of BMPs appears to be the most effective of the four sites that were sampled and will be considered for future implementation wherever applicable.

Stormwater samples at Reidy Place were taken from the catch basin that the curbside storm drain with the Filterra tree box empties into. It is important to note that the stormwater samples are not fully representative of this BMP because multiple storm drains empty into the catch basin that was sampled which do not have associated BMPs. Measures were taken for the samples to be taken directly from the pipe in the catch basin associated with the Filterra, but this was not always applicable due to flow rates. As such, these samples also included water that was draining directly off the street and into the catch basin where the sampling was conducted. Not surprisingly, both TP and TSS concentrations were the highest here compared with the other sampling sites. While this is not ideal for the sake of quantifying nutrient reductions associated with the Filterra unit, the stormwater samples give a relative idea of unfiltered pollutant concentrations from a residential street, similar to the locations where the other BMPs are located. It can then be inferred from these concentrations that the other three BMPs are efficiently reducing pollutant concentrations.

It should also be noted that during the field assessments of each of these project sites to observe their existing status, it was determined that all of the MTDs implemented under the 319 grants should be cleaned out, as they had not yet been cleaned this year and were showing varying signs of in-filling. Thus, the nutrient separating baffle boxes associated with the stormwater sampling are likely not functioning to their full capacity and would further reduce pollutant loads if properly maintained. It is not currently known if the MTDs had been cleaned out by the final stormwater sampling event in December; the MTDs would need to be opened for this assessment.

3. 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 required 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 lakes. Thus, a considerable amount of 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.

CANDIDATES FOR RETROFITS OR BMPS

This sub-section outlines a number of potential sites for the implementation of various watershed measures aimed at reducing the annual TP load of Greenwood Lake. A table is presented at the end of this sub-section that lists the proposed watershed measure, the amount of TP and TSS removed, and an estimated price (Table 9).

The location of all sites can be found on the Candidate BMP Site Map in Appendix I. In addition to the site map, technical sheets with relevant information on the various proposed BMP or MTDs can be found in Appendix V.

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 off of 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 be 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 Highlands Region. Due to the location of West Milford in the protected Highlands Region, additional permitting may be required.

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

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

The proceeding section is organized into two main sections; the first section will outline candidate sites for stormwater basin retrofits or BMPs and will include recommended restoration measures and estimated costs. The second section will outline candidate sites for streambank and riparian restoration along Belcher Creek and will include recommended restoration measures and very general price estimates.

SUB-WATERSHED G

SITE 1: FORMER WEST MILFORD LAKE AND DAM

Due to New Jersey Dam Safety compliance requirements, West Milford Lake has been lowered and is maintained in this state with siphons and pumps. The impoundment previously served as a forebay to Belcher Creek and Greenwood Lake where energy would be dissipated and nutrient-laden sediment would settle out of the water. In the lowered condition, it is not providing these benefits. The site of the former West Milford Lake still receives a large portion of stormwater runoff from sub-watershed G and the water is currently being siphoned near the dam. Drainage areas calculated from StreamStats reveal that runoff from the two major residential areas located south of the former lake drain almost entirely to this site, eventually flowing into a small tributary of Belcher Creek.

Recommended Measures: The former lake could be converted into a wetland BMP for sub-watershed G. Such a BMP would have the capacity to remove a substantial portion of the TP load that eventually flows into Belcher Creek and, in turn, Greenwood Lake. The concept would be to grade a channel through the impoundment, provide access to the floodplain in small stormwater events, provide a stable and natural connection to the downstream channel and plant native vegetation optimal for the hydrology within the impoundment. These improvements would lengthen the flow path, reduce the channel slope, provide flood storage, filter sediment and nutrients and sequester nutrients.

In addition to converting the site into a functional wetland BMP, the stabilization of the discharge channel and removal of the spillway and/or portion of the earthen embankment would be necessary to provide a connection of the channels. An additional benefit to the project is that it would deregulate the dam. While such a project has the potential to address a substantial portion of the phosphorus load entering Greenwood Lake, a considerable amount of planning, design work and public education would be required for its successful implementation.

Estimated Costs: To convert the existing site into a wetland BMP is estimated to cost approximately $2.5 million.

SITE 2: SHOP-RITE PARKING LOT (ACROSS FROM WEST MILFORD LAKE DAM)

The Shop-Rite and other retail stores are located at the intersection of Union Valley Road and Marshall Hill Road has a large paved parking lot with several catch basins located throughout. These catch basins are connected subsurface, eventually draining into an unnamed tributary of Belcher Creek located near the northeast corner of the parking lot. In addition to a large catch basin that is located in the northeast corner of the parking near the discharge point, there is also a large grassy area in the vicinity of the discharge pipe and the creek.

Recommended Measures: This site would be an ideal candidate for the connection of a manufactured treatment device (MTD) with a bioretention system located just downgradient, also referred to as a treatment train. The MTD would be located just upstream of the existing inlet box and serve as pretreatment for the bioretention system. It is anticipated that the existing inlet would need to be replaced to accommodate the MTD discharge and include a diversion of flows into the bioretention system. The project may also include curb cuts, invasive species control and stabilization of the pipe discharge location. This treatment train will provide removal of sediment and trash from the pipe network and filtration of the stormwater before being discharged back into the creek.

There are other catch basins and storm drains around the parking lot that could also be retrofit with smaller MTDs and/or Filterra tree boxes.

Estimated Costs: The estimated cost of the design and installation of a nutrient separating baffle box and the bioretention system is approximately $406,300. The estimated cost of the design and installation of a filterras is approximately $130,000 per unit.




SITE 3: TRIBUTARY AT THE END OF ADELAIDE TERRACE

A nutrient separating baffle box has already been installed at the end of Adelaide Terrace through previous 319 funds. As such, there is not much left to be done on the road itself, but the unnamed tributary that the baffle box discharges into is located at the terminus of the road. There is a landscaped area between the edge of pavement and the stream bank which is currently mulched with a few trees. Additionally, the streambank on river right is disconnected from the woody floodplain and is approximately vertical.

Recommended Measures: The first recommended measure at this location is the enhancement of the riparian buffer between the bank and Adelaide Terrace to better filter stormwater runoff and filter nutrients and sediment.

The streambank on the opposite side could be stabilized to include floodplain benches in addition to toe protection. This streambank can be graded back to a gentler slope, allowing for more flood storage during periods of heavy precipitation and could act as a wetland storage area, filtering nutrients and other pollutants.

Estimated Costs: The estimated cost of the enhanced riparian buffer is approximately $42,600. The river right bank stabilization is estimated to cost approximately $138,300.

SITE 4: REAR PARKING LOT ON NEW JERSEY AVENUE

The rear parking lot behind the small strip of stores on the corner of New Jersey Avenue and Union Valley Road is located directly next to Belcher Creek and is almost entirely made of loose gravel. The rear half of the parking lot was not being utilized during the two site visits that Princeton Hydro made to this site and appears to be unfinished due to the curbing within the vegetation. There is a lack of a riparian buffer between the parking lot and Belcher Creek and there is a large patch of the invasive *Phragmites australis* (phragmites) near the back corner of the parking lot where pollution from trash and other debris is extensive.

Recommended Measures: The rear gravel parking lot would be an ideal location for the conversion into a vegetative filter strip. This would involve replacing the loose gravel with grass and native meadow vegetation that would act as a nutrient reducing buffer between the remaining parking lot and Belcher Creek. This process would remove the loose gravel and sediment in this location that gets carried into Belcher Creek during storm events, and the vegetative buffer would filter out additional pollutants.

The patch of phragmites in the back corner of the parking lot should also be removed and replaced with native vegetation that would function as a rain garden. The installation of the rain garden could possibly require some minor modifications to deepen the depression but would work to further reduce the nutrient load into Belcher Creek.

Estimated Costs: The estimated cost of the design and implementation of the extended filter strip is approximately $203,500 and the rain garden is approximately $105,500.

SITE 5: FRONT PARKING LOT ON NEW JERSEY AVENUE

The parking lot on Union Valley Road in front of the small strip of stores located across from the Pinecliff Lake Dam has a substantial amount of sediment/road grit built up throughout. This parking lot is located directly adjacent to Belcher Creek and has a curbside storm drain that drains directly into the creek (see photo below). The right bank of Belcher Creek on the same side of the parking lot is eroding and is a source of sediment and nutrients to Belcher Creek.

Recommended Measures: All of the sediment/road grit should be cleared out of the parking lot before any further work is done to this site. This location appears to be the primary point where snow would be pushed and would benefit from a curb to stop the plows from pushing snow and sediment right to the bank of the creek as well as minor adjustment to the pavement grades so grit could accumulate in a location/system that is more maintainable. These improvements would be further beneficial if installed with nutrient separating baffle box MTD along the existing pipe at the end of the parking lot that drains directly into Belcher Creek. Additionally, the streambank in the vicinity of the pipe discharge should be stabilized to prevent future erosion. Bank stabilization methods could include the planting of vegetation where the slope allows and through the installation of rip-rap to prevent further bank scour.

Estimated Costs: The estimated cost of the design and installation of a nutrient separating baffle box and the streambank stabilization work is approximately $293,800.

SITE 6: PARKING LOT BEHIND BAGEL TOWN CAFÉ

This parking lot located between a small strip of stores and Belcher Creek already has two existing stormwater basins that can be modified and enhanced to reduce the nutrient loads to Belcher Creek and Greenwood Lake. There is currently a dry detention basin located in the middle of the parking lot that receives stormwater from this site. In addition to the dry detention basin, there is also a wet pond located just behind the parking spots in the southern end of the parking lot. This wet pond is located in close proximity to Belcher Creek and appeared to be discolored and in poor condition during the site visit. The wet pond receives that discharge from the dry detention basin in addition to overland flow from the adjacent parking lot. It is understood that the combination of these two basins provides compliance with the NJ stormwater regulations for the property and therefore the proposed imports shall restore the system to meet or exceed the minimum requirements for water quality, quantity and recharge if applicable.

Recommended Measures: There are multiple recommendations that will complement each other and can be completed as a single large project or multiple smaller projects.

1. Retrofit the dry detention basin in the middle of the property to function as a bioretention basin that would provide increased nutrient sequestration. This retrofit would likely include modifications of the existing pipe system to ensure the runoff enters the basin, minor regarding in the basin, possible curb cuts, and a berm along the down gradient edge of the basin to provide the necessary storage volume. Pending further investigation, installation of bioretention media with an underdrain will complete the conversion to a bioretention system. The basin area would be tilled and stabilized with native vegetation.
2. The wet pond located at the south end of the property would be improved to increase nutrient sequestration through the addition of vegetation and the likely elimination of a potential HABs source. The wet pond would likely be converted into a wetland basin. This conversion will likely include modifications to or replacement of the basin outlet structure, regrading of the basin side slopes, and vegetating the basins with native plant species. This project would benefit from the conversion of some parking spaces to allow the basin to be enlarged or alternatively, parking spots could be turned into vegetated pavers, allowing for increased filtration of stormwater while preserving the parking spots.

Pictures can be found on the following page.

Estimated Costs: The estimated cost of the design and implementation of the bioretention basin is approximately $253,100. The estimated cost of the design and implementation of the conversion of the wet pond to wetland basin is approximately $280,900.

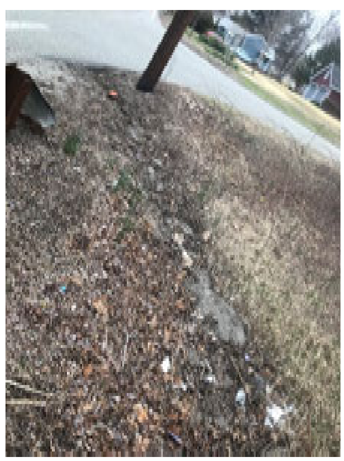
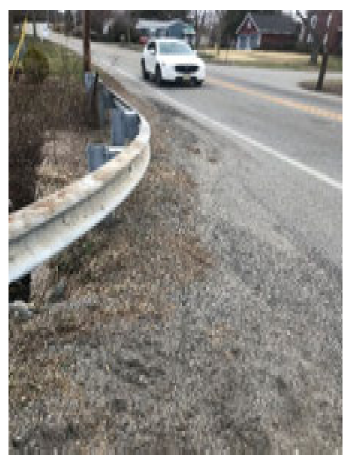
SITE 7: POND AT THE CORNER OF EDGECUMB ROAD AND UNION VALLEY ROAD

There is a pond located on the corner of Edgecumb Road and Union Valley Road that receives water from a small unnamed stream as well as stormwater from Union Valley Road and the adjacent intersection before eventually emptying into Belcher Creek. There is a small forebay where the stream enters the pond that is at capacity with sediment and organic matter. The drainage area immediately surrounding the forebay is eroding and sediment/road grit from the streets has built up because there are no curbs on Union Valley Road or Edgecumb Road to direct the stormwater towards the catch basin that is located directly in front of the forebay. This forebay needs to be cleared out and the loose sediment on the adjacent road should be cleaned up if the forebay is to efficiently reduce the TSS and nutrient loads entering Belcher Creek and Greenwood Lake.

Recommended Measures: The first recommended measure at this site involves the reconstruction of the forebay to better handle the sediment and associated nutrient loads before the pond discharges to Belcher Creek. This reconstruction would involve the removal of accumulated sediment and organic material from the forebay. Additionally, some boulders or other hard substrate could be added to better maintain the structure of the forebay and prolong the functionality. In addition to reconstructing the forebay, the current catch basin should be replaced with deep drop inlets that would capture sediment from the surrounding streets before it was to enter the forebay. It should be noted that the removal of accumulated materials from a drop inlet can more easily be completed with a vacuum truck. Curbs should be added to Union Valley Road and into Edgecumb Road to direct the stormwater into the deep drop inlet and prevent future erosion of the area surrounding the forebay. While these measures are largely directed at reducing TSS loads, the TP load would also be reduced in the process, and these measures have the potential to greatly reduce sediment loads.

Estimated Costs: The estimated cost of the forebay reconstruction and associated catch basin work is approximately $422,000.



SITE 8: GWYNETH ROAD AND GLENCROSS ROAD

There is a catch basin at the corner of Gwyneth Road and Glencross road that drains to Belcher Creek located behind Glencross Road. This catch basin is the last inlet on Gwyneth Road prior to a pipe connection to the existing floodplain. This inlet accommodates all of the stormwater runoff from this street. There is also a large grassy area directly behind the catch basin that is located between two separate properties on the corner of the two roads.

Recommended Measures: This site is an ideal candidate for the installation of an MTD that discharges into a vegetative filter strip, allowing for the further treatment of stormwater. The nutrient separating baffle box should be installed in the pavement between the inlet and the grassed buffer as this is the most down gradient catch basin to the discharge point and would therefore treat the largest quantity of stormwater from this community. Additionally, the discharge pipe could be daylighted closer to the edge of pavement and converted into a vegetated buffer or swale.

Estimated Costs: The estimated cost of the design and installation of a nutrient separating baffle box and the vegetated filter is approximately $217,700.

SITE 9: HEADWALL OF BELCHER CREEK AT GLENCROSS ROAD

The downstream side of Glencross Road at the Belcher Creek stream crossing is actively eroding from runoff and is creating a sediment bar just downstream in the channel to Belcher Creek. There are currently sandbags installed as a method to control the erosion and stabilize the area. The erosion of the bank is creating a sizeable hole in the road that is already a safety concern and will only get worse if not addressed. While this site is not a huge priority for nutrient reductions, the eroding road should be addressed as a safety concern.

Recommended Measures: This site would benefit from the construction of a headwall along Glencross Road to prevent the future erosion into Belcher Creek.

Estimated Costs: The estimated cost of the design and installation of a headwall is approximately $115,000.

SUB-WATERSHED H

SITE 10: ATHLETIC FIELDS AND FAMILY PUMP TRACK

The athletic fields and family pump track (bike course) are located behind a paved parking lot. The stormwater from the parking lot and approximately half of the athletic fields drains to a “swale” located between the two before draining to a small tributary of Morestown Brook on the west side of the property. There was pooling of water in the “swale” during the site visit and the drainage appeared to be extremely poor, with a large portion of the drainage path lacking any grass or other vegetation.

Recommended Measures: This site would be an ideal candidate for replacing the current “swale” with a bioretention swale that would capture, treat/filter, and convey the stormwater in a much more efficient manner. The bioretention swale would greatly reduce nutrient loads that drain to Morestown Brook and eventually Belcher Creek and Greenwood Lake. This site would also be a great location to incorporate educational material on a sign highlighting the importance of stormwater management because of all the foot traffic associated with the athletic fields and bike course. The slope from the athletic fields should be vegetated with meadow or similar lower maintenance vegetation with specified paths from the parking lot to the facilities.

Estimated Costs: The estimated cost of the design and installation of a bioretention swale, vegetated filter, and associated education materials is approximately $272,100.

SITE 11: MARSHALL HILL ELEMENTARY SCHOOL AND ROAD

This set of projects had already been designed under a previous 319 grant but was never implemented due to logistical complications relative to property ownership logistics with the Green Acres program and the related timing constraints as well as regulatory review. However, the plans were retained and currently make an excellent candidate for future grant funding under the 319 program. This set of plans is essentially shovel ready from a design standpoint.

Recommended Measures: The Marshall Hill Road and Marshall Hill School project would involve a series of activities including the enlargement of a culvert, the diversion of stormwater and vegetated conveyance, and some additional streambank stabilization work. In addition, a rain garden / biofiltration system would be installed in front of Marshall Hill School. The rain garden / biofiltration system would include some signage and would be used for educational purposes as well.

Estimated Costs: The estimated cost for the completion of the Marshall Hill Road and Marshall Hill School project is approximately $790,000. However, this does not account for any updating to the engineering design or permitting.

SITE 12: ALMOND BRANCH CHURCH

Almond Branch Church is located on Marshall Hill Road just west of Marshall Hill Elementary School and Morestown Brook. The church has a few grassy areas in front of the building along Marshall Hill Road. There are also a few catch basins located on Marshall Hill Road along the grassy area in front of the church property. The parking lot is paved in the front entrance area, but the back half of the parking lot is gravel. There are signs of accumulated gravel on the grass, likely a result of snow removal activities. There is a row of trees along Morestown Brook but there is room between the parking lot and the stream to extend the riparian buffer. This site would be an optimal demonstration site to showcase a few different BMPs due to the multiple locations on site that show relatively low daily traffic.

Recommended Measures: As mentioned above, this site has the potential to showcase a few different types of BMPs; the demonstration projects would reduce the pollutant load to Morestown Brook at this site and would exhibit different BMPs to the public.

1. The first recommended BMP at this site would be the installation of a bioretention system in the large grass area at the front of the property. There is another smaller grass area to the east of the large one, and it may be possible to create a second bioretention system here and connect it to the larger one; Morestown Brook is located just to the east of this smaller area.
2. The second recommendation at this site and the focus of the demonstration project would be the installation of pervious and/or vegetated pavers in the gravel section of the parking lot. This would eliminate the loose gravel that is accumulating along the side of the parking lot where Morestown Brook is located and would allow for most of the runoff in the parking lot to be filtered by the soil and vegetation instead of carrying pollutants into Morestown Brook. As part of the demonstration project, multiple types of pervious/porous/grass pavers could be implemented in different parts of the parking lot.

Estimated Costs: The estimated costs for the design and installation of the bioretention system(s) and pervious paver demonstration project is approximately $985,000.

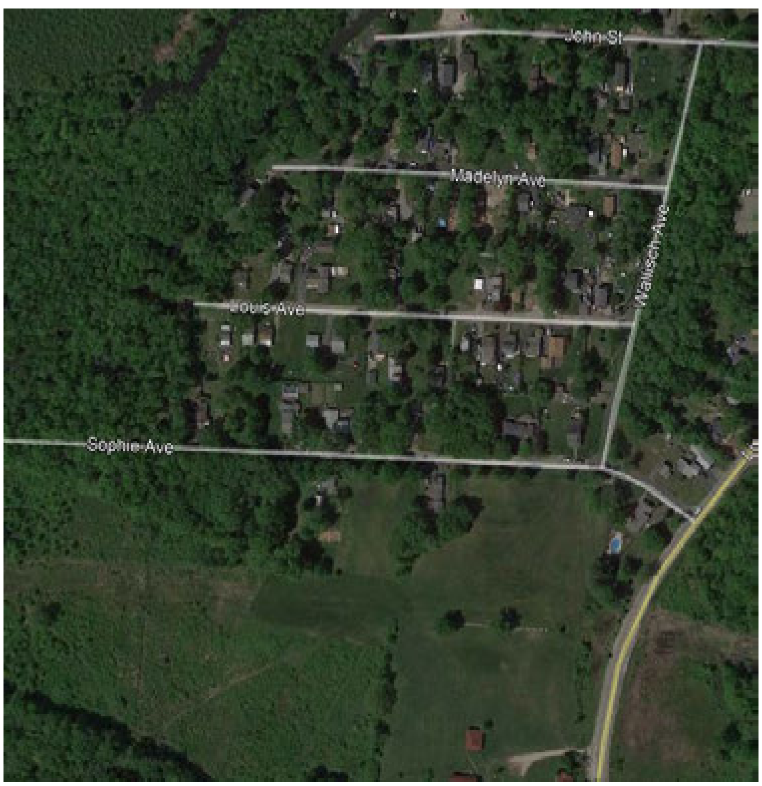
SUB-WATERSHED I

SITE 13: DEVELOPMENT WEST OF LINCOLN AVENUE (LOUIS, MADELYN, SOPHIE AVENUES AND JOHN STREET)

This entire area was included in the original SIP as a potential candidate for the installation of multiple BMPs although nothing was ever implemented due to complications with shallow groundwater and minimal public property. Due to the close proximity to Belcher Creek, this community is still viewed as a strong candidate for an implementation project. This entire community has individual onsite septic systems, and because of the proximity to Belcher Creek, even systems that are pumped regularly still release phosphorus to Belcher Creek and Greenwood Lake. It is understood that stormwater is not necessarily the primary nutrient source in this community as road side swales are vegetated with minimal signs of erosion, and minimal gradient. It should be noted that a large publicly owned upland property is located to the south this community. This proposed project would require a Highlands Preservation Area Approval Waiver from DEP, in which a public health and safety concern would need to be proved. While this would likely be an involved project, this site is still considered a strong candidate for the localized reduction of a large amount of phosphorus.

Recommended Measures: This community as well as Belcher Creek and Greenwood Lake would benefit from becoming a sewered community. The sewering would be not be connected to the other sewered sections of West Milford Township but instead have its own community treatment system located to the south of the community. The proposed system is anticipated to connect to the existing watertight septic tanks at each residence, flow via gravity pipes to the mains in each of the streets, a lift or pump station near the intersection of Sophie and Wallisch Avenues. The pump station would discharge to a treatment facility and ultimately be discharged via land application. It has also been suggested that this community might be well served by being connected to an existing plant like Birch Hill.

Estimated Costs: The estimated cost for the design and implementation of a community wastewater treatment system in the open green space is approximately $5.6 million. Connection to an existing plant has not yet been estimated.



SITE 14: UNION VALLEY ROAD AND WARWICK TURNPIKE

This was another site that was included in the original SIP as a potential candidate for the installation of multiple MTDs although nothing was ever implemented. This site is still viewed as a strong candidate for restoration work, although focused on the stream, Cooley Brook, rather than retrofitting the catch basins. The focus is the stream reach located between Union Valley Road and Warwick Turnpike, directly next to 3 Roads Deli and Grill. The streambanks on both sides are rather steep, lack sufficient vegetation and are eroding in multiple locations, with some of the erosion approaching the parking lot. Some of the drainage paths that lead from the road to the stream are also eroding. The stream is lacking a vegetated buffer, especially directly downstream and upstream of the wooden foot bridge.

Recommended Measures: This site is an ideal candidate for bioengineered streambank stabilization from Warwick Turnpike to Union Valley Road and on both streambanks. This could include boulder toe with vegetated soil wraps. This will require regrading of the slopes and excavation in order for proper placement of the stabilization measures. The increased vegetative cover along the streambanks will better hold the soil in place and the installation of boulder toe protection with vegetation will prevent future erosion. In addition to the stream, the drainage path between Warwick Turnpike and Cooley Brook could also be addressed to prevent the future erosion and to assist in nutrient removal from stormwater runoff. This work could consist of bioengineered stream bank with stabilized conveyance systems on both sides of the stream. It may be possible to replace the outflow pipe that drains water from Warwick Turnpike along the left bank of Cooley Stream with vegetated conveyance system that would aid in nutrient removal, but further investigations would be required.

Pictures can be found on the following page.

Estimated Costs: The estimated cost for the design and implementation of road to road bioengineered streambank stabilization is approximately $570,000.

The estimated cost for the design and implementation the bioengineered bank stabilization with vegetated conveyance systems is approximately $150,000.

SITE 15: OUR LADY QUEEN OF PEACE CHURCH

Our Lady Queen of Peace church is located on the corner of Union Valley Road and Elm Street. There is a catch basin located in a small depression on the grassy area of this corner. The concrete structure of the catch basin appeared to be in poor condition during the site visit and organic debris was built up on top of the grate. There are no curbs or swales on the adjacent road, and the grass area between the road and catch basin was also showing signs of erosion and sedimentation.

Recommended Measures: The catch basin in the grassy area on the corner of Union Valley Road and Elm Street is an ideal candidate for the installation of a rain garden. The rain garden would receive runoff from both Union Valley Road and Elm Street and would reduce the discharge rate of stormwater by allowing the water to infiltrate into the soil, and the plants would utilize some of the available nutrients.

Estimated Costs: The estimated cost of the design and installation of a rain garden on the corner of Union Valley Road and Elm street would be approximately $176,300.

SUB-WATERSHED J

SITE 16: ELKS LODGE

Cooley Brook passes across the back of the Elks Lodge property right before it empties into Green Brook. The streambanks appeared to be in relatively good condition, although the right bank lacked a sufficient vegetative buffer between the stream and the Elks Lodge property. Minor erosion is occurring under the foot bridge that is causing a widening of the stream here. There is also a downed tree just upstream of the foot bridge that is likely causing head cut erosion on the streambed.

Recommended Measures: The first recommended measure at this site is to enhance the riparian buffer between the stream and Elks Lodge from a grass to meadow buffer to help intercept stormwater and reduce the nutrient loads. The downed tree in the stream should also be removed to allow for the natural flow of water under the bridge.

Estimated Costs: The estimated cost for the enhancement of the riparian buffer and the removal of the downed tree is approximately $75,000.

Table 9: Proposed Stormwater Projects Summary

Site and Recommendations	Total P Removed (kg/yr)	Total Suspended Solids Removed (kg/yr)	Estimated Costs
West Milford Lake Constructed Wetland	15.0	54,000	$2,519,000
Shop Rite Nutrient separating baffle box Bioretention system	2.50	1,700	$536,300
Adelaide Terrace Stream Riparian buffer enhancement Right bank grade control	5.0	40,000	$180,900
New Jersey Avenue – Rear Lot Extended vegetative filter strip Rain garden	0.75	700	$308,500
New Jersey Avenue – Front Lot Nutrient separating baffle box Streambank stabilization	0.5	300	$293,800
Bagel Town Café Rear Lot Retrofit dry detention basin Retrofit wet pond Grade control / enhanced filter strip	1.0	650	$534,000
Union Valley and Edgecumb Rd Pond Forebay reconstruction Deep drop inlet and road curbs	2.0	6,500	$422,000
Gwyneth Road and Glencross Road Nutrient separating baffle box Bioretention system	0.75	1,000	$217,700
Belcher Creek at Glencross Road Headwall installation	-	-	$115,000
Athletic Fields Bioretention swale	1.0	1,000	$272,100
Marshall Hill Road and School Stream stabilization / water diversion Vegetated Swale Rain garden	5.5	20,000	$790,000
Almond Branch Church Bioretention system(s) Pervious pavement	1.0	1,000	$985,000
Development West of Lincoln Avenue Community wastewater system	23.0	-	$5,600,000
Union Valley Road and Warwick Tpk Bioengineered streambank stabilization Bioengineered stabilized conveyance systems	6.0	20,000	$570,000
Our Lady Queen of Peace Church Rain garden	0.5	150	$176,300
Elks Lodge Stream Enhanced riparian buffer Removal of downed tree	3.0	20,000	$75,000
Totals	**67.5**	**167,000**	**$13,745,600**

BELCHER CREEK ASSESSMENT

As numerous empirically and model-based studies have confirmed, Belcher Creek and its immediate drainage areas are the largest sources of TP and other pollutants (e.g. TSS) to Greenwood Lake. As such, Belcher Creek and the sub-watersheds immediately surrounding it were the main focus of the field assessments conducted to find potential project sites. In order to further assess Belcher Creek, a detailed field-based assessment of Belcher Creek was conducted to identify potential problems that contribute to water quality issues in Greenwood Lake. The survey was conducted from where the Creek enters the lake up to the dam of Pinecliff Lake.

This sub-section outlines a number of potential sites for streambank and riparian zone restoration. To aid in the survey of the stream sites, Princeton Hydro utilized stream visual assessment (SVA) scorecards that are largely based on the NJDEP Stream Visual Assessment Protocol. An example of the scorecards that were used can be found in Appendix VI. Assessment factors include the following habitat parameters:

- Vegetated buffer width
- Vegetated buffer condition
- Canopy cover
- Bank stability
- Channel condition
- Hydrologic alterations
- Aquatic plant community
- Invertebrate habitat
- Instream fish cover
- Barriers to fish movement
- Velocity / depth variability
- Pool variability

In addition to the above parameters, the streamside land use of each stream reach and any potential outfalls were also noted. The purpose of these stream assessments was to assess potential sites for streambank/riparian zone restoration that would reduce the TP and TSS loads entering Greenwood Lake. While all of the information on the scorecards is valuable to assess the overall ecological health of stream segments, the field assessments were focused on reducing TP and TSS sources in order to comply with the associated TMDLs.

The scorecards were filled out for 10 separate stream reaches in Belcher Creek. While there were 10 stream reaches that were formally assessed with a scorecard, a full day was spent traveling from the mouth of Belcher Creek in Greenwood Lake up to the dam at Pinecliff Lake, and back downstream to the mouth of Belcher Creek. During this time in the Creek, the entire creek was visually assessed on-site and again back in the office through photograph documentation.

Again, while there were 10 sites that were formally assessed with a scorecard, there are not 10 sites in Belcher Creek that are included as potential candidates for stream restoration. **It was determined during the assessment that the majority of the excess sediment and nutrients found in the creek originate in the sub-watersheds that directly surround the creek. Because of this, the majority of the recommended projects throughout the watershed are located immediately surrounding Belcher Creek.** For example, streambank erosion throughout the majority of Belcher Creek was not severe and is likely not a major source of sediment and phosphorus to Greenwood Lake. Additionally, outfalls in

Belcher Creek were traced to their origin wherever applicable and were recommended to be retrofit with MTDs or other BMPs in the previous section. Access to Belcher Creek is also limited in many locations, especially the middle portion that is not located near a major road. This was taken into account during the survey, as heavy machinery, trucks/vehicles, etc. are often needed for major restoration measures. Because of this, restoration measures at some sites were limited and the in-stream / riparian measures often involve smaller scale projects such as vegetative plantings that can be done by homeowners and volunteers and don't require large equipment.

In summary, 10 stream reaches along Belcher Creek were formally assessed using SVA scorecards that are largely based on the NJDEP Stream Visual Assessment Protocol. Restoration measures that will aid in the reduction of the TP and TSS load to Greenwood Lake are provided at these sites wherever applicable, but the sub-watersheds directly surrounding Belcher Creek were the main focus of the recommended restoration measures and BMP implementation. The main reason for focusing on the sub-watersheds is because this is where the majority of the TP in the Greenwood Lake watershed originates.

VISUAL ASSESSMENT RESULTS

The Belcher Creek visual assessment was conducted on 16 July 2019 by two members of Princeton Hydro. The data collected includes the semi-quantitative dataset gathered for each stream station whereby scores were assigned for specific parameters, as well as qualitative data which discusses the presence of erosion, land uses adjacent to the selected stream reach, presence and types of invasive species. Each criterion was scored from 0-10, with 10 typically representing an optimal condition, and lower scores representing some form of impairment. In some situations, not all criteria could be assessed, therefore, the final station score was divided by the number of criteria assessed.

Following scoring, each stream segment was ranked amongst all others in order to prioritize those segments that have shown impairment for active management while providing necessary information for those reaches which are in excellent condition.

Table 10: General SVA scores in Belcher Creek.

Stations	SVA Score	General Health	% of Stations
4	>7.5	Good	40%
2	6-7.5	Fair	20%
4	4-6	Some Impairment	40%
0	<4	Serious Impairment	0%

Table 11: Summary of all stream reaches assessed in Belcher Creek.

Station	SVA Score	General Health
B-1	4.0	Some Impairment
B-2	8.1	Good
B-3	5.1	Some Impairment
B-4	5.1	Some Impairment
B-5	7.3	Fair
B-6	6.5	Fair
B-7	8.4	Good
B-8	9.0	Good
B-9	8.5	Good
B-10	4.5	Some Impairment

CANDIDATES FOR STREAM RESTORATION

Estimating prices and load reductions for streambank restoration includes many variables and is difficult to estimate without detailed site-assessments. Thus, it must be emphasized that any estimates, in particular the cost estimates, need to take in to account many of the site-specific factors previously described for the candidate sites for retrofits or BMPs. Thus, the actual price of any implementation streambank / shoreline project may be lower (e.g. the volunteer planting of native vegetation) or higher (e.g. requires a substantial amount of earth-moving / re-grading) than the estimated price range. In addition, these cost estimates are for implementation, which includes labor and materials; however, this does not include design, engineering and/or permitting requirements. For the sake of this WIP, a preliminary pollutant load reductions and cost estimates for the implementation of these tasks are provided in Tables 12 and 13 at the end of this section.

The location of all of the proposed restoration sites can be found in the Candidate BMP Site Map in Appendix I.

ADDITIONAL MANAGEMENT MEASURES FOR BELCHER CREEK

In addition to the more specific measures mentioned for Belcher Creek, there are some measures that can be taken to reduce nutrient loading from the Creek to Greenwood Lake that would need more in depth evaluation before location and sizing can be decided.

Floating Wetland Islands (FWIs) are primarily used to control nutrient loading in lakes using biological nutrient uptake, a type of bioremediation. These systems provide a natural method to assist in nutrient removal relative to some of the other techniques, including chemical nutrient inactivants such as alum or ferric sulfate. Floating wetland islands are polymer mats that are anchored to the lake bed. The mats are planted with a variety of native wetland vegetation with the plants rooted in peat or other soil matrix and eventually growing down into the water column where they take up nutrients to support vegetative growth. In addition to the plants, the undersides of the islands are colonized by a variety of naturally-occurring beneficial microbes including bacteria and periphyton in biofilms that also remove nutrients from the water including both nitrogen and phosphorus. Literature indicates that the microbial community may have a larger effect in contributing to bioassimilation of nutrients. The removal of nutrients by plants and microbes in concert provide nutrient competition through uptake and sequestration that can limit local concentrations and reduce algal biomass. Typically, these units are not used in a stand-alone capacity and are meant to complement other nutrient control techniques. They are especially useful in treatment train applications. For instance, they are frequently deployed in near shore areas where stormwater BMPs have been installed to provide further pollution abatement, especially for dissolved substances. There are also a variety of secondary benefits including: habitat creation, refugia and nursery habitat for fish, reduction of suspended solids, and shoreline stabilization. They are aesthetically attractive, especially when some of the showy flowering plants are used including swamp rose mallow and blue flag iris. A 250 ft^2 FWI can remove ~10lbs of TP per year. FWIs can range in price based on size, with a series of islands totaling ~500t^2 costing approximately $20,000 to purchase, plant, install, and anchor.

Another measure that would provide management of nutrients into Greenwood Lake would include nutrient Inactivation injection systems to address TP in Belcher Creek before reaching the Lake, specifically ferric sulfate. Water from Belcher Creek would be collected in a basin that is injected with Ferric sulfate. These molecules then attach to the liquid phosphorus in the water and precipitate to the bottom of the basin and form a material that will be removed and re-used as fertilizer and other uses that are being developed.

The ferric sulfate dispenser unit and the basin becomes a part of the stream i.e. all water has to go through the treatment unit and should be installed as far upstream as possible so as to not impede boat traffic. Site evaluations need to be conducted on pollutant load, flow rates, and hydrology of the area to be installed in order to determine appropriate location and sizing for the system. Field assessment for installation site selection and implementation of the ferric sulfate system has an estimated cost of $135,000.

SITE 17: BELCHER CREEK (B-1: JUST UPSTREAM OF UNION VALLEY ROAD)

Just upstream of the Union Valley Road bridge crossing on Belcher Creek is a relatively wide section of the creek that has been altered by development. The major land use on both sides of the creek are residential properties that lack adequate riparian buffers. Some of the houses contain bulkheads along the shoreline and there was minimal aquatic plant growth or habitat for aquatic organisms. There is barely any canopy cover due to the lack of vegetation which increases the surface water temperatures. Habitat for aquatic organisms such as fish or invertebrates is limited here due to the lack of canopy cover or in-stream habitat.

Recommended Measures: A vegetative riparian buffer in this location would provide multiple benefits, including the prevention of potential shoreline erosion in areas without a bulkhead and increased filtration of nutrients from residential stormwater runoff. The right bank should be prioritized for a riparian buffer. Additionally, the placement of a floating wetland island in this section of the creek would sequester nutrients before the water empties into Greenwood Lake and would provide habitat and protection from the sun for fish and other aquatic organisms. There appear to be a few locations along either shoreline where a floating wetland island could be tucked in off the main channel, protecting the island during periods of heavy flow. The floating wetland island would have to be placed in a protective location and tied to the shoreline for protection.

Estimated Costs: The estimated costs for the riparian buffer and a floating wetland island is estimated to cost between $11,400 - $15,400.

SITE 18: (B-3: BELCHER CREEK ALONG BEAVER AVENUE)

The left Bank of Belcher Creek runs parallel to Beaver Avenue, and the creek is only separated from the road by a few feet of mowed grass. The shoreline here lacks any type of vegetative buffer that would act as a nutrient filter for any stormwater that drains from Beaver Avenue. This side of the creek also lacks adequate canopy cover which leads to increased surface water temperatures.

Recommended Measures: A vegetative riparian buffer in this location would provide multiple benefits, including the prevention of potential shoreline erosion and increased filtration of nutrients from stormwater runoff that originates on Beaver Avenue.

Estimated Costs: The estimated costs for the riparian buffer is approximately $3,600 - $13,500.

SITE 19: (B-5: RESIDENTIAL SHORELINE NEAR LOUIS AVENUE)

The right bank of Belcher Creek runs parallel to a residential shoreline just downstream of Louis Avenue. The shoreline here lacks an adequate riparian buffer that would act as a nutrient filter from any residential stormwater runoff.

Recommended Measures: A vegetative riparian buffer in this location would provide multiple benefits, including the prevention of potential shoreline erosion and increased filtration of nutrients from stormwater runoff that originates on the residential property.

Estimated Costs: The estimated costs for the riparian buffer is approximately $1,200 - $4,500.

SITE 20: (B-6: RIGHT BANK ALONG PARKING LOT DOWNSTREAM OF UNION VALLEY ROAD)

The right bank of Belcher Creek along the parking lot referenced in Site 4 is the site most in need of restoration measures, as determined during the field assessment on 16 July 2019. Extensive erosion, including undercutting and bank scour, was observed along the right bank. Sediment deposition was observed in Belcher Creek downstream from this site. In addition to the erosion, the right streambank lacks an adequate riparian buffer. The gravel parking lot referenced in site 4 likely washes into Belcher Creek during storm events due to the lack of vegetation.

Recommended Measures: The right bank of this stream is an ideal candidate for bank stabilization to help address the erosion and sedimentation that is occurring. The streambank should be regraded to a gentler slope to allow for floodplain connectivity; the streambank is currently very steep. Re-grading the streambank would also help prevent flooding that is reported to occur in the adjacent parking lot. Once re-graded, the streambank toe can be further stabilized with riprap or another stabilization method that will allow the bank to absorb the impact of the stormwater without eroding. Additionally, a vegetative buffer would further enhance this site by acting as a nutrient filter for stormwater runoff and by stabilizing the streambank from further erosion.

Estimated Costs: The estimated cost for the streambank stabilization and riparian buffer enhancement is approximately $7,500 – $33,300.

SITE 21: (B-9: RESIDENTIAL SHORELINE NEAR WINDSOR ROAD)

The left bank of Belcher Creek runs parallel to a residential shoreline just downstream of Windsor Road. The shoreline here lacks an adequate riparian buffer that would act as a nutrient filter from any residential stormwater runoff.

Recommended Measures: A vegetative riparian buffer in this location would provide multiple benefits, including the prevention of potential shoreline erosion and increased filtration of nutrients from stormwater runoff that originates on the residential property.

Estimated Costs: The estimated costs for the riparian buffer is approximately $1,200 - $4,500.

SITE 22: (B-10: BELCHER CREEK PARALLEL TO EDGECUMB ROAD)

There is a side channel of Belcher Creek that runs for approximately 375 feet from Glencross Road to the main channel of the creek. This it the same section of the creek that has a large sediment bar from erosion from Glencross Road that was referenced in site 9. The creek channel is surrounded by residential properties on both sides that lack adequate riparian buffers for the majority of the channel.

Recommended Measures: A vegetative riparian buffer in this location would provide multiple benefits, including the prevention of potential shoreline erosion and increased filtration of nutrients from stormwater runoff that originates on the residential property.

Estimated Costs: The estimated costs for the riparian buffer is approximately $1,800 - $6,750.

Table 12: Low and high pollutant removal estimates for proposed streambank projects.

Proposed Projects in Belcher Creek	Pollutant Removal	
Proposed Streambank Projects	**TP (kg)**	**TSS (kg)**
B-1: Upstream of Union Valley Road	6	10,000
B-3: Along Beaver Avenue	9	20,000
B-5: Residential shoreline near Louis Avenue	4	10,000
B-6: Downstream of Union Valley Road	4	33,000
B-9: Residential shoreline near Windsor Road	4	8,500
B-10: Channel parallel to Edgecumb Road	6	12,000

Table 13: Low and high cost estimates for proposed streambank projects.

Proposed Projects in Belcher Creek	Price Estimate	
Proposed Streambank Projects	**Low**	**High**
B-1: Upstream of Union Valley Road	$11,440	$15,400
B-3: Along Beaver Avenue	$3,600	$13,500
B-5: Residential shoreline near Louis Avenue	$1,200	$4,500
B-6: Downstream of Union Valley Road	$7,500	$33,300
B-9: Residential shoreline near Windsor Road	$1,200	$4,500
B-10: Channel parallel to Edgecumb Road	$1,800	$6,750

4. TECHNICAL AND FINANCIAL ASSISTANCE

Implementation of plan elements and project concepts is dependent on securing the funding and technical assistance to support those goals. As a crucial element of a WIP, this section addresses the fourth of the EPA nine elements.

Costs for the design, installation, and maintenance of each proposed stormwater structure are provided in this report and its associated appendices. Project specific costs are provided in Tables 9 and 12 in the previous section. The total cost of all proposed projects is estimated to cost in the range of $14 million.

FINANCIAL ASSISTANCE

From a practical perspective, one of the major limiters on successfully managing NPS pollution, meeting water quality standards and designated uses, and controlling stormwater is funding. The expense of these items is two-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.

Despite the costs of implementing individual implementation 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 options 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.

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 watershed Implementation plans (WIP) 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 WIP 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 WIP.

NJDEP FUNDED GRANTS IN 2020

The most recent round of 319 funding was released by NJDEP in December of 2019 with up to $3,500,000 in grants available for watershed restoration and enhancement measures with a request for proposals through February 2020. 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; the next round will be focused on the Northeast in 2022. Even so, NJDEP is making up to $1,000,000 of the 2020 319 grant funding available to mitigate Harmful Algal Blooms (HABs) through in-lake and watershed planning and implementation projects. As a lake that experienced sustained HABs throughout the 2019 season, the Greenwood Lake Commission and the Township of West Milford should pursue these available grant funds for the implementation of watershed and/or in-lake measures that will help mitigate these algae blooms.

In addition to the release of the standard 319 funding to address nonpoint source pollution throughout the state of New Jersey, NJDEP announced grant funding that will be made available to prevent, mitigate, and/or control freshwater HABs. The request for proposals for these grants were also released in December of 2019 and will be due in January 2020. NJDEP has made up to $2,500,000 available for in-lake methods or projects to mitigate and/or control freshwater HABs throughout the state of New Jersey. NJDEP will award up to $500,000 per approved applicant and will require a 33% in-kind match by the applicant. As mentioned above, the Commission and the Township of West Milford should pursue these available grant funds for the implementation of in-lake measures that will help mitigate and/or control freshwater HABs in Greenwood Lake.

NEW JERSEY HIGHLANDS COUNCIL

The New Jersey Highlands Council is a regional planning agency that works exclusively with municipalities and counties in the Highlands Region of New Jersey. The Highlands Council works to encourage a comprehensive regional approach regarding the protection and enhancement of the natural resources within the Highlands Region. As such, the Highlands Council offers grant funding for projects that will protect and enhance water quality throughout the region. These grants include the planning, design, and engineering aspects of watershed-based projects, but do not include the implementation of these projects. As a township located entirely in the Highlands Region, funding through the Highlands Council grants is a great way to get the early stages of project development completed, allowing money obtained through other grants to be used exclusively on implementation.

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 14). 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.

Table 14: Federal Grant Services

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
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

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.

5. EDUCATION AND OUTREACH

This section reviews the information and education (I/E) aspect of the WMP. 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.

The protection and preservation of water quality and the ability to address the TMDL in the Greenwood Lake watershed is contingent upon the education of the target audience including public officials, residents, landowners, farmers, and business in the watershed. Goals of I/E 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 TP.
- Celebrate successes to recognize continuing and noteworthy efforts, encourage participation, and continue the implementation of the WIP.
- 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 groups identified in the financial and technical assistance section should be consulted. 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 to include property owners or managers that contain or are adjacent to waterways, ponds, wetlands, and floodplains. These are the areas most susceptible to degradation of aquatic ecosystems, but also in the best position to implement projects that can mitigate these problems.

EDUCATION AND OUTREACH IN THE GREENWOOD LAKE WATERSHED

For this WIP, the educational component includes a series of public presentations and verbal project status reports, hosted by the Commission, as well as producing educational material for general distribution and posting on stakeholder websites.

The public presentations will focus on what the landowner can do to contribute toward reducing the NPS pollutant loading to the lake, with an emphasis on phosphorus. One presentation will focus more on behavioral changes in general land use / homeowner practices that will aid in protecting the lake, such as septic management, use of non-phosphorus fertilizers, expansion of buffers and simple land / soil stabilization techniques. Another presentation will focus more on projects that can be actively implemented to contribute toward reducing NPS pollution such as rain gardens, creating shoreline / streambank buffers and using rain barrels. Educational material will be developed for each presentation that can be distributed to the public and make available on stakeholder websites.

To minimize costs, Princeton Hydro utilized many of the existing information available on reducing NPS pollution (sources will include but not be limited to Rutgers University, NJDEP, US EPA, and the Center of Watershed Protection) to develop educational information for the WIP. However, the available information was slightly modified so it specifically addresses the needs and concerns of the Greenwood Lake watershed.

In summary, the public information and aspect component of this WIP includes:

1. Two public presentations with an emphasis on stormwater management.

2. The distribution of educational material with information related to each of the presentations.

6. 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, especially where watershed-wide implementation is necessary to meet pollution reduction goals and align with the TMDL as in the Greenwood Lake watershed. 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.

YEARS 1 TO 2

In the short term, approximately Years 1 and 2, the focus should be on addressing the highest priority projects that have a strong likelihood of being approved and implemented, **such as the essentially shovel ready Marshall Hill project, evaluating ferric sulfate injection feasibility, and installing FWIs**. These projects represent locations in the highest priority sub-watersheds that surround Belcher Creek. The focus, especially in the early going, is 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.

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. The short-term implementation schedule is provided below.

YEARS 3 TO 5

This phase of project implementation is primarily focused on the development of projects that have been identified as being of highest priority because they are located in sub-watersheds G, H, and I. These areas have been identified as the most problematic sources of TP and other NPS pollutants by virtue of load or concentration, size, and development characteristics. They are also associated with measured impairments in water quality in Belcher Creek and Greenwood Lake. The focus on implementing in these sub-watersheds should provide the greatest benefit in meeting reduction goals.

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, or have been completed or 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. The medium-term implementation schedule is provided below.

Table 15: Implementation Schedule – Years 3 to 5

Site ID	Location	BMP
1	West Milford Lake	Constructed Wetland
4	New Jersey Avenue – rear lot	Extended vegetative filter strip Rain garden
6	Bagel Town Café rear lot	Retrofit dry detention basin Retrofit wet pond
7	Union Valley and Edgecumb Road pond	Forebay reconstruction Deep drop inlet and road curbs
10	Athletic fields	Bioretention swale
14	Union Valley Road and Warwick Tpk	Bioengineered streambank stabilization Stabilized conveyance systems

YEARS 6 TO 10

This phase is focused on the implementation of the longer-term projects and some of the lower priority projects. These projects may include areas owned by private entities or more complex projects from a logistical and stakeholder standpoint. Projects that have less of a direct effect on Belcher Creek may be implemented in this phase.

Table 16: Implementation Schedule – Years 6 to 10		
Site ID	**Location**	**BMP**
2	Shop-Rite parking lot	NSBB Bioretention system
3	Adelaide Terrace stream	Riparian buffer enhancement Right bank grade control
5	New Jersey Avenue – front lot	NSBB Streambank stabilization
8	Gwyneth Road and Glencross Road	NSBB Extended Filter Strip
9	Belcher Creek at Glencross Road	Headwall installation
12	Almond Branch Church	Bioretention system(s)
15	Our Lady Queen of Peace Church	Rain garden
16	Elks Lodge stream	Enhanced riparian buffer Removal of downed tree

POST YEAR 10

This phase is focused on much longer-term projects that would likely require considerable coordination between property owners and regulatory authorities.

Table 17: Implementation Schedule – Years 6 to 10		
Site ID	**Location**	**BMP**
13	Development west of Lincoln Avenue	Community wastewater system

7. 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 EPA plan elements.

MILESTONES

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. It is recommended that TP load reductions be used as the main assessment of how the various watershed measures that are implemented work towards achieving compliance with the TMDL. An empirical approach can be taken by monitoring TP concentrations at site locations pre and post implementation of a BMP or other restoration measure. In addition to quantifying annual nutrient reductions through water sampling, there are a variety of other milestones can be used to encapsulate individual project data within the framework of the larger WIP 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, event attendees, volunteers, trainees and related
- Number of septic management projects in-progress or completed
- Tanks pumped, systems repaired, malfunctions corrected, and new sanitary sewer connections and related measures
- 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 stream feet stabilized, acres of buffer improved, trees and shrubs installed, in-stream grade controls installed, and other related metrics
- Pet waste and wildlife management projects in-progress and completed
- Signage erected, waste receptacles installed, waste bags provided, geese managed, and similar items
- Number of tracts and acres of land preserved
- Changes to land use regulations, adoption of new ordinance, dedication of funds, modification of operations, and similar local government initiatives enacted
- Attainment of designated uses, de-listing of impaired waters, and similar compliance with environmental quality standards

8. 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 EPA element.

As with the original SIP, the indicators used to measure progress towards TMDL compliance will be of two types. The first will be based on the specific water quality criteria that have already been established for Greenwood Lake for TMDL compliance; a targeted mean, growing season TP concentration of 0.03 mg/L. This indicator will be based on the collection of empirical, in- lake water quality data.

The second indicator will be the amount of TP removed through each implemented stormwater BMP or watershed actions. Typically, with each completed project, the amount of TP removed through that project is quantified on an annual basis. The resulting removed amount of TP can then be deducted from the lake's TP load targeted for reduction under the TMDL. In turn, the indicator will be the percent reduction associated with complete compliance with the lake's TMDL (obviously with an emphasis on the New Jersey end). Currently, the New Jersey end of the Greenwood Lake watershed TMDL is approximately 49% in compliance. The project-based, estimated TP 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 Greenwood Lake 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.

STREAMBANK STABILIZATION AND RIPARIAN BUFFER ENHANCEMENTS

This class of management measures includes in-stream and riparian area projects to address instability, erosion and sedimentation, hydraulics, habitat quality, and aquatic organism passage.

Measures related to modifying local hydraulics are typically evaluated on the following metrics:

- Channel and floodplain hydraulic geometry
- Flows including peak flow
- Velocity
- Flood storage capacity
- Channel roughness
- Shear stress

Substrate and solids characterization include:

- Particle size metrics such as D_{50} and D_{84}
- Bed load
- Solids metrics including total suspended solids and total solids

Riparian buffer enhancements have many benefits including cooling, 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. This WIP is particularly focused on the management of TP in the Greenwood Lake watershed, with a secondary focus on associated NPS pollution, particularly additional nutrient pollutants and solids.

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 at Greenwood Lake, 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

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
- Macroinvertebrate 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* 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 Greenwood Lake the following criteria are especially important:

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

9. 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 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.

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 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.

SURFACE WATER MONITORING

In-lake monitoring should also be conducted to gauge how Greenwood 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 original SIP and this updated WIP. This will provide an ever-increasing inter-annual database to identify long-term trends in water quality. Five (5) in-lake monitoring stations are typically monitored in Greenwood Lake for a variety of physical, chemical, and biological parameters; *in-situ* (dissolved oxygen, temperature, pH, and conductivity) data and discrete samples are collected from 4 of the in-lake stations.

INTERNAL NUTRIENT LOADING MONITORING AND MODELING

In addition to the project site monitoring and standard surface water monitoring that should occur after the implementation of watershed-based projects, Princeton Hydro recommends implementing monitoring that will aid in the quantification of Greenwood Lake's internal phosphorus load. It was determined in the original SIP that internal phosphorus loading from the bottom sediment was the single largest contributor to the overall TP load, accounting for 1,739 kg (42%). While the work in the original SIP and this updated WIP are focused on the watershed-based TP load, an internal phosphorus load greater than 40% is very high and warrants in-lake measures, such as hypolimnetic aeration or the application of a nutrient inactivant, to reduce this load. With the recent increase in large scale and sustained harmful algal blooms in Greenwood Lake and other lakes throughout the region, it is imperative that the overall phosphorus load to Greenwood Lake be reduced in a timely manner to prevent future blooms.

It is first recommended that the internal load be updated soon, as this current estimate was calculated over 14 years ago. In order to better quantify the internal load on a monthly and seasonal basis, relatively frequent water quality monitoring is required in the lake. This type of monitoring would likely need to be conducted at least once per month during the growing season months and up to twice per month during the peak growing season months. It is essential that the depth of anoxia throughout the lake be characterized frequently throughout the growing season in order to accurately calculate the internal load.

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 Greenwood Lake be updated and addressed accordingly in order to combat harmful algal blooms in the most effective manner.

REFERENCES

Day, L.D. 2001. Phosphorus impacts from on-site septic systems to surface waters in the Cannonsville Reservoir Basin, New York. Delaware County Soil and Water Conservation District. Walton, New York.

Gold, A. 2006. Special issue: fate of phosphorus in septic tanks (autonomous waste water treatment systems). Scope Newsletter No. 63.

New Jersey Department of Environmental Protection. 2004. *Amendment to the Northeast Water Quality Management Plan. Total Maximum Daily Load for Phosphorus to Address Greenwood Lake in the Northeast Water Region*. Division of Watershed Management. Trenton, New Jersey.

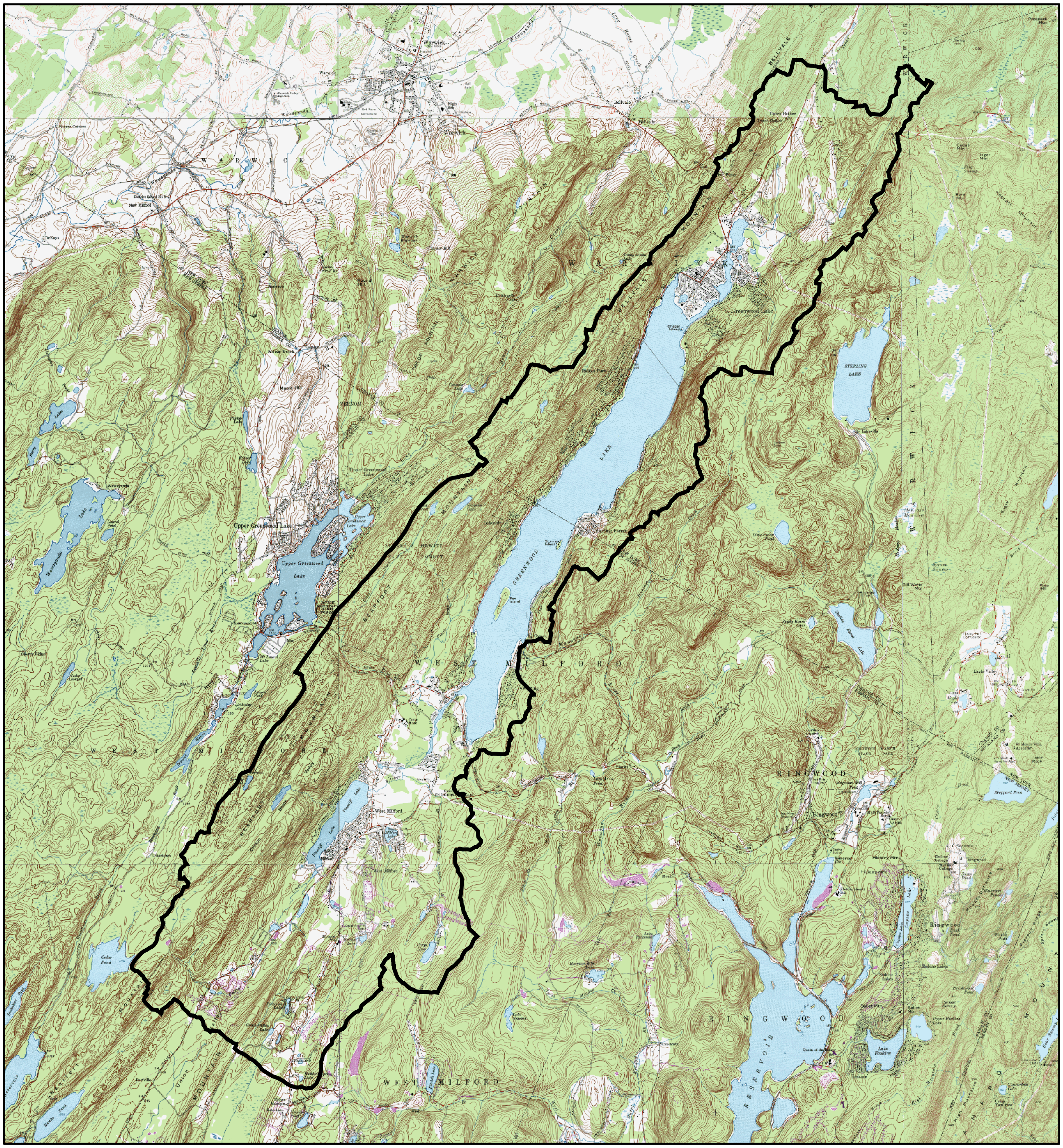
Princeton Hydro. 2006. *Stormwater Implementation Plan for the New Jersey End of the Greenwood Lake Watershed, Township of West Milford Passaic County, New Jersey.* Township of West Milford. West Milford, New Jersey.

Princeton Hydro. 2014. *Design and Implementation of a Set of Stormwater Projects to Reduce the Phosphorus and Sediment Loads Entering Greenwood Lake.* [Pursuant to 319(h) of the Clean Water Act (SFY2007)]. Township of West Milford. West Milford, New Jersey.

United States Environmental Protection Agency, Office of Water, Nonpoint Source Control Branch. 2008. *Handbook for Developing Watershed Plans to Restore and Protect Our Waters*. Washington, D.C. EPA 841 -B -08-002.

APPENDIX I:

MAPS



Princeton Hydro

FIGURE 1: GREENWOOD LAKE WATERSHED

West Milford - Greenwood Lake
319 Grant

West Milford Township
Passaic County, New Jersey

Legend

Watershed Boundary

N
W E
S

1 inch equals 9,100 feet

0 1,500 3,000 6,000
Feet

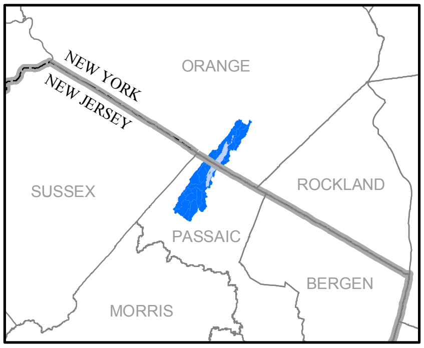
PRINCETON HYDRO, LLC.
1108 OLD YORK ROAD
P.O. BOX 720
RINGOES, NJ 08551

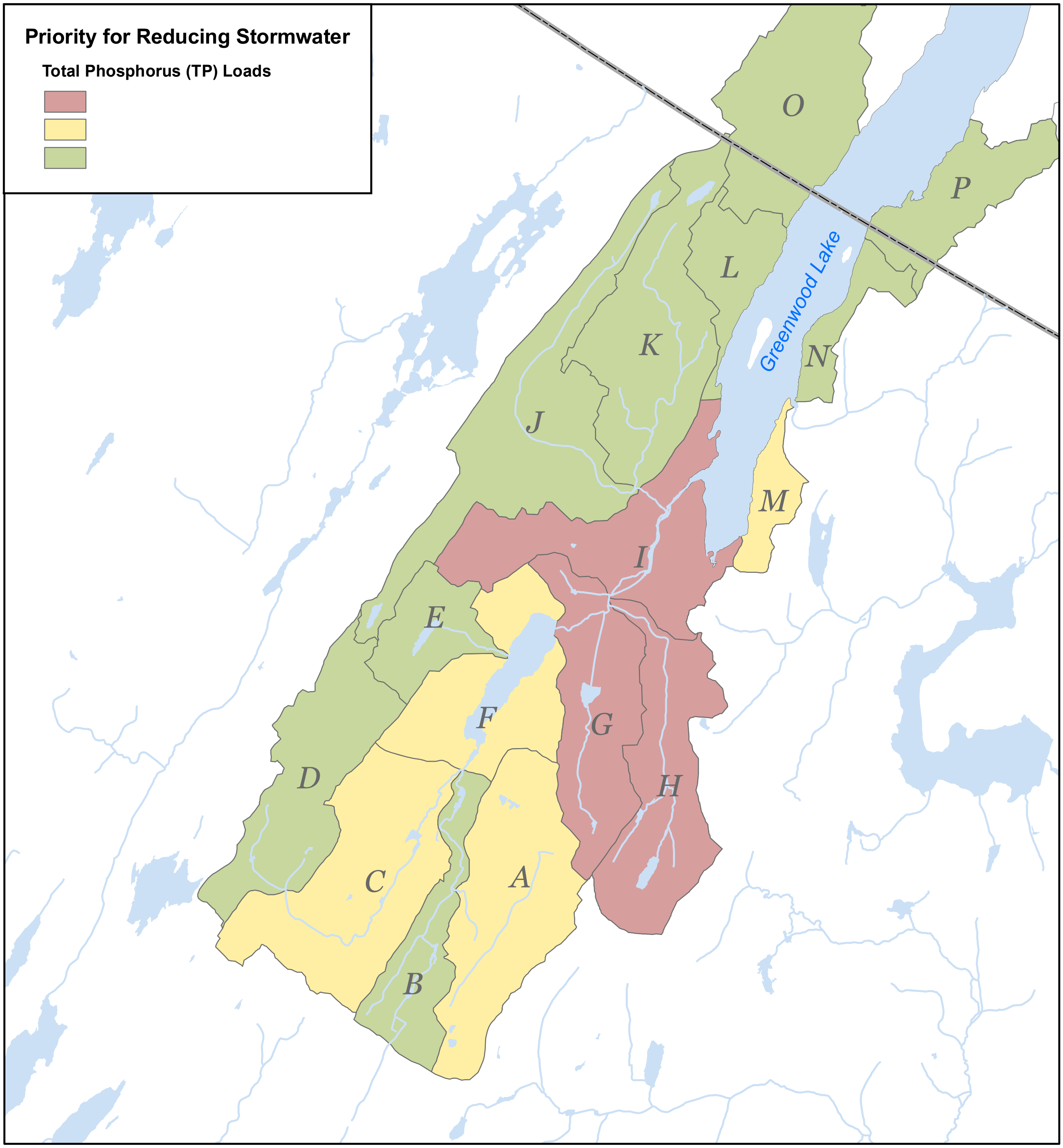
Sources:

1) Watershed Boundaries delineated with ESRI ArcGIS software and 10 meter DEM obtained from NJDEP

2) 3. USGS 7.5 Minute Series Topographic Map for Ramsey, Sloatsburg, Newfoundland, Wanaque, Wawayanda, Monroe, Pine Island, and Warwick as exported from Terrain Navigator Professional.

NEW JERSEY MAP





Princeton Hydro

FIGURE 2: PRIORITIZED SUB-WATERSHEDS

West Milford - Greenwood Lake
319 Grant

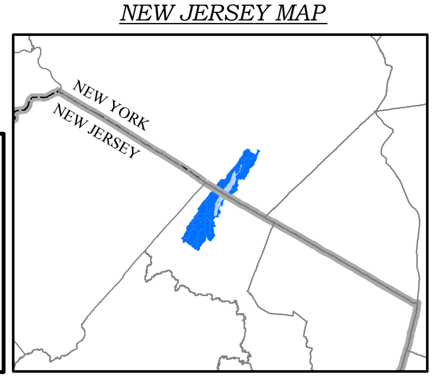
Legend

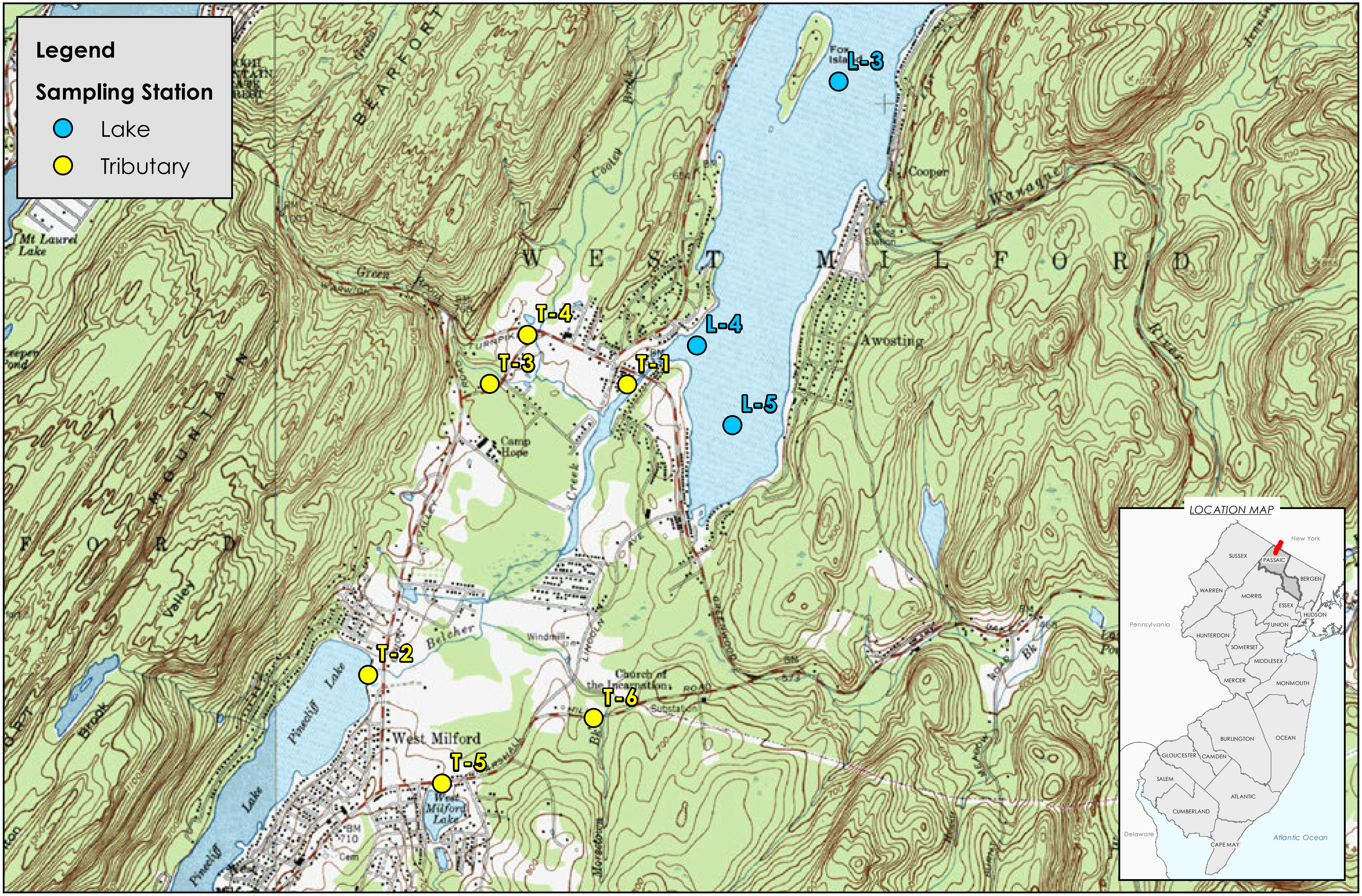
N
W E
S

1 inch equals 6,000 feet

0 1,500 3,000 6,000 Feet

NEW JERSEY MAP





NOTES:
1. Sample station locations are approximate.
2. USGS topographic digital raster graphic obtained from Terrain Navigator Pro, Greenwood Lake, NY-NJ quadrangle.

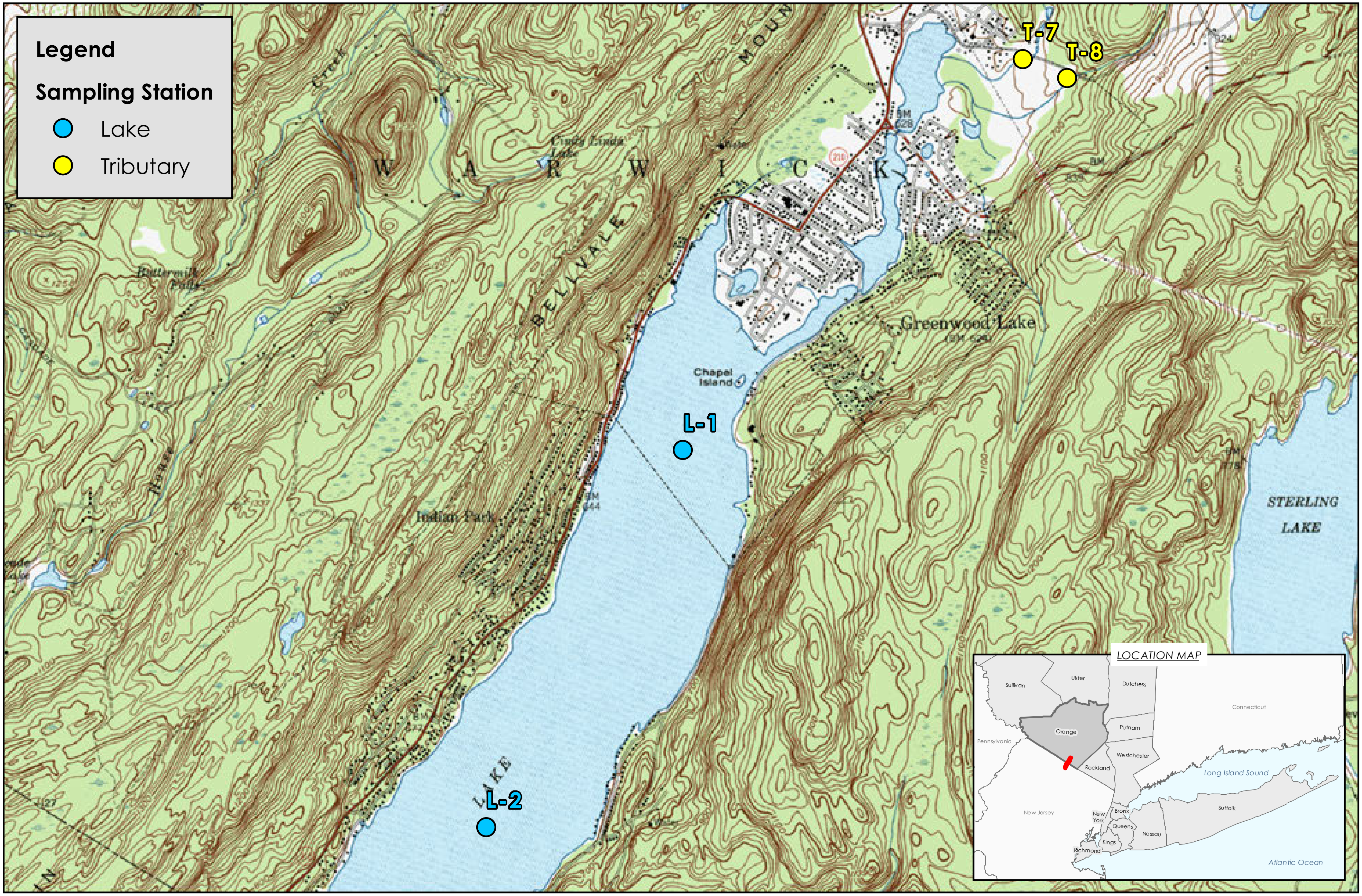
0 1,250 2,500 Feet

Map Projection: NAD 1983 StatePlane New Jersey FIPS 2900 Feet

SAMPLING STATION LOCATION MAP - NEW JERSEY

GREENWOOD LAKE
TOWNSHIP OF WEST MILFORD
PASSAIC COUNTY, NEW JERSEY

PRINCETON HYDRO
SCIENCE DESIGN ENGINEERING
www.PrincetonHydro.com



NOTES:
1. Sample station locations are approximate.
2. USGS topographic digital raster graphic obtained from Terrain Navigator Pro, Greenwood Lake, NY-NJ quadrangle.

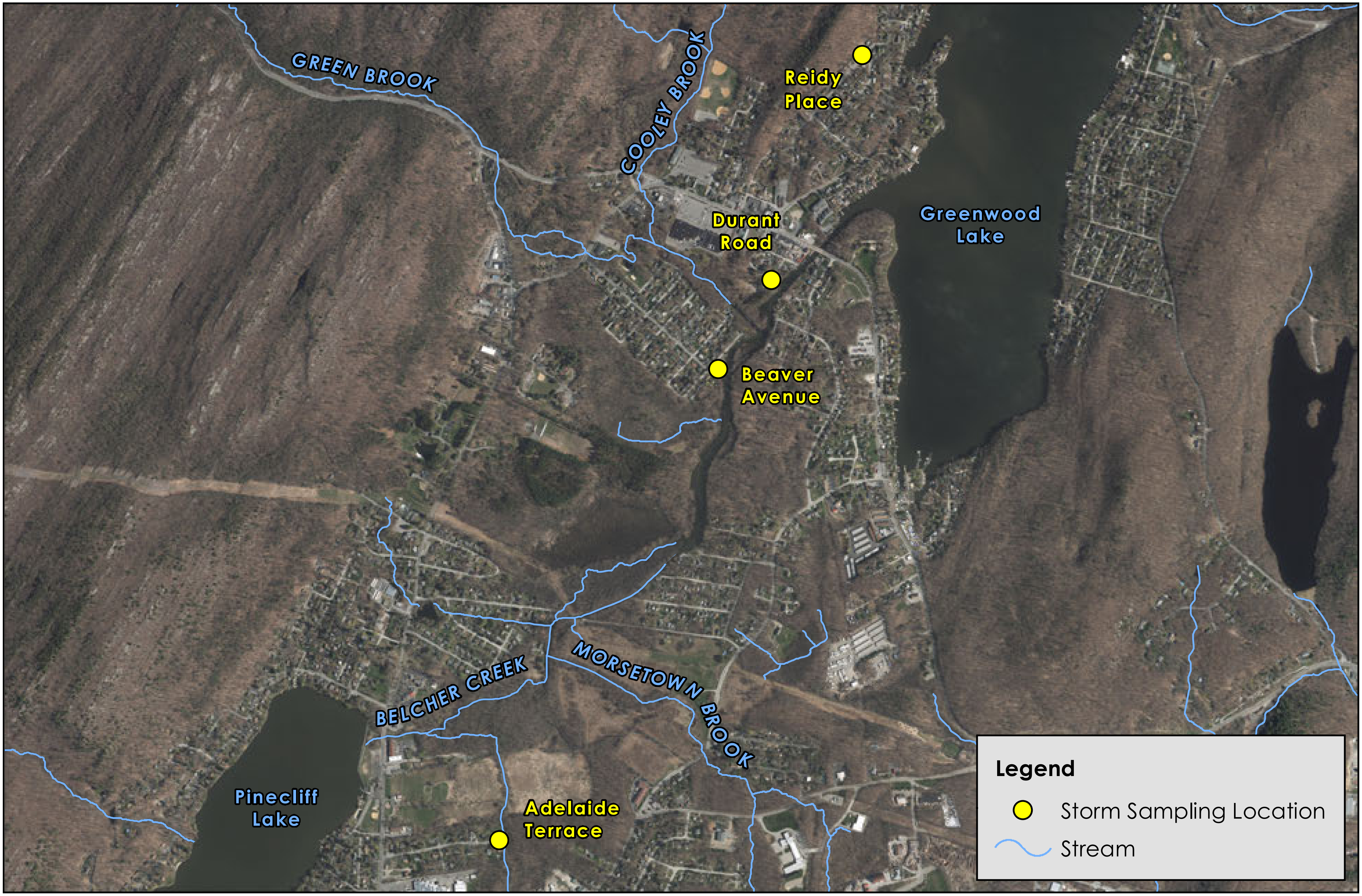
0 1,250 2,500 Feet

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

SAMPLING STATION LOCATION MAP - NEW YORK

GREENWOOD LAKE
TOWN OF WARWICK
ORANGE COUNTY, NEW YORK

PRINCETON HYDRO
SCIENCE DESIGN ENGINEERING
www.PrincetonHydro.com



STORM SAMPLING LOCATION MAP

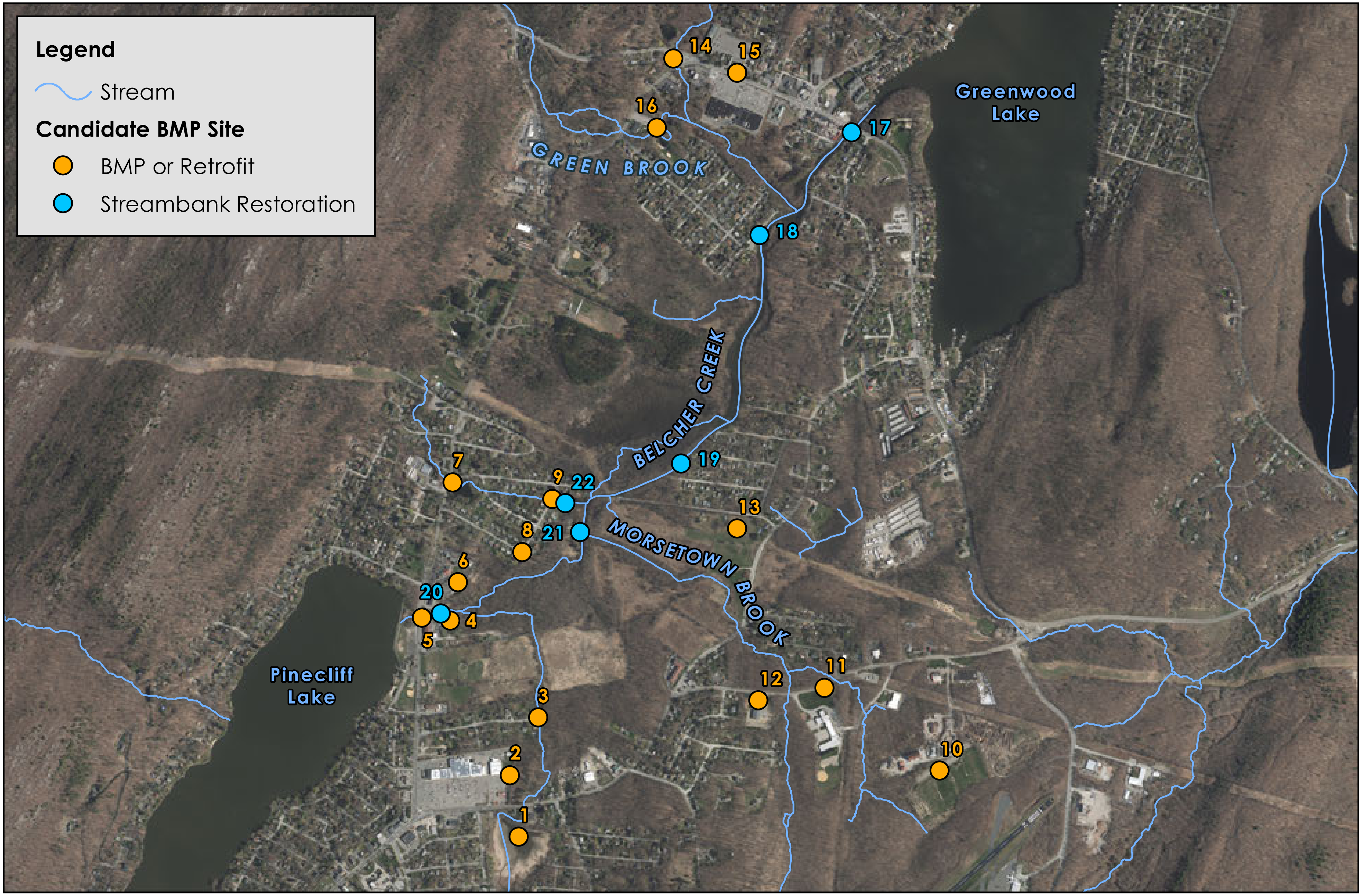
GREENWOOD LAKE
TOWNSHIP OF WEST MILFORD
PASSAIC COUNTY, NEW JERSEY

NOTES:
1. Sampling locations are approximate.
2. 2015 orthoimagery obtained from NJGIN Information Warehouse website: https://njgin.state.nj.us/NJ_NJGINExplorer

0 750 1,500 Feet

Map Projection: NAD 1983 StatePlane New Jersey FIPS 2900 Feet

PRINCETON HYDRO
SCIENCE DESIGN ENGINEERING
www.PrincetonHydro.com



File: P:\1850\Projects\185000\GIS\MXD\Candidate_BMP_Sites.mxd, 1/22/2020, Drawn by thopper, Copyright Princeton Hydro, LLC.

NOTES:
1. Candidate BMP site locations are approximate.
2. 2015 orthoimagery obtained from NJGIN Information Warehouse website: https://njgin.state.nj.us/NJ_NJGINExplorer

0 750 1,500 Feet

Map Projection: NAD 1983 StatePlane New Jersey FIPS 2900 Feet

CANDIDATE BMP SITE MAP

GREENWOOD LAKE
TOWNSHIP OF WEST MILFORD
PASSAIC COUNTY, NEW JERSEY

PRINCETON HYDRO
SCIENCE DESIGN ENGINEERING
www.PrincetonHydro.com

APPENDIX II:

TOTAL MAXIMUM DAILY LOAD

Amendment to the Northeast Water Quality Management Plan

Total Maximum Daily Load for Phosphorus To Address Greenwood Lake in the Northeast Water Region

Watershed Management Area 3

Proposed:	June 7, 2004
Established:	
Approved:	
Adopted:	

New Jersey Department of Environmental Protection
Division of Watershed Management
P.O. Box 418
Trenton, New Jersey 08625-0418

Contents

Figures

Tables

1.0 Executive Summary

The State of New Jersey's *2002 Integrated List of Waterbodies* identified Greenwood Lake in the Northeast Water Region as being eutrophic. This report establishes one total maximum daily load (TMDL) for total phosphorus (TP) to address eutrophication of Greenwood Lake.

This TMDL serves as the foundation on which a restoration plan will be developed to restore the lake and thereby attain applicable surface water quality standards. A TMDL is developed to identify all the contributors to surface water quality impacts and establish load reductions for pollutants of concern as necessary to meet Surface Water Quality Standards (SWQS). The pollutant of concern for this TMDL is phosphorus; phosphorus is the nutrient responsible for overfertilization of inland lakes leading to cultural eutrophication.

In order to prevent excessive primary productivity[1] and consequent impairment of recreational, water supply and aquatic life designated uses, the SWQS define both numerical and narrative criteria that address eutrophication in lakes due to overfertilization. All possible phosphorus sources were characterized on an annual scale (kg TP/yr), including runoff from the land surface, point sources, septic tank systems and internal loading from the lake sediment. Runoff from land surfaces and internal loading from the lake sediment comprise the most significant sources of phosphorus into the lake. An empirical model was used to relate annual phosphorus load and steady-state in-lake concentration of total phosphorus. To achieve the TMDL, overall load reductions were calculated for different source categories. In coordination with the bi-state Greenwood Lake Commission, an Implementation Plan has been developed for this TMDL, which includes a Lake Characterization and Restoration project, using funds made available to the New Jersey Department of Protection (NJDEP) under the Clean Water Act Section 319(h). The project will begin in July 2004. The bathymetric survey, in-lake monitoring and tributary monitoring proposed in this project will better quantify phosphorus contributions and tailor actions to achieve needed reduction as well as to identify any in-lake measures needed to supplement the nutrient reductions required by the TMDL. Stormwater runoff "hot spots" that would benefit from best management practices (BMPs) will be identified and prioritized. The efficiency of implemented BMPs will be monitored after installation. Other implementation measures include education projects that teach BMPs on lawn care, municipal ordinances to deal with phosphorus, remediation of septic systems, upgrading wastewater treatment facilities, and projects to reduce the internal loading from the sediment. The Department believes that these steps will result in attainment of New Jersey's SWQS for phosphorus.

This TMDL Report is consistent with EPA's May 20, 2002 guidance document entitled: "Guidelines for Reviewing TMDLs under Existing Regulations issued in 1992," (Sutfin, 2002) which describes the statutory and regulatory requirements for approvable TMDLs.

2.0 Introduction

Sublist 5 of the State of New Jersey's *2002 Integrated List of Waterbodies* (also known traditionally as the 303(d) List) identified Greenwood lake as being eutrophic, as evidenced by elevated total phosphorus (TP), elevated chlorophyll-*a*, and/or macrophyte density that impairs recreational use (a qualitative assessment). Total phosphorus was used as the pollutant of concern, since this "independent" causal pollutant results in "dependent "responses in chlorophyll-*a* concentrations and/or

[1] Primary productivity refers to the growth rate of primary producers, namely algae and aquatic plants, which form the base of the food web.

macrophyte density. This report establishes one TMDL for TP load to Greenwood Lake and the management approaches and restoration plan needed to attain applicable surface water quality standards.

3.0 Background

3.1 305(b) Report and 303(d) List

In accordance with Section 305(b) of the Federal Clean Water Act (CWA) (33 U.S.C. 1315(B)), the State of New Jersey is required biennially to prepare and submit to the United States Environmental Protection Agency (USEPA) a report addressing the overall water quality of the State's waters. This report is commonly referred to as the 305(b) Report or the Water Quality Inventory Report.

In accordance with Section 303(d) of the CWA, the State is also required biennially to prepare and submit to USEPA a report that identifies waters that do not meet or are not expected to meet surface water quality standards (SWQS) after implementation of technology-based effluent limitations or other required controls. This report is commonly referred to as the 303(d) List. The listed waterbodies are considered water quality-limited and require total maximum daily load (TMDLs) evaluations.

In November 2001, USEPA issued guidance that encouraged states to integrate the 305(b) Report and the 303(d) List into one report. This integrated report assigns waterbodies to one of five categories. Sublist 5 constitutes the traditional 303(d) List for waters impaired or threatened by a pollutant for which one or more TMDL evaluations are needed.

Following USEPA's guidance, the Department chose to develop an Integrated Report for New Jersey. New Jersey's *2002 Integrated List of Waterbodies* is based upon these five categories and identifies water quality limited surface waters in accordance with N.J.A.C. 7:15-6 and Section 303(d) of the CWA. This TMDL addresses the eutrophic Greenwood Lake, as listed on Sublist 5 of the State of New Jersey's *2002 Integrated List of Waterbodies.*

3.2 Total Maximum Daily Loads (TMDLs)

A TMDL represents the assimilative or carrying capacity of a waterbody, taking into consideration point and nonpoint source of pollutants of concern, natural background and surface water withdrawals. A TMDL quantifies the amount of a pollutant a water body can assimilate without violating a state's water quality standards and allocates that load capacity to known point sources in the form of wasteload allocations (WLAs), nonpoint sources in the form of load allocations (LAs), and a margin of safety (MOS). A TMDL is developed as a mechanism for identifying all the contributors to surface water quality impacts and setting goals for load reductions for pollutants of concern as necessary to meet SWQS.

Recent EPA guidance (Sutfin, 2002) describes the statutory and regulatory requirements for approvable TMDLs, as well as additional information generally needed for USEPA to determine if a submitted TMDL fulfills the legal requirements for approval under Section 303(d) and EPA regulations. The Department believes that this TMDL report addresses the following items in the May 20, 2002 guideline document:

1. Identification of waterbody, pollutant of concern, pollutant sources and priority ranking.
2. Description of applicable water quality standards and numeric water quality target(s).

3. Loading capacity – linking water quality and pollutant sources.
4. Load allocations.
5. Wasteload allocations.
6. Margin of safety.
7. Seasonal variation.
8. Reasonable assurances.
9. Monitoring plan to track TMDL effectiveness.
10. Implementation (USEPA is not required to and does not approve TMDL implementation plans).
11. Public Participation.

The State of New Jersey will be removing Greenwood Lake from the 303(d) List for phosphorus, once this TMDL is approved by USEPA.

4.0 Pollutant of Concern and Area of Interest

Greenwood Lake was designated as eutrophic on Sublist 5 of the *2002 Integrated List of Waterbodies* as a result of evaluations performed through the State's Clean Lakes Program. Indicators used to determine trophic status included elevated total phosphorus (TP), elevated chlorophyll-*a,* and/or macrophyte density. The pollutant of concern for this TMDL is total phosphorus. The mechanism by which phosphorus can cause use impairment is via excessive primary productivity. Phosphorus is an essential nutrient for plants and algae, but is considered a pollutant because it can stimulate excessive growth (primary production). Phosphorus is most often the major nutrient in shortest supply relative to the nutritional requirements of primary producers in freshwater lakes; consequently, phosphorus is frequently a prime determinant of the total biomass in a lake. Eutrophication has been described as the acceleration of the natural aging process of surface waters. It is characterized by excessive loading of silt, organic matter, and nutrients, causing high biological production and decreased basin volume (Cooke et al, 1993). Symptoms of eutrophication (primary impacts) include oxygen super-saturation during the day, oxygen depletion during night, and high sedimentation (filling in) rate. Algae and aquatic plants are the catalysts for these processes. Secondary biological impacts can include loss of biodiversity and structural changes to communities.

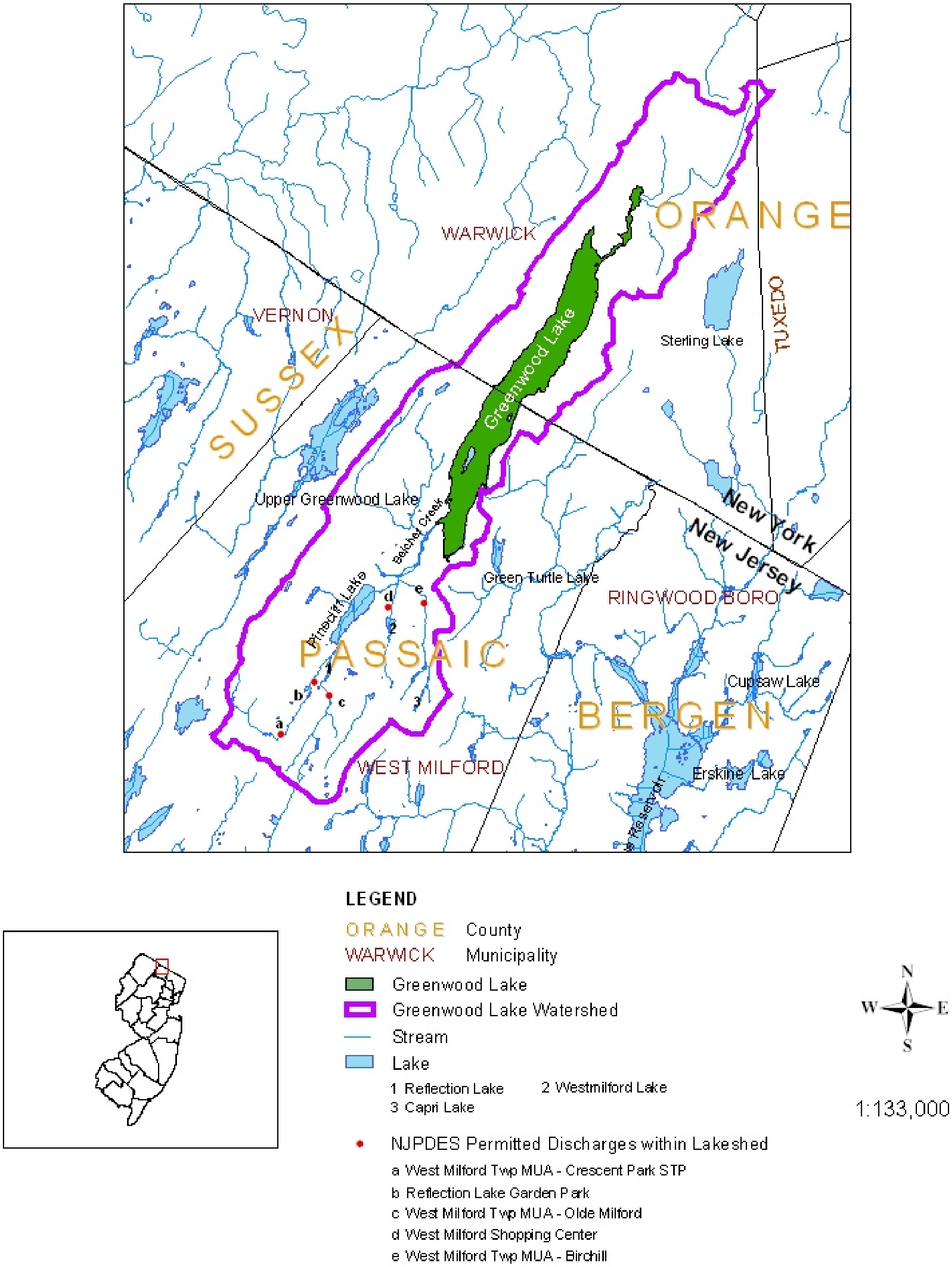
As reported in the *2002 Integrated List of Waterbodies*, the Department identified the Greenwood Lake as being eutrophic. The proposed 2004 list specifies the impairment in terms of the pollutants phosphorus, dissolved oxygen and sedimentation. This TMDL will address the phosphorus impairment and will cover 824 acres of the lake area located in New Jersey and 1060 acres of the lake area located in New York, corresponding to a total of 16,036 acres of land within the watershed. Eutrophic lake impairment is ranked as a Low Priority in the *2002 Integrated List of Waterbodies,* because it is not directly related to human health issues; however, eutrophication is an environmentally important issue. It is likely that the dissolved oxygen and sedimentation impairments are caused by primary productivity; this will be further evaluated as part of the implementation plan for this TMDL.

Table 1 Characteristics of Greenwood Lake

Lake Area (acre)	Lakeshed Area (acre)	Outflow[a] (m^3/yr)	Volume[a] (m^3)	Average Depth[a] (m)	Maximum Depth[a] (m)
1,884	16,036	3.45E+07	4.04E+07	5.2	17.4

a: taken from Phase 1 Study of Greenwood Lake (PAS, 1983)

Figure 1 Locations of Greenwood Lake and Its Watershed



As shown in Figure 1, Greenwood Lake is located on the border of New Jersey and New York. Greenwood Lake extends northward to the Town of Warwick, Orange County, New York and south to the Township of West Milford, Passaic County, New Jersey. The north and south basins are very different in terms of depth and bottom contours. The northern or New York section of the lake is characteristically deep, with a maximum depth of 18 meters and steeply sloped banks. In contrast, the southern or New Jersey section is shallow, with a maximum depth of 3 meters, gradually sloping banks. The lake's average depth is 5.2 meters, its surface area is 1884 acres and its volume is 4.04 x 10^7 m^3 (Table 1).

Several streams flow into the lake, and of these, Belcher Creek is the major tributary. Discharge from the lake is to the Wanaque River, a tributary of the Passaic River. Annual tributary inflow to the lake totals 1.8 x 10^7 m^3yr^{-1}, while total outflow is 4.04 x 10^7 m^3 (including evaporation). Greenwood Lake's watershed encompasses a total area of approximately 16,036 acres, exclusive of the lake's surface area (See Figure 1). The eastern and western boundaries of the watershed are defined by steep mountain ridges which parallel the lake's shoreline. Several small lakes are located within the watershed, including Pinecliff Lake, Reflection Lake, West Milford Lake, and Capri Lake. As shown in Figure 1, these small lakes serve as headwaters to Belcher Creek.

4.1 Geographic Information System (GIS) Coverage

In order to describe the lake and lakeshed (watershed of the lake), the Department's Geographic Information System (GIS), as well as GIS coverages from USGS and New York State, were used in this study, given the bi-state geographical location of Greenwood Lake. The coverages used in this study are specified below.

- Greenwood Lake Hydrology coverage (7.5 minute Quad Sheet) downloaded from Cornell University Geospatial Data Information Repository (CUGIR) was used to derive the entire lake boundary coverage. Hydrography (Census 2000) shapefiles were downloaded from CUGIR to describe the streams and lakes located in NY-side. http://cugir.mannlib.cornell.edu/browse_map/browse_map.html
- NJDEP Countywide Lakes and Streams (Shapefile) with Name Attributes for Passaic County, Sussex County and Bergen County to describe the lakes and streams located in NJ side. http://www.nj.gov/dep/gis/lakesshp.html and http://www.nj.gov/dep/gis/strmshp.html
- Lakesheds were delineated based on 14-digit hydrologic unit code coverage (HUC-14) and elevation contours.
  - NJDEP 14 Digit Hydrologic Unit Code delineations (DEPHUC14), published 4/5/2000 by New Jersey Geological Survey, http://www.state.nj.us/dep/gis/digidownload/zips/statewide/dephuc14.zip
  - Statewide Elevation Contours (10 Foot Intervals), unpublished, auto-generated from: 7.5 minute Digital Elevation Models, published 7/1/1979 by U.S. Geological Survey.
  - NJDEP Statewide Elevation Contours (20 Foot Intervals), published 1987 by Bureau of Geographic Information and Analysis (BGIA), http://www.state.nj.us/dep/gis/digidownload/zips/statewide/stcon.zip.
  - CUGIR's Elevation Data in the format of ASCII DEM
- National Land Cover Data (NLCD) for New York, last updated in July 2000, and for New Jersey, last updated in March 2000. The data was produced under the direction of the USGS as part of the Multi-Resolution Land Characterization (MRLC) Regional Land Cover Characterization Project. The data used the NLCD Land Cover Classification Systems to categorize land use. http://edcsgs9.cr.usgs.gov/pub/data/landcover/states/

- NJPDES Surface Water Discharges in New Jersey, (1:12,000), published 02/02/2002 by Division of Water Quality (DWQ), Bureau of Point Source Permitting - Region 1 (PSP-R1).
- NJDEP's 2000 Census Block Shapefile and Orange County, NY 2000 Census Block Shapefile from CUGIR
- NJDEP's 2002 Orthophotography Image.
- High Resolution Digital Orthoimagery 2000-2001 for Hudson Valley/Catskill Region in New York State, downloaded from New York Sate GIS Clearinghouse. http://www.nysgis.state.ny.us/gateway/mg/high_res.htm

4.2 Greenwood Lake Commission and New York State

A bi-state Greenwood Lake Commission has been formed to address the environmental issues in Greenwood Lake. New Jersey adopted the bill to create the Greenwood Lake Commission (S1788(1R); P.L. 1999 c.402) in January of 2000. The companion bill (A00294 S416-A) was adopted by New York State in January of 2001. The 11 voting members include representatives from: Passaic County, NJ; 2 representatives from the Township of West Milford, New Jersey; the Commissioner of the New Jersey Department of Protection (NJDEP) or designee; Orange County, New York; the Village of Greenwood Lake, New York; the Town of Warwick, New York; the Commissioner of the New York Department of Environmental Conservation (NYDEC) or a designee thereof; the Greenwood Lake Watershed Management District, a citizen advisory committee that has been active for more than 20 years; and from each state, an appointed representative from the public sector with related expertise. This TMDL has been developed in coordination with Greenwood Lake Commission.

New York has also listed Greenwood Lake as impaired, based on qualitative nutrient standards applicable to the lake in that state. At this time, New York is not establishing a TMDL for the portion of Greenwood Lake under its authority, but has been consulted on this proposed action to coordinate efforts to address the water quality impairment.

5.0 Applicable Surface Water Quality Standards

In order to prevent excessive primary productivity and consequent impairment of recreational, water supply and aquatic life designated uses, the Surface Water Quality Standards (SWQS, N.J.A.C. 7:9B) define both numerical and narrative criteria that address eutrophication in lakes due to overfertilization. The total phosphorous (TP) criterion for freshwater lakes at N.J.A.C. 7:9B – 1.14(c)5 reads as follows:

> For freshwater 2 classified lakes, Phosphorus as total phosphorus shall not exceed 0.05 mg/l in any lake, pond or reservoir or in a tributary at the point where it enters such bodies of water, except where site-specific criteria are developed to satisfy N.J.A.C. 7:9B-1.5(g)3.

N.J.A.C. 7:9B-1.5(g)3 states:

> "The Department may establish site-specific water quality criteria for nutrients in lakes, ponds, reservoirs or stream, in addition to or in place of the criteria in N.J.A.C. 7:9B-1.14, when necessary to protect existing or designated uses. Such criteria shall become part of the SWQS.

Presently, no site-specific criteria apply to Greenwood Lake.

Also at N.J.A.C. 7:9B-1.5(g)2, the following is discussed:

> "Except as due to natural conditions, nutrients shall not be allowed in concentrations that cause objectionable algal densities, nuisance aquatic vegetation, or otherwise render the waters unsuitable for the designated uses."

This TMDL is designed to meet both numeric and narrative criteria of the SWQS.

All of the waterbodies covered under this TMDL have a FW2 classification. The designated uses, both existing and potential, that have been established by the Department for waters of the State classified as such are as stated below:

In all FW2 waters, the designated uses are (N.J.A.C. 7:9B-1.12):
1. Maintenance, migration and propagation of the natural and established aquatic biota;
2. Primary and secondary contact recreation;
3. Industrial and agricultural water supply;
4. Public potable water supply after conventional filtration treatment (a series of processes including filtration, flocculation, coagulation and sedimentation, resulting in substantial particulate removal but no consistent removal of chemical constituents) and disinfection; and
5. Any other reasonable uses.

6.0 Source Assessment

As part of the 1983 Phase I Diagnostic-Feasibility Study of Greenwood Lake, New Jersey and New York (PAS, 1983), the potential sources of phosphorus in the lake were evaluated and the annual influx of phosphorus from different sources was quantified. The annual TP load was estimated to be 5936.4 kilograms. The majority of phosphorus originated from runoff from the land surface and the internal loading. However, septic tank and sewage treatment plant effluent are responsible for a sizable portion of the annual nutrient load as well. The Phase I Study was conducted over 20 years ago, so the contributions to the lake's annual phosphorus load were updated using the most recent data from these four major sources.

Phosphorus loads were characterized on an annual scale (kg TP/yr). Long-term pollutant loads are typically more critical to overall lake water quality than the load at any particular short-term time period (e.g. day). Storage and recycling mechanisms in the lake, such as luxury uptake and sediments dynamics, allow phosphorus to be used as needed regardless of the rate of delivery to the system. Also, empirical lake models use annual loads rather than daily or monthly loads to estimate in-lake concentrations.

6.1 Assessment of Point Sources other than Stormwater

The Department's GIS on New Jersey Pollution Discharge Elimination System (NJPDES) Surface Water Discharge was used to identify the point sources of phosphorus other than stormwater located within the New Jersey portion of the lakeshed. Five of them were selected with phosphorus requirements in their current permits and they are all Minor Municipal (MMI) discharges (Table 2). According to EPA's Envirofact Warehouse (http://oaspub.epa.gov/enviro/ef_home2.water), there are no facilities with National Pollutant Discharge Elimination System (NPDES) permits located within New York portion of the lakeshed.

The monthly average flow and TP concentration were obtained from Discharge Monitoring Reports (DMR) (July 2000 to December 2003) for each discharger. Only six months of data are available for year 2000; therefore, the annual TP load was calculated as a sum of the monthly loads for year 2001 through 2003. The average of three years' annual load was used as the representative value for the TP influx discharged from the identified facilities. As shown in Figure 1, three facilities (i.e., W Milford Twp MUA - Crescent Park STP, Reflection Lake Garden Apartments and West Milford Twp MUA-Olde Milford) discharge to Belcher Creek upstream of Pinecliff Lake. Considering the retention effects of Pinecliff Lake on phosphorus, the retention factor (0.56) used in the Phase 1 study (PAS, 1983) is applied to the calculated load from these three facilities. The sum of "reduced" load from these three facilities plus the calculated loads from the other two facilities comprise the point-source load of TP entering Greenwood Lake, which is about 70 kg/yr.

Table 2 NJPDES Discharges within Greenwood Lake Watershed

Identification	Facility Name	Discharge Type	Receiving Water	Maximum Allowable Flow, mgd
NJ0024414.001A	W Milford Shopping Center	MMI	Belchers Creek via unnamed tributary	0.02
NJ0028541.001A	West Milford Twp MUA - Birchill	MMI	Morestown Brook (Belchers Creek)	0.02
NJ0026174.001A	W Milford Twp MUA - Crescent Park STP	MMI	Belchers Creek	0.064
NJ0027201.001A	Reflection Lake Garden Apts	MMI	Belchers Creek via unnamed tributary and ditch	0.005
NJ0027677.001A	West Milford Twp MUA-Olde Milford	MMI	Belcher Creek via unnamed tributary	0.172

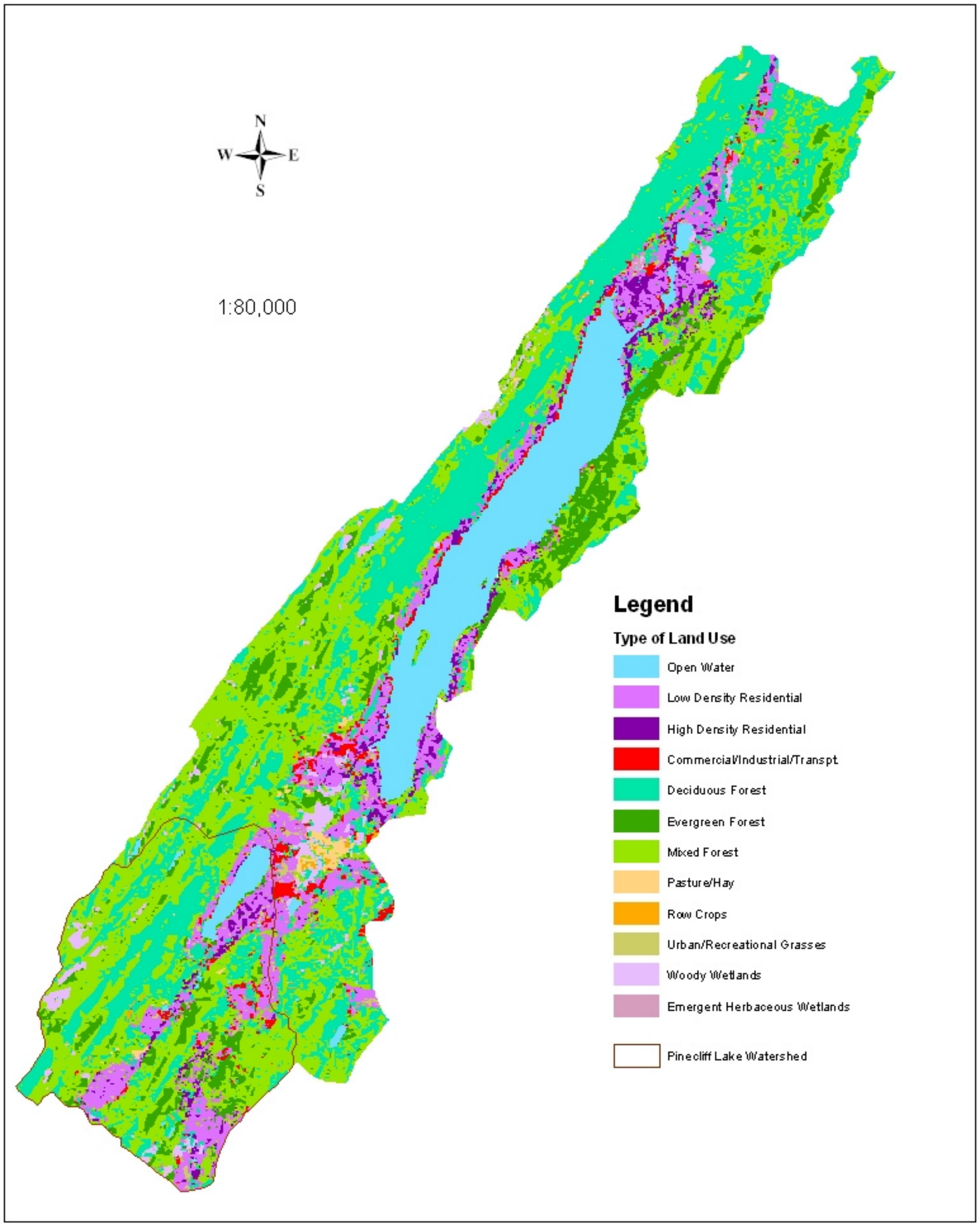
6.2 Assessment of Load from Land Surfaces Runoff

Runoff from land surfaces comprises most of the nonpoint and stormwater point sources of phosphorus into the lake. In the Phase I Study, the load from the surface runoff was calculated in two ways, the Unit Areal Load (UAL) methodology and the normalized flow-concentration methodology based on the tributary monitoring results. The tributary load suggested a much higher surface runoff load than the UAL method did. The normalized flow-concentration data were selected to represent the TP budget of the lake as they were computed from measured concentrations and precipitation adjusted flows.

Tributary monitoring has not been conducted in recent years. Therefore, the surface runoff load was updated using the UAL methodology, which applies pollutant export coefficients obtained from literature sources to the land use patterns within the watershed, as described in USEPA's Clean Lakes Program guidance manual (Reckhow, 1979b). In order to apply a uniform coverage for the entire watershed, land use was determined using the USGS 2000 National Land Cover Data (NLCD) for both New York and New Jersey (Figure 2). As part of the previous phosphorus TMDL development, an extensive database (Appendix B) was reviewed for phosphorus export coefficients and the Department selected the most representative values for different land use categories defined in the Department's

Land Use coverage. The NLCD classification of land use types is different from the Department's classification. Adjustments were made to assign an appropriate TP Export Coefficient for each type of NLCD land use. (Table 3).

Figure 2 Land Use Type in Greenwood Lake Watershed



A UAL of 0.07 kg TP/ha/yr was used to estimate air deposition of phosphorus directly onto the lake surface. This value was developed from statewide mean concentrations of total phosphorus from the New Jersey Air Deposition Network (Eisenreich and Reinfelder, 2001).

Land uses and calculated loading rates for the lakes are shown in Table 4. Since Pinecliff Lake is located within the Greenwood Lake watershed, the entire Greenwood Lake watershed was divided into two parts, Pinecliff Lake watershed and the remainder of the watershed. According to the Phase 1 Study, Pinecliff Lake has a detention effect on the phosphorus entering into it and the detention factor is estimated to be 0.56. Therefore, to account for TP retention in Pinecliff Lake, it is assumed that only 44% of the load contributed by the lands within the Pinecliff Lake watershed reach Greenwood Lake. This load added to the load that originates from the lands outside of the Pinecliff Lake watershed constitutes the load from surface runoff.

Table 3 Phosphorus export coefficients (Unit Areal Loads)

Landuse description	Gridcode	EC (kg TP/ha/yr)
Open Water	11	0.07
Low Intensity Residential	21	0.7
High Intensity Residential	22	1.6
Commercial/Industrial/Transportation	23	2.4
Deciduous Forest	41	0.1
Evergreen Forest	42	0.1
Mixed Forest	43	0.1
Pasture/Hay	81	1.5
Row Crops	82	1.5
Urban/Recreational Grasses	85	1
Woody Wetlands	91	0.1
Emergent Herbaceous Wetlands	92	0.1

Units: 1 hectare (ha) = 2.47 acres
1 kilogram (kg) = 2.2 pounds (lbs)
1 kg/ha/yr = 0.89 lbs/acre/yr

Table 4 Surface Runoff Source of Phosphorus Load

Land Use description	Pinecliff watershed		Greenwood Lake Watershed beyond Pinecliff watershed		Entire Greenwood Lake Watershed
	Area (acre)	TP load (kg/yr)	Area (acre)	TP load (kg/yr)	TP load (kg/yr)
Low Intensity Residential	612	173.3	1,199	339.7	415.9
High Intensity Residential	110	71.4	405	262.2	293.6
Commercial/Industrial/Transportation	75	73.2	284	275.5	307.7
Pasture/Hay	13	7.7	86	52.3	55.7
Row Crops	12	7.4	39	23.9	27.2
Urban/Recreational Grasses	32	13.0	51	20.5	26.3

Deciduous Forest	1,127	45.6	3,960	160.3	180.3
Evergreen Forest	371	15.0	1,021	41.3	47.9
Mixed Forest	1,941	78.6	4,148	167.8	202.4
Woody Wetlands	116	4.7	271	11.0	13.0
Emergent Herbaceous Wetlands	2	0.1	26	1.0	1.1
Open Water	157	6.4	102	4.1	6.9
Air deposition	-	-	1,884	53.4	53.4
Total		**496**		**1,413**	**1,631.6**

Note: Load from the entire Greenwood Lake watershed = load from the Greenwood Lake watershed beyond Pinecliff Lake watershed + (1-0.56) * load from the Pinecliff Lake watershed.

6.3 Assessment of Load from Septic Tank System

The TP load contributed to the lake as a result of onsite septic tank system use was quantified using the same methodology documented in the Phase 1 Study (PAS, 1983). The number of houses within 200 m of the lake's shoreline was determined from 2000 census data in conjunction with most recent aerial photos. A total of 2075 units that rely on septic tank systems were found within 200 meters of the lake's perimeter. 2000 census data indicated that the average size of these dwellings is 3 persons/dwelling. The loading coefficient used in the Phase 1 Study, 0.114 kg TP/capita/yr, was utilized to compute the annual load from septic tank systems. The resulting load is 710 kg TP/yr contributed to the lake via septic systems.

6.4 Internal Loading

In the Phase I Study, internal loading was quantified to be 1738.8 kg/yr, which accounted for 29.3% of the total annual load. There is no new data to update the current internal loading. Therefore, in this TMDL, it is assumed that the internal loading is still 1738.8 kg/yr.

7.0 Water Quality Analysis

In addition to the Phase I Study, in-lake monitoring was conducted for several growing seasons between 1992 and 2001 by Princeton Hydro. Samples were collected from three stations, one at the northern, New York end, one mid-lake station and one at the southern, shallow New Jersey end (Figure 3). Of a total of 120 samples, 16 (13 percent) had TP concentrations exceeding the standard (0.05 mg/L). Overall, the concentrations at the southern station were slightly higher than the concentrations at the other two stations and the exceedance frequency at the southern station was 23%, higher than the exceedance at other two stations.

The Department has chosen an empirical model as the most appropriate means, given data available, to relate annual phosphorus load and steady-state in-lake concentration of total phosphorus. The Department surveyed the commonly used models in Table 5. These empirical models consist of equations derived from simplified mass balances that have been fitted to large datasets of actual lake measurements. The resulting regressions can be applied to lakes that fit within the range of hydrology, morphology and loading of the lakes in the model database. Reckhow (1979a) model was selected because the hydrologic, morphological and loading characteristics of Greenwood Lake fit best within the assumptions of the model and because it appeared to give the best predictive results for phosphorus concentration.

Figure 3 Historic In-lake Monitoring Results for Greenwood Lake

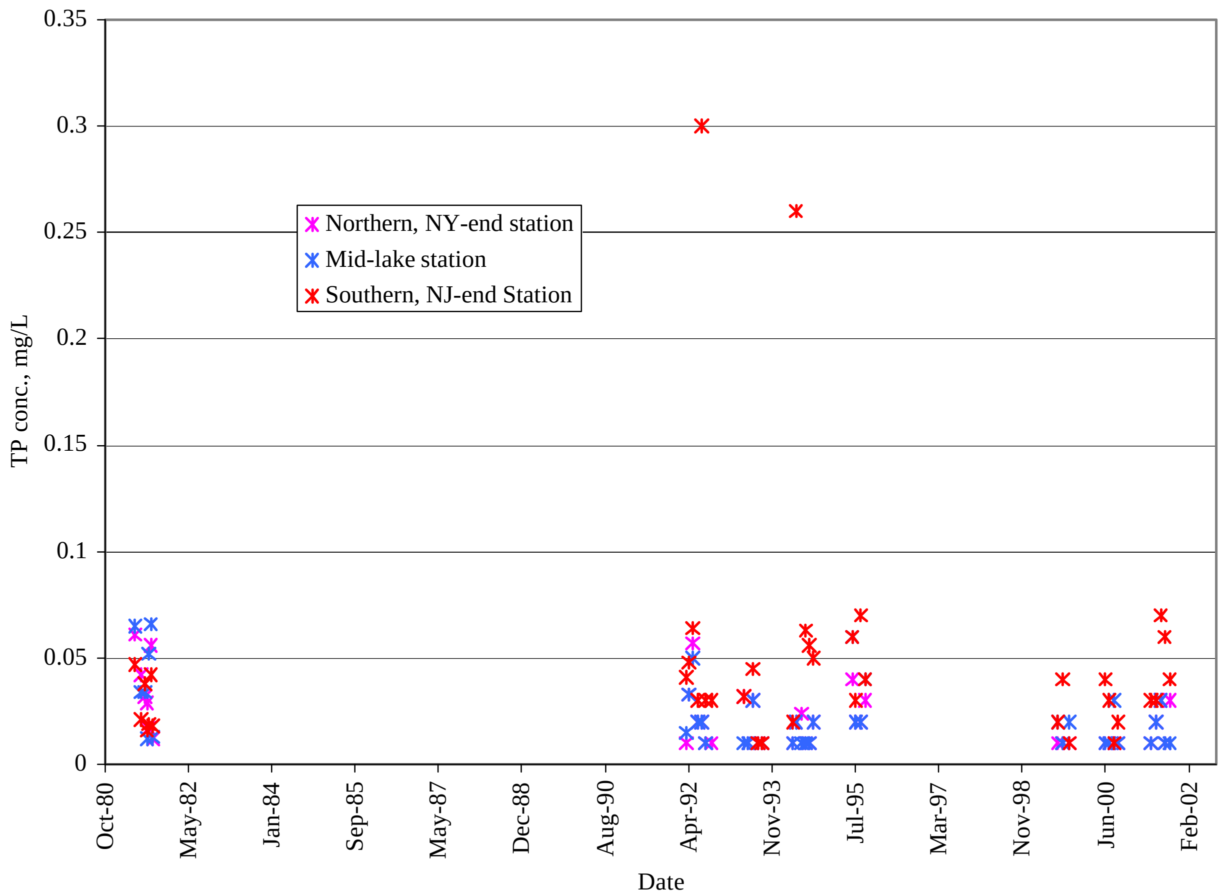


Table 5 Empirical models considered by the Department

reference	steady-state TP concentration in lake (mg/l)	Secondary term	Application
Rast, Jones and Lee, 1983	$1.81 \times NPL^{0.81}$	$NPL = \left(\frac{P_a \times DT / D_m}{1 + \sqrt{DT}} \right)$	expanded database of mostly large lakes
Vollenweider and Kerekes, 1982	$1.22 \times NPL^{0.87}$	$NPL = \left(\frac{P_a \times DT / D_m}{1 + \sqrt{DT}} \right)$	mostly large natural lakes
Reckhow, 1980	$\frac{P_a}{13.2}$	none	Upper bound for closed lake
Reckhow, 1979a	$\frac{P_a}{(11.6 + 1.2 \times Q_a)}$	$Q_a = \frac{Q_i}{A_l}$	General north temperate lakes, wide range of loading concentration, areal loading, and water load

reference	steady-state TP concentration in lake (mg/l)	Secondary term	Application
Walker, 1977	$\frac{P_a \times DT/D_m}{\left(1+0.824\times DT^{0.454}\right)}$	none	oxic lakes with $D_m/DT < 50$ m/yr
Jones and Bachmann, 1976	$\frac{0.84\times P_a}{\left(D_m \times \left(0.65 + DT^{-1}\right)\right)}$	none	may overestimate P in shallow lakes with high D_m/DT
Vollenweider, 1975	$\frac{P_a}{\left(D_m \times \left(DT^{-1} + S\right)\right)}$	$S = 10/D_m$	Overestimate P lakes with high D_m/DT
Dillon-Kirchner, 1975	$\frac{P_a}{\left(13.2 + D_m/DT\right)}$	none	low loading concentration range
Dillon-Rigler, 1974	$P_a \times DT/D_m \times (1-R)$	R = phosphorus retention coefficient	general form
Ostrofksy, 1978	Dillon-Rigler, 1974	$R = 0.201\times e^{(-0.0425\times Q_a)} + 0.5743\times e^{-0.00949*Q_a}$	lakes that flush infrequently
Kirchner-Dillon, 1975	Dillon-Rigler, 1974	$R = 0.426\times e^{\left(-0.271\times D_m/DT\right)} + 0.5743\times e^{-0.00949*D_m/DT}$	general application
Larsen-Mercier, 1975	Dillon-Rigler, 1974	$R = \frac{1}{1+\sqrt{1/DT}}$	Unparameterized form

where:

NPL = normalized phosphorus loading
P_a = areal phosphorus loading (g/m²/yr)
DT = detention time (yr)
D_m = mean depth (m)
Q_a = areal water load (m/yr)
Q_i = total inflow (m³/yr)
A_l = area of lake (m²)
S = settling rate (per year)

The Reckhow (1979a) model is described in USEPA Clean Lakes guidance documents: Quantitative Techniques for the Assessment of Lake Quality (Reckhow, 1979b) and Modeling Phosphorus Loading and Lake Response Under Uncertainty (Reckhow *et al*, 1980). The derivation of the model is summarized in Appendix C. The model relates TP load to steady state TP concentration, and is generally applicable to north temperate lakes.

As summarized in Table 6, Greenwood Lake has all the characteristics of the lakes upon which Reckhow based his analyses. Mean in-lake phosphorus concentrations at all sampling locations are within the range of 0.004 and 0.135, as in Reckhow's data set. The estimated areal phosphorous load is 0.55, again within the range of Reckhow's data set. The average influent phosphorus concentration is calculated to be 0.12, which meets the limitation of Reckhow model. Greenwood Lake's areal water load of 4.53 is also within Reckhow's range of 0.75 and 187. For the target condition (discussed in detail in Section 7), every parameter falls within the range suitable for the Reckhow model. Thus, the Reckhow model is applicable to Greenwood Lake under both the current condition and the target condition.

It should also be noted that no attempt was made to recalibrate the Reckhow (1979a) model for Greenwood Lake, since sufficient lake data were not available to make comparisons with model predictions of steady-state in-lake concentration of total phosphorus. The model was already calibrated to the dataset on which it is based, and is generally applicable to north temperate lakes that exhibit the range of characteristics listed in Table 6.

Table 6 Hydrologic and loading characteristics of lakes

Parameters	Ranges of Characteristics Reckhow Model can fit		Greenwood Lake	
	Min	Max	Current condition	Target Condition[3]
TP Conc. (mg/L)	0.004	0.135	0.032[1]	0.03
Avg. Influent TP Conc. (mg/L)[2]		0.298	0.12	0.11
Q_a, Areal Water Load (m/yr)	0.75	187	4.53	N/A
P_a, Areal TP Load (g/m^2/yr)	0.07	31.4	0.55	0.51

Note:

1. Predicted in-lake annual average concentration using Reckhow model (see section below).
2. Calculated using Pa*DT/Dm.
3. As explained below, the target concentration is 0.03 mg/L when considering the seasonal variability. The other parameters under target condition were all calculated based on the target concentration.

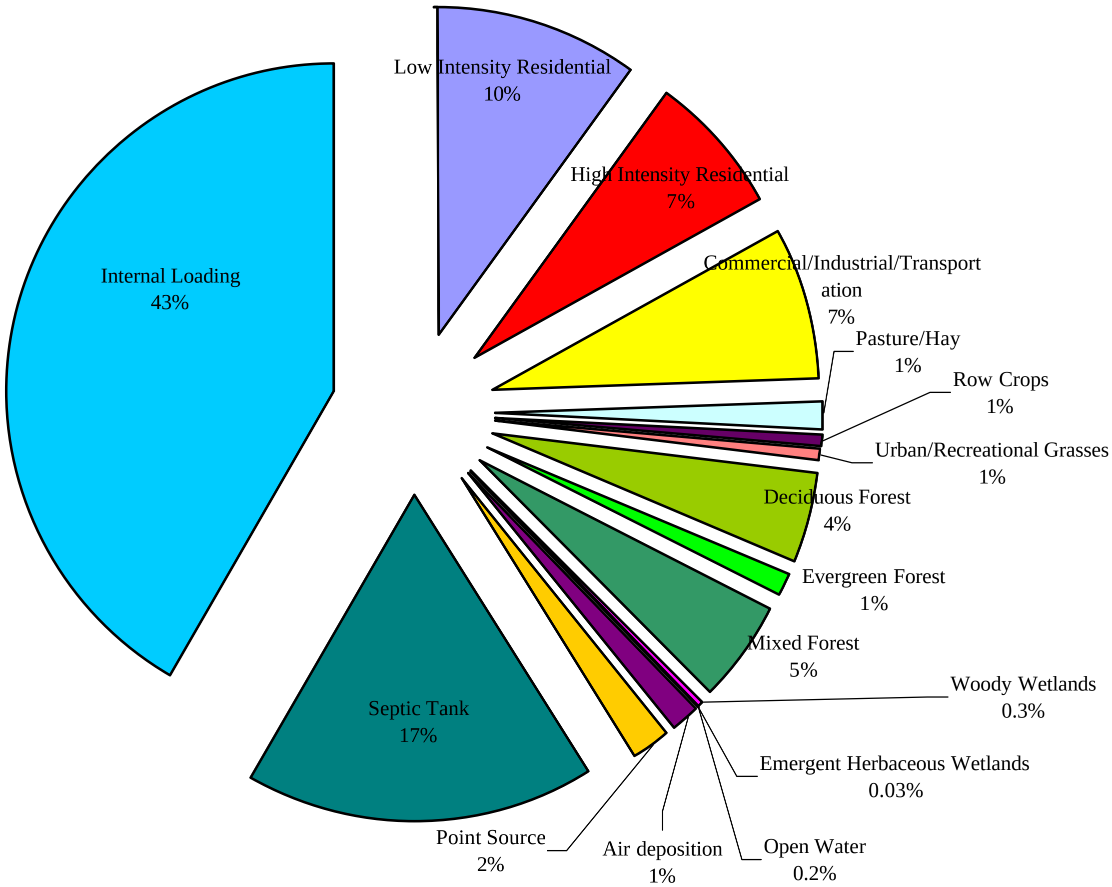
7.1 Current Condition

Using these physical parameters and estimated external loads, the predicted steady-state phosphorus concentration of the lake was calculated using the Reckhow (1979a) formulation and listed in Table 7. The current phosphorus load distribution for Greenwood Lake is shown in Figure 4 below.

7.2 Reference Condition

A reference condition for Greenwood Lake was estimated by calculating external loads as if the land use throughout the lakeshed were completely forest and wetlands and the loads from point sources, septic tank systems and internal recycling were assumed to be zero. Estimates of air deposition loads were included to calculate the reference condition. Using the same physical parameters and external loads from forest, wetlands and air deposition, a reference steady-state phosphorus concentration was calculated for Greenwood Lake using the Reckhow (1979a) formulation and listed in Table 7. The reference condition was developed to estimate what the TP concentration would be under pristine conditions and assure that the target concentration will not be lower than the one possible under pristine conditions. For Greenwood Lake, the target steady state concentration is 0.03 mg/l while the steady state concentration under the reference condition is only 0.005 mg/l. Therefore, the reference condition is not used for the TMDL calculations.

Figure 4 Current distribution of phosphorus load for Greenwood Lake



7.3 Seasonal Variation/Critical Conditions

Data from two lakes in New Jersey for which the Department had ready access to data (Strawbridge Lake, NJDEP 2000a; Sylvan Lake, NJDEP 2000b) exhibit peak (based on the 90th percentile) to mean ratios of 1.56 and 1.48, resulting in target phosphorus concentrations of 0.032 and 0.034 mg TP/l, respectively. Since the peak to mean ratios were close and the target concentration not very sensitive to differences in peak to mean ratios, the Department determined that a target phosphorus concentration of 0.03 mg TP/l is reasonably conservative. The seasonal variation was therefore assumed to be 67%, resulting in a target phosphorus concentration of 0.03 mg TP/l. Since it is the annual pollutant load rather than the load at any particular time that determines overall lake water quality (section 6), the target phosphorus concentration of 0.03 mg TP/l accounts for critical conditions.

7.4 Margin of Safety

A Margin of Safety (MOS) is provided to account for "lack of knowledge concerning the relationship between effluent limitations and water quality." (40 CFR 130.7(c)). A MOS is required in order to account for uncertainty in the loading estimates, physical parameters and the model itself. The margin of safety, as described in USEPA guidance (Sutfin, 2002), can be either explicit or implicit (i.e., addressed through conservative assumptions used in establishing the TMDL). For this TMDL calculation, implicit as well as explicit MOS are provided.

This TMDL contains an implicit margin of safety by using conservative critical conditions and total phosphorus as the basis for reductions. Critical conditions are accounted for by comparing peak concentrations to mean concentrations and adjusting the target concentration accordingly (0.03 mg TP/l instead of 0.05 mg TP/l). In addition, the use of total phosphorus, as both the endpoint for the standard and in the loading estimates, is a conservative assumption. Use of total phosphorous does not distinguish readily between dissolved orthophosphorus, which is available for algal growth, and unavailable forms of phosphorus (e.g. particulate). While many forms of phosphorus are converted into orthophosphorus in the lake, many are captured in the sediment, for instance, and never made available for algal uptake.

In addition to the conservative assumptions built in to the calculation, an additional explicit MOS was included to account for the uncertainty in the model itself. As described in Reckhow *et al* (1980), the Reckhow (1979a) model has an associated standard error of 0.128, calculated on log-transformed predictions of phosphorus concentrations. Transforming the terms in the model error analysis from Reckhow *et al* (1980) yields the following (Appendix D):

$$MoS_p = \sqrt{1 / ((1-r)*4.5)} \times \left(10^{0.128} - 1\right),$$

where: MoS_p = margin of safety as a percentage over the predicted phosphorus concentration;

ρ = the probability that the real phosphorus concentration is less than or equal to the predicted phosphorus concentration plus the margin of safety as a concentration.

Setting the probability to 90% yields a MOS of 51% when expressed as a percentage over predicted phosphorus concentration or estimated external load. The external load for each lake was therefore multiplied by 1.51 to calculate an "upper bound" estimate of steady-state phosphorus concentration. An additional explicit MOS was included in the analyses by setting the upper bound calculations equal to the target phosphorus concentration of 0.3 mg TP/l, as described in the next section and shown in Table 7. Note that the explicit MOS is equal to 51% when expressed as a percentage over the predicted phosphorus concentration; when expressed as a percentage of total loading capacity, the MOS is equal to 33.3%:

$$\left(MoS_{lc} = \frac{MoS_p \times P}{P + \left(MoS_p \times P\right)} = \frac{MoS_p}{1 + MoS_p} = \frac{0.51}{1.51} = 0.333 \right),$$

where: MoS_p = margin of safety expressed as a percentage over the predicted phosphorus concentration or external load;

MoS_{lc} = margin of safety as a percentage of total loading capacity;

P = predicted phosphorus concentration (or external load).

7.5 Target Condition

As discussed above, when considering the seasonal variation, the steady state concentration of phosphorus in the lake must be equal to or less than 0.03 mg/L to avoid exceeding the 0.05 mg/L phosphorus criterion. Using Reckhow (1979a), any predicted concentration has a MOS of 51% when expressed as a percentage over the predicted phosphorus concentration. To assure compliance with the 0.03 mg/L target, the predicted concentration can not be higher than 0.02 mg/L (0.02 + 0.02*51% = 0.03 mg/L) considering the effect of the MOS. Therefore, 0.02 mg/L is chosen as the target concentration to attain the standard while 0.03 mg/L is defined as the upper bound target condition. The load corresponding to a 0.03 mg/L in-lake concentration is defined as the allowable loading capacity of the lake. The overall reduction to attain the standard level in Greenwood Lake was calculated by comparing the current concentration (calculated using Reckhow Model) to 0.02 mg/L, the target concentration (Table 7).

Table 7 Current condition, reference condition, target condition and overall percent reduction for Greenwood Lake

Current condition [TP] (mg/l)	Reference Condition [TP] (mg/L)	Upper Bound Target Condition [TP] (mg/L)	Target Condition [TP] (mg/l)	Overall TP load Reduction (%)
0.032	0.005	0.03	0.02	37%

8.0 TMDL Calculations

8.1 Loading Capacity

The Reckhow (1979a) model was used to solve for loading rate given the upper bound target concentration of 0.03 mg/l. This loading rate is used as the loading capacity for the lake and 33.3% of it accounts for the MOS as determined by the uncertainty associated with Reckhow Model. The acceptable loading capacity for Greenwood Lake is provided in Table 9.

8.2 Reserve Capacity

Reserve capacity is an optional means of reserving a portion of the loading capacity to allow for future growth. The primary means by which future growth could increase phosphorus load is through the development of forest land within the lakeshed. The implementation plan includes the development of a Lake Restoration Plan that will require the collection of more detailed information about the lakeshed. If the development of forest within the watershed is planned, the issue of reserve capacity to account for the additional runoff load of phosphorus may be revisited. Currently, the loading capacities and accompanying WLAs and LAs must be attained in consideration of any new sources that may accompany future development.

8.3 Allocations

USEPA regulations at 40 CFR § 130.2(i), state that "pollutant loadings may be expressed in terms of either mass per time, toxicity, or other appropriate measure." For lake nutrient TMDLs, it is appropriate to express the TMDL on a yearly basis. Long-term average pollutant loadings are typically more critical to overall lake water quality due to the storage and recycling mechanisms in the lake. Also, most available empirical lake models, such as the Reckhow model used in this analysis, use annual loads rather than daily loads to estimate in-lake concentrations.

The TMDLs for total phosphorus are therefore calculated as follows (Table 9):

TMDL = loading capacity
= Sum of the wasteload allocations (WLAs) + load allocations (LAs) + margin of safety + reserve capacity.

WLAs are hereby established for all NJPDES-regulated point sources within each source category, while LAs are established for stormwater sources that are not subject to NJPDES regulation and for all nonpoint sources. This distribution of loading capacity between WLAs and LAs is consistent with recent EPA guidance that clarifies existing regulatory requirements for establishing WLAs for stormwater discharges (Wayland, November 2002). Stormwater discharges are captured within the runoff sources quantified according to land use, as depicted in Table 8. Distinguishing between regulated and unregulated stormwater is necessary in order to express WLAs and LAs numerically; however, "EPA recognizes that these allocations might be fairly rudimentary because of data limitations and variability within the system." (Wayland, November 2002, p.1) While the Department does not have the data to actually delineate lakesheds according to stormwater drainage areas subject to NJPDES regulation, the land use runoff categories previously defined can be used to estimate between the WLA and LA. Therefore allocations are established according to source categories as shown in Table 8. This demarcation between WLAs and LAs based on land use source categories is not perfect, but it represents the best estimate defined as narrowly as data allow. The Department acknowledges that there may be stormwater sources in the residential, commercial, industrial and mixed urban runoff source categories that are not NJPDES-regulated. Nothing in these TMDLs, including Table 8, shall be construed to require the Department to regulate a stormwater source under NJPDES that would not already be regulated as such, nor shall anything in these TMDLs be construed to prevent the Department from regulating a stormwater source under NJPDES. The WLAs and LAs in Table 9 are not themselves "Additional Measures" under proposed N.J.A.C. 7:14A-25.6 or 25.8.

Table 8 Distribution of WLAs and LAs among source categories

Source category	TMDL allocation
Point Sources other than Stormwater	WLA
Internal Loading	LA
Septic Tank System	LA
Nonpoint and Stormwater Sources	
medium / high density residential	WLA
low density / rural residential	WLA
commercial	WLA
industrial	WLA
Mixed urban / other urban	WLA
agricultural	LA
forest, wetland, water	LA
barren land	LA
air deposition onto lake surface	LA

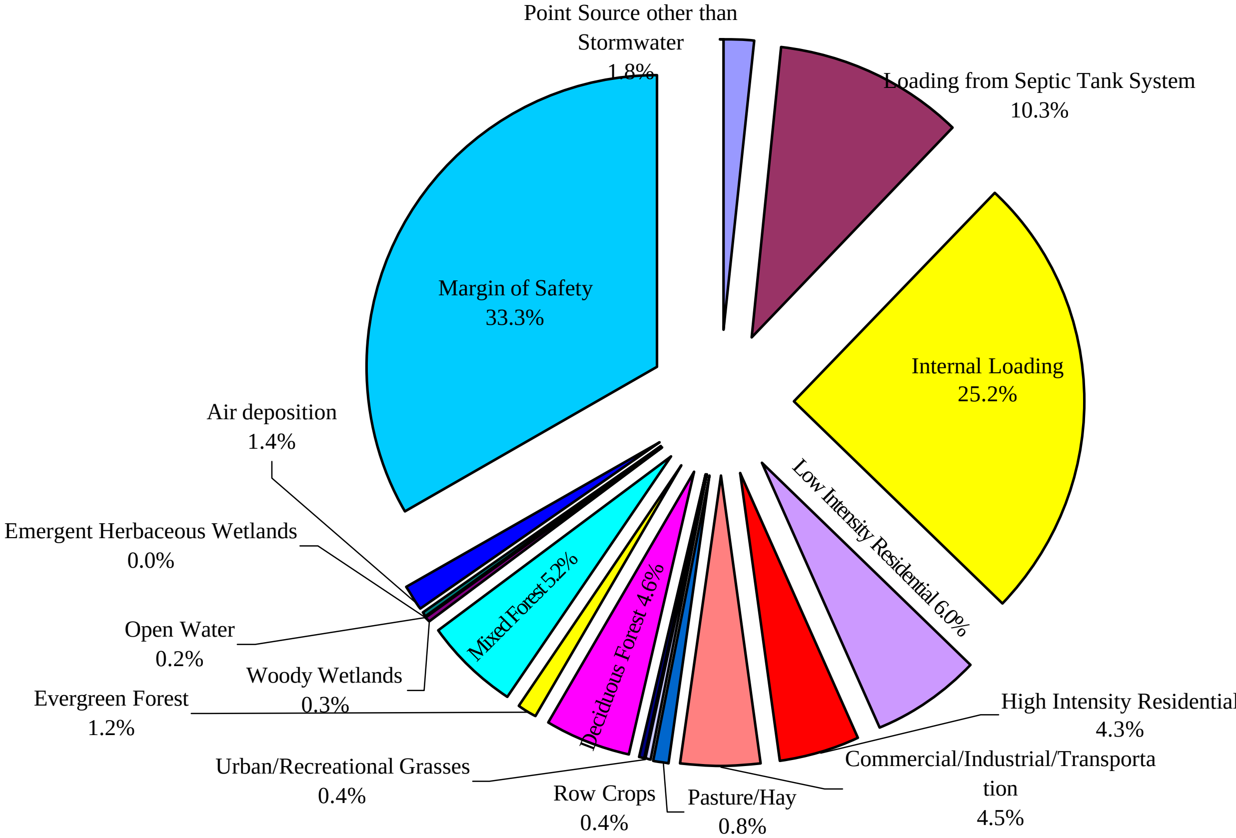
In order to attain the TMDL, the overall load reduction shown in Table 7 must be achieved. Since loading rates have been defined for multiple source categories, countless combinations of source reductions could be used to achieve the overall reduction target. The selected scenarios call for holding the load constant from wastewater treatment facilities and achieving reductions from land use sources that can be affected by BMP implementation or NJPDES regulation, requiring equal percent reductions from each in order to achieve the necessary overall load reduction. Note that no reduction is required for the discharge from the point sources. The flow data reported in the DMRs indicate that the wastewater treatment facilities are not at full capacity relative to the maximum allowable flow in the permits. If the facilities were to discharge at their full capacities assuming the current average effluent quality (around 0.6 mg/l), the load from this source would increase. At the maximum allowable flow under their current permits, in order to maintain the current loading of 70 kg/yr, the average concentration must be maintained at 0.35 mg/l. The wastewater treatment plants in question are relatively small and already have phosphorus treatment through chemical addition by either adding Alum or FeCl3. Therefore, the means to achieve the overall WLA for this source category may be most efficiently achieved by means other than having each treatment facility upgrade treatment capability to achieve 0.35 mg/l as a TP concentration limit. Options include: water quality trading among both point and nonpoint sources or revising permits to specify an allowable load equal to existing flow and effluent quality. The resulting TMDL, rounded to two significant digits, are shown in Table 9 and illustrated in Figure 5. The Lake Restoration and Characterization Plan developed for Greenwood Lake as part of the TMDL implementation (Section 10) will revisit the distribution of reductions among the various sources in order to reflect the outcome of the plan, implementation projects and the option(s) selected by wastewater treatment plant sources.

Table 9 TMDL calculations for Greenwood Lake (annual loads and percent reductions[a])

	Kg TP/yr	% of LC	Reduction %
Loading Capacity (LC)	3,895	100%	n/a
Point Source other than Stormwater	70	1.8%	0%
Loading from Septic Tank System	401	10%	43%
Internal Loading	983	25%	43%
Land Use Surface Runoff			
Low Intensity Residential	235	6.0%	43%
High Intensity Residential	166	4.3%	43%
Commercial/Industrial/Transportation	174	4.5%	43%
Pasture/Hay	32	0.8%	43%
Row Crops	15	0.4%	43%
Urban/Recreational Grasses	15	0.4%	43%
Deciduous Forest	180	5%	0%
Evergreen Forest	48	1.2%	0%
Mixed Forest	202	5%	0%
Woody Wetlands	13	0.3%	0%
Emergent Herbaceous Wetlands	1	0.03%	0%
Open Water	7	0.2%	0%
Air deposition	53	1.4%	0%
Other Allocation			
Margin of Safety	1,298	33%	n/a
Reserve Capacity	0	0%	n/a

a. Percent reductions shown for individual sources are necessary to achieve overall reductions in Table 7.

Figure 5 Phosphorus allocations for Greenwood Lake TMDL



9.0 Follow-up Monitoring

A Lake Characterization and Restoration project using funds made available to the Department under the Clean Water Act Section 319(h) will begin in July 2004. This project will provide in-lake water quality monitoring data, monitoring data for eight tributary stations within the watershed, and a bathymetric survey for New Jersey portion of the lake to provide site-specific information and data for the Lake Characterization and Restoration Plan.

In order to evaluate the current water quality conditions and to assess the seasonal variation of the water quality conditions, one spring, two summer (June/July and August) and one fall (September) water quality monitoring events are scheduled to be conducted in 2004 and 2005 for the above project. A total of five sampling stations will be identified for the monitoring program. The northern and mid-lake sampling stations will be located on the New York side of the lake. The remaining three will be located on the New Jersey side of the lake. *In-situ* water quality monitoring will be conducted at the five sampling stations for water column profiles of temperature, dissolved oxygen, pH and conductivity at 0.5 to 1.0 meter intervals from surface to bottom. Water clarity will be measured with a Secchi disk. In addition to the *in-situ* monitoring, discrete water samples will be collected and analyzed for Total Phosphorus, Soluble Reactive Phosphorus (SRP), organic-P, Nitrate and Nitrite (NO_3-N+NO_2-N), Ammonia (NH_4-N), Total Kjeldahl Nitrogen (TKN), TSS, alkalinity, and hardness during each sampling event. Limited samples will be collected for chlorophyll *a*, phytoplankton and zooplankton analyses. For summer sampling events, chemical sampling within specific vertical zones of the lake is taken into consideration.

In order to quantify the current phosphorus loads entering Greenwood Lake on a more site specific basis, eight tributary stations (six in NJ and two in NY) will be monitored over 10 sampling events from June 2004 to May 2005. The eight stations are as follows:

1. Belcher Creek entering Greenwood Lake, NJ
2. Belcher Creek at the outlet of Pinecliff Lake, NJ
3. Green Brook at Union Valley Road, NJ
4. Cooley Brook at Union Valley Road, NJ
5. Outlet from West Milford Lake at Marshall Hill Road, NJ
6. Morsetown Brook at Marshall Hill Road, NJ
7. Unnamed creek #1 at Old Tuxedo Road, NY
8. Unnamed creek #2 at Old Tuxedo Road, NY

During each proposed sampling event, discrete water samples will be collected for total phosphorus (TP) and total suspended solids (TSS) analysis. In addition, flow (flow meter USGS type AA model 6200) will be measured at each sampling site and *in-situ* data (Hydrolab, Surveyor IV) will be collected for temperature, dissolved oxygen, pH and conductivity. The goal of the proposed tributary sampling program is to collect flow and select water quality data over the course of nearly a year to quantify loads.

In addition, a complete bathymetric survey of the New Jersey end of Greenwood Lake will be conducted to update its morphometric conditions. This information will be utilized to update the internal loading for the southern portion of the lake. Additional study will also be conducted to determine the sedimentation rate and the cause of the dissolved oxygen impairment in order to allow companion TMDLs to be developed for these impairments.

10.0 Implementation

The Department, in coordination with the Greenwood Lake Commission will address the sources of impairment, using regulatory and non-regulatory tools, through systematic source assessment, matching management strategies with sources, selecting responsible entities and aligning available resources to effect implementation. Management measures are “economically achievable measures for the control of the addition of pollutants from existing and new categories and classes of nonpoint and stormwater sources of pollution, which reflect the greatest degree of pollutant reduction achievable through the application of the best available nonpoint and stormwater source pollution control practices, technologies, processes, citing criteria, operating methods, or other alternatives” (USEPA, 1993). Greenwood Lake is a bi-state lake and will necessitate implementation measures undertaken by both New Jersey and New York. As this TMDL is an amendment to the New Jersey Northeast Water Quality Management Plan, specific implementation strategies focus on the New Jersey portion of Greenwood Lake, although, to be successful, source reduction in the New York portion of the lake and lakeshed will be necessary.

The Department recognizes that TMDL designated load reductions alone may not be sufficient to restore eutrophic lakes. The TMDL establishes the required nutrient reduction targets and provides the regulatory framework to effect those reductions. However, the nutrient load only affects the eutrophication potential of a lake. The implementation plan therefore calls for the collection of additional monitoring data, as discussed in section 9.0, and the development of a Lake Characterization and Restoration Plan. The additional monitoring proposed will provide the information needed to update the Phase I diagnostic study of Greenwood Lake, which will provide the basis for the Lake Restoration Plan. The Restoration Plan will consider in-lake measures that need to be taken to supplement the nutrient reduction measures required by the TMDL. For example, the shallow portion of the lake supports macrophytes that, at some density, are a natural part of a healthy clear-water lake ecology, but, because of density or location, interfere with boating. Phosphorus reductions alone may not address this issue and macrophyte harvesting or other measures may be a long term maintenance measure needed in certain areas to facilitate the boating use. In addition, the plan will consider the ecology of the lake and adjust the eutrophication indicator target as necessary to protect the designated uses.

Generic measures

Phosphorus is contributed to the environment from a number of sources including fertilizer application on agricultural lands, fertilizer application on lawns, discharge from treatment plants, failing or improperly functioning septic systems, lack of pump-out facilities for boats, adherence to sediment particles and the natural process of decomposition. Phosphorus from these sources can reach waterbodies directly, through overland runoff, or through sewage or stormwater conveyance facilities. Each potential source will respond to one or more management strategies designed to eliminate or reduce that source of phosphorus. Each management strategy has one or more entities that can take lead responsibility to effect the strategy. Various funding sources are available to assist in accomplishing the management strategies. Generic management strategies for various source categories and responses are summarized below:

Table 10 Generic Management Strategies

Source Category	Responses	Potential Responsible Entity	Possible Funding options
Human Sources	Low phosphorus fertilizer ordinances, NPS public education, septic tank management to address failing systems, sewering target area	Municipalities, residents, watershed stewards	319(h), State sources
Non-Human Sources	Waterfowl ordinances, pet waste ordinances, goose management programs	Municipalities, residents, watershed stewards	319(h), State sources
Agricultural practices	Install BMPs, Prioritize for conservation programs	Property owner	EQIP, CRP, CREP

Regulatory Measures

On February 2, 2004 the Department promulgated two sets of stormwater rules: The Phase II New Jersey Pollutant Discharge Elimination System (NJPDES) Stormwater Rules, N.J.A.C. 7:12A and the Stormwater Management Rules, N.J.A.C. 7:8

Phase II Stormwater Permit Rules

The Phase II NJPDES Stormwater rules require municipalities, counties, highway systems, and large public complexes to develop stormwater management programs consistent with the NJPDES permit requirements. The stormwater discharged through "municipal separate storm sewer systems" (MS4s) will be regulated under the Department's Phase II NJPDES stormwater rules. Under these rules and associated general permits, the municipalities (and various county, State, and other agencies) in the Greenwood Lake Watershed will be required to implement various control measures that should substantially reduce phosphorus loadings. These control measures include adoption and enforcement of pet waste disposal ordinances, prohibiting the feeding of unconfined wildlife on public property, cleaning catch basins, performing good housekeeping at maintenance yards, and providing related public education and employee training. The basic requirements will provide for a measure of load reduction from existing development. Follow up monitoring may determine that additional measures are required, which would then be incorporated into Phase II permits. Additional measures that may be considered include, for example, more frequent street sweeping and inlet cleaning, or retrofit of stormwater management facilities to include nutrient removal. .

In the State of New York one of the communities within the Greenwood Lake drainage basin is the Village of Greenwood Lake. Within this village, an ordinance was adopted on April 2, 2001 (Ordinance # 2-2001) prohibiting the use of fertilizer containing phosphorus. As the Phase II stormwater rules were a federal mandate New York has also developed new stormwater rules providing the same basic requirements. In New Jersey, the contributory drainage area into Greenwood Lake is limited to West Milford Township. Adoption of a comparable ordinance will be required as an additional measure at this time for West Milford.

Stormwater Management Rules

The Stormwater Management Rules have been updated for the first time since their original adoption in 1983. These rules establish statewide minimum standards for stormwater management in new development, and the ability to analyze and establish region-specific performance standards targeted to the impairments and other stormwater runoff related issues within a particular drainage basin through regional stormwater management plans. The Stormwater Management rules are currently implemented through the Residential Site Improvement Standards (RSIS) and the Department's Land Use Regulation Program (LURP) in the review of permits such as freshwater wetlands, stream encroachment, CAFRA, and Waterfront Development.

The Stormwater Management Rules focus on the prevention and minimization of stormwater runoff and pollutants in the management of stormwater. The rules require every project to evaluate methods to prevent pollutants from becoming available to stormwater runoff and to design the project to minimize runoff impacts from new development through better site design, also known as low impact development. Some of the issues that are required to be assessed for the site are the maintenance of existing vegetation, minimizing and disconnecting impervious surfaces, and pollution prevention techniques. In addition, performance standards are established to address existing groundwater that contributes to baseflow and aquifers, to prevent increases to flooding and erosion, and to provide water quality treatment through stormwater management measures for TSS and nutrients.

As part of the requirement under the NJPDES Phase II program, municipalities, such as West Milford, are required to adopt and implement municipal stormwater management plans and stormwater control ordinances consistent with the requirements of the stormwater management rules. As such, in addition to changes in the design of projects regulated through the RSIS and LURP, West Milford Township will also be updating their regulatory requirements to provide the additional protections in the stormwater management rules within approximately two years of the issuance of the NJPDES General Permit Authorization.

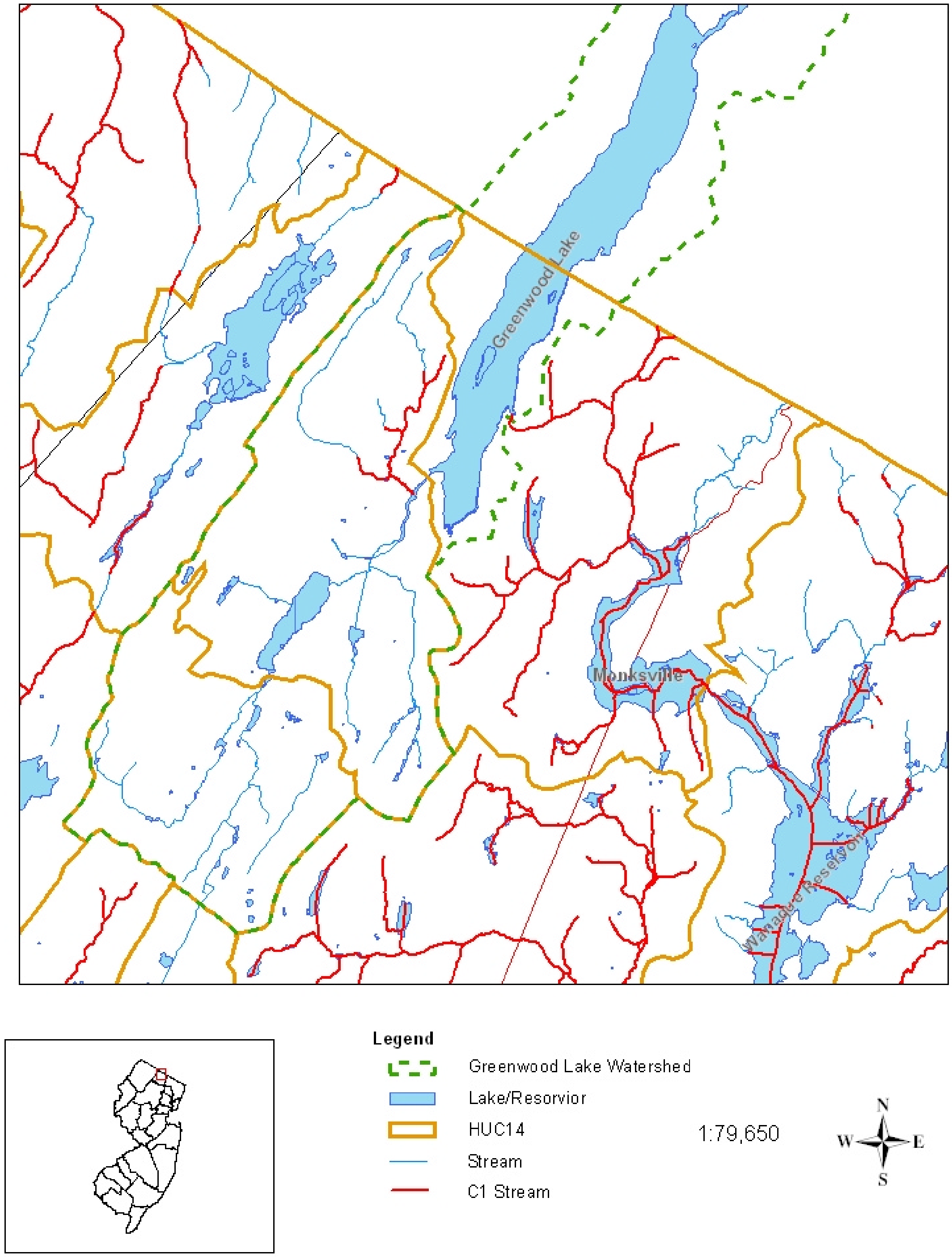
Furthermore, the New Jersey Stormwater Management rules establish a 300-foot special water resource protection area (SWRPA) around Category One (C1) waterbodies and their intermittent and perennial tributaries, within the HUC14 subwatershed. In the SWRPA, new development is typically limited to existing disturbed areas to maintain the integrity of the C1 waterbody. C1 waters receive the highest form of water quality protection in the state, which prohibits any measurable deterioration in the existing water quality. Certain segments of waterbodies tributary to Greenwood Lake as well as the Wanaque River, immediately downstream of Greenwood Lake, have been designated C1 waterbodies, and are therefore, accorded this additional protection as shown on the map in Figure 6.

These rules will provide protection with respect to new development in the lakeshed.

Short-term Management Measures

Short-term management measures include projects recently completed; underway or planned that will address sources of the phosphorus load. Some short-term management measures may provide relief during an interim period as implementation of source reductions begins to provide long-term benefits.

Figure 6 C1 Waterbodies Located Upstream and Downstream of Greenwood Lake



Greenwood Lake Characterization and Restoration Plan

The TMDL for Greenwood Lake was developed with assistance from the Greenwood Lake Commission, stakeholders in Watershed Management Area 3, as part of the Department's ongoing watershed management efforts.

Under the funding provided in the 319(h) grant discussed in section 9.0 the Department has awarded $152,330 to the Township of West Milford and the Greenwood Lake Commission to complete a Lake Characterization and Restoration Plan. Stormwater related tasks that are funded under the New Jersey grant include: identification of stormwater/surface runoff "hot spots" in need of restoration and/or protection; development of the stormwater component of the Lake Characterization and Restoration Plan; installation of a series of BMPs and retrofits in West Milford; and Best Management Practices (BMP) monitoring in order to objectively assess the relative success of the BMP installation/retrofit projects that will be conducted as part of this project. The BMP monitoring will analyze total phosphorus (TP), total nitrogen (TN) and total suspended solids (TSS) prior to and after the BMP/retrofits are installed to quantify the NPS pollutant reductions associated with the various BMP/retrofit technologies that will be installed. While empirically derived percent reductions for NPS pollutants may be available within the existing literature (i.e. New Jersey BMP Manual), the collection of this BMP data will provide site specific information on the relative efficiencies of these installed BMPs and retrofits. Site specific removal efficiencies can be used to quantify the degree of load reduction that can be obtained through BMPs and retrofits. A similar proposal for the New York portion of the Greenwood Lake watershed was submitted to the New York State Department of Environmental Conservation (NYSDEC) under the Statewide Nonpoint Source Abatement and Control Program (EPF/PPG). The status of that grant application is uncertain at the time of the writing of this document.

Greenwood Lake has ecological differences within the lake itself along with the geographic/political boundaries. The New Jersey portion of the lake is shallow, having a maximum depth of 3 meters, meaning that at this end, most of the lake volume is within the photic zone and therefore more able to support aquatic plant growth (Holdren *et al*, 2001) while the New York portion of the lake has a greater mean and maximum depth. Addressing the ecological nuances of shallow and deep portion of the lake separately will potentially be the most valuable outcome of the Lake Characterization and Restoration Plan. Shallow lakes are generally characterized by either abundant submerged macrophytes and clear water or by abundant phytoplankton and turbid water. From an aquatic life and biodiversity perspective, it is desirable for shallow lakes to be dominated by aquatic plants rather than algae, especially phytoplankton. While lower nutrient concentrations favor the clear/plant state, either state can persist over a wide range of nutrient concentrations. Shallow lakes have ecological stabilizing mechanisms that tend to resist switches from clear/plant state to turbid/algae state, and vice-versa. The clear/plant state is more stable at lower nutrient concentrations and irreversible at very low nutrient concentrations; the turbid/algae state is more stable at higher nutrient concentrations. Although a macrophyte-dominated lake may be preferable, excessive growth of aquatic plants can, and does in Greenwood Lake, lead to impairment and the loss of designated uses. Aquatic growth in Greenwood Lake includes *Lyngbya latissima*, *Potamogeton robbinsii*, *Myriophyllum spicatum*, *Cabomba caroliniana* and *Potamogeton amplifolius*, which are invasive species (PAS, 1983).

The Lake Characterization and Restoration Plan developed for the lake may revisit the distributions of reductions required among the various sources. It will be on the basis of refined source estimates and reduction efficiencies that more specific or revised strategies for reduction of nonpoint sources will be developed. Issues such as cost and feasibility will be considered when specifying the refined reduction targets for any source or source type. If needed, additional measures to be applied to stormwater point sources through NJPDES permits will be adopted by the Department as amendments to the applicable areawide Water Quality Management Plan.

The Township of West Milford has already initiated stormwater management activities. They have completed GIS mapping of all stormwater outfalls under funding from a separate grant. Passaic County has also provided mapping of all stormwater outfalls on County roads. Information from both of these projects will provide important information for the development of the stormwater plan under the planned 319(h) project. Under an earlier 319(h) project, the Township of West Milford received $90,000 for nonpoint source pollution control through the installation of 19 catch basins in the Belcher's Creek subwatershed. Removal of sediment from these catch basins as part of the maintenance program will remove an estimated 2,452 ft^3 of sediment annually.

The Village of Greenwood Lake, New York conducts weed-harvesting on several occasions during the summer months. The Greenwood Lake Commission is working with the Township of West Milford to conduct select harvesting events beginning in the summer of 2004. Harvesting can provide some limited reduction in nutrient concentrations by removal of organic material from the lake compared to allowing settling of organic material within the sediments as a potential phosphorus reservoir.

Dredging is another short-term measure to reduce the internal load of phosphorus and increase the distance between the photic zone and the sediments, impeding growth of rooted aquatic plants. Without addressing all sources of sedimentation and phosphorus loading this measure provides limited, short-term relief. A Bill has been introduced to the New Jersey Legislature (Assembly Bill No. 1369) on January 13, 2004 and was referred to the Assembly Environmental and Solid Waste Committee. The bill is for dredging of Greenwood Lake and associated activities. The Greenwood Lake Commission is also investigating the possibility of dredging under a proposal with the Army Corps of Engineers as a component of a stump removal project. The Village of Greenwood Lake, New York has just completed a $250,000 dredging project on the New York portion of the lake under a federal grant.

Drawdown, or lowering of water levels to expose bottom sediments, of a lake can be an effective tool for controlling some aquatic weed species. A Drawdown/Water Level Management Plan was adopted for Greenwood Lake in 1997. Ownership of the dam impounding the waters of Greenwood Lake and the sluice gates lies within the authority and responsibility of the New Jersey Department of Environmental Protection, Division of Parks and Forestry. The goal of this plan is to provide a means for aquatic weed control and enhancement of water quality while maintaining the required minimum passing flow of 3 million gallons per day (MGD) below the dam. The Greenwood Lake Watershed Management District, Inc. is the unit requesting the drawdown and coordinating the activities. A drawdown of five feet is scheduled for 2005. The GLMDI will also submit a report to the Division of Parks and Forestry evaluating the effect of the drawdown, including the extent and type of vegetation control achieved, the percentage of vegetation remaining in the littoral zone, the changes in species composition noted, the effects on the density and species composition of the macroinvertebrate community and any other factors which may affect the need for continued drawdowns. Drawdowns are on a scheduled 5-year basis.

Long-term Management measures

Long-term management measures are strategies that will effect a measurable reduction in pollutant loads by addressing the source and remediating the problem. The stormwater implementation plan will provide a list of activities that may not be economically feasible during the current year but would provide for a significant reduction in phosphorus as they are implemented over time. The stormwater implementation projects that will be installed under the pending project will begin immediately to provide source reduction, and are considered a long-term solution to phosphorus loading.

On-site wastewater systems

Septic management measures will be an important component of the implementation plan. As a component of this TMDL the septic loading has been updated from the Phase I diagnostic study. As septic loads are a significant source of phosphorus, long-term management measures to address septic problems on both the New York and the New Jersey portion of the lake are a necessary component. Failing or improperly functioning septic system can be a source of phosphorus, and the extent of the load is significantly determined by geologic and soil constraints. On Greenwood Lake's northern New York side there are apparent severe restrictions to the proper operation of septic systems based on lack of depth to bedrock and steep slopes. An aggressive septic management plan, possibly including alternative treatment measures, will be necessary. Towards this end, the Village of Greenwood Lake adopted an ordinance on April 2, 2001, which requires proof of proper functioning systems and pump-out every three years as an on-going requirement. Alternative treatment may still be needed due to the environmental constraints in the area. The New Jersey portion of Greenwood Lake also has septic management concerns, although the geology and slopes are less severe. There are documented instances of septic failure. The Department is working with the Greenwood Lake Commission to address these issues. As this is a local county issue the Department, Division of Compliance and Water Enforcement, has submitted a request to verify a failure and provide a written report within 30 days of the incident. The Department will continue to actively pursue issues of septic problems within its purview. The Department, Division of Watershed Management is planning a partnership with the United States Department of Agriculture and the Natural Resource Conservation Service newly formed section, the Liberty RC&D (which covers Hudson, Essex, Passaic and Bergen counties) to provide a septic management workshop for the fall of 2004. This workshop will be provided to the Greenwood Lake Commission, municipal officials from both towns and county and other interested private and public stakeholders.

An in-depth investigation of septic issues will be required to complete the Lake Characterization and Restoration Plan. Issues to be covered include detailed information on the number of septic systems which potentially impact the lake, the percentage of failing or improperly functioning systems, the ability of standard systems to function given specific geologic and soil restrictions, the area required for a properly functioning leach field given the environmental constraints, other options and a cost analysis.

Agricultural Activities

Agricultural activities are another example of potential sources of phosphorus. Implementation of conservation management plans and best management practices are the best means of controlling agricultural sources of phosphorus. Several programs are available to assist farmers in the development and implementation of conservation management plans and best management practices. The Natural Resource Conservation Service is the primary source of assistance for landowners in the development of resource management pertaining to soil conservation, water quality improvement, wildlife habitat enhancement, and irrigation water management. The USDA Farm Services Agency performs most of the funding assistance. All agricultural technical assistance is coordinated through the locally led Soil Conservation Districts. Agricultural sources within the watershed provide greater than 25 kg/yr from runoff and should be addressed through Best Management Practices. The available funding programs in New Jersey include:

- **The Environmental Quality Incentive Program (EQIP)** is designed to provide technical, financial, and educational assistance to farmers/producers for conservation practices that address natural resource concerns, such as water quality. Practices under this program include integrated crop management, grazing land management, well sealing, erosion control systems, agri-chemical handling facilities, vegetative filter strips/riparian buffers, animal waste management facilities and irrigation systems.

- **The Conservation Reserve Program (CRP)** is designed to provide technical and financial assistance to farmers/producers to address the agricultural impacts on water quality and to maintain and improve wildlife habitat. CRP practices include the establishment of filter strips, riparian buffers and permanent wildlife habitats. This program provides the basis for the Conservation Reserve Enhancement Program (CREP).

- **Conservation Reserve Enhancement Program (CREP)** The New Jersey Departments of Environmental Protection and Agriculture, in partnership with the Farm Service Agency and Natural Resources Conservation Service, signed a $100 million CREP agreement earlier this year. This program matches $23 million of State money with $77 million from the Commodity Credit Corp. within USDA. Through CREP, financial incentives are offered for agricultural landowners to voluntarily implement conservation practices on agricultural lands. NJ CREP will be part of the USDA's Conservation Reserve Program (CRP). There will be a ten-year enrollment period, with CREP leases ranging between 10-15 years. The State intends to augment this program to make these leases permanent easements. The enrollment of farmland into CREP in New Jersey is expected to improve stream health through the installation of water quality conservation practices on New Jersey farmland.

Many similar programs would also be available in New York under similar federal programs.

Reasonable Assurance

With the implementation of follow-up monitoring, source identification and source reduction as described, the Department has reasonable assurance that New Jersey's Surface Water Quality Standards will be attained for phosphorus in Greenwood Lake.

The phosphorus reductions proposed in this TMDL require that the existing NJPDES permitted facilities will receive effluent limits commensurate with holding the load from this source, subject to the options, such as water quality trading, as described. Stormwater point sources will be controlled by requirements of the Phase II stormwater permitting program and additional measures. Nonpoint source controls are also planned, as described.

The Department's ambient monitoring network will be the means to determine if the strategies identified have been effective. Ambient monitoring will be evaluated to determine if additional strategies for source reduction are needed.

11.0 Public Participation

The Water Quality Management Planning Rules NJAC 7:15-7.2 encourage the Department to initiate a public process prior to the development of each TMDL and to allow public input to the Department on policy issues affecting the development of the TMDL. An informal presentation of the findings and results of this TMDL was provided at the May 19, 2004 Greenwood Lake Commission meeting. Additional public participation will be solicited during the Public Hearing for the Greenwood Lake TMDL scheduled for July 7, 2004 at 6:30 PM at the Long Pond Iron Works Museum of Ringwood State Park.

Additional public participation and input was received through the New Jersey EcoComplex. The Department contracted with Rutgers NJEC in July 2001. The role of NJEC is to provide comments on the Department's management strategies, including those related to the development of TMDL values. NJEC consists of a review panel of New Jersey University professors who provide a review of the technical approaches developed by the Department. The New Jersey Statewide Protocol for Developing Eutrophic Lakes TMDLs was presented to NJEC on September 27, 2002 and was subsequently reviewed. Feedback received from NJEC was incorporated into the TMDLs to address lake eutrophication. New Jersey's Statewide Protocol for Developing Lake and Fecal TMDLs was also presented at the SETAC Fall Workshop on September 13, 2002.

In accordance with N.J.A.C. 7:15–7.2(g), this TMDL is hereby proposed by the Department as an amendment to the Northeast Water Quality Management Plan. N.J.A.C. 7:15-3.4(g)5 states that when the Department proposes to amend the areawide plan on its own initiative, the Department shall give public notice by publication in a newspaper of general circulation in the planning area, shall send copies of the public notice to the applicable designated planning agency, if any, and may hold a public hearing or request written statements of consent as if the Department were an applicant. The public notice shall also be published in the New Jersey Register.

Notice of this TMDL was published June 7, 2004 pursuant to the above noted Administrative Code, in order to provide the public an opportunity to review the TMDL and submit comments. The Department has determined that due to the level of interest in this TMDL, a public hearing will be held. Public notice of the hearing, provided at least 30 days before the hearing, was published in the New Jersey Register and in two newspapers of general circulation and will be mailed to the applicable designated planning agency, if any, and to each party, if any, who was requested to issue written statement of consents for the amendment.

All comments received during the public notice period and at any public hearings will become part of the record for this TMDL. All comments will be considered in the establishment of this TMDL and the ultimate adoption of this TMDL. When the Department takes final agency action to establish this TMDL, the final decision and supporting documentation will be sent to U.S.E.P.A. Region 2 for review and approval pursuant to 303(d) of the Clean Water Act (33 U.S.C. 1313(d)) and 40 CFR 130.7.

Appendix A: References

Annadotter, H., G. Cronberg, R. Aagren, B. Lundstedt, P.-A. Nilsson and S. Ströbeck, 1999. Multiple techniques for lake restoration. Hydrobiologia 395/396:77-85.

Birch, S. and J. McCaskie, 1999. Shallow urban lakes: a challenge for lake management. Hydrobiologia 395/396:365-377.

Center for Watershed Protection, 2001. *Watershed Protection Techniques: Urban Lake Management*. T.R. Schueler, Ed.in Chief. Ellicott City, MD. www.cwp.org.

Cooke, G.D., P. Lombardo and C. Brant, 2001. Shallow and deep lakes: determining successful management options. Lakeline, Spring 2001, 42-46.

CH2MHILL (2000) PLOAD Version 3.0 An Arc View GIS Tool to calculate Nonpoint Sources of Pollution in Watershed and Stomwater projects, CH2MHILL, Herndon, VA

Cooke, G.D., E.B. Welch, S.A. Peterson, P.R. Newroth. 1993. Restoration and Management of Lakes and Reservoirs. Lewis Publishers.

Dillon, P.J. and F.H. Rigler, 1974. A test of a simple nutrient budget model predicting the phosphorus concentration in lake water. J. Fish. Res. Board Can. 31:1771-1778.

Donabaum, K., M. Schagerl and M.T. Dokulil, 1999. Integrated management to restore macrophyte domination. Hydrobiologia 395/396:87-97.

Eisenreich, S.J. and J. Reinfelder. 2001. The New Jersey Air Deposition Network: Interim Report. Department Environmental Sciences, Rutgers University.

Holdren, C., W. Jones, and J. Taggart, 2001. Managing Lakes and Reservoirs. North American Lake Management Society and Terrene Institute, in cooperation with U.S. Environmental Protection Agency. Madison, WI.

Hosper, S.H., 1998. Stable states, buffer and switches: an ecosystem approach to the restoration and management of shallow lakes in The Netherlands. Water Science Technology 37(3):151-164.

Madgwick, F.J., 1999. Strategies for conservation management of lakes. Hydrobiologia 395/396:309-323.

Melzer, A., 1999. Aquatic macrophytes as tools for lake management. Hydrobiologia 395/396:181-190.

Moss, B., J. Madgwick, G. Phillips, 1996. A Guide to the restoration of nutrient-enriched shallow lakes. Norfolk Broads Authority, 18 Colegate, Norwich, Norfolk NR133 1BQ, Great Britain.

Moss, B., M. Beklioglu, L. Carvalho, S. Kilinc, S. McGowan and D. Stephen. Vertically-challenged limnology; contrasts between deep and shallow lakes. Hydrobiologia 342/343:257-267.

National Research Council, Assessing the TMDL Approach to water quality management. National Academy Press, Washington, D.C. 2001

New Jersey Department of Environmental Protection. 2000. Report on the Establishment of TMDL for Phosphorus in Strawbridge Lake. Amendment to Tri-County WQMP.

New Jersey Department of Environmental Protection. 1998. Identification and Setting of Priorities for Section 303(d) Water Quality Limited Waters in New Jersey, Office of Environmental Planning.

Ostrofsky, M.L., 1978. Modification of phosphorus retention models for use with lakes with low areal water loading. J. Fish. Res. Bd. Can. 35(12):1532-1536.

PAS (Princeton Aqua Science) 1983. Phase 1: Diagnostic-Feasibility Study of Greenwood Lake, New Jersey and New York. In Accordance with Section 314: Clean Water Act 33 USC 1251 et seq & 40 CFR 35.1600 NJAC-7:9-15.5 et seq

Perrow, M.R., A.J.D. Jowitt, J.H. Stansfield, G.L. Phillips, 1999. The practical importance of the interaction between fish, zooplankton and macrophytes in shallow lake restoration. Hydrobiologia 395/396:199-210.

Phillips, G., A. Bramwell, J. Pitt, J. Stansfield and M. Perrow, 1999. Practical application of 25 years' research into the management of shallow lakes. Hydrobiologia 395/395:61-76.

Rast, W., A. Jones and G.F. Lee, 1983. Predictive capability of U.S. OECD phosphorus loading-eutrophication response models. Journal WPCF 55(7):990-1002.

Reckhow, K.H., 1979a. Uncertainty analysis applied to Vollenweider's phosphorus loading criterion. J. Water Pollution Control Federation 51(8):2123-2128.

Reckhow, K.H., 1979b. Quantitative Techniques for the Assessment of Lake Quality. EPA-440/5-79-015.

Reckhow, K.H., 1977. Phosphorus Models for Lake Management. Ph.D. dissertation, Harvard University.

Reckhow, K.H., M.N. Beaulac and J.T. Simpson, 1980. Modeling phosphorus loading and lake response under uncertainty: a manual and compilation of export coefficients. EPA 440/5-80-011.

Rodiek, R.K., 1979. Some watershed analysis tools for lake management. In Lake Restoration, EPA 400/5-79-001.

Scheffer, M., 1990. Multiplicity of stable states in freshwater systems. Hydrobiologia 200/201:475-486.

Sutfin, C.H. May, 2002. Memo: EPA Review of 2002 Section 303(d) Lists and Guidelines for Reviewing TMDLs under Existing Regulations issued in 1992. Office of Wetlands, Oceans and Watersheds, U.S.E.P.A.

U.S.E.P.A., 1999. Protocol for Developing Nutrient TMDLs. Watershed Branch, Assessment and Watershed Protection Division, Washington, DC.

Vollenweider, R.A., and J. Kerekes, 1982. Eutrophication of Waters: Monitoring, Assessment and Control. Organization for Economic Cooperation and Development (OECD), Paris. 156 p.

Wayland, R.H. III. November 22, 2002. Memo: Establishing Total Maximum Daily Load (TMDL) Wasteload Allocations (WLAs) for Storm Water Sources and NPDES Permit Requirements Based on Those WLAs. Office of Wetlands, Oceans and Watersheds, U.S.E.P.A.

Appendix B: Database of Phosphorus Export Coefficients

In December 2001, the Department concluded a contract with the USEPA, Region 2, and a contracting entity, TetraTech, Inc., the purpose of which was to identify export coefficients applicable to New Jersey. As part of that contract, a database of literature values was assembled that includes approximately four-thousand values accompanied by site-specific characteristics such as location, soil type, mean annual rainfall, and site percent-impervious. In conjunction with the database, the contractor reported on recommendations for selecting values for use in New Jersey. Analysis of mean annual rainfall data revealed noticeable trends, and, of the categories analyzed, was shown to have the most influence on the reported export coefficients. Incorporating this and other contractor recommendations, the Department took steps to identify appropriate export values for these TMDLs by first filtering the database to include only those studies whose reported mean annual rainfall was between 40 and 51 inches per year. From the remaining studies, total phosphorus values were selected based on best professional judgement for eight land uses categories.

The sources incorporated in the database include a variety of governmental and non-governmental documents. All values used to develop the database and the total phosphorus values in this document are included in the below reference list.

<u>Export Coefficient Database Reference List</u>

Allison, F.E., E.M. Roller, and J.E. Adams, 1959. Soil Fertility Studies in Lysimeters Containing Lakeland Sand. Tech. Bull. 1199, U.S. Dept. of Agriculture, Washington, D.C. p. 1-62.

Apicella, G., 2001. Urban Runoff, Wetlands and Waterfowl Effects on Water Quality in Alley Creek and Little Neck Bay. TMDL Science Issues Conference, WEF Specialty Conference.

Athayde, D. N, P. E. Shelly, E. D. Driscoll, D. Gaboury and G.B. Boyd, 1983. Results of the Nationwide Urban Runoff Program: Final Report. USEPA Water Planning Division. Washington, DC.

Avco Economic Systems Corporation, 1970. Storm Water Pollution from Urban Land Activity. Rep.11034 FKL 07/70, Federal Water Qual. Adm., U.S. Dept. of Interior, Washington, D.C. p. 325.

Bannerman, R., K. Baun, M. Bohm, P. E. Hughes, and D. A. Graczyk, 1984. Evaluation of Urban Nonpoint Source Pollution Management in Milwaukee, County, Wisconsin, Report No. PB84-114164, U.S. Environmental Protection Agency, Region V, Chicago, IL.

Bengtson, R.L. and C.E. Carter, 1989. Simulating Soil Erosion in the Lower Mississippi Valley with the CREAMS Model. From: Application of Water Quality Models for Agricultural and Forested Watersheds, edited by D.B. Beasley and D.L Thomas. Southern Cooperative Series Bulletin No. 338.

Broadbent, F.E., and H.D. Chapman, 1950. A Lysimeter Investigation of Gains, Losses and Balance of Salts and Plant Nutrients in an Irrigated Soil. Soil Sci. Soc. Amer. Proc. 14:261-269.

Carter, Gail P., 1998. Estimation of Nonpoint Source Phosphorus and Nitrogen Loads in Five Watersheds in New Jersey's Atlantic Coastal Drainage Basin. Surveying and Land Information Systems, Vol. 58, no 3. pp167-177.

CH2M Hill, 2000. Technical Memorandum 1, Urban Stormwater Pollution Assessment, prepared for North Carolina Department of Environment and Natural Resources, Division of Water Quality.

Claytor, R.A. and T.R. Schueler, 1996. “Design of Stormwater Filtering Systems,” The Center for Watershed Protection, Prepared for Chesapeake Research Consortium, Inc.

Corsi, S.R., D.J. Graczyk, D.W. Owens, R.T. Bannerman, 1997. Unit-Area Loads of Suspended Sediment, Suspended Solids, and Total Phosphorus From Small Watersheds of Wisconsin. USGS FS-195-97.

Delaware Valley Regional Planning Commission, 1977. Average Pollutant Concentrations Associated with Urban Agriculture and Forest Land Use. Working Paper 5.01-1, Extent of NPS Problems.

Eck, P., 1957. Fertility Erosion Selectiveness on Three Wisconsin Soils. Ph. D. Thesis, Univ. of Wisconsin, Madison, WI.

F.X. Brown, Inc., 1993. Diagnostic-Feasibility Study of Strawbridge Lake. FXB Project Number NJ1246-01.

Frink, C.R., 1991. Estimating Nutrient Exports to Estuaries. Journal of Environmental Quality. 20:717-724.

Horner, R., B. W. Mar, L. E. Reinelt, J. S. Richey, and J. M. Lee, 1986. Design of monitoring programs for determination of ecological change resulting from nonpoint source water pollution in Washington State. University of Washington, Department of Civil Engineering, Seattle, Washington.

Horner, R.R., 1992. Water Quality Criteria/Pollutant Loading Estimation/Treatment Effectiveness Estimation. In R.W. Beck and Associates. Covington Master Drainage Plan. King County Surface Water Management Division., Seattle, WA.

Horner, Richard R., Joseph J. Skupien, Eric H. Livingston, and H. Earl Shaver, 1994. Fundamentals of Urban Runoff Management: Technical and Institutional Issues. Prepared by the Terrene Institute, Washington, DC, in cooperation with the U.S. Environmental Protection Agency. EPA/840/B-92/002.

Johnston, W.R., F. Ittihadieh, R.M. Daum, and A.F. Pillsbury, 1965. Nitrogen and Phosphorus in Tile Drainage Effluent. Soil Sci. Soc. Amer. Proc. 29:287-289.

Knoblauch, H.C., L. Kolodny, and G.D. Brill, 1942. Erosion Losses of Major Plant Nutrients and Organic Matter from Collington Sandy Loam. Soil Sci. 53:369-378.

Loehr, R.C., 1974. Characteristics and comparative magnitude of non-point sources. Journal of WPCF 46(11):1849-1872.

Lopes, T.J., S.G. Dionne, 1998. A Review of Semivolatile and Volatile Organic Compounds in Highway Runoff and Urban Stormwater. U.S. Geological Survey, U.S. Department of Interior.

Marsalek, J., 1978. Pollution Due to Urban Runoff: Unit Loads and Abatement Measure, Pollution from Land Use Activities Reference Group. International Joint Commission, Windsor, Ontario.

McFarland, Anne M.S and L. M. Hauck, 2001. Determining Nutrient Export Coefficients and Source Loading Uncertainty Using In-stream Monitoring Data. Journal of the American Water Resources Association, pp. 223, 37. No. 1, February.

Menzel, R. G., E. D. Rhoades, A. E. Olness, and S. J. Smith, 1978. Variability of Annual Nutrient and Sediment Discharges in Runoff from Oklahoma Cropland and Rangeland. Journal of Environmental Quality, 7:401-406.

Mills, W.B., D.B. Porcella, M.J. Ungs, S.A. Gherini, K.V. Summers, L. Mok, G.L. Rupp, G.L. Bowie, 1985. Water Quality Assessment – A Screening Procedure for Toxic and Conventional Pollutants in Surface and Ground Water – Part I and II. EPA-600/6-85-002A&B.

Minshall, N.E., M.S. Nichols, and S.A. Witzel, 1969. Plant Nutrients in Base Flow of Streams in Southwestern Wisconsin. Water Resources. 5(3):706-713.

Mundy, C., M. Bergman, 1998. Technical Memorandum No. 29, The Pollution Load Screening Model: A tool for the 1995 District Water Management Plan and the 1996 Local Government Water Resource Atlases, Department of Water Resources, St. Johns River Water Management District.

NCDWQ, 1998. Neuse River Basinwide Water Quality Plan, Chapter 5, Section A.

Nelson, M.E., 1989. Predicting Nitrogen Concentrations in Ground Water An Analytical Model. IEP, Inc.

Northeast Florida Water Management District, 1994. St. Marks and Wakulla Rivers Resource Assessment and Greenway Protection Plan. Appendix 4.

Northern Virginia Planning District Commission, 1979. Guidebook for Screening Urban Nonpoint Pollution Management Strategies. Prepared for the Metropolitan Washington Council of Governments.

Novotny, V., H. Olem, 1994. Water Quality: Prevention, Identification, and Management of Diffuse Pollution. Van Nostrand Reinhold, NY

Omernik, J. M., 1976. The influence of land use on stream nutrient levels, US EPA January. EPA-60/3-76-014

Omni Environmental Corporation, 1991. Literature Search on Stormwater Pollutant Loading Rates. Literature cited from DVRPC 1977; Wanielista et al. 1977; Whipple and Hunter 1977; NVPDC 1980; USEPA 1983; Mills et al. 1985; Nelson 1989; Walker et al. 1989.

Omni Environmental Corporation, 1999. Whippany River Watershed Program Stormwater Model Calibration and Verification Report.

Overcash, M. R., F. J. Humenik, and J. R. Miner, 1983. Livestock Waste Management, Vol. II, CRC Press, Inc., Boca Raton, Florida.

Pacific Northwest Environmental Research Laboratory, 1974. Relationships Between Drainage Area Characteristics and Non-Point Source Nutrients in Streams. Prepared for the National Environmental Research Center, August 1974.

Panuska, J.C. and R.A. Lillie, 1995. Phosphorus Loadings from Wisconsin Watersheds: Recommended Phosphorus Export Coefficients for Agricultural and Forested Watersheds. Research Management Findings, Bureau of Research, Wisconsin Department of Natural Resources, Number 38.

Pitt, R.E., 1991. Nonpoint Source Water Pollution Management. Dep. Civil Eng., Univ. Alabama, Birmingham, AL.

Polls, Irwin and Richard Lanyon, 1980. Pollutant Concentrations from Homogeneous Land Uses. Journal of the Environmental Engineering Division.

Prey, J., D. Hart, A. Holy, J. Steuer, J. Thomas, 1996. A Stormwater Demonstration Project in Support of the Lake Superior Binational Program: Summary. Wisconsin Dept. of Natural Resources. (http://www.dnr.state.wi.us/org/water/wm/nps/tpubs/summary/lakesup.htm)

Rast, W. and G.F. Lee, 1978. Summary Analysis of the North American (U.S. Portion) OECD Eutrophication Project: Nutrient Loading -- Lake Response Relationships and Trophic State Indices., EPA-600/3-78-008.

Reckhow, K.H., M.N. Beaulac and J.T. Simpson, 1980. Modeling of Phosphorus Loading and Lake Response Under Uncertainty: A Manual and Compilation of Export Coefficients. Report No. EPA 440/5-80-011. U.S. EPA, Washington, D.C.

Ryding, S. and W. Rast, 1989. The Control of Eutrophication of Lakes and Reservoirs. Man and the Biosphere Series, United Nations Educational Scientific and Cultural Organization, Paris, France.

Schueler, T.R., 1987. Controlling Urban Runoff: A Practical Manual for Planning and Designing Urban BMPs. Prepared for the Metropolitan Washington Council of Governments.

Sonzogni, W.C. and G.F. Lee, 1974. Nutrient Sources for Lake Mendota - 1972. Trans. Wisc. Acad. Sci. Arts Lett. 62:133-164.

Uchrin, C.G. and T.J. Maldanato, 1991. Evaluation of Hydrocarbons in Urban Runoff and in Detention Basins. Water Writes. Water Research Institute, Division of Coastal and Environmental Studies, Rutgers University.

United States Geological Survey, U.S. Department of the Interior, 1998. Comparison of NPDES Program Findings for Selected Cities in the United States, USGS Fact Sheet, January

USEPA, 1987. Guide to Nonpoint Source Pollution Control. U.S. EPA, Criteria and Standards Division, Washington D.C.

USEPA, 1993. Urban Runoff Pollution Prevention and Control Planning (handbook). EPA/625/R-93/004.

USEPA, 2000. Watershed Analysis and Management (WAM) Guide for Tribes. (http://www.epa.gov/owow/watershed/wacademy/wam/)

Uttormark, P.D., J.D. Chapin, and K.M. Green, 1974. Estimating nutrient loadings of lakes from non-point sources. U.S. Environmental Protection Agency, Washington, D.C. 112 p. (WRIL 160609). EPA-660/3-74-020.

Walker, J.F., 1989. Spreadsheet Watershed Modeling for Nonpoint Source Pollution Management in a Wisconsin Basin, Water Resources Bulletin, Vol. 25, no. 1, pp. 139-147.

Wanielista, M.P., Y.A. Yousef, and W.M. McLellon, 1977. Nonpoint Source Effects on Water Quality, Journal Water Pollution Control Federation, Part 3, pp. 441-451.

Washington State Department of Ecology, 2000. Stormwater Management Manual for Western Washington: Volume I Minimum Technical Requirements. Publication No. 99-11.

Weidner, R.B., A.G. Christianson, S.R. Weibel, and G.G. Robeck, 1969. Rural Runoff as a Factor in Stream Pollution. J. Water Pollution. Con. Fed. 36(7):914-924.

Whipple, W. and J.V. Hunter, 1977. Nonpoint Sources and Planning for Water Pollution Control. Journal Water Pollution Control Federation. pp. 15-23.

Whipple, W., et al., 1978. Effect of Storm Frequency on Pollution from Urban Runoff, J. Water Pollution Control Federation. 50:974-980.

Winter, J.G. and H.C. Duthie, 2000. Export Coefficient Modeling to assess phosphorus loading in an urban watershed. Journal of American Water Resources Association. Vol. 36 No. 5.

Zanoni, A.E., 1970. Eutrophic Evaluation of a Small Multi-Land Use Watershed. Tech. Completion Rep. OWRR A-014-Wis., Water Resources Center, Univ. of Wisconsin, Madison, WI.

Appendix C: Summary of Reckhow (1979a) model derivation

The following general expression for phosphorus mass balance in lake assumes the removal of phosphorus from a lake occurs through two pathways, the outlet (M_o) and the sediments (ϕ):

$$V \cdot \frac{dP}{dt} = M_i - M_o - f \qquad \textbf{Equation 1}$$

where:
- V = lake volume (10^3 m³)
- P = lake phosphorus concentration (mg/l)
- M_i = annual mass influx of phosphorus (kg/yr)
- M_o = annual mass efflux of phosphorus (kg/yr)
- ϕ = annual net flux of phosphorus to the sediments (kg/yr).

The sediment removal term is a multidimensional variable (dependent on a number of variables) that has been expressed as a phosphorus retention coefficient, a sedimentation coefficient, or an effective settling velocity. All three have been shown to yield similar results; Reckhow's formulation assumes a constant effective settling velocity, which treats sedimentation as an areal sink.

Assuming the lake is completely mixed such that the outflow concentration is the same as the lake concentration, the phosphorus mass balance can be expressed as:

$$V \cdot \frac{dP}{dt} = M_i - v_s \cdot P \cdot A - P \cdot Q \qquad \textbf{Equation 2}$$

where:
- v_s = effective settling velocity (m/yr)
- A = area of lake (10^3 m²)
- Q = annual outflow (10^3 m³/yr).

The steady-state solution of Equation 2 can be expressed as:

$$P = \frac{P_a}{v_s + z/T} = \frac{P_a}{v_s + Q_a} \qquad \textbf{Equation 3}$$

where:
- P_a = areal phosphorus loading rate (g/m²/yr)
- z = mean depth (m)
- T = hydraulic detention time (yr)
- Q_a = Q/A = areal water load (m/yr).

Using least squares regression on a database of 47 north temperate lakes, Reckhow fit the effective settling velocity using a function of areal water load: $P = \dfrac{P_a}{11.6 + 1.2 \cdot Q_a}$. **Equation 4**

Appendix D: Derivation of Margin of Safety from Reckhow *et al* (1980)

As described in Reckhow *et al* (1980), the Reckhow (1979a) model has an associated standard error of 0.128, calculated on log-transformed predictions of phosphorus concentrations. The model error analysis from Reckhow *et al* (1980) defined the following confidence limits:

$$P_L = P - h \cdot \left(10^{(\log P - 0.128)} - P\right)$$
$$P_U = P + h \cdot \left(10^{(\log P + 0.128)} - P\right)$$
$$r \geq 1 - \frac{1}{2.25 \cdot h^2}$$

where:

- P_L = lower bound phosphorus concentration (mg/l);
- P_U = upper bound phosphorus concentration (mg/l);
- P = predicted phosphorus concentration (mg/l);
- h = prediction error multiple
- r = the probability that the real phosphorus concentration lies within the lower and upper bound phosphorus concentrations, inclusively.

Assuming an even-tailed probability distribution, the probability (r_u) that the real phosphorus concentration is less than or equal to the upper bound phosphorus concentration is:

$$r_u = r + \frac{1-r}{2} = r + \frac{1}{2} - \frac{r}{2} = r \cdot \left(1 - \frac{1}{2}\right) + \frac{1}{2} = \frac{1}{2} \cdot r + \frac{1}{2}$$

Substituting for r as a function of h:

$$r_u = \frac{1}{2} \cdot \left(1 - \frac{1}{2.25 \cdot h^2}\right) + \frac{1}{2} = \frac{1}{2} - \frac{1}{4.5 \cdot h^2} + \frac{1}{2} = 1 - \frac{1}{4.5 \cdot h^2}$$

Solving for h as a function of the probability that the real phosphorus concentration is less than or equal to the upper bound phosphorus concentration:

$$\frac{1}{4.5 \cdot h^2} = 1 - r_u$$
$$h^2 = \frac{1}{4.5(1 - r_u)}$$
$$h = \sqrt{\frac{1}{4.5(1 - r_u)}}$$

Expressing Margin of Safety (MoS_p) as a percentage over the predicted phosphorus concentration yields:

$$MoS_p = \frac{P_U}{P} - 1 = \frac{P_U - P}{P}$$

Substituting the equation for P_U:

$$MoS_p = \frac{P + h \cdot \left(10^{(\log P + 0.128)} - P\right) - P}{P} = \frac{h \cdot \left(10^{(\log P + 0.128)} - P\right)}{P}$$

$$P \cdot MoS_p = h \cdot \left(10^{(\log P + 0.128)} - P\right)$$

$$\frac{P \cdot MoS_p}{h} = 10^{(\log P + 0.128)} - P$$

$$\frac{P \cdot MoS_p}{h} + P = 10^{(\log P + 0.128)}$$

Taking the log of both sides and solving for margin of safety:

$$\log\left(\frac{P \cdot MoS_p}{h} + P\right) = \log P + 0.128$$

$$\log\left(\frac{P \cdot MoS_p}{h} + P\right) - \log P = 0.128$$

$$\log\left(P\left(\frac{MoS_p}{h} + 1\right)\right) - \log P = 0.128$$

$$\log P + \log\left(\frac{MoS_p}{h} + 1\right) - \log P = 0.128$$

$$\log\left(\frac{MoS_p}{h} + 1\right) = 0.128$$

$$\frac{MoS_p}{h} + 1 = 10^{0.128}$$

$$\frac{MoS_p}{h} = 10^{0.128} - 1$$

$$MoS_p = h\left(10^{0.128} - 1\right)$$

Finally, substituting for *h* yields Margin of Safety (MoS_p) as a percentage over the predicted phosphorus concentration, expressed as a function of the probability (r_u) that the real phosphorus concentration is less than or equal to the upper bound phosphorus concentration:

$$MoS_p = \sqrt{1 / \left((1 - r_u) * 4.5\right)} \times \left(10^{0.128} - 1\right)$$

APPENDIX III:

QUALITY ASSURANCE PROJECT PLAN

QUALITY ASSURANCE PROJECT PLAN (QAPP)

Revise and Update the New Jersey End of the Greenwood Lake Watershed Restoration Plan to an NJDEP and USEPA Approved Watershed Implementation Plan

Lead Organization:
Greenwood Lake Commission
Paul Zarrillo, 319(h) grantee
2019H Greenwood Lake Turnpike
Hewitt, New Jersey 07421

Principal Investigator:
Dr. Fred Lubnow
Director of Aquatic Programs
Princeton Hydro, LLC,
1108 Old York Road, PO Box 720, Ringoes, NJ 08551
908-237-5660, flubnow@princetonhydro.com
www.princetonhydro.com

PREPARED FEBRUARY 2019

TABLE OF CONTENTS

TITLE AND APPROVAL PAGE - QUALITY ASSURANCE PROJECT PLAN (QAPP)
Revise and Upgrade the Upper Musconetcong Watershed Restoration Plan to an NJDEP and USEPA approved Watershed Implementation Plan

Prepared by: Fred S. Lubnow Date: Apr 26, 2019
Fred Lubnow, Ph.D., Principal Investigator
Princeton Hvdro. LLC

Reviewed by: ____________ Date: May 13, 2019
Chris Mikolajczyk, QA/QC Officer
Princeton Hydro, LLC

Reviewed by: ____________ Date: ____________
Paul Zarrillo, 319(h) Grantee
Greenwood Lake Commission

Reviewed by: ____________ Date: May 8, 2019
Keri Green, Project Administrator
State of New Jersey Highlands Council

QAPP Approval Date ____________

1.0 TITLE PAGE

Revise and Update the New Jersey End of the Greenwood Lake Watershed Restoration Plan to an NJDEP and USEPA approved Watershed Implementation Plan

HUC 14 Numbers: 02030103070030

Anticipated Sampling Dates: May 2019 – September 2019

Project Requested By: Greenwood Lake Commission

Date Project Initiated: 2019

Project Administrator: Keri Green, Administrator
Address: State of New Jersey Highlands Council
100 North Road
Chester, New Jersey 07930
Phone: 908-879-6737
Email: keri.green@highlands.nj.gov

Principal Investigator: Fred Lubnow, Ph.D.
Address: Princeton Hydro, LLC
P.O. Box 720, 1108 Old York Road, Suite 1
Ringoes, New Jersey 08551
Phone: (908) 237-5660
Email: flubnow@princetonhydro.com

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

2.0 Distribution List

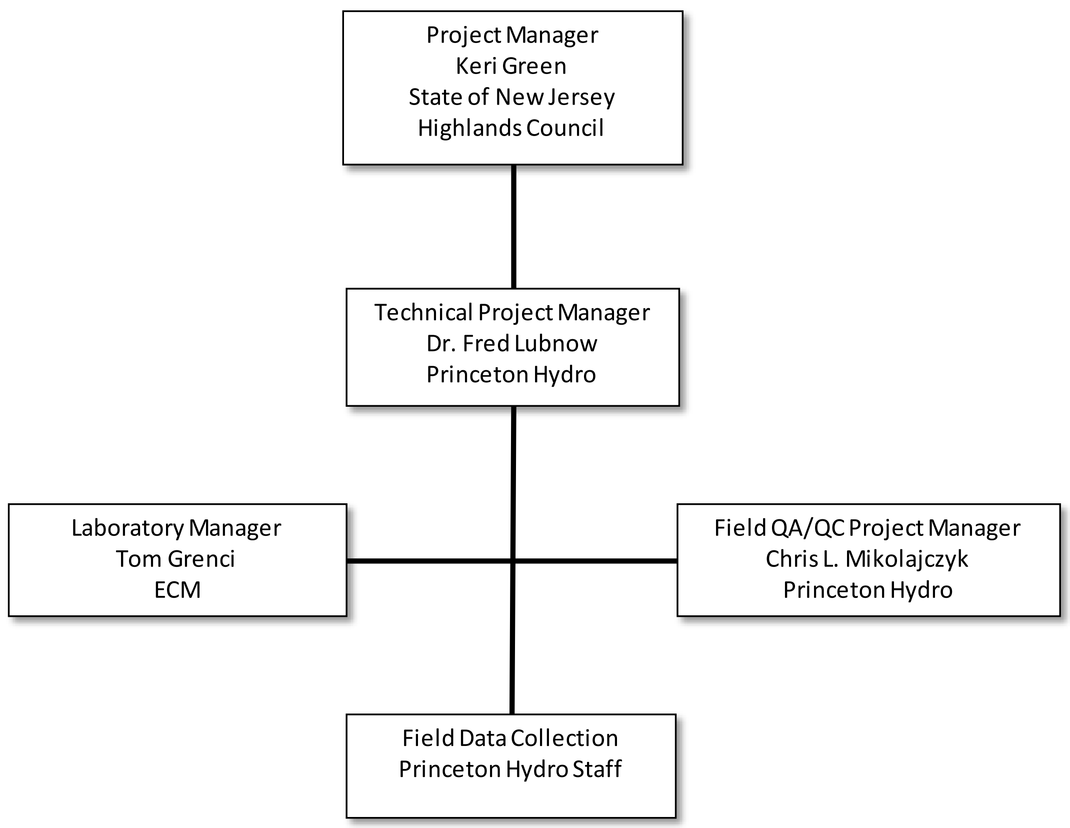
Keri Green, Administrator State of New Jersey Highlands Council 100 North road Chester, New Jersey 07930 908-879-6737 Keri.green@highlands.nj.gov	Fred Lubnow, Ph.D. Princeton Hydro, LLC Suite 1, 1108 Old York Rd. P.O. Box 720 Ringoes, NJ 08551 908-237-5660 flubnow@princetonhydro.com
Chris Mikolajczyk Princeton Hydro, LLC 1108 Old York Rd., Suite 1 P.O. Box 720 Ringoes, NJ 08551 908-237-5660 cmiko@princetonhydro.com	Paul Zarrillo Greenwood Lake Commission 1616 D Union Valley Road West Milford, NJ 07480 917-597-3423 pzarrillo@GWLC.org

3.0 PROJECT ORGANIZATION

The following identifies the key Greenwood Lake Commission staff and contractors involved in the project. This information is summarized in Figure 1, Project Organization Chart. The role and responsibility of each key team member are discussed further in Section 5 and the summarized in Table 3. Contact information for key project and personnel is provided in Sections 1 and 2 above.

Project Manager:	Keri Green, Administrator
Address:	State of New Jersey Highlands Council 100 North Road Chester, New Jersey 07930
Phone:	908-879-6737
Email:	keri.green@highlands.nj.gov
Principal Investigator:	Fred Lubnow, Ph.D.
Address:	Princeton Hydro, LLC P.O. Box 720 1108 Old York Road, Suite 1 Ringoes, New Jersey 08551
Phone:	(908) 237-5660
Email:	flubnow@princetonhydro.com
QA/QC Officer:	Chris Mikolajczyk
Address:	Princeton Hydro, LLC 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
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 chart (Figure 1) illustrates the overall program management structure of this project. As noted, the entire project will be under the direction of the Greenwood Lake Commission and Keri Green will serve as the Project Manager.

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.

Mr. Mikolajczyk will function as the QA/QC Officer, a role he routinely fulfils 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 will be responsible for the QA/QC associated with the lab analyses conducted of the collected discrete water quality samples. He has worked extensively in a similar capacity on other Princeton Hydro projects including CERCLA, NJDEP, USACOE, USGS and 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 a Ph.D. with extensive expertise in the collection and analysis of water quality samples. Where applicable, all field staff will possess State of New Jersey Boating Safety Certificates.

5.0 PROBLEM DEFINITION / BACKGROUND

A Restoration Plan was developed for the New Jersey end of the Greenwood Lake Watershed for the Greenwood Lake Commission (the Commission) and the Township of West Milford in the mid-2000's. Funding for the Plan was provided through the New Jersey Department of Environmental Protection's Non-Point Source 319(h) Program and Princeton Hydro was hired to develop it. The watershed-based plan linked the existing total phosphorus (TP) TMDL, developed by NJDEP, to existing and targeted loads from the New Jersey end of the watershed. In turn, the NJ end of the watershed was divided into a series of sub-watersheds and a phosphorus loading priority analysis was conducted to rank the sub-watersheds from "high" to "low" relative to stormwater and watershed restoration needs.

The sub-watersheds that produce the highest human-related (e.g. residential, commercial, farmland, transportation, etc.) TP loads were ranked highest in terms of the prioritization of stormwater and other watershed-based projects. Not surprising, the three highest ranked sub-watersheds were those that immediately surround Belchers Creek, the main inlet of Greenwood Lake. Thus, this proposed development of a Watershed Implementation Plan (WIP) for the New Jersey side of the Greenwood Lake watershed will focus on, but not be limited to, these three sub-watersheds.

The original TMDL identified the targeted reductions in TP for both the New Jersey and New York ends of the Greenwood Lake watershed, in order achieve full water quality compliance. However, the 2006 Restoration Plan was funded through a NPS 319(h) grant by the NJDEP and focused on the New Jersey end of the watershed relative to watershed-based recommendations. In spite of this, the water quality monitoring associated with the Plan did include locations in both states, although the focus was mostly the New Jersey. As will be described below, the proposed in-lake and stream monitoring for this updated WIP will mirror that implemented in 2004 and 2005 but will be slightly expanded to include some limited monitoring associated with cyanotoxins.

6.0 PROJECT DESCRIPTION

A. Scope Statement and Project Objectives

Greenwood Lake has not been monitored under a State-approved Quality Assurance Protection Plan (QAPP) since 2005. Thus, it is absolutely critical that a set of growing season water quality sampling events, similar to those implemented in 2004 and 2005, are conducted so any changes or shifts in either in-lake or watershed (e.g. the tributaries) water quality conditions are documented. Since Greenwood Lake has a TMDL for TP, the original QAPP must include field protocol and laboratory methodology that are accepted by NJDEP. Thus, Princeton Hydro, is State-certified for the collection of the *in-situ* parameters listed below (State ID # 10006) and Environmental Compliance Monitoring, Inc. (ECM), a State-certified laboratory, will run the analysis of the water quality samples. These are the same organizations who collected field data and analyzed water samples during the 2004-2005 monitoring program. Thus, this high level of consistency will provide the means of objectively comparing the two datasets and identifying any changes or trends in water quality.

After the New Jersey Restoration Plan for Greenwood Lake was completed, the Commission and the Township of West Milford received funds through the State’s NPS 319(h) program in 2004 and 2007 to design and implement a variety of watershed projects / BMPs to reduce the NPS pollutant load entering the lake, with an emphasis on TP. At the request of the Highlands Council, Princeton Hydro will conduct field assessments of each of these project sites to determine their existing status and if any maintenance or clean-outs are required. Princeton Hydro will coordinate with the Town of West Milford or Passaic County to access and inspect each project site. Field notes and photographs of each project site will be compiled and put into a concise report to be submitted to the Commission, Township, County, and Council providing a formal assessment as well as recommendations on any maintenance and/or upgrades that may be required.

In addition to the field assessment, Princeton Hydro will also conduct three storm sampling events, where stormwater samples will be collected from a sub-set of the project sites to quantify the pollutant removal efficiency of the installed MTDs or BMPs. During each event, upgradient and downgradient samples will be collected for TP and TSS at four of the eight project sites. Again, the goal of this collected data is to quantify the pollutant removal efficiency of the existing MTDs and BMPs. Such data will be useful as the WIP is being developed, to determine if similar projects should be considered for future implementation.

B. Scope of Work

Storm water

At the request of the Commission and the Highlands Council, this revised WIP will include the collection of stormwater samples to aid in the quantification of stormwater pollutant loading to the lake. The pollutants of concern are TP and TSS. Eight stormwater Best Management Practices (BMPs) were installed as a result of the previous 319(h) grant. These eight sites will be assessed to determine their existing status and maintenance needs.

Four of these stormwater BMPs will be sampled during three (3) different storm events, using standard storm sampling procedures (NJDEP 2005). All stormwater sampling sites will be located with GPS and placed onto a GIS-generated map, to be included in the WIP. Grab samples will be collected during or immediately after each storm event for the analysis of total phosphorus (TP) and total suspended solids (TSS).

The four BMP sites selected for sampling are:

- Beaver avenue NSBB and polishing unit
- Adelaide Terrace NSBB
- Durant Road NSBB and filter strip
- Reidy Place Filterra unit

Surface Water

A set of three water quality monitoring events are proposed for Greenwood Lake and will closely mirror the 2004-2005 monitoring program. Along with the stormwater monitoring, the Greenwood Lake monitoring program will be placed into a QAPP. Note, that the proposed monitoring program for 2019 will be very similar to those used during the development of the 2004-2005 sampling program.

Five in-lake monitoring stations will be established and sampled three times over the 2019 growing season (spring, summer and fall). At each monitoring station, in-situ data will be collected at 0.5 to 1.0 meter intervals from surface to bottom for temperature, dissolved oxygen, pH and conductivity. Water clarity will be measured with a Secchi disk. Princeton Hydro is State certified for the collection of these *in-situ* parameters (State ID # 10006).

Discrete water samples will be collected during each sampling event. Discrete surface, mid-depth (within the thermocline), and bottom water samples will be collected for TP, soluble reactive phosphorus (SRP), total dissolved phosphorus (TDP), nitrate-N (NO_3-N), ammonia-N (NH_3-N), TSS at L-1 (New York) and L-3 (New Jersey). At the two "shallow" sampling stations (both located in New Jersey (L-4 and L-5)), discrete mid-depth samples will be collected for TP, SRP, TDP, NO_3-N, NH_3-N, TSS. Chlorophyll a samples will also be collected from surface and mid-depths at all four of these stations. A field duplicate and rinse blank will also be collected during each in-lake sampling event. Field duplicates will be collected from a different sampling station, and for a different water quality parameter, during each individual sampling event.

Abraxis test strips will be used to field test the potential presence of two types of cyanotoxins (microcystins and cylindrospermopsin) at two shore-line beaches, one at the New Jersey end of the lake and one at the New York end. These two cyanotoxins have US EPA draft Health Advisories for recreational waterbodies so this warrants some monitoring at Greenwood Lake. Meanwhile, NJDEP is developing protocols for the monitoring of cyanotoxins.

In addition to the water quality data, plankton samples will be collected at the surface and mid-depths at stations L-1 and L-3 for the identification / enumeration of the existing algae. Plankton will be identified down to genus or species and will focus on the blue-green algae (also known as cyanobacteria) portion of the community since this is the algal group that has the potential to generate cyanotoxins. Finally, during each sampling event a semi-quantitative assessment of the resident submerged aquatic vegetation will be conducted.

In addition to the in-lake sampling stations, a total of eight tributary stations will be monitored throughout the watershed. Six will be established in the New Jersey end and two will be established in the New York end (see included maps). A total of three tributary sampling events will be scheduled. Again, these are the same tributary sampling stations monitored during the 2004 – 2005 monitoring program. At each tributary monitoring station, in-situ data will be collected for temperature, dissolved oxygen, pH and conductivity. Discrete water samples will also be collected during each sampling event for TP.

7.0 QUALITY OBJECTIVES AND CRITERIA FOR MEASUREMENT DATA

Within Section 7 of this QAPP below, the criteria for deciding to accept, reject, or qualify the data generated through both field and lab testing is outlined. 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 water quality improvements as measured in Greenwood Lake. The specific parameters that will be lab measured are TP, SRP, TDP, NO_3-N, NH_3-N, TSS and chlorophyll *a* within the lake and TP and TSS for storm water. This testing will be conducted by the NJDEP certified analytical laboratory ECM (#18630). *In-situ* data collection will entail the measurement of temperature, dissolved oxygen (DO), pH and specific conductivity. Princeton Hydro is certified by the NJDEP for the collection of *in-situ* data (NJDEP Lab Certification #10006).

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, 23rd Edition* (American Public Health Association, 2017), State protocol (NJDEP, 2005) and/or any applicable USEPA guidance document.

D. Water Quality Monitoring Parameters and Frequency

1. This QAPP specifically covers the sampling period of the 2019 growing season. Grab samples will be collected in the lake once during the spring season, once in summer, and once during the fall season. Tributary samples will also be collected for three (3) events. Three (3) storm sampling events will be conducted at four (4) completed BMP projects.
2. All water quality grab samples will be collected following procedures found in the "NJDEP Field Sampling Procedures manual, August 2005."
3. The sample location will be marked and verified with GPS, reported in decimal degrees NAD83. In addition, sampling staff will use detailed site sketches to locate the sampling location on the first and subsequent visits.

4. Surface samples will be collected at a depth of less than half a meter, while deep samples will be collected approximately half a meter above the sediment. Samples will be collected at mid-water level at the shallow depth stations. 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 6°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 Table 1. This table was developed in coordination with the independent analytical laboratory; Environmental Compliance Monitoring, Inc. (ECM; #18630). ECM will conduct the chemical laboratory analysis of TP, SRP, TDP, TSS, NO_3-N, NH_3-N and chlorophyll *a*. Princeton Hydro will conduct the *in-situ* analysis following the methods and protocols listed in Table 1.

Table 1 - Proposed Sample Parameters			
Parameter	**Analytical Method Reference* (Standard Methods)**	**Sample Container and Preservation Method**	**Holding Time (Max)**
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
Soluble Reactive Phosphorous	4500-P E	1 Pint plastic, cool to 4°C	48 hours
Total Dissolved Phosphorus	4500-P B-5 and 4500-P E	1 Pint plastic, Filter, H_2SO_4 added to pH <2, cool to 4°C	28 days
Total Suspended Solids	2540 D	1 Pint plastic, cool to 4°C	7 days
Chlorophyll *a*	10200H 1 & 2	1000 mL opaque plastic bottle, cool to 4°C	ASAP – filter within 48 hours
Nitrate-N	352.1	1 Pint plastic, cool to 4°C	48 hours
Ammonia-N	SM 4500-NH3 D	1 Pint plastic, H_2SO_4 added to pH <2, cool to 4°C	28 days
pH	SM 4500-H+ B-2011	Analyzed *In-situ*	Analyze Immediately
Specific Conductivity	SM 2510 B-2011	Analyzed *In-situ*	Analyze Immediately
Temperature	SM 2550 B-00	Analyzed *In-situ*	Analyze Immediately
Dissolved Oxygen	SM 4500-O G-11	Analyzed *In-Situ*	Analyze Immediately

Information on project required parameter detection limits (sensitivity), reporting levels, levels of interest, precision and accuracy for parameters of interest is listed in Table 2. 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.

H. Data Comparability

Analytical data comparability will be achieved by following the analytical methodology, preservation practices and holding times described in Table 1. 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 Township of West Milford, Greenwood Lake Commission and Highlands Council in accordance with the sampling and analytical methodology, as well as the required Quality Assurance/ Quality Control (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.

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 2).

Table 2 - Information on 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*
Total Phosphorus	Water	0.02 mg/L	0.03 mg/L	0.03 mg/L	-9 to 9	92 - 122
Soluble Reactive Phosphorus	Water	0.002 mg/L	0.003 mg/L	0.005 mg/L	-3 to 3	87 – 123
Total Dissolved Phosphorus	Water	0.02 mg/L	0.03 mg/L	0.03 mg/L	-6 to 6	88 – 112
Total Suspended Solids	Water	3.0 mg/L	4.0 mg/L	5.0 mg/L	-10 to 10	N/A
Chlorophyll *a*	Water	0.3 mg/M^3	0.4 mg/L	5 mg/M^3	-72 to 72	N/A
Nitrate-N	Water	0.02 mg/L	0.02 mg/L	0.05 mg/L	-27 to 27	42 - 162
Ammonia-N	Water	0.02 mg/L	0.01 mg/L	0.05 mg/L	-27 to 27	0 - 181

*** As supplied by ECM**

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.

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 2), 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 2), 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 2, the original value will be used for all analyses and included in all reports.

Precision of the nutrient data generated from the lab 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 2) 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 or the academic or research institution performing the review and compilation of the data. If the facility cannot provide the required storage, the data shall be transferred for archival storage to the Greenwood Lake Commission and Highlands Council.

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 2 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 D.

Representativeness will also be assured by the project team participants who have been engaged in other similar projects involving the testing of stormwater BMP performance and in the collection of tributary and 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 3. Fiscal management, administration, overall project management of the project will be the responsibility of Ms. Keri Green of the Highlands Council since she will serve as the Project Manager. Dr. Fred Lubnow of Princeton Hydro will serve as the Principle Investigator. He will work directly with Ms. Green, in the execution of the field sampling activities detailed above. The responsibilities of the Principle Investigator will include overall project coordination, data management and documentation. The Project Manager will coordinate the sampling efforts, including working with the Field Team personnel to ensure sampling is scheduled, samples are collected and samples are delivered to ECM in a manner fully consistent with this QAPP. Mr. Chris Mikolajczyk will serve as the QA/QC Officer for the project.

Table 3 - Key Project Personnel and Related Project Responsibility

Area of Responsibility	Name	Affiliation
Overall Project Coordination	Keri Green	State of New Jersey Highlands Council
Principal Investigator	Dr. Fred Lubnow	Princeton Hydro, LLC
Laboratory Analysis	Thomas Grenci	Environmental Compliance Monitoring, Inc.
Laboratory QC	Beth Birmingham-Fagan	Environmental Compliance Monitoring, Inc.
Performance Auditing	Beth Birmingham-Fagan	Environmental Compliance Monitoring, Inc.
Data Processing	Katie Walston	Princeton Hydro, LLC
QA/QC Officer	Chris Mikolajczyk	Princeton Hydro, LLC
Data Quality Review	Dr. Fred S. Lubnow	Princeton Hydro, LLC
Phytoplankton	Katie Walston	Princeton Hydro, LLC

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 COC form is provided in Appendix A. The COC will confirm the process and procedure as well as confirm the analytes (TP, SRP, TDP, TSS, NO_3-N, NH_3-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. 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. These procedures are in accordance with all applicable New Jersey Laboratory Certification Program regulations.

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 also plans to make use 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 Greenwood Lake Commission will keep all data in a digital format on file. These data will be transferred to the Greenwood Lake Commission and Highlands Council 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.

13.0 Performance and Systems Audits

A. Performance Auditing
ECM (#18630) is a State of NJ certified laboratory. The laboratory participates in Performance Evaluation (PE) 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 periodically conducts 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 2 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 or the academic or research institution performing the review and compilation of the data. If the facility cannot provide the required storage, the data shall be transferred for archival storage to the Greenwood Lake Commission and the Highlands Council.

D. Field Auditing
The NJDEP can be notified prior to any field sampling event so that they may conduct on on-site audit of the field sampling procedures. If necessary, the finding of this audit, together with the

New Jersey Laboratory Certification Program Performance Evaluation Program results, will then be used to update the Princeton Hydro *in-situ* certification status.

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.

F. Reports

All data collected, will be complied and summarized by Princeton Hydro and provided to the Greenwood Lake Commission and Highlands Council. Princeton Hydro will provide the analysis of the data, as well as formal project / data documentation within 180 days of the close of the project.

14.0 REFERENCES

American Public Health Association. 2017. *Standard Methods for the Analysis of Water and Wastewater, 23rd 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 Custodies

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

COC NO:

CHAIN OF CUSTODY RECORD

PROJECT NO.	PROJECT NAME Lake Holiday REGULATORY? ____ YES _x_ NO	
DATE	SAMPLERS NAME	

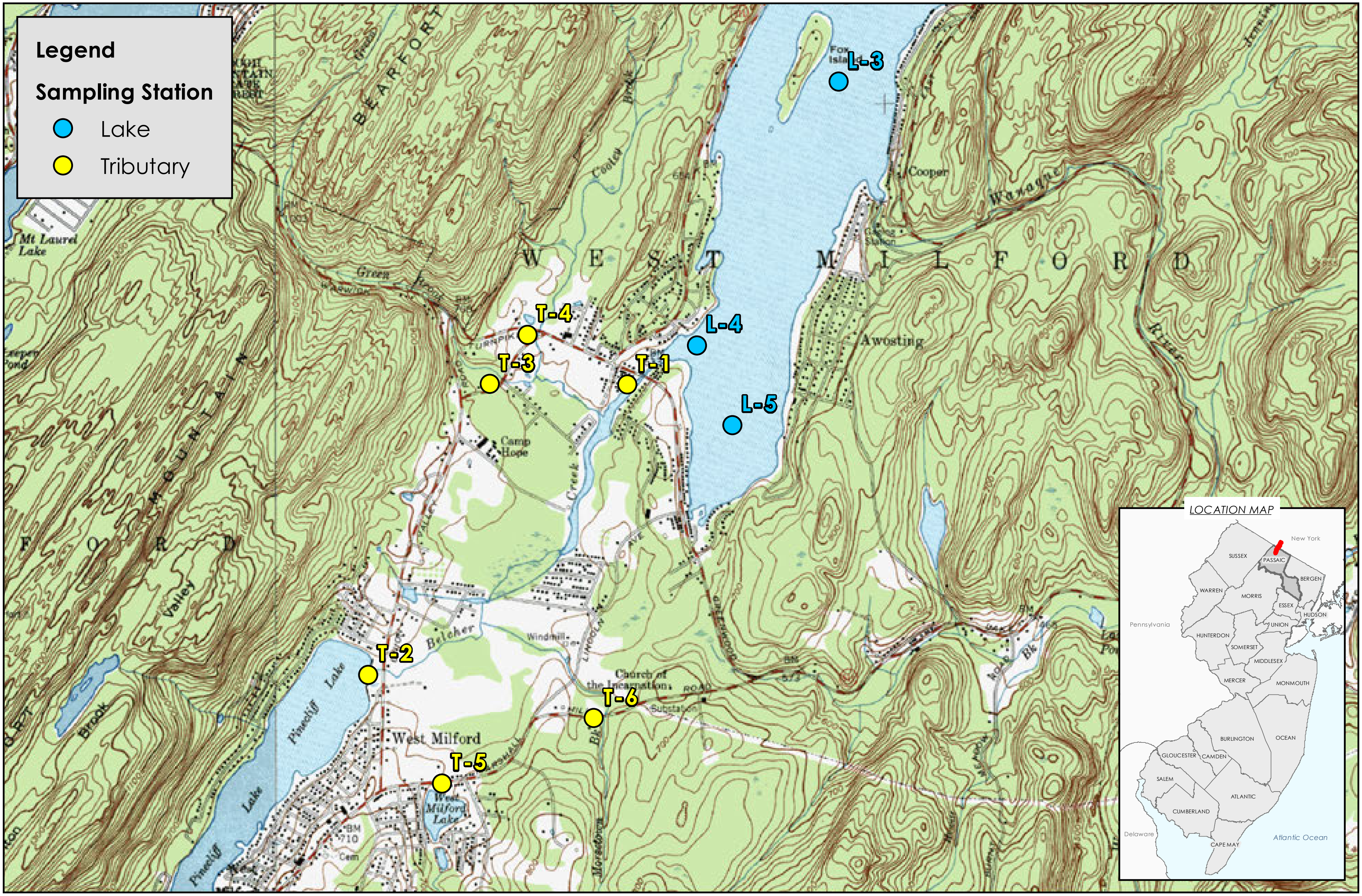
SAMPLE DATE	TIME	COMP OR GRAB	STATION LOCATION	NO. OF CONTAINERS	pH (For Nitrate/Nitrite Analysis)	NO PRESERVATIVE	SULFURIC ACID	NITRIC ACID	HYDROCHLORIC ACID	OTHER	LAB USE ONLY JOB NO: ________ LOT NO: ________ SAMPLE NUMBERS
		Grab	S-2	2		1	1				
		Grab	S-3	2		1	1				
		Grab	M-3	2		1	1				
		Grab	I-1	2		1	1				
		Grab	S-11	2		1	1				
		Grab	S-12	2		1	1				
		Grab	S-15	2		1	1				
		Grab	S-16	2		1	1				

COOLER TEMP: DATE & TIME: INITIALS:	pH < 2 Y N N/A pH > 10 Y N N/A	COMMENTS: TP & TSS	
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 to ensure samples are analyzed correctly. Unless specified on the Chain of Custody Form, ECM cannot presume regulatory compliance criteria

APPENDIX B

Sampling Site Map



File: P:\1850\Projects\1850001\GIS\MXD\Greenwood_Sampling_Location_NJ.mxd, 2/18/2019. Drawn by thopper. Copyright Princeton Hydro, LLC.

NOTES:
1. Sample station locations are approximate.
2. USGS topographic digital raster graphic obtained from Terrain Navigator Pro, Greenwood Lake, NY-NJ quadrangle.

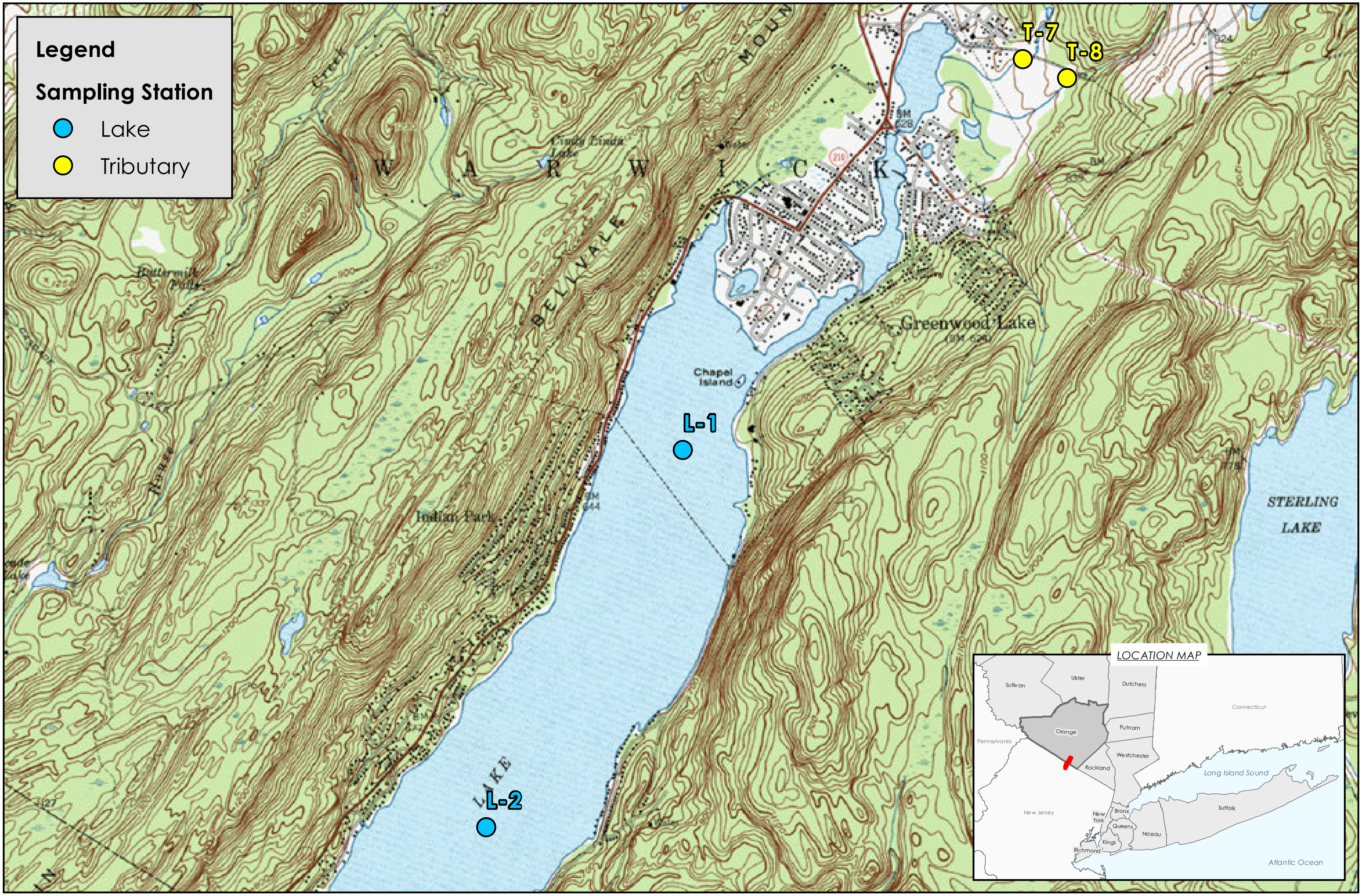
0 1,250 2,500 Feet

Map Projection: NAD 1983 StatePlane New Jersey FIPS 2900 Feet

SAMPLING STATION LOCATION MAP - NEW JERSEY

GREENWOOD LAKE
TOWNSHIP OF WEST MILFORD
PASSAIC COUNTY, NEW JERSEY

PRINCETON HYDRO
SCIENCE DESIGN ENGINEERING
www.PrincetonHydro.com



File: P:\1850\Projects\1850001\GIS\MXD\Greenwood_Sampling_Location_NY.mxd, 2/18/2019, Drawn by thopper, Copyright Princeton Hydro, LLC.

NOTES:
1. Sample station locations are approximate.
2. USGS topographic digital raster graphic obtained from Terrain Navigator Pro, Greenwood Lake, NY-NJ quadrangle.

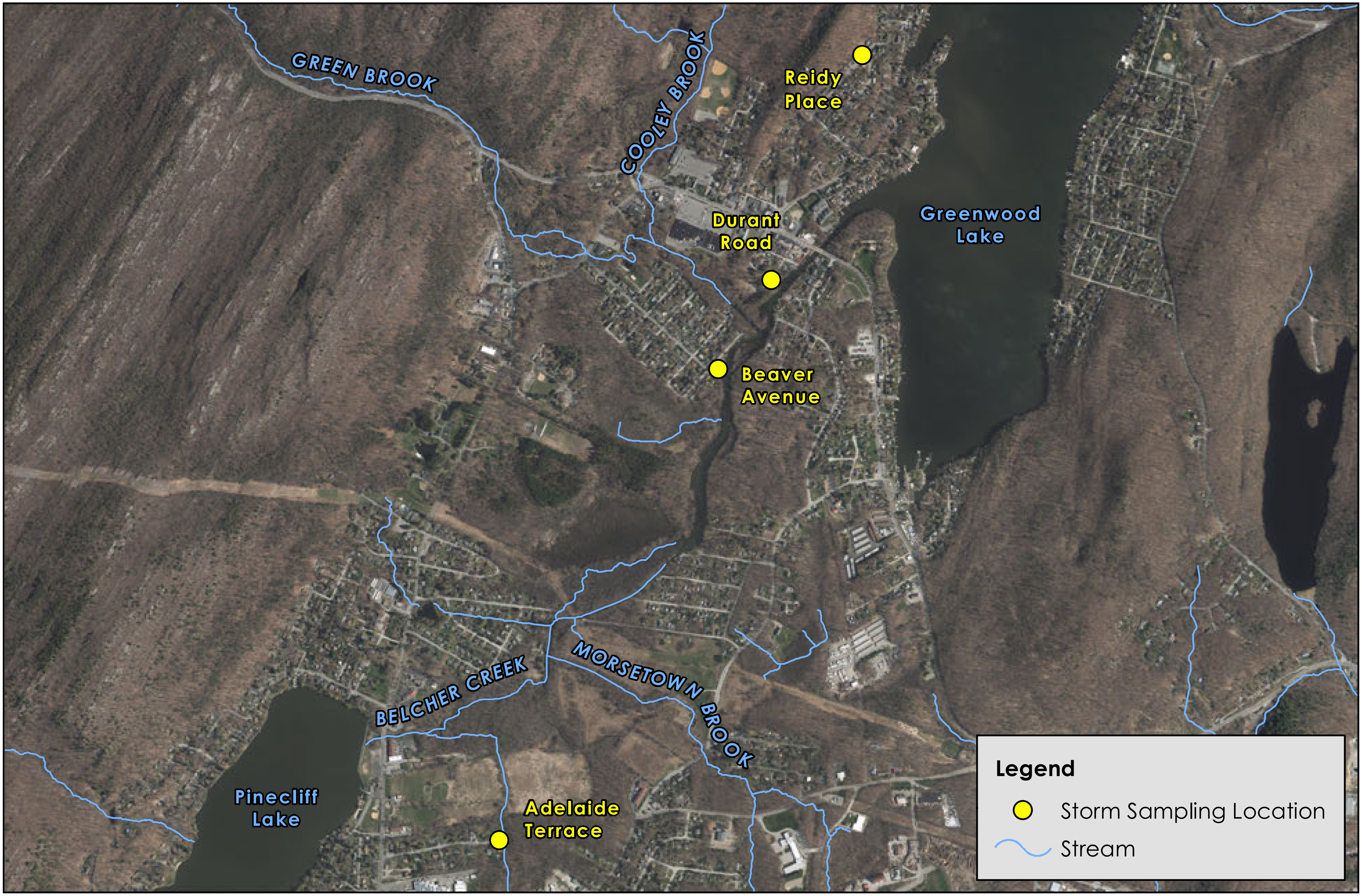
0 1,250 2,500
Feet

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

SAMPLING STATION LOCATION MAP - NEW YORK

GREENWOOD LAKE
TOWN OF WARWICK
ORANGE COUNTY, NEW YORK

PRINCETON HYDRO
SCIENCE DESIGN ENGINEERING
www.PrincetonHydro.com



File: P:\1850\Projects\1850001\GIS\MXD\Storm_Sampling_Location_Map.mxd, 4/26/2019, Drawn by thopper, Copyright Princeton Hydro, LLC.

NOTES:
1. Sampling locations are approximate.
2. 2015 orthoimagery obtained from NJGIN Information Warehouse website: https://njgin.state.nj.us/NJ_NJGINExplorer

0 750 1,500 Feet

Map Projection: NAD 1983 StatePlane New Jersey FIPS 2900 Feet

STORM SAMPLING LOCATION MAP

GREENWOOD LAKE
TOWNSHIP OF WEST MILFORD
PASSAIC COUNTY, NEW JERSEY

PRINCETON HYDRO
SCIENCE DESIGN ENGINEERING
www.PrincetonHydro.com

APPENDIX IV:

GREENWOOD LAKE WATER QUALITY REPORT 2019

Greenwood Lake
Water Quality Report 2019
West Milford Township, Passaic County, New Jersey

Prepared for:
Greenwood Lake Commission
Attn: Paul Zarrillo
2019F Greenwood Lake Turnpike
Hewitt, NJ 07421

Prepared by:

Princeton Hydro, LLC
1108 Old York Road, Suite 1
P.O. Box 720
Ringoes, New Jersey 08551
(P) 908.237.5660
(F) 908.237.5666
www.princetonhydro.com
Offices in New Jersey, Pennsylvania and Connecticut

November 2019

Table of Contents

1.0 Introduction

Princeton Hydro, LLC conducted general water quality monitoring of Greenwood Lake during the 2019 growing season (May through September) to provide an up-to-date water quality and ecological assessment of conditions within Greenwood Lake. A Restoration Plan was developed for the New Jersey end of the Greenwood Lake Watershed for the Greenwood Lake Commission and the Township of West Milford in the mid- 2000's. Funding for the Plan was provided through the New Jersey Department of Environmental Protection's (NJDEP) Non-Point Source (NPS) 319(h) Program and Princeton Hydro was hired to develop it. The watershed-based plan linked the existing total phosphorus (TP) TMDL, developed by NJDEP, to existing and targeted loads from the New Jersey end of the watershed. In turn, the NJ end of the watershed was divided into a series of sub-watersheds and a phosphorus loading priority analysis was conducted to rank the sub-watersheds from "high" to "low" relative to stormwater and watershed restoration needs. The 2019 water quality monitoring program was funded by the Greenwood Lake Commission and the New Jersey Highlands Council.

The original TMDL identified the targeted reductions in TP for both the New Jersey and New York ends of the Greenwood Lake watershed, in order achieve full water quality compliance. However, the 2006 Restoration Plan was funded through an NPS 319(h) grant by the NJDEP and so it focused on the New Jersey end of the watershed relative to watershed-based recommendations. In spite of this, the water quality monitoring associated with the Plan did include locations in both states, although the focus was mostly the New Jersey portion of the lake. In-lake and stream monitoring conducted during 2019 for this updated WIP is a modified version of the program that was implemented back in 2004 through 2006 and was expanded to include some limited monitoring associated with cyanotoxins.

The current water quality monitoring program is valuable in terms of assessing the overall "health" of the lake, identifying 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 continues to be an important component in the evaluation of the long-term success of the implementation of the phosphorus TMDL-based Restoration 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 Greenwood Lake.

2.0 Materials and Methods

In-lake water quality monitoring was conducted at the following five (5) locations in Greenwood Lake (represented in Figures 1 and 2, Appendix A):

Station Number	Description
L1	New York, northernmost mid-lake station
L2*	New York, mid-lake station
L3	New Jersey, mid-lake station
L4	New Jersey, near-shore outlet station
L5	New Jersey, southern near-shore station

* *In-situ* monitoring only

The 2019 sampling dates were 13 May, 11 July, and 23 September. A Eureka Amphibian PDA with Manta multi-probe unit was used to monitor the *in-situ* parameters: dissolved oxygen (DO), temperature, pH, and specific conductance during each sampling event. Data were recorded at 1.0 m increments starting at 0.25 m below the water's surface and continued to within 0.5-1.0 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.

Discrete water quality samples were collected with a Van Dorn sampling device at 0.5 m below the lake surface, at mid-depth and 0.5 m above the sediments at the mid-lake both stations L1 and L3. Discrete samples were collected from a sub-surface (0.5 m) position at the remaining two (2) shallow sampling stations (L4 and L5). Discrete water samples were appropriately preserved, stored on ice, and transported to a State-certified laboratory for the analysis of the following parameters:

- total suspended solids
- total phosphorus-P
- total dissolved phosphorus-P
- soluble reactive phosphorus-P
- nitrate-N
- ammonia-N
- chlorophyll *a*

All laboratory analyses were performed in accordance with *Standard Methods for the Examination of Water and Wastewater, 18th Edition* (American Public Health Association, 1992). Monitoring at station L2 consisted of collecting *in-situ* and Secchi disk data; no discrete water samples were collected from this station for laboratory analyses. Discrete data can be found in Appendix C.

During each sampling event, surface and mid-depth grabs were collected at stations L1 and L3 for phytoplankton quantification. A Schindler trap was also used to sample zooplankton densities at surface and mid-depths at these stations. Surface grab samples were also taken at near-shore or beach areas on both the New Jersey and New York ends for phytoplankton quantification and cyanotoxin testing. Phytoplankton data can be found in Appendix D.

Tributary monitoring was also conducted at eight (8) tributaries entering Greenwood Lake, with two established at the NY end and six at the NJ end. These eight stations were monitored during the 2004-2006 monitoring program. *In-situ* and discrete monitoring for TP and TSS were conducted at each stream sampling.

3.0 Results and Discussion

3.1 In-situ Parameters

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.

During the May sampling event, each of the sampling stations were well-mixed, with exception to L2. While temperatures at L1 declined with depth, the degree of decline was not severe enough to be considered stratified. L2 exhibited thermal stratification starting at 9 m, declining from surface temperatures of 14.18°C to 10.89°C above the sediment. By the July sampling event, the shallow near-shore stations L4 and L5 remained thermally mixed, while weak thermal stratification in the bottom waters of L3. Both L1 and L2 were stratified by this sampling event, with epilimnions extending through 3 m and 4 m, respectively. Stratification persisted through the final event at L1 and L2 to lesser degrees, with epilimnions extending to 8 m at both stations.

L3 continued to exhibit weaker stratification, declining from surface temperatures of 22.25°C to 20.27°C at 3 m. Stations L4 and L5 remained well-mixed throughout the 2019 growing season.

Strong and extensive amounts of thermal stratification can effectively "seal off" the bottom waters from the surface waters and overlying atmosphere, which can result in a depletion of dissolved oxygen (DO) in the bottom waters. With the exception of a few groups of bacteria, all aquatic organisms require measurable amounts of DO (> 1 mg/L) to exist. Thus, once the bottom waters of a lake are depleted of DO, a condition termed anoxia, that portion of the lake is no longer available as viable habitat.

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 for 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 is 5.0 mg/L or greater, for a healthy and diverse aquatic ecosystem.

DO at L1 and L2 declined with depth during each sampling event conducted during the 2019 season. During the May sampling, DO at L1 declined from supersaturated measures (DO > 100%) at the surface to 5.38 mg/L above the sediment. L2 exhibited a similar pattern, only declining below the NJDEP recommended threshold of 5.0 mg/L in the bottom meter of the lake. L3, L4 and L5 were characterized by ample DO throughout the water column. Supersaturated conditions were observed at L3 and L5. By July, thermal stratification caused sharper declines in DO at L1 and L2. L1 contained supersaturated conditions in the surface waters during this event, declining below the NJDEP threshold at 4 m before becoming anoxic at 5 m through the remainder of the water column. Once again, a similar pattern was observed at L2, declining to anoxic conditions at 5 m. L3 yielded elevated DO concentrations at the surface (10.55 mg/L), dropping to 6.35 mg/L in the deeper waters. Supersaturated DO was observed throughout the water column at stations L4 and L5. Conditions at stations L3 through L5 persisted through the final sampling event. Supersaturated conditions were observed in the surface waters of both L1 and L2 during the September sampling. Anoxic conditions were established at both of these stations at 9 m through the bottom of the lake.

Overall, a depression of DO was mainly limited to the hypolimnion of L1 and L2, while the shallower stations on the New Jersey side retained ample DO throughout the season. Thus, the majority of the lake had a sufficient amount of DO to support a diverse and healthy aquatic ecosystem (Appendix B). Elevated DO can be attributed to increased photosynthetic activity due to elevated plant growth, especially in the shallow areas, as well as increased algal productivity observed throughout the surface waters of the lake.

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 is for an optimal range between 6.5 and 8.5.

pH was highly variable from station to station during the May sampling event, with surface measures ranging from 7.99 at L4 to 9.71 at L5. Stations L1, L2 and L4 yielded surface measures within the NJDEP optimal range. Values declined with depth at each of these stations, with exception to a slight incline in the first few meters at L2. Extremely elevated pH was noted at L3 and L5, with pH values in the mid to high 9's. These locations were characterized by dense curly leaf pondweed (*Potamogeton crispus*) growth during these events, which resulted in high amounts of photosynthesis, which in turn elevates the pH. pH increased at L1 and L2 during the July sampling event, with surface measures of 8.76 and 8.70, respectively. Elevated pH was noted through the first few meters of these stations, before declining with depth, indicating high productivity due to algal densities in the surface waters. The New Jersey stations all declined from measures noted during the initial sampling event, ranging from values of 7.56 at L4 to 8.77 at L3. Surface values during this event contravened to optimal pH range at each sampling station, except L4. Further decline was observed at each of the sampling stations by the final sampling event, with pH values ranging from 7.28 at L3 to 8.23 at L1. pH was variable throughout the water column, but typically declined with depth. Elevated pH in 2019 was attributed to the elevated cyanobacteria densities as well as dense plant growth observed during the growing season.

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 northern 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).

Water clarity at stations on the New Jersey end (L3-L5) were variable throughout the season. Seasonal maximum Secchi depths were noted during the May event at each of these stations, with measures ranging from 1.0 m at L4 to 1.6 m at L3. Each sampling station remained at or above the 1.0 m recommended threshold. By the July sampling, clarity declined overall at stations L3 through L5, dropping below the threshold at each. Secchi depths were generally consistent through the final sampling event, with Secchi depths ranging from 0.7 m at L4 to 0.9 m at L3. Reduced water clarity was noted at these shallower stations due to the elevated algal productivity during the latter portions of the sampling season. The New York mid-lake stations were consistent throughout the sampling year. L1 yielded 1.5 m during each sampling event, while L2 varied between 1.2 m and 1.3 m, remaining above the recommended 1.0 m threshold.

3.2 Discrete Parameters

Ammonia-Nitrogen (NH_3-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 NH_4^+. In aerobic systems bacteria then break down excess ammonia in a process termed nitrification to nitrate (NO_3^-). 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 NH_3-N concentrations above 0.05 mg/L tend to stimulate elevated rates of algal growth.

Overall, surface and mid-depth NH_3 concentrations ranged from non-detectable measures (ND < 0.01 mg/L) to 0.01 mg/L during the May sampling. Deep water ammonia concentrations were low during this sampling, yielding non-detectable concentrations at L1 and 0.03 mg/L at L3. By the July sampling event, ammonia measures increased slightly, with surface concentrations ranging from non-detectable at L2 and L5 to 0.04 mg/L at L4. Mid-depth concentrations at L1 and L3 were both 0.01 mg/L, while deep water concentrations ranged from 0.01 mg/L at L2 and 0.04 mg/L at L1. By the final sampling event, surface and mid concentrations ranged between 0.01 mg/L and 0.03 mg/L. Ammonia concentrations spiked to 0.22 mg/L in the deep waters of L1 during this event, attributed to anoxic conditions and the bacterial decomposition of settled organic material. With exception to this elevation, ammonia levels were consistently below the 0.05 mg/L recommended threshold during each sampling event during the 2019 season.

In summary, the excessively high concentration of NH_3-N in the deep (hypolimnetic) waters at L1 was attributed to the depletion of DO and the bacterial decomposition of the organic matter raining to the bottom from the surface waters. Surface water NH_3-N concentrations were consistently low through the majority of the season, at no point exceeding recommended thresholds.

Nitrate-Nitrogen (NO_3-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.

During the May 2019 sampling, Nitrate-N concentrations at the surface stations ranged between non-detectable measures (ND < 0.02 mg/L) to 0.15 mg/L. Concentrations were especially low at L1 and L3, remaining well below the 0.10 mg/L threshold. Only L4 exceeded 0.10 mg/L during this event, while all surface measures were below nitrogen-loading indicators (0.30 mg/L). Mid-depth concentrations were comparable to surface measures at L1 and L3 during this event. By the July sampling event, surface concentrations were all below recommended thresholds, ranging between 0.05 mg/L at L4 and 0.09 mg/L at L3 and L5. Mid-depths increased from the May sampling with measures of 0.13 mg/L at L1 and 0.09 mg/L at L3. Mid-depth samples at L1 exceeded the 0.10 mg/L threshold. Nitrate concentrations at the surface declined by the final event, ranging from non-detectable measures at L1 and L4 to 0.04 mg/L at L3. Similarly, concentrations declined at mid-depths from those noted in July, remaining below 0.10 mg/L at both L1 and L3. The conditions observed throughout the 2019 growing season were not indicative of nitrogen loading to the waterbody.

The deep-water nitrate concentrations were variable from station to station throughout the 2019 season. Seasonal minimum values in the deep waters were noted during the May sampling with concentrations of 0.03 mg/L at L3 and 0.08 mg/L at L1 observed. Peak nitrate concentrations were noted during the July sampling spiking to 0.18 mg/L at L1 and 0.10 mg/L at L3. Nitrate concentrations declined by the final sampling event, falling below 0.10 mg/L at each station.

In summary, all in-lake nitrate-N concentrations were consistently below the State and Federal drinking water standard of 10.0 mg/L. Nitrate-N concentrations at the surface only exceeded the 0.10 mg/L threshold (stimulates elevated amounts of algal and aquatic plant growth) during the May sampling event, yielding measures of 0.15 mg/L at L5. While high accumulations of rain fell early in the 2019 season (May – July), elevated phytoplankton densities noted throughout the season likely kept nitrate concentrations below the 0.10 mg/L threshold as utilization rates would be high.

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. Greenwood Lake has established a phosphorus TMDL, which was approved by NJDEP in September 2004. Based on its refined phosphorus TMDL, the long-term management goal is to maintain a target TP concentration of 0.02 mg/L within the surface waters of Greenwood Lake, with an upper limit of 0.03 mg/L.

The May sampling event was characterized by overall elevated TP concentrations at the surface, ranging from measures of 0.02 mg/L at L3 and 0.04 mg/L at the remaining sampling stations. L1, L4 and L5 exceeded the TMDL upper limit threshold of 0.03 mg/L, but remained below the State surface water standard of 0.05 mg/L. Concentrations in the mid-depths of both L1 and L3 both exceeded the TMDL threshold with measures of 0.04 mg/L. A wider range was noted during the July sampling event, with non-detectable concentrations (ND < 0.02 mg/L) at L1 and seasonal maximum surface concentrations of 0.05 mg/L at L5. Both stations L1 and L3 yielded surface measures below the 0.02 mg/L TMDL target TP concentration. Elevated TP persisted through the July event at L4 and L5. Mid-depth concentrations were variable at stations L1 and L3, exceeding the TMDL thresholds at L3, doubling the upper limit. The surface range lessened by the final event, with TP ranging from 0.01 mg/L in the surface waters of L1 to 0.03 mg/L at L3 and L4. Both L3 and L4 yielded concentrations contravening the target TP threshold, but remained at the upper limit of 0.03 mg/L. At no point during the 2019 season did surface TP concentrations exceed the State surface standard of 0.05 mg/L.

Deep water TP concentrations at both L1 and L3 were elevated during the May sampling, with a measure of 0.04 mg/L at each station. Deep water concentrations declined slightly during the July sampling event at L1 to 0.03 mg/L, while TP increased to 0.06 mg/L at L3. By the final event, concentrations declined to the TMDL upper limit of 0.03 mg/L at L3. TP spiked to 0.30 mg/L in the deep waters of L1 at this time. These elevated measures in the bottom waters of L1 were caused by the extended thermal stratification and anoxia observed, causing internal loading of phosphorus. Overall, TP remained above the TMDL target concentration of 0.02 mg/L in the deep waters throughout the 2019 season.

In summary, surface concentrations were elevated throughout the growing season, exceeding the TMDL target at various sampling stations during each sampling event. Elevated measures early in the season were attributed to the high accumulations of rain during the 2019 season. Deep water concentrations were elevated during the 2019 season, exceeding the TMDL target during each event. Elevations of TP in the deeper stations can be explained by the continuing anoxic conditions and internal loading of phosphorus.

Total Dissolved Phosphorus (TDP)

Total dissolved phosphorus represents the dissolved portion of total phosphorus metrics. As such, TDP represents dissolved organic and inorganic phosphorus species. This metric, in concert with total phosphorus and soluble reactive phosphorus concentrations, is utilized to determine P species ratios and the amount of phosphorus which is readily available for biological assimilation.

Surface TDP concentrations were low at each sampling station during the May sampling evet, ranging from non-detectable concentrations (ND < 0.01 mg/L) at L5 to 0.03 mg/L at L1. Mid and deep water concentrations were also low, with non-detectable measures at L1 and 0.02 mg/L at L3. Overall, TDP remained low during the July sampling event with non-detectable surface measures at each of the sampling stations. Elevated TDP was noted in the mid-depths of L3, yielding concentrations of 0.06 mg/L. Surface TDP once again remained low by the final sampling event, with measures of 0.01 mg/L and 0.02 mg/L. Seasonal maximum TDP concentrations were noted in the deep waters of L1 during this event (0.22 mg/L), attributed to the extended anoxia present at this station.

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.

Surface SRP concentrations varied slightly across sampling stations during the May event, ranging from non-detectable (ND < 0.002 mg/L) at L3 to 0.006 mg/L at L4. Each of the sampling stations were at or below the 0.005 mg/L threshold, with exception to L4. Mid-depth and deep water SRP were low at this time. Overall, the majority of sampling stations and depths declined by the July sampling, with six of the eight samples yielding non-detectable measures. A slight increase in

SRP was observed in the deep waters of L1. SRP spiked to seasonal highs during the final sampling event, with surface concentrations of 0.003 mg/L at L1, L4 and L5 and 0.015 mg/L at L3. While surface measures were elevated at L3, mid-depth and deep-water concentrations were below the 0.005 mg/L threshold. The deep-water samples collected at L1 yielded especially elevated concentrations of 0.210 mg/L. This exceedance was attributed to the extended thermal stratification causing internal loading of phosphorus.

Chlorophyll a

Chlorophyll *a* is the primary photosynthetic component of all algae and as such is often used as a proxy indicator of total algal biomass. Increases in chlorophyll *a* 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.

The May sampling event was mainly characterized by low chlorophyll *a* measures at the surface, ranging from 2.9 µg/L at L4 and 23 µg/L at L1. Each of the five stations remained below the 20 µg/L threshold, with exception to L1, which yielded elevated *Aphanizomenon* densities. By the July sampling, chlorophyll *a* concentrations declined below this threshold at the surface of L1, while the remaining sampling stations increased greatly from their May counterparts. Surface concentrations ranged from 35 µg/L at L3 to a seasonal maximum of 50 µg/L at L5. Elevated chlorophyll *a* was attributed to the elevated algal densities during this event, as a cyanobacteria bloom was observed during this event, especially prolific along the New Jersey end. Mid-depth measures were comparable to those noted in the surface at each station. Chlorophyll *a* concentrations declined by the final sampling event, ranging from surface measures of 22 µg/L at L1 and 28 µg/L at L4 and L5. Both surface and mid-depth concentrations exceeded the recommended threshold during this event.

Total Suspended Solids

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

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.

Overall, TSS concentrations remained low throughout the 2019 season. Surface concentrations during the May event ranged from non-detectable concentrations (ND < 2 mg/L) at multiple stations to 8 mg/L at L4. By the July sampling event, TSS concentrations were between 4 mg/L and 11 mg/L at each sampling station. TSS declined slightly across each sampling station during the September sampling. Each of the sampling events yielded TSS concentrations below the 25 mg/L recommended threshold. Similarly, low TSS measures were noted in both the mid-depth and deep waters at each station throughout the season.

3.3 Biological Parameters

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.

The phytoplankton community observed at L1 during the May sampling was characterized by a bloom of the cyanobacteria *Aphanizomenon* and moderate densities of the diatoms *Melosira* and *Asterionella*. Species richness was high during this event, yielding 17 identified genera, with representations from the diatoms, chlorophytes, dinoflagellates, cyanobacteria, chrysophytes and cryptomonads. Both surface and mid-depth samples yielded communities dominated by *Aphanizomenon*, with counts of 79,962 cells/mL and 102,506 cells/mL, respectively. By the July sampling event, *Aphanizomenon* remained the dominant organism, with counts of 50,475 cells/mL at the surface and 49,437 cells/mL at mid-depths. Moderate densities of the cyanobacteria *Dolichospermum* (formerly *Anabaena*) were also noted, along with various diatoms, green algae and cryptomonads. Elevated densities of *Aphanizomenon* persisted through the final event, declining to surface and mid-depth measures of 18,740 cells/mL and 38,462 cells/mL, respectively.

A similar community was observed at L3 during the 2019 growing season. The phytoplankton community at L3 during the May event was dominated by *Aphanizomenon*, with moderate densities of *Asterionella* and *Fragilaria*. Both the surface and mid-depth samples was mostly made up of cyanobacteria, with counts of 45,296 cells/mL and 31,521 cells/mL, respectively. By the July sampling event, *Aphanizomenon* remained the dominant organism, with counts of 145,636 cells/mL at the surface and 153,398 cells/mL at mid-depths. *Dolichospermum* was also abundant during this sampling event. Cyanobacteria remained the dominant algae by the final sampling event with cell counts of 88,443 cells/mL at the surface and 62,264 cells/mL at mid-depth. Peak species richness was observed during this sampling with 22 identified genera.

Cyanobacteria were dominant throughout the 2019 season. Cyanobacteria monitoring was conducted during each sampling event at two near-shore areas in New York and New Jersey to determine if a harmful algal bloom (HAB) was present. Various cyanobacteria, such as *Aphanizomenon* and *Dolichospermum*, can produce toxins that can be harmful to people and animals, and greatly affect the water quality and aquatic life. Cyanobacteria monitoring consisted of quantifying cyanobacteria cell densities and cyanotoxin concentrations (microcystin, cylindrospermopsin) in the water. There are a variety of recreational criteria for microcystin and cylindrospermopsin from both the NJDEP, NYSDEC, and EPA. The EPA recreational thresholds are 8 ppb for microcystin and 15 ppb for cylindrospermopsin. The NJDEP has established a draft recreational health advisory for both of these cyanotoxins, with thresholds of 3 ppb for microcystin and 8 ppb for cylindrospermopsin. The NYSDEC breaks cyanotoxin concentrations into multiple categories. These include No Bloom (<4 ppb), Confirmed Bloom (≥4 ppb) and Confirmed with High Toxins Bloom (≥10 ppb open water; ≥20 ppb on shorelines). Overall, microcystin and cylindrospermopsin levels remained below their respective NJDEP and NYSDEC draft recreational health advisories at each station during these sampling events.

Both the WHO and NJDEP have established cell count-based criteria for the relative probability of acute health effects of these HABs. NJDEP has a Health Advisory Guidance Level of 20,000 cells/mL, while the WHO criteria are defined as Low (<20,000 cells/mL), Moderate (20,000-100,000 cells/mL), High (100,000-10,000,000 cells/mL) and Very High (>10,000,000 cells/mL). Stations L1 and L3 both yielded algal densities above the NJDEP Health Advisory Guidance Level and were characterized as Moderate or High by WHO criteria throughout the season. Both beach shorelines were clear during the May sampling. During the July monitoring event, the NY beach yielded a total of 69,971 cells/mL, indicating a Moderate probability of acute health effects. Larger cyanobacteria densities were noted along the NJ shoreline (231,752 cells/mL), characterized as a High probability of acute health effects. By the final sampling, both the NY and NJ beaches were characterized as Moderate by WHO standards.

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.

Due to elevated densities of phytoplankton throughout the year, moderate to high zooplankton richness was observed. The zooplankton community at L1 was dominated by *Polyarthra* during the May sampling event, with moderate densities of *Keratella*, *Microcyclops* and copepod nauplii. Peak species richness was noted during this event, with 11 identified genera. *Polyarthra* retained dominance by the July sampling event. Similarly, *Keratella* and copepod nauplii were noted in moderate densities. By the final sampling event, the zooplankton community was characterized by lower densities and dominated by rotifers.

A similar community was noted at L3, as moderate densities of *Keratella* and *Polyarthra* were observed during the May sampling event. The sample taken during the July event was dominated by the colonial rotifer *Conochilus*. Moderate densities of *Polyarthra*, *Keratella* and copepod nauplii were also noted during this sampling event. Peak species richness of 10 identified genera was noted was observed during the September sampling, with co-dominance exerted by *Polyarthra* and *Keratella*. This sample also contained moderate densities of *Bosmina*, *Conochilus* and copepod nauplii.

3.4 Tributary Monitoring

In addition to lake monitoring throughout the 2019 season, Princeton Hydro conducted sampling of various tributaries to Greenwood Lake (Appendix A). The purpose of this sampling is to determine sources of nutrient loading throughout the watershed in order to pin-point areas which may be prioritized for management efforts. The following sections provide a brief summary of the tributary data collected at eight (8) stations (Appendix B and C) throughout the 2019 sampling season.

In-situ Data

Temperatures were variable amongst the eight stations during each sampling event. During the May sampling event, temperatures ranged from 8.77°C at T3 to 14.46°C at T2. By the July sampling, a wider range was noted with temperatures between 17.75°C at T4 and 28.51°C at T2. By the final sampling event, temperatures varied from 15.89°C at T3 and 23.42°C at T2. Highest temperatures at each sampling event were noted at T2, likely due to the lack of tree cover. Dissolved oxygen was ample overall during each of the sampling events, only dropping below the 5.0 mg/L threshold at T5 during July and T3 during September. Each of the streams during the three sampling events had pH values within the optimal 6.5 – 8.5 range, with exception to T2 during the height of the season.

Discrete Data

TP concentrations were elevated overall throughout the 2019 season. During the May sampling event, TP concentrations ranged from 0.02 mg/L at T8 to 0.10 mg/L at T2 and T5. Each of the sampling stations during this sampling event, with exception of T8, exceeded the TMDL thresholds. By the July sampling event, five of the eight stream stations yielded very low TP concentrations. T4, T5 and T6 all exceeded the TMDL threshold at this time, with especially elevated measures of 0.30 mg/L at T5 and 1.80 mg/L at T6. During the September sampling, TP ranged from 0.01 mg/L at T3 to a maximum of 0.89 mg/L at T6. Only T3 remained below the TMDL thresholds during this event. Especially elevated measures were once again noted at T6 (0.89 mg/L). Based on these results, T6 yielded the most elevated TP throughout the season, however, each tributary station yielded elevated TP measures.

3.5 Interannual Analysis of Water Quality Data

As mentioned above, a similar monitoring program was conducted during the 2004 through 2006 season. Data collected during the 2005 and 2006 seasons will be utilized for comparison to those in 2019. The main focus for this interannual comparison will be placed on the 24 August 2005, 1 August 2006 and 11 July 2019 sampling data.

Thermal stratification was noted during each of these three sampling events, with strong stratification noted at the deeper stations. L3 was well-mixed during the 2005 and 2006 sampling seasons, only exhibiting slight stratification in the bottom meter of the lake during the 2019 sampling. Persistent thermal stratification in the deeper stations caused anoxic conditions starting at 5-7 meters during each of the three sampling events at L1 and L2. During the 2005 and 2006 samplings, DO declined below the 5.0 mg/L threshold above the sediments at L3. In contrast, ample DO was noted throughout the water column at L3 during the 2019 sampling. Water clarity was variable throughout the sampling period. The deep-water station L1 exceeded the 1.0 m threshold during each sampling season, with maximum Secchi depth noted in 2006 (2.4

m). The shallower L3 had Secchi depths ranging from 0.5 m during 2005 to 1.3 m during 2006. Clarity dropped below the 1.0 m threshold during both 2005 and 2019 (0.9 m).

TP concentrations at the surface of both L1 and L3 declined as time progressed. TP dropped from 0.05 mg/L and 0.07 mg/L during the 2005 season to non-detectable concentrations (ND < 0.01 mg/L) and 0.01 mg/L at L1 and L3, respectively, during the 2019 season. Surface concentrations were at or below the TMDL upper limit of 0.03 mg/L at each station during the sampling events in 2006 and 2019. Both mid-depth and deep-water TP at L1 were consistent from year to year, with measures of 0.02 mg/L and 0.03 mg/L. Deep water TP was variable at L3 during this sampling period, ranging from a minimum of 0.04 mg/L during 2006 and 0.07 mg/L during 2005.

Chlorophyll *a* measures were variable during each sampling event. Seasonal maximums in the surface waters of both L1 and L3 were noted during the 2005 season, with concentrations of 27.4 µg/L and 55.2 µg/L, respectively. Both of these stations exceeded the 20 µg/L threshold during this event. Chl *a* declined sharply during the 2006 season to surface concentrations of 4 µg/L at L1 and 15.7 µg/L at L3. Chlorophyll increased again at each station by the 2019 season, with surface measures ranging from 16 µg/L at L1 to 35 µg/L at L3. L3 continuously yielded higher chlorophyll *a* concentrations, aided by dense planktonic algal and macrophyte growth.

3.6 Trophic State Index

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 chlorophyll *a* concentrations 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.

Carlson's trophic state index for L1 and L3, as based on chlorophyll *a*, total phosphorus concentrations and Secchi disk depths are hereby presented in table 3.6.1.

3.6.1: Historic TSI at Greenwood Lake

Historic TSI at Greenwood Lake				
Station	**Parameter**	**8/24/2005**	**8/1/2006**	**7/11/2019**
L1	TP	59	47	37
	Chla	63	44	58
	Secchi	59	47	54
L3	TP	65	53	37
	Chla	70	58	65
	Secchi	67	56	62

TSI was highest during the 2005 season, with TSI values ranging from 59 to 70 at L1 and L3. Values noted during the 2005 sampling year were indicative of eutrophic waterbodies and blue-green and macrophyte dominated communities. Chlorophyll *a* concentrations were greater than Secchi depth and TP, which is suggestive of large particulates like *Aphanizomenon* colonies. TSI declined at both L1 and L3 by 2006, ranging from 44 to 58. Mesotrophic conditions were noted at the deep station, as L1 yielded a marked decline in TSI with measures of 44 and 47 noted. Eutrophic conditions were still noted at L3 during this event. TSI was variable by the 2019 sampling season, with values ranging from 37 to 65. Overall, TP values were low, yielding a TSI of 37 at both L1 and L3. Both TSI based on Secchi and Chlorophyll *a* were indicative of eutrophic conditions, with slightly elevated TSI at L3 comparatively due to high cyanobacteria and macrophyte densities. Overall, TSI values were continuously elevated in the New Jersey end of the lake compared to the New York end during each sampling year.

4.0 Summary

This section provides a summary of the 2019 water quality conditions observed at Greenwood Lake.

1. Thermally stratified waters were noted in the deeper waters by the first sampling event, which then persisted throughout the remainder of the growing season. The waters were well oxygenated during the first sampling event, only dropping below the recommended DO threshold at the sediments. By the July event, the deep-water stations became anoxic at 5 meters. Anoxic conditions persisted at L1 and L2 through the September sampling, while ample DO was noted at the shallower stations.

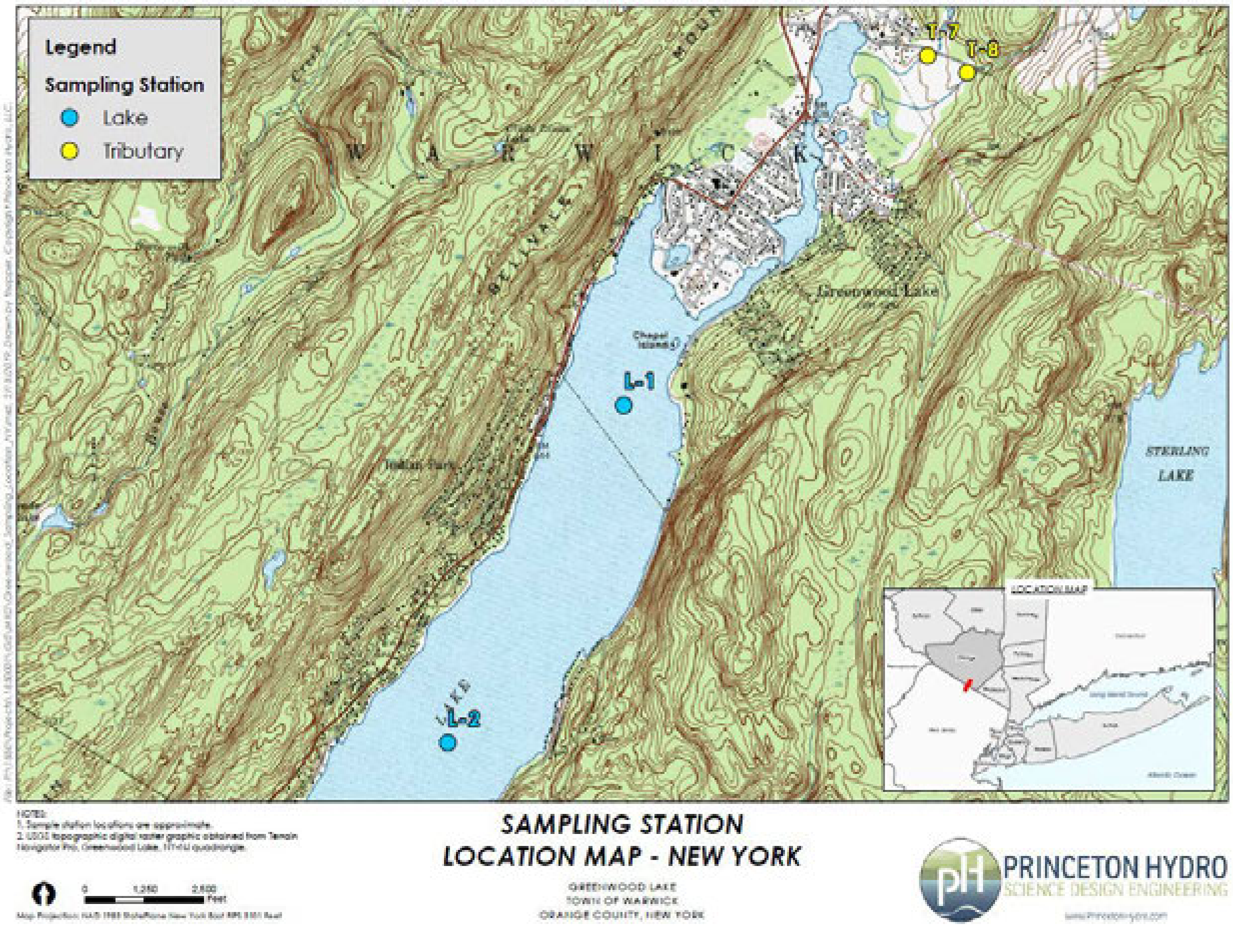
2. A TMDL was established for TP in the New Jersey end of Greenwood Lake. TP concentrations in the surface waters of Greenwood Lake varied between non-detectable concentrations and 0.05 mg/L. TP concentrations contravened the TMDL upper limits during both the May and July sampling events. Deep water concentrations consistently exceeded the TMDL target during the 2019 season. Extremely elevated TP was noted in the deep waters of L1 due to extended periods of anoxia causing internal loading of P.

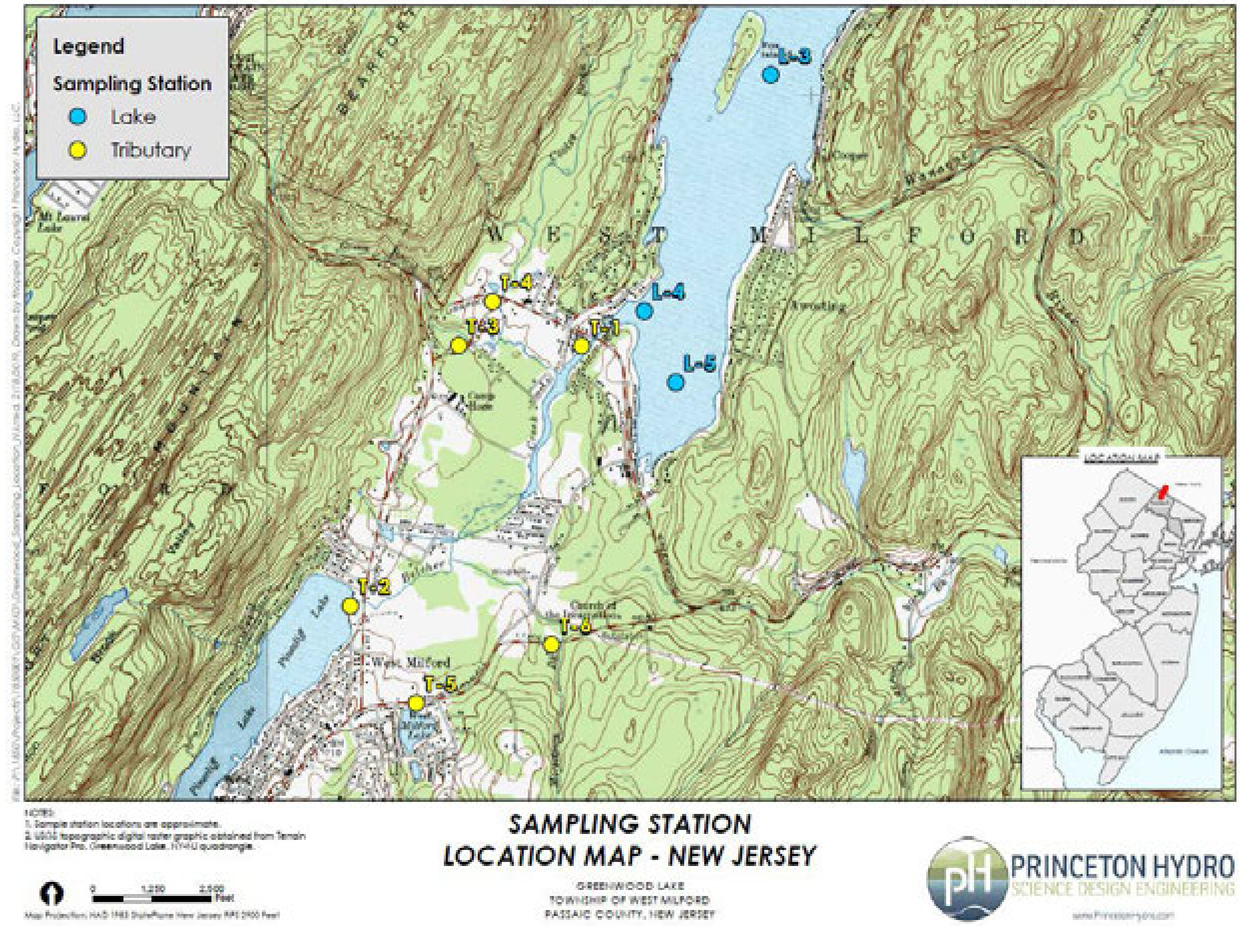
3. Elevated cyanobacteria densities were noted throughout the 2019 season at Greenwood Lake. Stations L1 and L3 both yielded algal densities above the NJDEP Health Advisory Guidance Level and were characterized as Moderate or High by WHO criteria throughout the season. During the July monitoring event, both the NJ and NY beach shoreline exceeded the NJ Health Advisory Guidance Level, characterized as High and Moderate, respectively, by WHO criteria. By the final sampling, both the NY and NJ beaches were characterized as “Moderate” by WHO standards. However, overall microcystin and cylindrospermopsin levels remained below their respective NJDEP draft recreational health advisories at each station during each sampling events.

4. Stream sampling showed elevated TP throughout the season. TP contravened TMDL standards during each sampling event. T6 yielded the most elevated TP throughout the season with maximum concentrations of 1.80 mg/L.

APPENDIX A

FIGURES


Legend
Sampling Station
Lake
Tributary
T-7
T-8
L-1
L-2
Greenwood Lake
Chapel Islands
STERLING LAKE
NOTES:
1. Sample station locations are approximate.
2. USGS topographic digital raster graphic obtained from Terrain Navigator Pro, Greenwood Lake, NY-NJ quadrangle.
0 1,250 2,500 Feet
Map Projection: NAD 1983 StatePlane New York East FIPS 3101 Feet
SAMPLING STATION
LOCATION MAP - NEW YORK
GREENWOOD LAKE
TOWN OF WARWICK
ORANGE COUNTY, NEW YORK
PRINCETON HYDRO
SCIENCE DESIGN ENGINEERING


Legend
Sampling Station
Lake
Tributary
L-3
L-4
L-5
T-1
T-2
T-3
T-4
T-5
T-6
W E S T M I L F O R D
NOTES:
1. Sample station locations are approximate.
2. USGS topographic digital raster graphic obtained from Terrain Navigator Pro. Greenwood Lake, NY-NJ quadrangle.
0 1,250 2,500 Feet
SAMPLING STATION
LOCATION MAP - NEW JERSEY
GREENWOOD LAKE
TOWNSHIP OF WEST MILFORD
PASSAIC COUNTY, NEW JERSEY
PRINCETON HYDRO
SCIENCE DESIGN ENGINEERING

APPENDIX B

IN-SITU DATA

Greenwood Lake - Insitu 5/13/19								
Station	Depth			Temp	SpC	DO	DO%	pH
	Max	Secchi	Sample					
	(m)	(m)	(m)	(°C)	(mS/cm)	(mg/L)	(%)	(units)
L1	12.8	1.5	0.1	13.53	0.272	10.37	102.1	8.20
			1	13.58	0.272	10.32	101.7	8.14
			2	13.57	0.272	10.31	101.6	8.09
			3	13.56	0.272	10.28	101.3	8.08
			4	13.54	0.271	10.28	101.2	8.06
			5	13.49	0.271	10.24	100.8	8.04
			6	13.45	0.272	10.18	100.0	7.97
			7	13.40	0.272	10.09	99.0	7.94
			8	13.37	0.272	10.02	98.3	7.87
			9	12.59	0.275	8.86	85.4	7.57
			10	11.77	0.276	8.35	79.0	7.47
			11	11.19	0.279	6.23	58.2	7.24
			12	10.82	0.280	5.38	49.8	7.14
L2	12.7	1.3	0.1	14.18	0.271	10.53	105.1	8.46
			1	14.21	0.271	10.52	105.1	8.51
			2	14.23	0.271	10.54	105.4	8.51
			3	14.22	0.271	10.55	105.5	8.50
			4	14.23	0.271	10.55	105.4	8.49
			5	14.23	0.271	10.54	105.4	8.50
			6	14.23	0.271	10.54	105.4	8.50
			7	14.12	0.272	10.55	105.2	8.37
			8	14.07	0.272	10.33	102.9	8.16
			9	11.61	0.277	7.13	67.3	7.43
			10	11.37	0.278	6.13	57.4	7.24
			11	10.95	0.280	5.49	50.9	7.13
			12	10.89	0.280	4.84	44.9	7.06
L3	2.9	1.6	0.1	13.54	0.271	10.86	106.9	9.33
			1	13.54	0.270	10.97	108.0	9.38
			2	13.58	0.271	11.04	108.8	9.38
L4	1.1	1.0	0.1	11.47	0.213	9.86	92.6	7.99
			0.5	11.50	0.213	9.56	89.8	7.80
			1	11.51	0.213	9.48	89.1	7.75
L5	1.9	1.1	0.1	14.24	0.276	10.35	103.5	9.71
			1	14.24	0.276	10.18	101.8	9.73
			1.5	14.22	0.275	10.16	101.5	9.71
T1	N/A	N/A	N/A	11.61	0.221	9.70	91.4	7.19
T2	N/A	N/A	N/A	14.46	0.272	9.50	95.4	7.42
T3	N/A	N/A	N/A	8.77	0.102	10.93	96.3	7.24
T4	N/A	N/A	N/A	8.81	0.029	10.28	90.6	7.19
T5	N/A	N/A	N/A	9.88	0.271	9.63	87.2	7.32
T6	N/A	N/A	N/A	10.18	0.184	10.60	96.6	7.50
T7	N/A	N/A	N/A	9.75	0.181	10.72	96.8	7.67
T8	N/A	N/A	N/A	9.96	0.161	10.82	98.1	7.64

Greenwood Lake - Insitu 7/11/19								
Station	Depth			Temp	SpC	DO	DO%	pH
	Max	Secchi	Sample					
	(m)	(m)	(m)	(°C)	(mS/cm)	(mg/L)	(%)	(units)
L1	12.5	1.5	0.1	27.77	0.276	9.80	124.4	8.76
			1	27.78	0.276	9.84	124.9	8.77
			2	27.72	0.275	9.82	124.6	8.76
			3	27.48	0.276	8.87	112.1	8.61
			4	24.31	0.271	2.72	32.4	7.18
			5	20.84	0.270	0.48	5.3	6.95
			6	19.80	0.270	0.29	3.1	6.87
			7	19.10	0.270	0.15	1.6	6.84
			8	17.16	0.271	0.09	0.9	6.80
			9	15.24	0.272	0.08	0.8	6.79
			10	13.14	0.277	0.08	0.8	6.76
			11	12.11	0.288	0.09	0.8	6.63
			12	11.61	0.294	0.10	0.9	6.68
L2	12.3	1.2	0.1	27.46	0.277	10.10	127.6	8.79
			1	27.44	0.277	10.16	128.3	8.81
			2	27.33	0.276	10.19	128.4	8.83
			3	27.09	0.276	9.85	123.5	8.74
			4	26.31	0.275	8.75	108.2	8.23
			5	22.16	0.271	0.89	10.1	7.21
			6	20.61	0.270	0.51	5.7	7.08
			7	18.96	0.271	0.18	1.9	6.95
			8	16.12	0.273	0.12	1.3	6.92
			9	14.12	0.276	0.09	0.9	6.86
			10	12.50	0.286	0.10	0.9	6.80
			11	12.08	0.290	0.10	0.9	6.77
			12	11.80	0.293	0.10	0.9	6.75
L3	2.7	0.9	0.1	27.80	0.278	10.55	134.1	8.77
			1	27.70	0.278	10.53	133.5	8.75
			2	26.08	0.274	6.35	78.2	7.48
L4	0.9	0.6	0.1	27.75	0.289	8.53	108.3	7.56
			0.5	27.67	0.289	8.71	110.5	7.53
L5	1.8	0.7	0.1	27.74	0.275	10.34	131.3	8.58
			1	27.61	0.276	10.52	133.2	8.61
T1	N/A	N/A	N/A	25.69	0.351	6.27	76.7	7.21
T2	N/A	N/A	N/A	28.51	0.301	7.03	90.5	8.81
T3	N/A	N/A	N/A	21.41	0.281	8.46	95.4	7.29
T4	N/A	N/A	N/A	17.75	0.101	9.16	96.0	7.25
T5	N/A	N/A	N/A	24.57	0.607	3.54	42.5	6.96
T6	N/A	N/A	N/A	21.91	0.940	7.58	86.5	7.03
T7	N/A	N/A	N/A	23.08	0.289	7.76	90.5	7.68
T8	N/A	N/A	N/A	22.31	0.237	8.80	101.0	7.73

Greenwood Lake - Insitu 9/23/19								
Station	Depth			Temp	SpC	DO	DO%	pH
	Max	Secchi	Sample					
	(m)	(m)	(m)	(°C)	(mS/cm)	(mg/L)	(%)	(units)
L1	12.5	1.5	0.1	22.12	0.279	9.63	110.4	8.23
			1	21.90	0.279	9.77	111.6	8.27
			2	21.67	0.278	9.84	111.9	8.28
			3	21.63	0.278	9.72	110.4	8.17
			4	21.30	0.278	9.06	102.3	7.89
			5	21.11	0.278	8.78	98.7	7.81
			6	20.73	0.278	8.58	95.8	7.75
			7	20.21	0.277	7.14	78.9	7.54
			8	19.80	0.278	5.09	55.8	7.32
			9	18.06	0.284	0.76	8.1	7.06
			10	15.12	0.303	0.40	4.0	7.03
			11	12.79	0.393	0.18	1.7	6.91
			12	12.12	0.312	0.14	1.3	6.85
L2	12.3	1.3	0.1	22.00	0.281	8.91	101.9	7.53
			1	21.82	0.280	9.30	106.1	7.71
			2	21.36	0.280	9.29	105	7.77
			3	21.20	0.279	9.00	101.5	7.71
			4	21.23	0.279	8.54	96.1	7.64
			5	21.10	0.279	8.38	94.2	7.60
			6	20.67	0.278	7.86	87.7	7.52
			7	20.22	0.277	6.33	69.9	7.35
			8	19.66	0.278	3.27	35.7	7.12
			9	17.29	0.303	0.95	9.9	7.07
			10	13.39	0.301	0.49	4.7	6.97
			11	12.53	0.307	0.33	3.1	6.90
			12	12.39	0.308	0.24	2.2	6.86
L3	3.1	0.9	0.1	22.25	0.284	9.17	105.5	7.28
			1	21.91	0.282	9.27	105.8	7.35
			2	20.30	0.278	6.12	67.8	7.24
			3	20.27	0.278	5.76	63.7	7.18
L4	0.9	0.7	0.1	22.94	0.291	8.86	103.2	7.34
			0.5	23.10	0.290	8.97	104.9	7.35
L5	1.8	0.8	0.1	22.64	0.290	8.70	100.7	7.64
			1	22.18	0.288	9.00	103.3	7.59
			1.5	21.76	0.288	9.20	104.8	7.52
T1	N/A	N/A	N/A	20.61	0.480	7.83	87.2	7.46
T2	N/A	N/A	N/A	23.42	0.320	8.71	102.5	8.50
T3	N/A	N/A	N/A	15.89	0.830	3.54	35.9	7.21
T4	N/A	N/A	N/A	19.63	0.179	8.07	88.1	7.65
T5	N/A	N/A	N/A	21.94	1.083	8.25	94.5	7.86
T6	N/A	N/A	N/A	20.52	1.849	5.07	56.6	7.45
T7	N/A	N/A	N/A	17.28	0.287	8.24	85.8	7.68
T8	N/A	N/A	N/A	19.41	0.322	8.57	93.1	7.60

APPENDIX C

DISCRETE DATA

Discrete Data 5/13/2019							
Station	**Chlorophyll a**	**NH3-N**	**NO3-N**	**SRP**	**TDP**	**TP**	**TSS**
	(ug/L)	**(mg/L)**	**(mg/L)**	**(mg/L)**	**(mg/L)**	**(mg/L)**	**(mg/L)**
L-1 Surface	23.0	ND<0.01	0.02	0.005	0.03	0.04	ND<2
L-1 Mid	16.0	ND<0.01	0.04	ND<0.002	0.02	0.04	ND<2
L-1 Deep	-	0.03	0.08	0.002	ND<0.01	0.04	ND<2
L-3 Surface	7.2	ND<0.01	ND<0.02	ND<0.002	0.01	0.02	ND<2
L-3 Mid	8.7	ND<0.01	0.02	ND<0.002	0.01	0.04	ND<2
L-3 Deep	-	ND<0.01	0.03	ND<0.002	0.02	0.04	2
L-4	2.9	ND<0.01	0.15	0.006	0.01	0.04	8
L-5	6.6	0.01	0.10	0.003	ND<0.01	0.04	ND<2
T-1	-	-	-	-	-	0.06	-
T-2	-	-	-	-	-	0.10	-
T-3	-	-	-	-	-	0.05	-
T-4	-	-	-	-	-	0.04	-
T-5	-	-	-	-	-	0.10	-
T-6	-	-	-	-	-	0.09	-
T-7	-	-	-	-	-	0.06	-
T-8	-	-	-	-	-	0.02	-
Duplicate	-	-	-	-	-	0.02	-
Blank	-	-	-	-	-	ND<0.01	-

Discrete Data 7/11/2019							
Station	**Chlorophyll a**	**NH3-N**	**NO3-N**	**SRP**	**TDP**	**TP**	**TSS**
	(ug/L)	**(mg/L)**	**(mg/L)**	**(mg/L)**	**(mg/L)**	**(mg/L)**	**(mg/L)**
L-1 Surface	16.0	0.01	0.06	ND<0.002	ND<0.01	ND<0.01	4
L-1 Mid	18.0	0.01	0.13	ND<0.002	0.02	0.02	4
L-1 Deep	-	0.04	0.18	0.004	0.01	0.03	4
L-3 Surface	35.0	ND<0.01	0.09	ND<0.002	ND<0.01	0.01	5
L-3 Mid	36.0	0.01	0.09	ND<0.002	0.06	0.06	5
L-3 Deep	-	0.01	0.10	ND<0.002	ND<0.01	0.06	6
L-4	37.0	0.04	0.05	ND<0.002	ND<0.01	0.04	11
L-5	50.0	ND<0.01	0.09	0.003	ND<0.01	0.05	7
T-1	-	-	-	-	-	0.01	-
T-2	-	-	-	-	-	ND<0.01	-
T-3	-	-	-	-	-	ND<0.01	-
T-4	-	-	-	-	-	0.04	-
T-5	-	-	-	-	-	0.30	-
T-6	-	-	-	-	-	1.80	-
T-7	-	-	-	-	-	0.01	-
T-8	-	-	-	-	-	0.01	-
Duplicate	-	-	-	-	-	0.03	-
Blank	-	-	-	-	-	ND<0.01	-

Discrete Data 9/23/2019							
Station	Chlorophyll a	NH3-N	NO3-N	SRP	TDP	TP	TSS
	(ug/L)	(mg/L)	(mg/L)	(mg/L)	(mg/L)	(mg/L)	(mg/L)
L-1 Surface	22.0	0.01	ND <0.01	0.003	0.01	0.01	2
L-1 Mid	23.0	0.01	ND <0.01	0.002	0.01	0.02	2
L-1 Deep	-	0.22	0.06	0.210	0.22	0.30	2
L-3 Surface	23.0	0.03	0.04	0.015	0.02	0.03	5
L-3 Mid	25.0	0.02	0.07	0.004	0.01	0.02	3
L-3 Deep	-	0.02	0.09	0.002	ND <0.01	0.03	5
L-4	28.0	0.01	ND <0.01	0.003	0.01	0.03	6
L-5	28.0	0.01	0.03	0.003	0.01	0.02	7
T-1	-	-	-	-	-	0.04	-
T-2	-	-	-	-	-	0.09	-
T-3	-	-	-	-	-	0.01	-
T-4	-	-	-	-	-	0.04	-
T-5	-	-	-	-	-	0.06	-
T-6	-	-	-	-	-	0.89	-
T-7	-	-	-	-	-	0.06	-
T-8	-	-	-	-	-	0.05	-
Duplicate	-	-	-	-	-	0.04	-
Blank	-	-	-	-	-	ND <0.01	-

APPENDIX D

PLANKTON DATA

Phytoplankton and Zooplankton Community Composition Analysis																		
Sampling Location:Greenwood Lake							Sampling Date: 5/13/19							Examination Date: 7/23/19				
Site 1: L-1 Tow				Site 2: L-1 Surface			Site 3: L-1 Mid				Site 4: L-3 Tow			Site 5: L-3 Surface				Site 6: L-3 Mid
Phytoplankton																		
Bacillariphyta	1	2	3	4	5	6	**Chlorophyta**	1	2	3	4	5	6	**Cyanophyta**	1	2	3	4	5	6
Synedra	R	198	125	R		299	*Chlamydomonas*				R	635	299	*Aphanocapsa*						299
Melosira	C	1,387	876	P			*Pediastrum*	P						*Aphanizomenon*	B	79,962	102,506	A	45,296	31,222
Cyclotella	R			R			*Chlorella*	R	66	63				*Microcystis*				R		
Asterionella	C	330	375	C			*Closterium*				R			*Coelosphaerium*	P			P		
Fragilaria	P			C			*Staurastrum*	R			R									
Tabellaria	P			P			*Scenedesmus*	P	528	501		254	299							
Stephanodiscus	R						*Pleodorina*				R									
							Eudorina	R		250				**Euglenophyta (Euglenoids)**						
							Ankistrodesmus			63		191	75							
Chrysophyta																				
Uroglena				R										**Pyrrhophyta (Dinoflagellates)**						
Mallomonas	R			R										*Ceratium*						
														Gymnodium	R					
														Cryptomonads						
														Cryptomonas	R	726	250	P	93	449
Zooplankton																				
Cladocera (Water Fleas)	1	2	3	4	5	6	**Copecoda (Copepods)**	1	2	3	4	5	6	**Rotifera (Rotifers)**	1	2	3	4	5	6
Bosmina	P			P			Nauplii	C			P			*Polyarthra*	A			C		
Chydorus	P			P			*Microcyclops*	C			P			*Keratella*	C			C		
														Brachionus	R					
														Kellicottia	P					
														Ascomorpha	P					
														Conochilus	R					
														Tricocerca				R		
														Euchlanis				P		
														Asplanchna	P					
Sites:	1	2	3	4	5	6	**Comments:**													
Total Phytoplankton Genera / Cells per mL	17	83,197	105,009	16	46,469	32,942														
Total Cyanobacteria cell/mL	2	79,962	102,506	3	45,296	31,521														
Total Zooplankton Genera	11			8																
Sample Volume (mL)							**Phytoplankton Key: Bloom (B), Common (C), Present (P), and Rare (R)**													
							Zooplankton Key: Dominant (D), Abundant (A), Present (P), and Rare (R); Herbivorous (H) or Carnivorous (C)													

Phytoplankton and Zooplankton Community Composition Analysis																				
Sampling Location: Greenwood Lake							Sampling Date: 7/11/19							Examination Date: 7/23/19						
Site 1: L-1 Surface				Site 2: L-1 Mid			Site 3: L-3 Surface				Site 4: L-3 Mid			Site 5: NJ Shoreline				Site 6: NY shoreline/Beach		
Phytoplankton																				
Bacillariphyta	1	2	3	4	5	6	**Chlorophyta**	1	2	3	4	5	6	**Cyanophyta**	1	2	3	4	5	6
Synedra	237	162	533		1,144	640	*Crucigenia*				477	381	171	*Dolichospermum*	2485	7,795	52,755	47,178	48,409	20,296
Cyclotella	59				95		*Pediastrum*					1,525	171	*Aphanizomenon*	50,475	49,437	145,626	153,398	182,962	35,561
Melosira			710		953	725	*Chlorella*	355	808	355	477	667	1,833	*Pseudanabaena*		2,706		5,318		13,261
Stephanodiscus					95		*Scenedesmus*		242		409	1,334	682	*Coelosphaerium*	237	8,926	118	2,250	381	853
Fragilaria	414	202				128	*Staurastrum*				273	286								
Navicula						85	*Schroederia*			59										
Cymbella						43	*Oocystis*	237				191								
							Haematococcus	59						**Euglenophyta (Euglenoids)**						
							ankistrodesmus	59			68	191		*Trachelomonas*					191	
							Actinastrum				750	762								
Chrysophyta							*Eudorina*					1,525		**Pyrrhophyta (Dinoflagellates)**						
Dinobryon							*Terastrum*					381		*Ceratium*			118			
							Sphaerocystis				750									
							Atractomorpha				68			**Cryptomonads**						
														Cryptomonas	59	162	118	68	191	85
Zooplankton																				
Cladocera (Water Fleas)	1	2	3	4	5	6	**Copecoda (Copepods)**	1	2	3	4	5	6	**Rotifera (Rotifers)**	1	2	3	4	5	6
Bosmina	48	21	19	8			Nauplii	209	161	231	184			*Polyarthra*	409	504	157	92		
Chydorus	10			12			*Microcyclops*	57	91	46	58			*Keratella*	276	210	120	54		
Ceriodaphnia			9				*Diaptomus*		7					*Brachionus*				4		
														Tricocerca	19	49	46	35		
														Conochilus		7	463	314		
														Asplanchna	10					
Sites:	1	2	3	4	5	6	**Comments:**													
Total Phytoplankton Cells per mL	54,203	70,238	200,392	209,916	238,901	74,278														
Total Cyanobacteria cell/mL	53,197	68,864	198,499	208,144	231,752	69,971														
Total Zooplankton Number per mL	1038	1050	1091	761																
Sample Volume (mL)							**Phytoplankton Key: Bloom (B), Common (C), Present (P), and Rare (R)**													
							Zooplankton Key: Dominant (D), Abundant (A), Present (P), and Rare (R); Herbivorous (H) or Carnivorous (C)													

Phytoplankton and Zooplankton Community Composition Analysis																				
Sampling Location: Greenwood Lake							Sampling Date: 9/23/19							Examination Date: 10/22/19						
Site 1: L-1 Surface				Site 2: L-1 Mid			Site 3: L-3 Surface			Site 4: L-3 Mid				Site 5: NJ Shoreline			Site 6: NY shoreline/Beach			
Phytoplankton																				
Bacillariphyta	**1**	**2**	**3**	**4**	**5**	**6**	**Chlorophyta**	**1**	**2**	**3**	**4**	**5**	**6**	**Cyanophyta**	**1**	**2**	**3**	**4**	**5**	**6**
Synedra	448	581	287	145	206	257	*Crucigenia*			459		247		*Dolichospermum*	7291	2,806	14,300		9,815	15,077
Cyclotella		48					*Pediastrum*		145	459	774	1,196	206	*Aphanizomenon*	18,740	38,462	51,401	47,750	43,468	74,871
Melosira		1,161	4,307	6,434	1,526	103	*Chlorella*	1535	726	747	581	1,980	772	*Pseudanabaena*	3902	12,724	22,455	11,514	19,383	3,962
Stephanodiscus	64						*Scenedesmus*	384		1,493	629	1,815		*Coelosphaerium*	128	97	287	97	165	206
Cymbella		48			41		*Staurastrum*			57	145	206	51	*Raphidiopsis*	128	194			41	206
Tabellaria			172				*Oocystis*			345	194		515	*Aphanocapsa*				2,903		
Navicula			172	48	124	257	*Eudorina*			689				*Microcystis*					1,526	
Fragilaria					536		*Haematococcus*		48	115		41	51	**Euglenophyta (Euglenoids)**						
Asterionella						103	*ankistrodesmus*	64			97	124		*Phacus*			57			
							Gloeocystis	8954	194			5568	3602	*Trachelomonas*					412	51
Chrysophyta							*Gloeotila*	959	1451		532			**Pyrrhophyta (Dinoflagellates)**						
Dinobryon		48	57	145	124		*Atractomorpha*	64	48					*Ceratium*		48				
							Sphaerocystis	320	290	747		907								
							Terastrum			230				**Cryptomonads**						
							Golenkinia			57				*Cryptomonas*	512	145	172	290	165	51
							Lagerheimia					41								
							Cosmarium					82								
							Dictyosphaerium						617							
							Coelastrum					454								
Zooplankton																				
Cladocera (Water Fleas)	**1**	**2**	**3**	**4**	**5**	**6**	**Copecoda (Copepods)**	**1**	**2**	**3**	**4**	**5**	**6**	**Rotifera (Rotifers)**	**1**	**2**	**3**	**4**	**5**	**6**
Bosmina	8	10	99	315			Nauplii	8	95	110	126			*Polyarthra*	15	86	572	399		
Chydorus							*Microcyclops*	30	48	55	116			*Keratella*	188	257	352	725		
Ceriodaphnia	15	10												*Brachionus*	8		77	126		
														Tricocerca	8	29	33	32		
														Conochilus	30	10	66	200		
														Ploesoma			11			
														Gastropus				11		
														Asplanchna			33	32		
Sites:	**1**	**2**	**3**	**4**	**5**	**6**	**Comments:**													
Total Phytoplankton Cells per mL	33,068	57,185	97,630	71,456	82,192	96,379														
Total Cyanobacteria cell/mL	30,189	54,283	88,443	62,264	74,398	94,322														
Total Zooplankton Number per mL	310	545	1408	2082																
Sample Volume (mL)							**Phytoplankton Key: Bloom (B), Common (C), Present (P), and Rare (R)**													
							Zooplankton Key: Dominant (D), Abundant (A), Present (P), and Rare (R); Herbivorous (H) or Carnivorous (C)													

APPENDIX V:

BEST MANAGEMENT PRACTICES FACT SHEETS

BEST MANAGEMENT PRACTICES FACT SHEETS

WEST MILFORD TOWNSHIP, NEW JERSEY

JANUARY 2020

PREPARED FOR:

GREENWOOD LAKE COMMISSION
ATTN: PAUL ZARILLO
2019F GREENWOOD LAKE TURNPIKE
HEWITT, NJ 07421

PREPARED BY:

PRINCETON HYDRO, LLC
1108 OLD YORK ROAD, SUITE 1
P.O. BOX 720
RINGOES, NJ 08551
908-235-5660

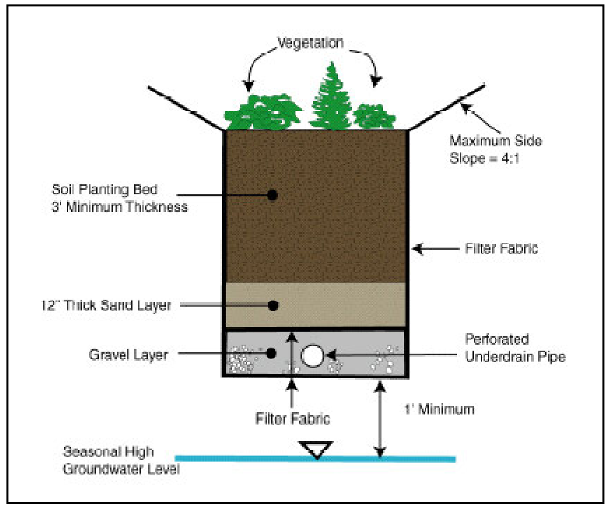
TABLE OF CONTENTS

BIORETENTION SYSTEMS

Bioretention systems mimic the functions of a natural forest ecosystem, treating stormwater runoff by filtering it through vegetation and soil and then infiltrating it into the surrounding soil. The systems have three main components:

1) a soil bed planted with native vegetation
2) a sand layer
3) an underground gravel layer (with or without perforated drainage pipes)

After stormwater has filtered through the vegetation, soil and sand, it is infiltrated into through the surrounding soil into the groundwater. A portion may also be conveyed through pipes to a storm sewer system or waterbody.



Source: NJDEP 2004.

Advantages:

- Flexibility: can be designed in a variety of sizes and installed in lawns, median strips, parking lot islands, unused lot areas and certain easements.
- Can provide groundwater recharge and reduce volume of water discharging into receiving streams.
- Can remove a variety of pollutants including solids, nutrients, metals, hydrocarbons and bacteria.
- Can reduce peak runoff rates and increase stormwater infiltration.
- Native vegetation used in these systems can remove some nutrients and other stormwater pollutants, improve the aesthetic value of the site, and provide wildlife habitat and shade. Environment around root systems can also break down some pollutants.

Disadvantages:

- Vulnerable to clogging and failure due to excessive sediment loads; may require frequent maintenance to restore infiltrative capacity.
- Should only be used on smaller sites (max. 5 acres) because of tendency to clog when used for larger drainage areas (EPA 2002).

Estimated Costs:

See Table A

Maintenance Requirements:

- At project completion: water plants daily for 2 weeks, apply mulch
- As needed: replace mulch (spring), treat diseased trees and shrubs, mow turf areas
- Monthly: inspect soil and repair eroded areas, remove litter and debris.
- Twice/year: remove and replace dead and diseased vegetation
- Once/year: add mulch, replace tree stakes and wires, remove sediment, test soil for toxins and heavy metals, inspect after a storm event to ensure that filter is draining within normal time (max. 72 hours; if infiltration rate has dropped to an unacceptable level, the system may need to be removed and reconstructed)

Ascribed Pollutant Removal Efficiencies:

TSS reduction in postconstruction runoff: 90%
Total phosphorus removal rate: 60%
Total nitrogen removal rate: 30%

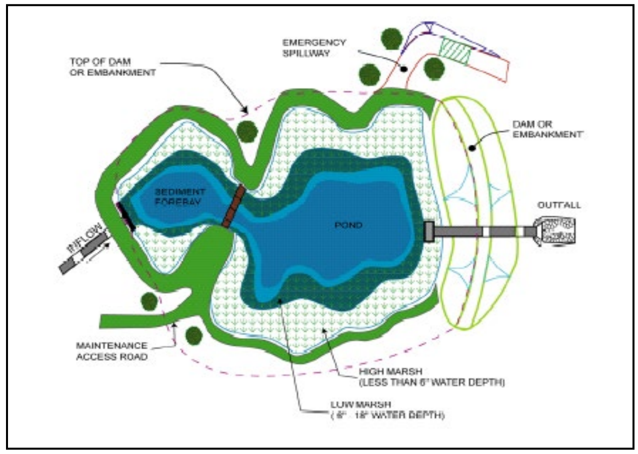
CONSTRUCTED WETLANDS

Constructed stormwater wetlands are designed to temporarily store stormwater runoff in shallow, vegetated pools. Similar to bioretention systems, they mimic natural systems by using wetland plants to filter runoff, remove pollutants and provide erosion and flood control. They usually have three zones:

1) **Pool** (pond, micropond or forebay): 2 to 6 ft deep, supports submerged and floating vegetation, provides most particulate settling
2) **Marsh** (high or low, depending on standing water depth): 6 to 18 in. deep, mainly emergent wetland vegetation
3) **Semi-wet**: located above pool and marsh zones, inundated only during storm events, supports both wetland and upland plants

Depending on the presence/relative storage volume of each of these zones, constructed wetlands are categorized as either **pond** (relatively deep pool with smaller marsh zone outside it), **marsh** (marsh area > pool zone) or **extended detention wetland** (pool and marsh zones within an extended detention basin).

A constructed wetland must be able to maintain a permanent pool level and is especially suitable for areas where groundwater is close to the surface. If the soil is not sufficiently impermeable, an impermeable liner must be used or other soil modifications must be completed.



Source: NJDEP 2004

Advantages:

- Can remove sediment and pollutants adhering to sediment particles (e.g., phosphorus, metals and hydrocarbons)
- Wetland plants and ponds can improve the aesthetic value of a site and provide wildlife habitat.
- Water is generally flushed through the wetlands within a week, reducing opportunities for mosquito breeding.

Disadvantages:

- Limited to areas where sufficient water is available to sustain aquatic vegetation between rainfall/runoff events.
- Long-term effectiveness is not well known; pollutant removal rates may decrease over time.
- Without pretreatment (e.g., forebay), wetlands will tend to accumulate sediment rapidly.
- Occupies more land than many other stormwater BMPs (minimum drainage area = 10 to 25 acres).
- If designed too small, tends to dry out frequently and may require re-planting.
- If improperly designed, may encourage mosquito breeding.
- May release nutrients during nongrowing season.

Estimated Costs:

See Table A

Maintenance Requirements:

- One-time: replace wetland vegetation to maintain at least 50% surface area coverage after second growing season
- As needed: repair eroded areas; remove sediment when 6 in. accumulates (usually 5 to 10 years); mow side slopes
- Three to four times/year: clean and remove debris from inlet and outlet structures
- Twice/year: inspect and remove accumulated debris
- Once/year: inspect for invasive vegetation and remove where possible; supplement wetland plants if at least 50% of surface area has not established; remove wetland plants "choked out" by sediment build-up. Inspect after a rainfall event for clogging of outlet, water releasing too rapidly, erosion at inlet, outlet and on banks, sediment accumulation, and condition of vegetation and emergency spillway

Ascribed Pollutant Removal Efficiencies:

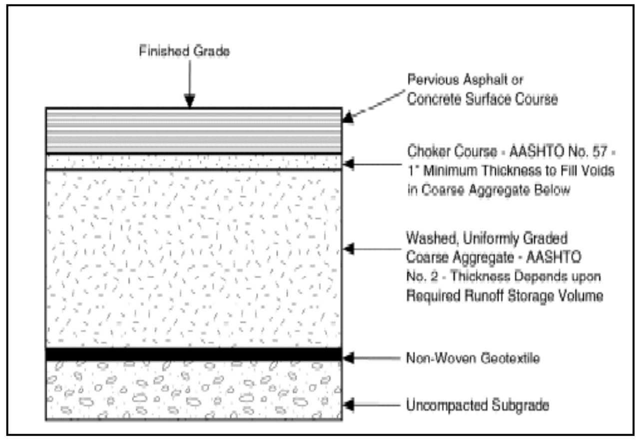
(NJDEP 2004)

TSS reduction in postconstruction runoff: 90%
Total phosphorus removal rate: 50%
Total nitrogen removal rate: 30%

PERVIOUS PAVING SYSTEMS

Pervious paving systems are paved areas that infiltrate rain or runoff either through a permeable layer of pavement or through the spaces between individual pavers, reducing runoff from a site and filtering some pollutants. They are divided into three types:

1) **Porous paving**: porous asphalt or concrete paving constructed over a runoff storage bed of uniformly graded broken stone
2) **Permeable pavers with storage bed**: impervious concrete pavers with spaces over a runoff storage bed of broken stone
3) **Permeable pavers without storage bed**: impervious concrete pavers with spaces over a structural bed of sand and crushed stone



Source: Cahill Associates in NJDEP 2004

Pervious paving can be substituted for conventional pavement in parking lots and areas with light traffic, provided that the slopes are very gentle and the soils have field-verified permeability rates of at least 0.5 in./hour. Paved areas should be clearly marked and frequent use by equipment, excess traffic volume and resurfacing with non-porous pavement should be prohibited.

Advantages:

- Flexibility: can be used in intensely developed residential and commercial areas and on small urban sites.
- Useful for driveways, streets and commercial parking areas.
- Can reduce stormwater volume and remove some pollutants for other BMPs in a "treatment train."

Disadvantages:

- Lifespan may be short because of high risk of clogging.
- Not appropriate for areas where high pollutant or sediment loading is anticipated, due to the potential for groundwater contamination and clogging.
- More expensive than traditional asphalt.
- Can only be used in areas without high volumes of traffic or heavy equipment.
- Use of de-icing chemicals and sand must be limited in pervious pavement areas.

Estimated Costs:

See Table A

Maintenance Requirements:

Monthly: Ensure that paving area is clean of debris, that it drains between storms and that area is clean of sediments

Three to four times/year: Mow upland and adjacent areas; seed bare areas; vacuum or jet-wash to remove sediment from pores

Once/year: Inspect surface for deterioration; repair if necessary

Ascribed Pollutant Removal Efficiencies:

(NJDEP 2004)

TSS reduction in postconstruction runoff:

- Porous paving - 80%
- Permeable pavers with storage bed - 80%
- Permeable pavers without storage bed - no TSS removal credit

Total phosphorus removal rate: 60%

Total nitrogen removal rate: 50%

VEGETATIVE FILTERS

Vegetative filters are designed to remove suspended solids and other pollutants from stormwater runoff flowing through them. They may be composed of planted and/or naturally occurring grasses and herbaceous and woody vegetation. NJDEP recommends using plants with dense growth patterns (e.g., turf-forming grasses and dense forest floor vegetation). The required length of the vegetative filter is based in part upon the type of soils within its drainage area.

In order to maintain pollutant removal, all runoff to a vegetated filter must both enter and flow through as sheet flow (e.g., from yards, parking lots and driveways).

Advantages:

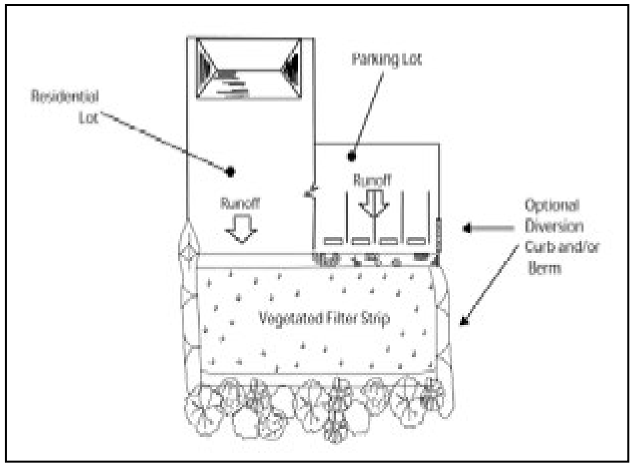
- Effective in reducing sediment and other solids and particulates, as well as associated pollutants such as hydrocarbons, heavy metals, and nutrients.
- Very useful for parking and driveway areas on residential and commercial sites.
- Can provide wildlife habitat.
- Can create shade along waterbodies, lowering aquatic temperatures.

Disadvantages:

- Occupies more land than many other stormwater BMPs.
- Can only treat sheet flow.
- Only effective on gentle slopes (<2%) and/or areas that slow down, pond and/or disperse runoff over the entire filter width.
- Not intended to treat concentrated discharges from storm sewers, swales, and channels.
- Only useful for small areas (<1 acre); maximum drainage area is 100 feet long for impervious surfaces and 150 feet long for pervious surfaces.
- Vegetation must be fully established (min. one full growing season) before filter is functional

Estimated Costs:

See Table B



Source: Adapted from Claytor and Schueler 1996 in

Maintenance Requirements:

<u>At project completion</u>: Repair or replace any damage to the sod, vegetation, or evenness of grade as need

<u>As needed</u>: Mow grass (maintain 3 to 4 in. height); remove sediment when accumulated to 25% of original capacity

<u>After every rainfall >1 inch</u>: Ensure that filter is draining within normal time (max. 72 hours; if infiltration rate has dropped to an unacceptable level, the filter may need to be tilled and replanted)

<u>Four times/year (twice during both growing and nongrowing season)</u>: Remove debris; inspect vegetation health, density and diversity and replant if necessary (maintain vegetative cover at 85%)

<u>Once/year</u>: Inspect vegetation for rills and gullies and repair if necessary; seed or sod bare areas.

Ascribed Pollutant Removal Efficiencies:

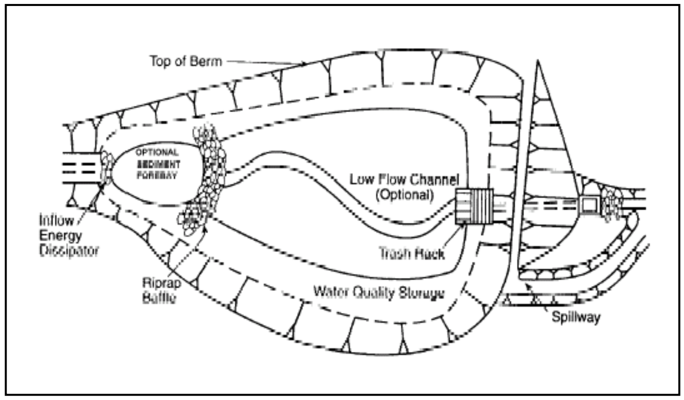
(NJDEP 2004)

TSS reduction in postconstruction runoff:
- turf grass – 60%
- native grasses, meadow, planted woods – 70%
- indigenous woods – 80%

Total phosphorus removal rate: 30%

Total nitrogen removal rate: 30%

EXTENDED DETENTION BASINS



Source: Adapted from Pennsylvania Handbook of BMPs for Developing Areas in NJDEP 2004.

Extended detention basins provide temporary storage of stormwater runoff, detaining it for a prescribed period of time (typically 24 hours) and then releasing it slowly through an appropriately-sized outlet to a downstream system. They address stormwater quantity by slowing runoff and infiltrating some of it, and improve stormwater quality by allowing sediment particles and associated pollutants to settle out into the basin. (The longer the detention time, the greater the pollutant removal efficiency.) They are effective on sites of 10 acres or more.

Extended detention basins are typically designed as multi-stage facilities ranging from 3 to 12 feet deep. (They may also be located entirely below ground, where runoff is stored in a vault, perforated pipe and/or stone bed.) Although these basins should normally remain dry between storm events, they can be designed with small permanent "micropools" that function as wetlands or retention basins at the inlet and outlet. To increase their pollutant removal capacity, NJDEP recommends that they incorporate pretreatment systems to help remove sediment and pollutants (e.g., vegetative filters, forebays or manufactured treatment devices).

Advantages:

- Flexibility: can be used at residential, commercial, and industrial development sites; can be used with almost all soils and geology; can be used on sites with slopes up to about 15%.
- Considered by EPA to be one of the least expensive stormwater BMPs (cost per unit area treated).
- Can accept runoff from "hot spots" (areas that generate highly contaminated runoff) provided there is adequate separation from seasonal high water table (min. 1 foot).
- **Useful retrofit:** existing basins can be modified to function as extended detention; new extended detention basins can be constructed to capture runoff from existing development.

Disadvantages:

- Limited effectiveness in removing both particulate and soluble pollutants.
- Occupies a relatively large amount of land, so has limited applicability in highly urbanized settings.
- May encourage mosquito breeding.

Estimated Costs:

See Table A

Maintenance Requirements:

Every 2 weeks during first growing season: Ensure vegetation becomes established; address problems without fertilizers and pesticides whenever possible
Once/month during growing season: Repair eroded areas; mow side slopes; remove litter and debris
After every storm <1 in.: Ensure basin is draining within normal time (if infiltration rate has dropped to an unacceptable level, the basin may need to be removed and reconstructed)
Four times/year: Inspect for clogging
Twice/year: Check for erosion of side slopes or bottom; inspect vegetation health, density and diversity
Once/year: check for damage to embankment; ensure that inlet and outlet are free of debris and operational; seed or sod to restore dead or damaged ground cover if needed; remove unwanted vegetation
Every 5 to 7 years: Remove sediment from forebay
Every 25 to 50 years: Monitor sediment accumulation and remove when basin volume is reduced by 25%

Ascribed Pollutant Removal Efficiencies:

(NJDEP 2004)

TSS reduction in postconstruction runoff: 40%
Total phosphorus removal rate: 20%
Total nitrogen removal rate: 20%

INFILTRATION STRUCTURES

Infiltration structures are basins or trenches constructed within highly permeable soils (min. rate of 0.5 in/hour) that provide temporary storage of stormwater runoff. Normally, outflow from these structures infiltrates through the surrounding soil into the groundwater, rather than being conveyed through a structural outlet to a downstream waterbody or storm sewer system. When designed and maintained properly, infiltration basins can recharge the groundwater and remove pollutants as runoff is filtered through the soil.

Infiltration basins should be designed to drain within 72 hours after a storm to function properly and avoid mosquito problems. To maintain proper drainage and filtration, the bottom of the basin should be at least 2 feet above the seasonal high water table and covered by a 6-inch sand layer that can be removed and replaced during regular cleanouts.

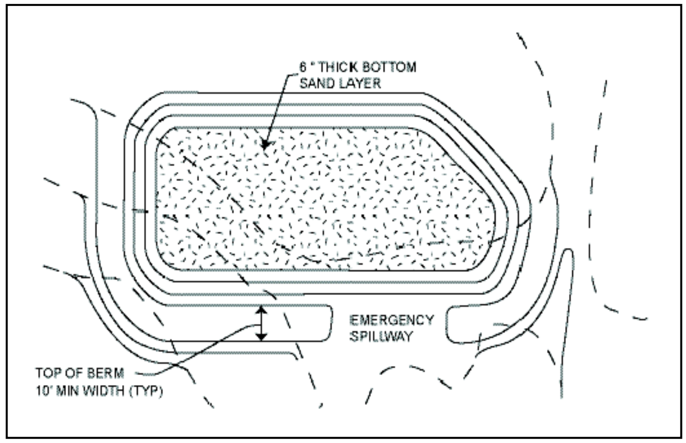
Subsurface infiltration basins are located below ground and generally include a vault, perforated pipe and/or stone bed. However, because they are difficult to access and clean out, they require pretreatment of runoff to remove 80% of total suspended solids. Alternately, they may be used solely for groundwater recharge as long as excess runoff is diverted around the basin.

Advantages:

- May be used to meet NJDEP groundwater recharge requirements.
- Cost-effective; typically consumes only about 2 to 3% of the drainage area.
- Relatively high pollutant removal rate as compared to other BMPs.

Disadvantages:

- Limited to soils in hydrologic groups A and B with the required permeability rates.
- Useful only for small drainage areas (max. 10 acres).
- Not appropriate where there is risk of basement flooding, surface flooding of groundwater, or interference with subsurface sewage disposal systems and other subsurface structures.
- Should not receive runoff from “hot spots,” (areas that generate highly contaminated runoff) or areas with high sediment loading unless already treated by another BMP.
- EPA notes that some studies have shown relatively high failure rates compared with other BMPs (EPA 2002); may need to be replaced after 2 to 10 years.



Source: Adapted from T&M Associates in NJDEP 2004.

Estimated Costs:

See Table A

Maintenance Requirements:

As needed: mow side slopes and remove litter and debris; stabilize eroded banks; inspect for erosion at inflow structure(s) and repair (if needed).
After every storm <1 in: Ensure that basin drains completely within 72 hours after storm
Four times/year and.: Inspect for clogging and excessive debris and sediment accumulation; remove sediment (if needed) when completely dry
Two times/year: Inspect for signs of wetness or damage to structures; repair eroded areas; check for signs of petroleum contamination and remediate (if needed)
Once/year: Disc or otherwise aerate bottom; remove bottom vegetation.
Once/five years: Remove and replace sand layer and accumulated sediment; restore original infiltration rate; seed or sod to restore ground cover.

Ascribed Pollutant Removal Efficiencies:

(NJDEP 2004)
TSS reduction in postconstruction runoff: 80%
Total phosphorus removal rate: 60%
Total nitrogen removal rate: 50%

SAND FILTERS - SURFACE

Sand filters can be used to remove relatively large amounts of sediments, metals, hydrocarbons and floatables from stormwater runoff, but they do not provide groundwater recharge. Although they can be constructed above or below ground, surface filters are the least expensive and most widely used design. In general, they consist of four zones:

1) Forebay
2) Sand bed
3) Sand bed underdrain
4) Overflow

Stormwater runoff enters the filter through the forebay, which removes debris and coarse sediment, and then flows through the sand bed, which removes pollutants through settling and filtration. Stormwater leaves the sand filter through an underdrain (a perforated pipe system in a gravel bed) installed on the bottom, and is conveyed either to another BMP in a "treatment train" or to a storm sewer system. Although they are unlikely to contaminate groundwater supplies, sand filters require at least 2 feet of separation between the bottom of the filter and the seasonal high water table.

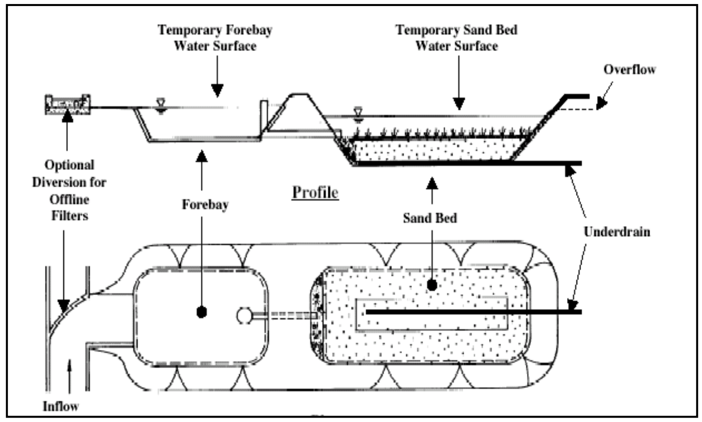
The sand used must meet specifications for clean medium aggregate concrete sand in accordance with AASHTO M-6 or ASTM C-33, certified by a professional engineer licensed in New Jersey (NJDEP 2004).

Advantages:

- Can accept runoff from "hot spots" (areas that generate highly contaminated runoff) because stormwater treated by sand filters has little or no interaction with groundwater.
- Can be used on sites with slopes up to about 6%.
- Can be used on almost any soil.
- Can be used as pretreatment for infiltration BMPs.

Disadvantages:

- Not recommended for pervious drainage areas where high coarse sediment loads and organic material (e.g., leaves) can clog the sand bed.
- Require frequent maintenance.
- Usually not aesthetically pleasing.
- Require relatively complicated design procedure to achieve pollutant removal.
- Useful only for small drainage areas (max. 10 acres); risk of clogging when used on larger drainage areas without larger sedimentation chamber or more intensive regular maintenance.



Source: Adapted from Claytor and Schueler 1996 in NJDEP 2004.

- Except on small sites or urban areas, may be more expensive as retrofits than BMPs which treat larger drainage areas (e.g., basins or wet ponds).

Estimated Costs:

See Table A

Maintenance Requirements:

At project completion: Inspect vegetation health at least biweekly until established
Once/month: Mow and/or trim grass and other vegetation (during the growing season); clean debris out of sand filter, inlets and outlets; ensure that filter surface is not clogging; ensure that oil, grease and sediment inputs are minimized
Four times/year (twice during both growing and nongrowing season): Inspect vegetation health, density and diversity and replant if over 50% damaged
Four times/year and after every storm <1 in.: Inspect for clogging and debris and sediment accumulation; remove sediment (if needed) when completely dry
Two times/year: Ensure that water infiltrates the sand bed within 72 hours and remediate if necessary
Once/year: Inspect vegetated areas, inlets, outlets and overflow spillway for erosion; ensure that flow is not bypassing filter; inspect bottom for underbrush and tree growth; ensure that odors are not detected outside filter; inspect structural parts for subsidence and deterioration; remediate if necessary

Ascribed Pollutant Removal Efficiencies:

(NJDEP 2004)
TSS reduction in postconstruction runoff: 80%
Total phosphorus removal rate: 50%
Total nitrogen removal rate: 35%

SAND FILTERS - SUBSURFACE

Sand filters can be used to remove relatively large amounts of sediments, metals, hydrocarbons and floatables from stormwater runoff, but they do not provide groundwater recharge or control flooding. Subsurface sand filters tend to have higher construction costs than the aboveground types, but consume very little surface space and are especially useful for urban areas and small sites.

The components of subsurface filters are similar to those of other sand filters, but are located underground. Stormwater runoff enters the filter through the forebay, which removes debris and coarse sediment, and then flows through the sand bed, which removes pollutants through settling and filtration. Stormwater leaves the sand filter through an underdrain (a perforated pipe system in a gravel bed) installed on the bottom and is conveyed either to another BMP in a "treatment train" or to a storm sewer system. Although they are unlikely to contaminate groundwater supplies, sand filters require at least 2 feet of separation between the bottom of the filter and the seasonal high water table.

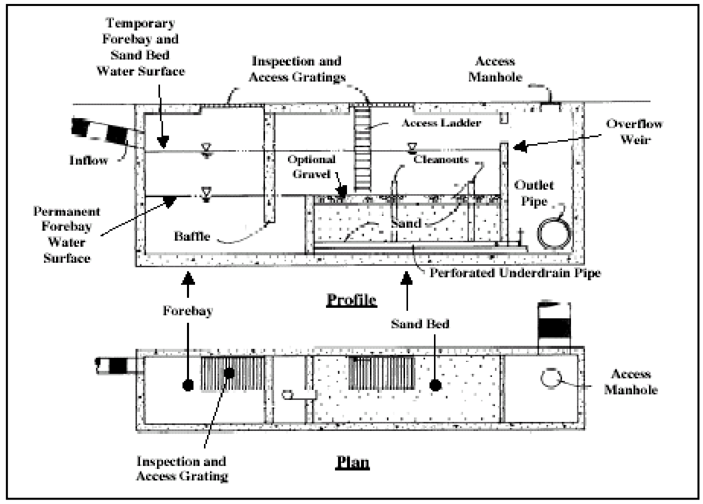
Subsurface filters have a few special design considerations, including the need for a drain and valve in the forebay to allow standing water and sediment to be removed and the requirement that they be watertight.

Advantages:

- Can be used in areas with limited surface space.
- Can accept runoff from "hot spots" (areas that generate highly contaminated runoff) because stormwater treated by sand filters has little or no interaction with groundwater.
- Can be used on sites with slopes up to about 6%.
- Can be used on almost any soil.
- Can be used as pretreatment for infiltration BMPs.

Disadvantages:

- Not recommended for pervious drainage areas where high coarse sediment loads and organic material (e.g., leaves) can clog the sand bed.
- Require frequent maintenance – more difficult when system is underground ("out of sight, out of mind").
- Require relatively complicated design procedure to achieve pollutant removal.
- Useful only for small drainage areas (max. 2 acres for subsurface filters); risk of clogging when used on larger drainage areas without larger sedimentation chamber or more intensive regular maintenance.



Source: Adapted from Claytor and Schueler, 1996 in NJDEP 2004.

- Except on small sites or urban areas, may be more expensive as retrofits than BMPs which treat larger drainage areas (e.g., basins or wet ponds).

Estimated Costs:

See Table A

Maintenance Requirements:

Once/month: Clean debris out of sand filter, inlets and outlets; ensure that filter surface is not clogging; ensure that oil, grease and sediment inputs are minimized
Four times/year and after every storm <1 in.: Inspect for clogging and debris and sediment accumulation; remove sediment (if needed) when completely dry
Two times/year: Ensure that water infiltrates the sand bed within 72 hours and remediate if necessary
Once/year: Inspect inlets, outlets and overflow spillway for erosion; ensure that flow is not bypassing filter; ensure that odors are not detected outside filter; inspect structural parts for subsidence and deterioration; remediate if necessary

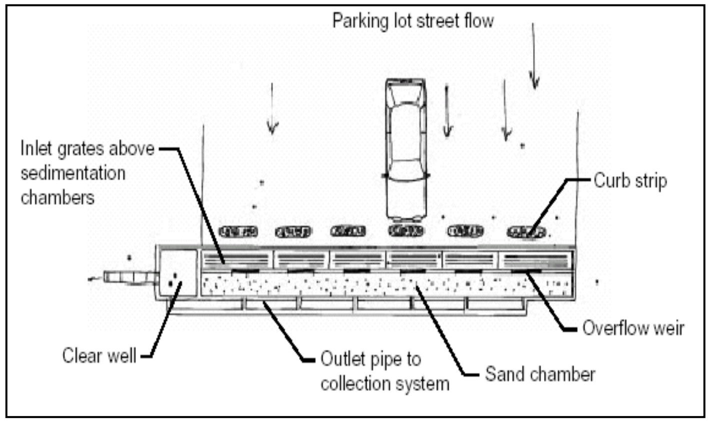
Ascribed Pollutant Removal Efficiencies:

(NJDEP 2004)

TSS reduction in postconstruction runoff: 80%
Total phosphorus removal rate: 50%
Total nitrogen removal rate: 35%

SAND FILTERS - PERIMETER

Sand filters can be used to remove relatively large amounts of sediments, metals, hydrocarbons and floatables from stormwater runoff, but they do not provide groundwater recharge or control flooding. Perimeter sand filters are usually located at the edges of parking lots. Stormwater runoff enters the filter as sheet flow through a series of grates and flows into a wet pool in the first chamber where pretreatment occurs. It then flows through a sand bed which filters pollutants, and is conveyed either to another BMP in a "treatment train" or to a storm sewer system. (Very large runoff flows overflow to an outlet chamber and are not treated.) Like other sand filters, perimeter filters require at least 2 feet of separation between the bottom of the filter and the seasonal high water table.



Source: Center for Watershed Protection 1996.

Like subsurface filters, perimeter filters are located underground, tend to have higher construction costs than aboveground filters and consume very little surface space. They also share a few special design considerations, including the need for a drain and valve in the forebay to allow standing water and sediment to be removed and the requirement that they be watertight.

Advantages:

- Good options for areas of low relief because they require little elevation drop ("hydraulic head") to function.
- Can be used in areas with limited surface space.
- Especially useful for parking lots and similar areas of impervious surfaces.
- Can accept runoff from "hot spots" (areas that generate highly contaminated runoff) because stormwater treated by sand filters has little or no interaction with groundwater.
- Can be used on sites with slopes up to about 6%.
- Can be used on almost any soil.
- Can be used as pretreatment for infiltration BMPs.

Disadvantages:

- Not recommended for pervious drainage areas where high coarse sediment loads and organic material (e.g., leaves) can clog the sand bed.
- Require frequent maintenance – more difficult when system is underground ("out of sight, out of mind").
- Require relatively complicated design procedure to achieve pollutant removal.
- Useful only for small drainage areas (max. 2 acres for subsurface filters); risk of clogging when used on larger drainage areas without larger sedimentation chamber or more intensive regular maintenance.
- Except on small sites or urban areas, may be more expensive as retrofits than BMPs which treat larger drainage areas (e.g., basins or wet ponds).

Estimated Costs:

See Table A

Maintenance Requirements:

<u>Once/month</u>: Clean debris out of sand filter, inlets and outlets; ensure that filter surface is not clogging; ensure that oil, grease and sediment inputs are minimized
<u>Four times/year and after every storm <1 in.</u>: Inspect for clogging and debris and sediment accumulation; remove sediment (if needed) when completely dry
<u>Two times/year</u>: Ensure that water infiltrates the sand bed within 72 hours and remediate if necessary
<u>Once/year</u>: Inspect inlets, outlets and overflow spillway for erosion; ensure that flow is not bypassing filter; ensure that odors are not detected outside filter; inspect structural parts for subsidence and deterioration; remediate if necessary

Ascribed Pollutant Removal Efficiencies:

(NJDEP 2004)

TSS reduction in postconstruction runoff: 80%
Total phosphorus removal rate: 50%
Total nitrogen removal rate: 35 %

WET PONDS

Wet ponds (sometimes called retention basins) typically have two main components: a forebay and a permanent pool. As stormwater enters the forebay, its rate is slowed and sediment and pollutants are allowed to “settle out”; this process continues in the permanent pool, where biological activity helps to remove additional pollutants. In general, the larger the pool, the higher the pollutant removal capability. Pollutant removal can be further increased by using an extended detention basin above the wet pond to detain stormwater runoff and provide additional settling, and/or by using multiple wet ponds in a series as part of a “treatment train.”

Wet ponds can provide flood control, channel protection and pollutant removal, but do not provide groundwater recharge. They can also provide aquatic habitat if the permanent pool is maintained at a depth of three to six feet. **Note: NJDEP does <u>not</u> allow existing lakes and ponds to be used for stormwater treatment.**

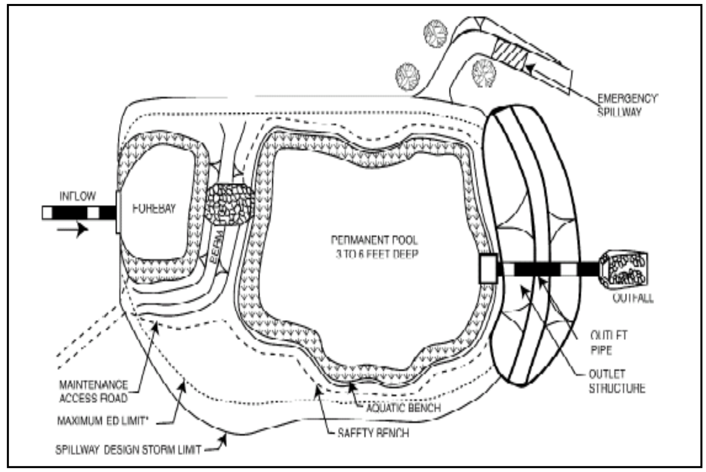
A wet pond must be able to maintain a permanent pool level and is especially suitable for areas where groundwater is close to the surface. If the soil is not sufficiently impermeable, an impermeable liner must be used or other soil modifications must be completed.

Advantages:

- Relatively long lifespan (up to 20 years).
- If properly landscaped, can provide habitat and aesthetic values.
- Can provide cost-effective water supply for fire protection and/or irrigation (e.g., golf courses).
- Useful on sites with upstream slopes up to 15%.
- Can accept runoff from “hot spots” (areas that generate highly contaminated runoff) provided there is adequate separation from seasonal high water table (min. 1 foot).
- Wide applicability; few limits on soils or geology.
- **Useful retrofit**: existing flood control detention ponds can be modified to include a permanent wet pool for water quality control and a smaller outlet structure for channel protection.

Disadvantages:

- Need relatively large continuous area to maintain permanent pool (approximately 2-3% of total drainage area); limited applicability in urban areas.
- Sediment removal can be expensive.
- May encourage mosquito breeding.
- Permanent pool can heat runoff during hot weather, affecting downstream areas.



Source: Adapted from Claytor and Schueler, 1996 in NJDEP 2004.

- In winter, road salt and sand can impact vegetation and increase sediment loading.

Estimated Costs:

See Table A

Maintenance Requirements:

<u>As needed</u>: Repair eroded areas; mow side slopes
<u>Every 2 weeks during first growing season</u>: Ensure vegetation becomes established; address problems without fertilizers and pesticides whenever possible
<u>After every storm <1 in.</u>: Remove debris from inlet and outlet structures; check for clogging
<u>Four times/year (twice during both growing and nongrowing season)</u>: Check outlet valves; remove debris from inlets and outlets; check for clogging; inspect vegetation health, density and diversity and replant if necessary (maintain vegetative cover at 85%)
<u>Twice/year</u>: Remove invasive vegetation if necessary
<u>Once/year</u>: Manage and harvest wetland plants; inspect for signs of hydrocarbon buildup and sediment or debris accumulation; inspect structural parts for subsidence and deterioration; remediate if necessary
<u>Once/5 to 10 years</u>: Remove sediment from forebay
<u>Once/20 to 50 years</u>: Remove sediment and re-construct pond when pool volume is significantly reduced or pond becomes eutrophic

Ascribed Pollutant Removal Efficiencies:

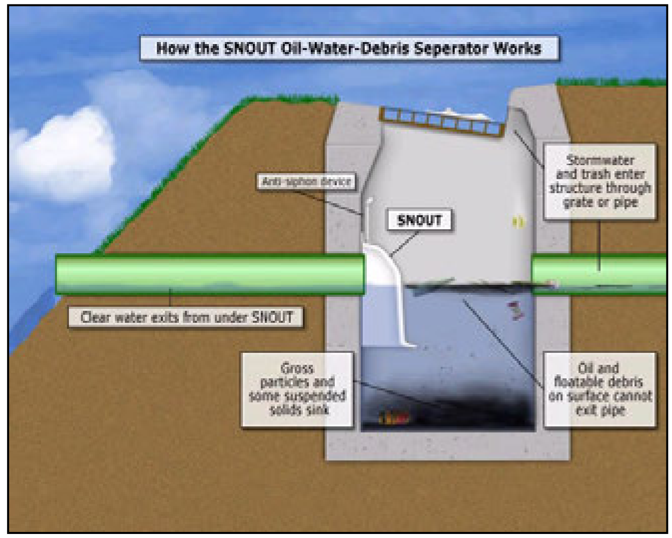
(NJDEP 2004)
TSS reduction in postconstruction runoff: 50%
Total phosphorus removal rate: 50%
Total nitrogen removal rate: 30%

MANUFACTURED TREATMENT DEVICE: THE "SNOUT"

Except where otherwise noted, the information presented in this factsheet has been provided by the manufacturer, Best Management Products, Inc. < http://www.bmpinc.com/>

Manufactured treatment devices are intended to capture sediments, metals, hydrocarbons, floatables, and/or other pollutants in stormwater runoff before being conveyed to a storm sewer system, additional stormwater quality treatment measure or waterbody (NJDEP, 2004). The SNOUT is a retrofit device that can be installed within an existing stormwater catch basin to provide treatment of stormwater. It consists of a fiberglass hood (trap) that fits over the outlet pipe of a sumped catch basin or other water quality structure.

The SNOUT can be adapted to filter a variety of different pollutants, but is primarily used to remove sediment, floatables and oil from stormwater.



Source: Best Management Products, Inc.

Advantages:

- Manufactured treatment devices are appropriate for small drainage areas with high impervious cover likely to contribute high hydrocarbon and sediment loadings (e.g., small parking lots and gas stations) (NJDEP, 2004).
- Low cost compared to other BMPs.
- Easy to install with hand tools.
- Available in a variety of sizes and configurations; optional add-ons available (e.g., odor control filters, oil booms, custom debris screens).
- Includes "anti-siphon vent" which prevents siphon from developing and drawing surface layer pollutants downstream under full pipe flows.
- **Useful retrofit**: designed to modify existing stormwater infrastructure (catch basins).

Disadvantages:

- For larger sites, multiple devices may be necessary.
- Manufactured treatment devices are normally used for pretreatment of runoff before discharging to other, more effective stormwater quality treatment facilities (NJDEP, 2004).
- May not function as effectively under low flows or in catch basins with shallow sumps (i.e., depth from beneath the invert of the outlet pipe to the bottom of the structure).
- **Pollutant removal rates are not verified by NJDEP.**

Estimated Costs:

Based on information provided by the manufacturer, the cost for materials to retrofit one catch basin ranges from approximately $200 to over $6,000 (excluding shipping and labor), depending on the size of the catch basin and the number of additional components installed (www.bestmp.com).

Maintenance Requirements:

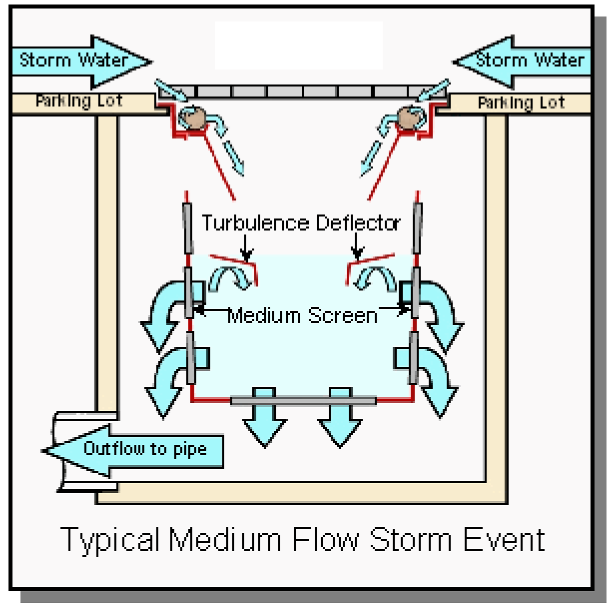
Monthly for the first year: Monitor to ensure proper functioning of device
As needed: clean out sump when half full (usually requires vacuum truck)
Four times/year and after every storm <0.5 in.: inspect all device components expected to receive and/or trap debris for clogging and excessive debris and sediment accumulation; dispose of debris, sediment and other waste material at suitable disposal/recycling sites and in compliance with applicable waste regulations
Once/year: Inspect all structural components for cracking, subsidence and deterioration; flush anti-siphon vent and open and close access hatch

Ascribed Pollutant Removal Efficiencies (estimates provided by Best Management Products, Inc.):

TSS reduction in postconstruction runoff: up to 50%
Total phosphorus removal rate: not provided
Total nitrogen removal rate: not provided

MANUFACTURED TREATMENT DEVICE: GRATE INLET SKIMMER BOX

Except where otherwise noted, the information presented in this factsheet has been provided by the manufacturer, Suntree Technologies Inc. <www.suntreetech.com>



Source: Suntree Technologies Inc.

Manufactured treatment devices are intended to capture sediments, metals, hydrocarbons, floatables, and/or other pollutants in stormwater runoff before being conveyed to a storm sewer system, additional stormwater quality treatment measure, or waterbody (NJDEP, 2004). The Suntree Grate Inlet Skimmer Box is a retrofit device that can be installed within an existing stormwater inlet / catch basin. It uses a series of filtration screens to remove sediment, floatables and debris from stormwater.

Advantages:

- Manufactured treatment devices are appropriate for small drainage areas with high impervious cover likely to contribute high hydrocarbon and sediment loadings (e.g., small parking lots and gas stations) (NJDEP, 2004).
- Debris collected in the unit is stored in a dry state (helps to contain nutrient pollutant load and reduces mosquito breeding).
- Can be sized to fit any size inlet.
- Low cost compared to other BMPs.
- Easy to install and maintain with hand tools.
- **Useful retrofit**: designed to modify existing stormwater infrastructure (catch basins).

Disadvantages:

- For larger sites, multiple devices may be necessary.
- Manufactured treatment devices are normally used for pretreatment of runoff before discharging to other, more effective stormwater quality treatment facilities (NJDEP 2004).
- **Pollutant removal rates are not verified by NJDEP.**

Estimated Costs:

Based on information provided by the manufacturer, the cost for materials to retrofit one catch basin ranges from approximately $1,000 to $1,5000.

Maintenance Requirements:

Monthly for the first year: Monitor to ensure proper functioning of device
As needed: remove skimmer tray and deflection shield; turn over filter box and empty for disposal
Four times/year and after every storm <0.5 in.: inspect all device components expected to receive and/or trap debris for clogging and excessive debris and sediment accumulation; dispose of debris, sediment and other waste material at suitable disposal/recycling sites and in compliance with applicable waste regulations
Once/year: Inspect all structural components for cracking, subsidence and deterioration

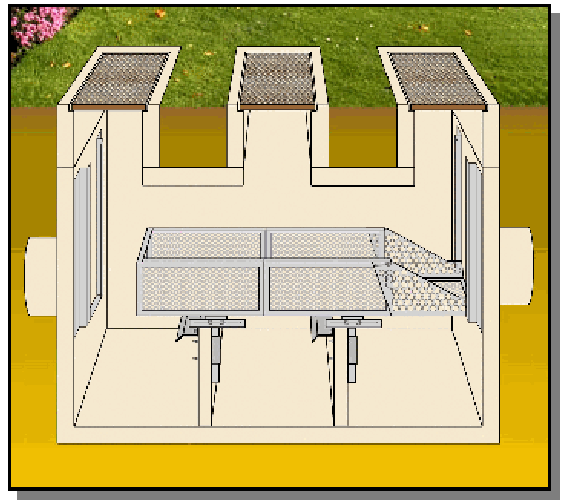
Ascribed Pollutant Removal Efficiencies:

TSS reduction in postconstruction runoff: 73% (England, 2001)
Total phosphorus removal rate:71% (suntreetech.com)
Total nitrogen removal rate: 65% (suntreetech.com)

THREE CHAMBERED NUTRIENT SEPARATING BAFFLE BOX

Except where otherwise noted, the information presented in this factsheet has been provided by the manufacturer (Suntree Technologies, Inc. www.suntree.com)

Manufactured treatment devices are intended to capture sediments, metals, hydrocarbons, floatables, and/or other pollutants in stormwater runoff before being conveyed to a storm sewer, or waterbody (NJDEP 2004). The Three Chambered Nutrient Separating Baffle Box captures rich vegetation and litter in a filtration screen and allows sediment to settle to the bottom of the structure. Thus, the organic pollutant load is separated from the water. After stormevents, the vegetation and litter dry out. Baffle boxes are concrete or fiberglass structures with a series of settling chambers.



Advantages: (EPA 2001)

- Simple, inexpensive stormwater BMPs that effectively remove sediment and suspended solids.
- Can be retrofitted in existing storm lines.

Disadvantages: (EPA 2001)

- Require significant maintenance to remove accumulated sediment.
- Trash racks may release accumulated trash during high flows.
- Not designed for nutrient removal.

Estimated Costs:
Installation for most pre-cast baffle boxes is between $150,000 and $200,000.

Maintenance Requirements:
Baffle boxes need regular maintenance such as routine inspections and cleaning. The frequency of cleaning the baffle boxes depends on the amount of rain and accumulated material. Baffle boxes are cleaned using vacuum trucks and are accessed though manholes.

Ascribed Pollutant Removal Efficiencies:
TSS reduction: 90% (Suntree) 71% (EPA 2001)
Total phosphorus removal rate: 38% (EPA 2001)
Total nitrogen removal rate: N/A

AQUA-SWIRL

Except where otherwise noted, the information presented in this factsheet has been provided by the manufacturer or representative (AquaShield Stormwater Treatment Solutions http://aquashieldinc.com or Shri Agencies)

The Aqua-Swirl is an effective way to remove sediments, floating debris, and free-oil from stormwater. Both gravitational and hydrodynamic forces allow solids to settle at the bottom of the device. Treated water exits the MTD behind an arched outer baffle. A vent pipe exposes the backside of the baffle to atmospheric conditions; this prevents a siphon from forming at the bottom of the baffle.

The Aqua-Swirl can be shipped fully assembled after leak testing in the factory since the units are light weight.

Advantages:

- The Aqua-Swirl is highly adaptable
- Allows for easy retrofit

Disadvantages:

- No data on phosphorus and nitrogen removal efficiencies.

Estimated Costs:
The estimated cost per unit ranges from $10,000 to $75,000, depending on the size and configuration. Prices are available upon request on a case by case basis.

Maintenance Requirements:
Inspections and maintenance can take place from the surface; free-floating oil and debris can be removed through the service access. It is recommended that inspections are conducted quarterly for the first year of operation in order to determine an appropriate maintenance schedule. Once the usable storage volume is occupied, the accumulated material needs to be removed using a vacuum truck.

Ascribed Pollutant Removal Efficiencies:

- TSS reduction: 50%
- Total phosphorus removal rate: No data
- Total nitrogen removal rate: No data

AQUA-GUARDIAN

Except where otherwise noted, the information presented in this factsheet has been provided by the manufacturer or representative (AquaShield Stormwater Treatment Solutions http://aquashieldinc.com or Shri Agencies)

The Aqua-Guardian (Aqua-Guard) is a catch basin insert that is suspended inside the catch basin by a stainless steel support collar. The collar acts as a funnel to direct stormwater runoff into the sediment collection/ storage area. In addition, the collar traps floatable debris by forming a baffle around the inside of the insert. As water flows through the locked filter screen standpipe it is filtered by media (100% hydrophobic cellulose) that removed fine sediments, nutrients, and heavy metals.

The Aqua-Guard comes in three sizes to fit into the catch basin opening. These inserts are typically used for retrofit applications and can also be used as pretreatment devices before a swirl separator or Aqua-Filter.

Advantages:

- The Aqua-Swirl is highly adaptable.
- Allows for easy retrofit.

Disadvantages:
No data on pollutant removal efficiencies.

Estimated Costs:
Installation for most Aqua-Guardians is approximately $15,000.

Maintenance Requirements:
In most cases, the Aqua-Guard MTD should be inspected monthly and after significant storm events. The MTD can be visually inspected from the surface and a tape measure can be used to determine the amount of sediment in the collection area. Once the sediment reaches the bottom "filter screen outlets" the unit needs to be serviced. Servicing is conducted by using a wet/dry shop-vac to remove sediment and debris inside the chamber. The filter bag also needs to bee removed and replaced; sediment in the filter area should be removed prior to inserting a new filter.

Ascribed Pollutant Removal Efficiencies:
TSS reduction: No data
Total phosphorus removal rate: No data
Total nitrogen removal rate: No data

FILTERRA BIORETENTION SYSTEM

Except where otherwise noted, the information presented in this factsheet has been provided by the manufacturer or representative (Contech Engineered Solutions, (https://www.conteches.com/stormwater-management/biofiltration-bioretention/filterra).

Filterra is an engineered biofiltration device with components that make it similar to bioretention in pollutant removal and application, but has been optimized for high volume/flow treatment in a compact system. Its small footprint allows Filterra to be used on highly developed sites such as landscaped areas, parking los, and streetscapes. Filterra is adaptable and can be used alone or in combination with perforated pipes or chambers to optimize runoff reduction.

Advantages:

- **Regulatory Compliance** – Multiple third-party field tests confirmed Filterra meets regulatory requirements for pollutant removal, including NJCAT testing.
- **Value** – Filterra offers a cost effective stormwater treatment system featuring easy installation and simple maintenance.
- **Aesthetics** – Landscaping enhances the appearance of sites while removing pollutants.
- **Flexible** – Multiple sizes and a variety of configurations available to meet site-specific needs.
- **Easy Installation** – Delivered on-site, ready to life and place.
- **Maintenance** – Simple and safe (no confined space access), and the first year of maintenance is included with the purchase of every system.


Source: Contech

Disadvantages:
Yearly maintenance required.

Estimated Costs:
Installation for one Filterra is approximately $40,000 - $60,000.

Maintenance Requirements

- The first year of maintenance is included with every system.
- Maintenance is low-cost, low-tech and simple:
- Remove trash, sediment, and mulch.
- Replace with a fresh layer of 3” of mulch.
- Can be done by landscape contractor.
- No confined space entry.

Ascribed Pollutant Removal Efficiencies (Contech 2019):
(Ranges varying with particle size, pollutant loading and site conditions)
TSS reduction: 80%
Total phosphorus removal rate: 70%
Total nitrogen removal rate: 40%

REFERENCES CITED

AquaShield. 2019. https://www.aquashieldinc.com/. Chattanooga, TN.

Best Management Products, Inc. 2019. http://www.bmpinc.com/. East Haddam, CT.

Brown, W., and T. Schueler. 1997. The Economics of Stormwater BMPs in the Mid-Atlantic Region. Prepared for Chesapeake Research Consortium. Edgewater, MD. Center for Watershed Protection. Ellicott City, MD.

Claytor, R. and T. Schueler. 1996. Design of Stormwater Filtering Systems. The Center for Watershed Protection. Ellicott City, MD.

Center for Watershed Protection (CWP). 1998. Better Site Design: A Handbook for Changing Development Rules in Your Community. Center for Watershed Protection, Ellicott City, MD.

Center for Watershed Protection (CWP). 1997. Stormwater BMP Design Supplement for Cold Climates. Prepared for U.S. Environmental Protection Agency, Office of Wetlands, Oceans and Watersheds, Washington, DC, by the Center for Watershed Protection, Ellicott City, MD.

Contech Engineered Solutions. 2019. https://www.conteches.com/stormwater-management/biofiltration-bioretention/filterra#

Maryland Department of the Environment Science Services Administration. King, D. and P. Hagan, University of Maryland. Costs of Stormwater Management Practices in Maryland Counties (Draft). CBL 11-043. Solomons, MD. 2011.

New Jersey Department of Environmental Protection (NJDEP). 2004. The New Jersey Stormwater Best Management Practices Manual, February 2004. https://www.njstormwater.org/bmp_manual2.htm

Schueler, T. 1987. Controlling Urban Runoff: A Practical Manual for Planning and Designing Urban BMPs. Metropolitan Washington Council of Governments, Washington, DC.

Schueler, T., 1992. A Current Assessment of Urban Best Management Practices. Metropolitan Washington Council of Governments.

Schmitt, T. et al. Summary of Three Innovative Storm Water BMPs. Sixth Biennial Stormwater Research & Watershed Management Conference, September 14-17, 1999. <http://www.stormwater-resources.com/Library/078B3BMPs.doc>

Southeastern Wisconsin Regional Planning Commission (SWRPC). 1991. Costs of Urban Nonpoint Source Water Pollution Control Measures. Technical report no. 31. Southeastern Wisconsin Regional Planning Commission, Waukesha, WI.

Suntree Technologies. 2018. https://www.suntreetech.com/index.html. Cocoa, FL.

United States Environmental Protection Agency. 2001. Storm Water Technology Fact Sheet: Baffle Boxes. Office of Water. Washington, DC.

United States Environmental Protection Agency (EPA). 2002a. National Menu of Best Management Practices for Storm Water Phase II. Post-Construction Storm Water Management in New Development & Redevelopment.

United States Environmental Protection Agency (EPA). 2002b. Storm Water Technology Fact Sheet: Sorbent Materials in Storm Water Applications.

United States Environmental Protection Agency (EPA). Last updated on August 24th, 2004a. Storm Water and Wastewater Virtual Trade Show: Continuous Deflective Separation (CDS) Unit.

United States Environmental Protection Agency (EPA). Last updated on August 24th, 2004b. Storm Water and Wastewater Virtual Trade Show: Vortechs Stormwater Treatment System.

APPENDIX VI:

STREAM VISUAL ASSESSMENT SCORING SHEET

Belcher Creek - Stream Visual Assessment Scoring Sheet

Stream ID # ________________________________ Downstream: _______ Upstream: __________

Road Crossing: _____________________________ Stream Name: _____________________________

Town: ___________________________________ County:___________________________________

Survey Team:____

Date: __________________________ Weather: _______________________________________

Channel Width:_________ Depth:_________ Water Appearance:_________________________________

Dominant Substrate: ___ cobble ___ gravel ____ sand ___ silt ____ clay ___ mud

GPS Latitute:______________________________Longitude:_____________________________

Assessment Scores

Vegetated Buffer Width	RB LB	10 Width of buffer zone >50ft; no impacts (parking lots, roads, clear-cuts, lawns, crops) 7 Width of buffer zone 25-50 ft.; human activity impacts 3 Width of buffer zone 10-25 feet 1 Width of buffer zone <10 feet
Vegetated Buffer Condition	RB LB	10 3 habitat layers present. Low invasive plants. 7 One habitat layer impaired. Scattered invasive plants. 3 Two habitat layers impaired. Invasive species dominant. 1 Two or more habitat layers missing. Low diversity. Invasive species dominant Severely degraded.
Canopy Cover		10 > 75% of water shaded and upstream well shaded 7 > 50% shaded in reach, or upstream poorly shaded 3 20-50% of water surface in reach is shaded 1 < 20% of water surface in reach shaded
Bank Stability		10 Banks are stable; at elevation of active flood plain 7 Moderately stable; at elevation of active flood plain; < 33% bends eroding, protected by roots at baseflow. 5 Moderately unstable; outside bends are actively eroding (Overhanging vegetation, falling trees, some slope failure) 1 Unstable; some straight reaches, inside and outside bends are eroding, falling trees, numerous slope failures)
Channel Condition		10 Natural channel; no structures, no channelization of stream 7 Recovery of past channel alteration, access to floodplain 3 Altered channel <50% of reach with riprap, Channelization, mid-channel gravel bars, braided channel. Stream is actively down cutting or widening. 1 >50% of reach is altered, rip rapped, channelized or gravel bars. Access to floodplain is restricted
Hydrologic Alterations		10 No evidence of hydrologic alterations (dams, channels or ditches) 7 Minor hydrologic alterations. Withdrawals not affecting habitat 3 Moderate hydrologic alterations. Withdrawals significantly affect available low flow habitat for biota. 1 Significant hydrologic alterations. Withdrawals have caused severe loss of low flow habitat.
Floodplain Encroachment (Don't add to score)		10 No evidence of floodplain encroachment or manmade structures 7 Minor floodplain encroachment: fill materials, development, or manmade structures, but not effecting floodplain function. 3 Moderate floodplain encroachment in the form of filling, land development, or manmade structures, some affect on floodplain 1 Significant floodplain encroachment (i.e., fill, development or manmade structures). Significant effect on floodplain function.
Aquatic Plant Community		10 Clear water along entire reach: diverse aquatic plant community; little algal growth present. 7 Fairly clear or slightly greenish water along entire reach; moderate algal growth on stream substrates. 3 Greenish water along entire reach; over abundance of algal,

		macrophytes 1 Pea green, gray, or brown water along entire reach; dense stands of macrophytes clog stream; severe algal blooms & mats
Invertebrate Habitat: fine woody debris, submerged logs, leaf packs, undercut banks, cobble, boulders, coarse gravel		10 5 types of habitat available, full insect colonization 7 3 to 4 types of habitat, such as overhanging trees, 3 1 to 2 types of habitat, substrate is disturbed, covered, or scoured 1 None to 1 type of habitat.
Instream Fish Cover: logs/large woody debris, deep pools, over hanging vegetation, boulders/cobble, riffles, undercut banks, thick root mats, dense macrophyte beds, isolated/backwater pools		10 >7 cover types available 8 6 to 7 cover types available 5 4 to 5 cover types available 3 2 to 3 cover types available 1 0 to 1 cover type available
Barriers to Fish Movement:		10 No Barriers 7 Drop structures, culverts or diversions (<1' drop) within reach 3 Drop structures, culverts, or diversions (> 1' drop) within 3 miles 1 Drop structures, culverts, or diversions (> 3' drop) within reach
Velocity / Depth Variability		10 All four velocity/depth regimes present (slow-deep, slow-shallow, fast-deep, and fast-shallow) 7 Only 3 of the 4 regimes present 3 Only 2 of the 4 habitat regimes present 1 Dominated by 1 velocity/depth regime (usually slow-deep)
Pool Variability		10 Mix of large-shallow, large deep, small shallow, small-deep pools 7 Majority of pools large-deep; very few shallow 3 Shallow pools much more prevalent than deep pools 1 Majority of pools small-shallow or pools absent
Manure Present		5 Evidence of livestock access to riparian zone. 3 Occasional manure or waste storage located in floodplain. 1 Extensive amount of manure on banks/stream Or Untreated human waste discharge pipes present

Total Points	
Number of Categories Scored	
OVERALL SCORE (Divide Total Points by Number of Categories Scored)	

Scoring scheme TBD based on results

Wildlife: ____

Notes on Reach (biggest problem(s): ____

____

____

____

____

____

Streamside Land Use (NJ): (1. Present 2. Clearly impacting the stream)

Type of Use	**Within 100' of stream**	*As interpreted from aerial photos*	*If significant impact evident, GPS Coordinates/ Description of Location and take photos*
Agricultural grazing land			
Agricultural cropland (soy, hay, corn)			
Agricultural feed lots/animal holding areas			
Inactive agricultural land/fields			
Residential single-family housing			
Residential multifamily housing			
Industrial			
Commercial/Institutional			
Residential Lawns			
Waterfowl (w/approx number)			
Recreational hiking/paths			
Horse trails			
Paved Roads			
Unpaved Roads			
Road drainage impacts			
Timbering/woodland management			
Construction Underway for:			*Note if 100 ft or 150 ft buffer is being protected. If not, take pictures and contact Soil Conservation Service.*
Housing development			
Commercial			
Road/bridge construction repair			
Utility impacts/crossings (gas pipelines, electrical lines)			
ATV and recreational vehicle crossings/damage			
Other:			