WATERSHED PROTECTION AND RESTORATION PLAN FOR THE MANALAPAN BROOK WATERSHED

Middlesex and Monmouth Counties, New Jersey

Prepared for:

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Executive Summary

In response to a total phosphorus (TP) Total Maximum Daily Load (TMDL) established by the New Jersey Department of Environmental Protection (NJDEP) for Manalapan Lake (Monroe Township, Middlesex County, New Jersey) the New Jersey Water Supply Authority (NJWSA) hired Princeton Hydro, LLC to develop a restoration plan for the lake to comply with the existing TMDL. As part of this project two years of water quality and watershed monitoring was conducted. The result of this monitoring, as well as the application of several lake-based water quality models, revealed that it would be more appropriate, in terms of improving overall water quality in the watershed, to identify total suspended solids (TSS) as the primary pollutant of concern, instead of TP. Therefore, the focus of the project was modified and the scope of the project broadened to include the entire Manalapan Brook watershed instead of just the contributory drainage area to Manalapan Lake.

Manalapan Brook is 105 miles in length, originates in Monmouth County and drains north into Middlesex County where it joins the mainstem Raritan River. Manalapan Lake is the largest impoundment on the Brook and is addressed throughout the protection and restoration plan. The Manalapan Brook watershed is 43 square miles and includes nine municipalities throughout two counties.

A number of tasks were conducted to develop a site-specific, yet comprehensive protection and restoration plan. One of the main tasks is to address and satisfy the nine elements required by both NJDEP and US EPA to approve and recognize the watershed protection and restoration plan. To develop this comprehensive plan and address the nine elements, the following tasks were conducted:

- develop a GIS-based characterization and assessment of the watershed;
- conduct a stream visual assessment of stations throughout the watershed;
- collect additional water quality and ecological data of Manalapan Lake;
- apply of the ArcView Generalized Watershed Loading Function (AVGWLF) model to quantify TSS loads on a municipal and sub-watershed basis.

The resulting tasks were then synthesized into this watershed protection and restoration plan. This included identifying watershed initiatives and specific restoration projects that should be implemented to reduce the existing TSS loads. The plan is specifically geared towards decreasing TSS loads to levels that would result in compliance with the state's Surface Water Quality Standards (SWQS) for a FW2-NT water.

In addition to identifying locations for the implementation of restoration measures, specific Best Management Practices (BMPs) or other watershed restoration activities were described for each site assessed throughout the watershed. This included an approximate cost for their implementation and a prioritization of these projects. Two of these projects, a demonstration rain garden and shoreline buffer planting, were designed and installed in 2010 at Thompson Park in Middlesex County immediately adjacent to Manalapan Lake. Existing conditions surveys and engineering design plans were developed for five additional project locations. This provides a unique opportunity to seek grant funds for the implementation of these five design projects. Finally, recommendations on how to proceed with the implementation of the plan from a public outreach, financial and administrative perspective are provided.

Introduction

Manalapan Brook is 105 miles in length and originates in Monmouth County and drains north into Middlesex County where it joins the Mainstem Raritan River. The Manalapan Brook watershed drains 43 square miles, and includes portions of ten municipalities: South Brunswick Township, Jamesburg Borough, Helmetta Borough, East Brunswick Township, Monroe Township, and Spotswood Borough in Middlesex County and Englishtown Borough, Freehold Township, Manalapan Township, and Millstone Township in Monmouth County as shown below in Figure 1. This map is also provided in full size with additional detail in Map 1 of Appendix A.

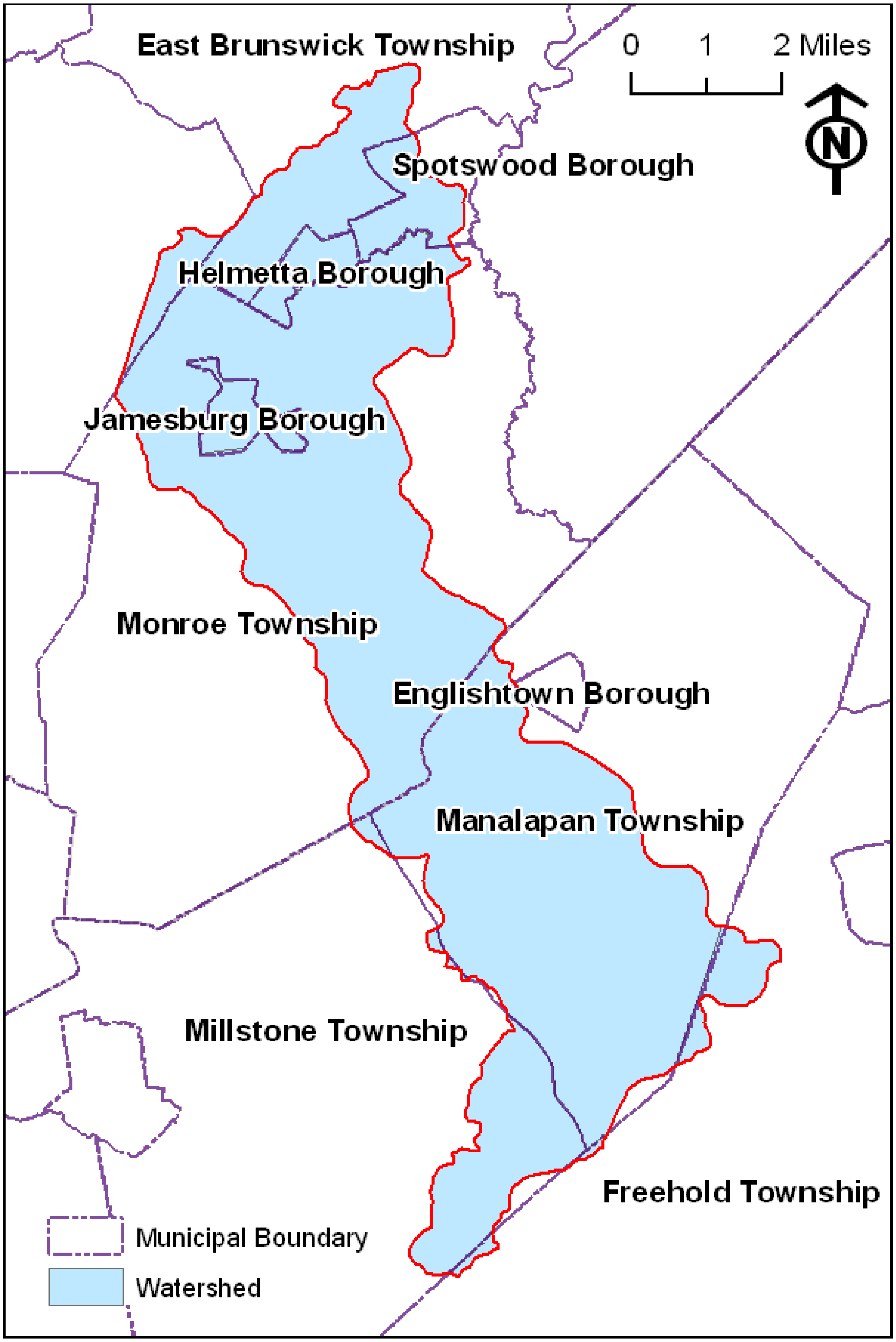

Figure 1. Municipality map of the Manalapan Brook watershed.

The Manalapan Brook is part of the NJDEP Watershed Management Area (WMA) #9, which includes the Lower Raritan, South River, and Lawrence Brook watersheds. The confluence of the Manalapan and Matchaponix Brooks form the South River, which begins at DeVoe Lake in Spotswood and flows to the Duhernal Reservoir and Raritan River at Sayreville. Prior to recent residential development (circa 1990 to present), land use in the upper portion of the Manalapan Brook watershed was predominantly agriculture, wetlands and forests. The lower segment of the watershed includes a predominance of existing residential and commercial developments in the historic communities of Jamesburg, Spotswood, and Helmetta, along with some new, large commercial warehouse developments. The entire 43 square mile watershed is estimated to be covered by approximately 12% impervious surfaces. Major tributaries in the watershed include Barclay Brook, Cedar Brook, Gander Brook, South River, Wigwam Brook, and Stillhouse Brook.

The 2000 US Census data reports that the populations within the municipalities in the Manalapan Brook region grew by approximately 33,500 people or 22% during the ten years from 1990 to 2000. The urban development of over 2,000 acres of forest and farms has occurred from 1995 to 2002. Critical habitats designated by the federal and state government as habitat for endangered and threatened species are also present in the watershed including bald eagle foraging grounds, bog turtle habitat, and wood turtle habitat. Continued population growth and development are expected to impact this region and its water resources in the near future.

Project Justification:

In 2004, Princeton Hydro was selected by the New Jersey Water Supply Authority (NJWSA) to develop a Restoration / Implementation Plan for Manalapan Lake and its watershed to comply with the New Jersey Department of Environmental Protection's (NJDEP's) targeted 86% reduction of the annual total phosphorus (TP) load entering Manalapan Lake, as per the established Total Maximum Daily Load (TMDL) (NJDEP, 2003). As part of this plan, selected water quality and ecological data were collected on Manalapan Lake to determine if the TMDL's modeled TP concentrations reasonably agree with existing in-lake concentrations. While the Manalapan Lake dataset was limited in size and scope (five sampling events over the course of 2004 and 2005), existing TP concentrations diverged significantly from modeled concentrations. Additional water quality (i.e. TP and TSS) and flow data were collected, under an approved QAPP, to generate a Lake Characterization and Assessment Report to, at a minimum, partially fulfill the established requirements of the phosphorus TMDL.

The mean measured TP concentration (0.04 mg/l) in Manalapan Lake was substantially lower than the predicted TP concentration (0.13 mg/l) based on the Reckhow model (Reckhow, 1980). The mean measured growing season TP concentration in Manalapan

Lake was below the state Surface Water Quality Standard (SWQS, N.J.A.C. 7:9B – 1.14(c) 5) of 0.05 mg/l for TP in a freshwater lake.

While the hydrologic and morphometric parameters of Manalapan Lake fall within the appropriate range of characteristics for the Reckhow model (NJDEP, 2003), the model did not reasonably predict in-lake TP concentrations. Therefore, the Reckhow model was deemed by Princeton Hydro to not be applicable for Manalapan Lake. Other factors that complicate the TMDL approach for Manalapan Lake include:

1. Link between TP and chlorophyll *a* concentrations was not strong in Manalapan Lake. Therefore, reducing the TP loads and concentrations may not necessarily result in improved water quality conditions, at least in terms of the magnitude and frequency of algal blooms.
2. Based on some inter-relationships among various in-lake trophic parameters (TP, chlorophyll *a* and Secchi depth), the highly turbid conditions experienced in Manalapan Lake tended to be the result of inorganic particulate material and not algal blooms (Carlson and Havens, 2005).
3. In addition to visual evidence of streambank erosion, another observed potential source of the inorganic turbidity in Manalapan Lake was the composition of the lake's fishery community. Of over 350 fish collected during a 2004 fishery survey of the lake, 75% of the identified fish were yellow bullhead. This fish is a benthic feeder which stirs up the sediments through feeding activities. Thus, the large population of yellow bullhead may be a major contributing factor to the turbid conditions of Manalapan Lake.

In addition to the observed conditions and ecological relationships described above, the lake is already in compliance with the state's numerical criteria for total phosphorus in a lake ecosystem. Based on these data, Princeton Hydro presented the following interim conclusions to NJWSA and NJDEP:

1. In the case of Manalapan Lake and its watershed, site-specific conditions require some modifications to the means and strategies that should be employed in the restoration and long-term management of this ecosystem.
2. The pollutant of primary concern for the Manalapan Lake watershed should be total suspended solids (TSS), not TP.
3. A watershed-based, stream assessment approach should be used to develop a Watershed Protection and Restoration Plan for the Manalapan Lake watershed.

As a result of these interim conclusions and with NJDEP concurrence, NJWSA requested a modified Scope of Work from Princeton Hydro to develop a revised Watershed Protection and Restoration Plan with an emphasis on TSS. The revised plan expands the study area to include the entire Manalapan Brook watershed, instead of terminating where the brook enters Manalapan Lake.

Further documentation and project justification is provided in Appendix F which contains the original white paper discussing this issue.

The Watershed Protection and Restoration Plan developed for the Manalapan Brook watershed focuses on reducing the TSS loads to a targeted load. To ensure that the proposed Manalapan Brook Watershed Protection and Restoration Plan be accepted for implementation by both state and federal agencies, the plan will address the nine (9) elements of a comprehensive watershed plan as identified by US EPA. These Nine Elements include:

1. Identify the sources of TSS and a prioritized ranking of these sources on a subwatershed and site-specific basis.
2. Estimate pollutant load reductions expected for the NPS management measures described in the plan.
3. Describe specific NPS management measures that should be implemented and include a description of their location in the watershed.
4. Estimate the amount and potential sources of technical and financial assistance needed to implement the plan.
5. Describe the information/education component designed to enhance public understanding of the plan and encourage early and ongoing public participation in selecting, designing and implementing the identified NPS management measures, including: creation and maintenance of a project mailing list, development of appropriate informational materials and several public meetings held over the course of the project.
6. Provide a "reasonably expeditious" schedule for implementing the identified NPS management measures, including the development of a ranking system matrix to identify priority areas where resources should be targeted.
7. Describe interim, measurable milestones (e.g., water chemistry data, number of acres permanently protected, number of streambank miles restored) for verifying whether NPS management measures are being implemented effectively.
8. Describe a set of criteria that can be used to determine whether load reductions are being achieved over time and substantial progress is being made towards attaining water quality standards and, if not, the criteria for determining whether this watershed-based plan needs to be revised.
9. Describe a monitoring plan to evaluate the effectiveness of implementation efforts over time, including recommendations for corrective actions to be taken if plan goals are not met and/or NPS management measures are not implemented properly.

Through the course of this Watershed Protection and Restoration Plan, the Nine Elements will be specifically identified and addressed within the context of the Manalapan Brook Watershed. Thus, this plan complies with both the tasks originally established in the proposed Scope of Work as well as with the requirements for an approved watershed plan. Table 1 identifies the nine elements and where they can be found in the plan.

Table 1. Watershed Work Elements for the Manalapan Brook Watershed

Watershed Plan Elements For Manalapan Brook Restoration Plan	Resulting Product (Section of Plan)
Preliminary Step – Characterize current status of the watershed, identify the primary pollutant of concern and determine what issues should be addressed through a watershed restoration plan.	Characterization and Assessment
Preliminary Step – Revise and establish the watershed objective for the Manalapan Brook watershed through the characterization process and the water quality assessment.	Stream Visual Assessment, Water Quality Monitoring
1. Identification of the **causes and sources** that will need to be controlled to achieve the load reductions estimated in this watershed-based restoration plan.	Stream Visual Assessment
2. An estimate of the **load reductions needed to be achieved from management measures**, by source(s) listed in (1).	Table 27
3. Description of the **NPS management measures** that will need to be implemented to achieve necessary load reductions and identification of critical areas in which those measures will be needed to implement the plan.	Watershed Protection and Restoration Implementation Strategy
4. Estimate the amounts of **technical and financial assistance needed, associated costs, and/or the sources and authorities** that will be relied upon to implement the plan.	Table 27, Implementation Strategy
5. An **information/education component** that will be used to enhance public understanding of the project and encourage the public's early and continued participation in selecting, designing and implementing the NPS management measures.	Technical / Financial Assistance
6. A reasonably expeditious **schedule for implementing** the NPS management measures identified in the plan	Table 31
7. Description of **interim, measureable milestones** for determining whether NPS management measures or other control actions are being implemented.	Table 31, Schedule and Milestones
8. A set of **criteria that can be used to determine whether loading reductions are being achieved** over time and substantial progress is being made toward attaining desired water quality standards. If not attained, criteria for determining if the watershed-based plan needs to be revised.	Schedule and Milestones
9. A **monitoring component** to evaluate the effectiveness of the implementation efforts over time, measured again the criteria established in (8).	Schedule and Milestones

The Scope of Work for the development of the Watershed Protection and Restoration Plan for the Manalapan Brook watershed was broken into eight (8) separate tasks as follows.

- Task 1: Characterization of the watershed
- Task 2: AVGWLF model of the watershed
- Task 3: Stream visual assessment
- Task 4: Supplemental water quality sampling
- Task 5: Targeted endpoint or long-term goal
- Task 6: Watershed protection and restoration plan
- Task 7: Implementation of a demonstration project
- Task 8: Engineering design plans for five projects

Each task of the Manalapan Brook watershed Scope of Work has been addressed in detail within the plan.

Characterization and Assessment of the Watershed

Introduction:
Manalapan Lake is a 48-acre impoundment of Manalapan Brook located in Thompson County Park, Monroe Township, Middlesex County, New Jersey. The initial Manalapan Lake Watershed Restoration/TMDL Implementation Plan encompassed the Manalapan Lake watershed (27 mi^2). The revised plan expanded the study area to include the entire Manalapan Brook watershed (43 mi^2), instead of terminating at Manalapan Lake. The Manalapan Brook watershed encompasses approximately 43 square miles divided among South Brunswick Township, Jamesburg Borough, Helmetta Borough, East Brunswick Township, Monroe Township, and Spotswood Borough in Middlesex County and Englishtown Borough, Freehold Township, Manalapan Township, and Millstone Township in Monmouth County. See Map 1 in Appendix A.

Census Data:
The 2000 US Census data reports that the populations within the municipalities in the Manalapan Brook region grew by approximately 35,000 people or 22% during the ten years from 1990 to 2000. Additional growth has occurred within the nine years since the census. The population of Middlesex County grew by 22,136 or 12%. The data also indicates that three communities significantly surpassed this rate, including: South Brunswick Township (46% growth), Helmetta Borough (50%), and Monroe Township (26%). Spotswood Borough was the only municipality that reported a population decline (1.3%). Monmouth County reported a similar population growth of 11%, three communities in the watershed significantly surpassed this rate, including: Englishtown Borough (39%), Manalapan Township (25%) and Millstone Township reported the highest population growth rate of 77%. While Millstone Township had the highest population growth, the overall population density remained the lowest at 244 people per square mile. The 2000 US Census data are summarized below in Table 2.

Table 2. United States census data for the Manalapan Brook region.

Municipality	Pop. 1990	Pop. 2000	% Change	Housing Units	Area (mi^2)	Pop. Den. ($\#/mi^2$)
South Brunswick	25,792	37,734	46%	13,862	41.1	920
Jamesburg Borough	5,294	6,025	14%	2,240	0.85	7,100
Helmetta Borough	1,211	1,825	51%	769	0.9	2,200
East Brunswick Township	43,548	46,756	7.4%	16,640	22.38	2,100
Monroe Township	22,255	27,999	26%	13,259	42.04	680
Spotswood Borough	7,983	7,880	-1.3%	3,158	2.49	3,400
Englishtown Borough	1,268	1,764	39%	680	0.58	3,100
Freehold Township	10,742	10,976	2.2%	3,821	2	5,500
Manalapan Township	26,716	33,423	25%	11,066	30.87	1,100
Millstone Township	5,069	8,970	77%	2,797	37.18	240

Subwatershed Delineation:

Subwatersheds were delineated using contours derived from 10-meter USGS Digital Elevation Model (DEM) data. The purpose of this subdivision was to provide a more detailed breakdown and analysis of the watershed. This approach enables the analysis to incorporate spatial data at a higher resolution as compared to the HUC-14 boundaries. A total of 20 subwatersheds were identified throughout the Manalapan Brook watershed by Princeton Hydro. The subwatersheds range in size from 0.26 mi^2 to 4.7 mi^2, with an average area of 2.2 mi^2 as shown in Table 3. Map 2 in Appendix A details other spatial characteristics of the subwatershed delineations.

Table 3. Summary of subwatershed delineations.

Subwatershed	Area (mi^2)
1	3.32
2	2.52
3	4.65
4	3.97
5	2.26
6	0.263
7	1.13
8	2.20
9	4.93
10	2.34
11	2.73
12	2.37
13	1.97
14	2.17
15	0.900
16	0.919
17	0.811
18	0.730
19	1.16
20	1.97
Sum	**43.3**

Land Use Land Cover:
In order to quantify existing and future impacts of land-based activities on the water quality of Manalapan Brook, it was necessary to generate a reasonably up-to-date land use/land cover GIS database for the Manalapan Brook watershed. As identified in the original project Scope of Work, the initial foundation for this watershed database was the NJDEP 1995/97 land use/land cover (LU/LC) data (NJDEP, 2000). The delineated watershed for Manalapan Lake and its associated LU/LC data are consistent with that used in the NJDEP *Total Maximum Daily Loads for Phosphorus to Address 5 Eutrophic Lakes in the Raritan Water Region* (NJDEP, 2003). To ensure that the LU/LC database of the Manalapan Lake watershed represents existing conditions as closely as possible, the most recent digital LU/LC (NJDEP) data were obtained. These data were acquired from the NJDEP Bureau of Geographic Information Systems website. The LU/LC data used were the 2002 LU/LC data released on March 10, 2008. These data were then edited by Princeton Hydro representatives based on the 2005 aerial photography to reflect recent (2002-2005) land use changes in the watershed. Maps of the land use in the watershed are provided in Map 3 in Appendix A.

Based on NJDEP 2002 LU/LC data, the watershed encompassed approximately 14% agricultural land, 2.6% barren land, 23% forested land, 36% urban land, 1.4% water, and 25% wetlands. The LU/LC data analyzed for this project are summarized in Table 4.

Table 4. Summary of LU/LC data (acres).

Land Cover Type	1995	%	2002	%	2005	%
Agricultural Land	4985	18	3925	14	3428	12
Barren Land	547.6	2.0	733.1	2.6	397.5	1.4
Forested Land	7373	26	6352	23	6010	21
Urban Land	7685	27	9710	35	10922	39
Water	364.1	1.3	394.5	1.4	394.5	1.4
Wetland	7155	25	6997	25	6959	25

Based on land use/land cover data, the three land uses that comprise the majority of the watershed are urban land, forested land, and wetlands. The most obvious trend is the conversion of agricultural and forested land to urban land as shown in Table 5.

Table 5. Summary of LU/LC changes.

Land Cover	1995 to 2002	2002 to 2005
Agricultural Land	-3.8%	-1.8%
Barren Land	0.66%	-1.2%
Forested Land	-3.6%	-1.2%
Urban Land	7.2%	4.3%
Water	0.11%	0.00%
Wetland	-0.56%	-0.13%

Graphical representation of this change in LU/LC is provided in Map 4 in Appendix A.

Water Resource Designation:
The Federal Clean Water Act (CWA) (33 U.S.C. 1315(B)), requires the State of New Jersey to prepare and submit to the USEPA reports addressing the overall water quality of the state's waters. This report is now referred to as the *New Jersey Integrated List of Waterbodies* which summarizes the 305(b) Report of the Water Quality and the 303(d) List of Impaired Waters. The Integrated Report identifies water quality in accordance with N.J.A.C. 7:15-6 and Section 303(d) of the CWA.

The NJDEP Surface Water Quality Standards (N.J.A.C. 7:9) designate Manalapan Brook as a FW2-NT waterway, or a non-trout freshwater stream (does not support trout production or trout maintenance).

The NJDEP has four stations on Manalapan Brook that monitor the aquatic macroinvertebrate diversity, referred to as the Ambient Biomonitoring Network or AMNET stations. Two of the monitoring stations in the watershed (AN0437 and AN0439) were found to be non-impaired, with a rich diversity of macroinvertebrates; however, the station at the Route 33 crossing (AN0438) in Monmouth County was reported as impaired with a low diversity of macroinvertebrates, as was the station on Old Forge Road downstream of Jamesburg (AN0440) (NJDEP, 2008). The AMNET data is summarized below in Table 6.

Table 6. Manalapan Brook, NJDEP AMNET data summary.

Municipality	NJDEP AMNET Station ID#	Location	AMNET 1993/94	AMNET 1998	AMNET 2002
Millstone Twp, Monmouth Cty	AN0437	Stage Coach Rd crossing	None	None	None
Manalapan Twp, Monmouth Cty	AN0438	Route 33 crossing	Moderate	None	Moderate
Monroe Twp, Middlesex Cty	AN0439	Federal Rd crossing	Severe	Moderate	None
Monroe Twp, Middlesex Cty	AN0440	Old Forge Rd crossing	Moderate	Moderate	Moderate

Stations AN0437 and AN0440 have not changed over the three assessments. Station AN0439 has steadily improved over the three assessments, and station AN0438 has gone from moderately impaired to non-impaired and back to a moderately impaired status.

The 2010 NJDEP Draft Integrated Report listed Manalapan Brook as non-attaining for aquatic life at all three monitoring stations (Assessment Units: 02030105140010-01, 02030105140020-01, 02030105140030-01) A map of these monitoring stations can be found in the Stream Visual Assessment report found in Appendix B. This source for this impairment is listed as TP (originally listed 2006) except below Manalapan Lake where the cause is unknown (originally listed 2008). This lower section is also non-attaining for public water supply (arsenic, 2006) and fish consumption (mercury, 2008).

The 2010 NJDEP Draft Integrated Report also identifies the entire Manalapan Brook as non-attaining water quality standards for primary contact recreation based on elevated levels of fecal coliform (originally listed in 2006). Fecal coliform concentrations were found to exceed New Jersey's Surface Water Quality Standards (N.J.A.C. 7-9B), and these waterbodies have a high priority ranking. The impaired stream segments for pathogens include the upstream portions of Manalapan Brook from the headwaters of Manalapan Brook extending downstream to the confluence of Manalapan Brook with Matchaponix Brook at Duhernal Lake. In 2003 the USEPA approved the TMDLs established by NJDEP to reduce pathogens (fecal coliform) by 89% in the entire Manalapan Brook (see Table 7). The NJDEP identified onsite wastewater treatment systems (OWTS) or septic systems as a major potential source of this pollution; however, it should be noted that horse farms and geese are also abundant in this watershed and may also be contributing sources of pathogens.

Table 7. Manalapan Brook, NJDEP Pathogen Data 2002.

Municipality	NJDEP Station ID#	Location	Primary Recreation
Manalapan Twp, Monmouth Cty	02030105140010-01	Manalapan Brook above Manalapan Lake	Non-attaining TMDL approved by USEPA
Monroe Twp, Monmouth Cty	02030105140020-01	Manalapan Brook at Manalapan Lake	Non-attaining TMDL approved by USEPA
Monroe Twp, Middlesex Cty	02030105140030-01	Manalapan Brook below Manalapan Lake	Non-attaining TMDL approved by USEPA

As stated in N.J.A.C. 7:9B-1.14(c) of the New Jersey Surface Water Quality Standards, "Fecal coliform levels shall not exceed a geometric average of 200 CFU/100 ml nor should more than 10 percent of the total samples taken during any 30-day period exceed 400 CFU/100 ml in FW2 waters." Nonpoint and stormwater point sources are the primary contributors to fecal coliform loads in these streams and can include storm-driven loads transporting fecal coliform from sources such as geese, farms, and domestic pets to the receiving water. Nonpoint sources also include steady-inputs from sources such as failing sewage conveyance systems and failing or inappropriately located septic systems. The total point source contribution other than stormwater (i.e. publicly-owned treatment works, POTWs) is an insignificant portion of the total load therefore, these fecal coliform TMDLs will not impose any change in current practices for POTWs and will not result in changes to existing effluent limits (NJDEP, 2005); however, it should be noted that indicator organisms were not the focus of this plan. It should be noted that while pathogenic organisms were not the primary pollutant of concern for the plan, as of 2007 *E. coli* has replaced fecal coliform as the pathogenic organism of concern in New Jersey waterways; however, the state's health departments still collect samples for fecal coliform analysis at swimmable beaches throughout the state.

Stream Network:
In addition to the LU/LC data, stream data were also updated in 2002 and released on August 3rd 2006. The updated data were obtained and used to calculate total stream length within the Manalapan Brook watershed. These data indicate that the watershed contains approximately 150 total stream miles. A summary of the total stream length for each subwatershed is provided in Table 8.

Table 8. Stream length calculations for subwatersheds.

Subwatershed	Length (mi)
1	4.94
2	9.52
3	11.8
4	14.1
5	0.894
6	1.06
7	5.03
8	9.26
9	23.3
10	9.37
11	10.3
12	6.94
13	6.49
14	9.24
15	3.70
16	3.04
17	2.35
18	2.68
19	4.91
20	8.02
Sum	**150**

Geology:
The surficial geologic deposits within the watershed are an important natural characteristic of the watershed. These geologic units are the basis of the soils found in the watershed and therefore have significant hydrologic and water quality (TSS, pH) implications for the watershed.

The Manalapan Brook watershed flows in a northerly direction and is entirely contained in the Coastal Plain physiographic province of New Jersey; however, the watershed's northern extent is located within only three (3) miles of the Piedmont province. The watershed transects numerous geologic outcrops all of which are associated with typical coastal plain depositional processes. The extreme headwaters (southern end) of the watershed contain portions of the Lower Member of the Kirkwood Formation. Further north in the watershed the area transects outcrops of the deeper formations including large outcrop areas of the Wenonah, Marshalltown, Englishtown, Woodbury, Merchantville, and Magothy formations. Many of these formations contain high quantities of glauconitic sand deposits; most notably the Tinton, Navesink, Mt. Laurel and Marshalltown formations (Map 5 in Appendix A). These deposits are associated with the acid producing soils which are found throughout the watershed.

Soils:
Soil survey data for Monmouth and Middlesex Counties were downloaded from the United Stated Department of Agriculture Natural Resources Conservation Service's (USDA NRCS's) Soil Survey Geographic (SSURGO) Database and Web Soil Survey (NRCS, 2008a; NRCS, 2008b). These data were then edited to contain only those soils found within the Manalapan Brook watershed (Map 6 in Appendix A). In addition to soil series, data on hydrologic soil groups, organic matter, water holding capacity, erosivity were incorporated into the digital database. A total of 36 soil series were identified within the watershed. Soil series are defined and delineated as soils that have similar major horizon composition, thickness, and arrangement.

The erosion factor (K) is an empirical representation of the soil's susceptibility to erosion used in the Universal Soil Loss Equation (USLE). This value ranges from 0.02 to 0.69, with higher values indicating soils that are more susceptible to erosion. The average erosion factor throughout the watershed was determined to be 0.29, which implies a moderate susceptibility to erosion. This is one of the main parameters used in the calculation of sediment loads from both surface erosion and streambank erosion (Map 7 in Appendix A).

The volume of water that a soil is capable of storing for uptake by vegetation is defined by the USDA as the soil's available water capacity (AWC) (NRCS, 1998). AWC has the unit of centimeters of water per centimeter of soil for each layer and is highly influenced by the amount of organic matter, soil texture, and soil structure. The average AWC for the Manalapan Brook watershed was 0.11 cm/cm, which is consistent with the loamy sands and sandy loams that are common in the watershed. Decomposing plant and animal matter in the soil is known as organic matter. Organic matter is expressed as a percentage (by weight) of organic soil material (combustible) that is less than 2 millimeters in diameter. As previously stated, AWC is highly influenced by organic matter; more specifically, organic matter increases AWC and has a positive effect on infiltration, soil organism activity, and soil structure. In addition, organic matter provides nutrients to plants and soil organisms. The ArcView Generalized Watershed Loading Function (AVGWLF) model requires that the AWC be supplied as an actual depth of water, not as a percentage as described by the raw AWC parameter in the SSURGO soil database. The soil database also lists the AWC for the specific soil profile depth. The average value for the Manalapan Brook watershed was determined to be 6.9 cm. This value is directly used in the GWLF hydrologic balance calculations (Haith et al., 1992).

Hydrologic soil groups (HSG) were identified using NRCS soils data for each soil type present in the watershed. HSGs represent the soil's propensity to create runoff. There are a total of four hydrologic soil groups: A, B, C, and D (Map 8 in Appendix A). The HSG with the lowest propensity to produce runoff are 'A' soils, typically these include coarse-grained materials like sands or loamy sands. The HSG with the highest propensity to produce runoff are HSG 'D' soils, which often include clays or soils with a shallow depth to groundwater. Based on the soils data, approximately 15% of the soils within the watershed were HSG A, 47% were HSG B, 13% were in HSG C, and 25% were in HSG D. It should be noted that approximately 411 acres were unclassified because they contained water or sand and gravel pits. The HSG are an important input parameter for the model because they are used (along with the LU/LC data) in the curve number calculations.

The NRCS soils database was also used to map the areas of the watershed which are mapped with soil as having formed in marine sediments containing glauconite. These soils exhibit unique physical and chemical properties and are typically considered acid producing soils. The soil series in the Manalapan Brook watershed with the highest glauconite content are the Colemantown and Marlton soil series (NRCS 2009). Map 5 in Appendix A displays the extent and location of acid producing soils in the watershed.

The New Jersey Flood Hazard Area Control Act Rules (NJAC. §7:13) define "acid producing soils" as “soils that contain geologic deposits of iron sulfide minerals (pyrite or marcasite) which, when exposed to oxygen from the air or from surface waters, oxidize to produce sulfuric acid.” Acid producing soils, upon excavation, generally have a pH of 4.0 or lower. After exposure to oxygen, these soils generally have a pH of 3.0 or lower (NJAC §7:13-1.2).

Princeton Hydro field staff observed water quality impacts related to high iron content, dense iron associated bacteria, and acidic seeps at multiple stations throughout the watershed as is further detailed in the Stream Visual Assessment section of this plan. The exposure of the acid producing soils at these locations has been exacerbated by development activities at many of the field sampling stations.

Groundwater Recharge:
The majority of the watershed (62%) contains areas mapped as HSG type A and B soils. These soils are generally conducive to infiltration and consequent groundwater recharge. The New Jersey Geological Survey Geological Survey Report GSR-32 (NJGS, 1993) provides estimates for annual groundwater recharge which are mapped according to the USDA soil series mapping and are based on a multitude of factors including soil conditions, land use / land cover, and climate-related conditions. Of specific importance to the Manalapan Brook watershed it should be noted that the GSR-32 methodology does not account for any groundwater recharge occurring from surface water bodies, wetlands, or hydric soils. The annual groundwater recharge estimates for the Manalapan Brook Watershed are provided in Appendix A. Large portions of the watershed are indicated to provide no annual recharge according to the GSR-32 methodology. These areas are primarily located in riparian areas, with a large concentration in the center (north to south orientation) where the soil mapping contains hydric soils.

Critical Habitat:
New Jersey is the most densely populated state in the United States; as such, natural habitats are being increasingly impacted due to developmental pressures. Fragmentation

decreases habitat health, and, depending on the species, reduces survivability of imperiled species. In 1994 the NJDEP, Division of Fish and Wildlife's Endangered and Nongame Species Program (ENSP) started the Landscape Project. The Landscape Project identifies important habitat for the protection of imperiled species, which can be used in planning and protection programs. Each landscape region has similar flora and fauna communities. Specifically, the database compiles information on the distribution, biology, status, and preservation needs of identified species and communities. The Landscape Project is a GIS managed database which helps to identify areas of suitable habitat for various wildlife, and provides an ecosystem-level approach to the long-term protection of imperiled and priority species and their important habitats in New Jersey.

NJDEP generally classifies species as follows (NJDEP, 2008):

Endangered:
Applies to a species whose prospects for survival within the state are in immediate danger due to one or several factors, such as loss or degradation of habitat, over-exploitation, predation, competition, disease or environmental pollution, etc. An endangered species likely requires immediate action to avoid extinction within NJ.

Threatened:
Applies to species that may become endangered if conditions surrounding it begin to or continue to deteriorate. Thus, a threatened species is one that is already vulnerable as a result of, for example, small population size, restricted range, narrow habitat affinities, significant population decline, etc.

Species of Special Concern:
Applies to species that warrant special attention because of some evidence of decline, inherent vulnerability to environmental deterioration, or habitat modification that would result in their becoming a threatened species. This category would also be applied to species that meet the foregoing criteria and for which there is little understanding of their current population status in the state.

The Landscape Project GIS mapping assesses five general habitat types: forest, forested wetland, grassland, emergent wetland and beach. The data layer delineates potential rare species habitat and ranks "species-based patches."

- Rank 5: This rank is assigned to patches containing wildlife species listed on the federal list of endangered and threatened species.
- Rank 4: This rank is assigned to patches with state endangered species.
- Rank 3: This rank is assigned to patches with state threatened species.
- Rank 2: This rank is assigned to patches with non-listed state special concern species, priority concern.
- Rank 1: This rank is assigned to patches that meet habitat suitability requirements, but that does not have confirmed occurrences.

For the Manalapan Brook watershed, the critical wildlife habitats were reported for the following species:

- bog turtle (federal endangered species) habitat areas were designated in Manalapan Township;
- bald eagle (state endangered species) foraging habitat is defined as the amount of habitat required to support a nesting pair of eagles throughout the year, as breeding bald eagles are year-round residents in NJ. The bald eagle foraging habitat was designated throughout most of the watershed;
- wood turtle (state threatened species) habitat areas were designated in Manalapan and Monroe Township and Helmetta Borough;
- box turtle and Fowler toad (state species of priority concern) habitat areas are designated throughout the watershed;
- grassland bird habitat (state species of priority concern) habitat areas are designated throughout the watershed.

These critical wildlife habitat areas are shown in Map 9 in Appendix A.

Open Space:
Spatial data identifying open space within the watershed was assembled from various open space datasets maintained by the Green Acres Program, managed through the NJDEP. Some of these open spaces are owned by federal, state, county, or non-profit organizations and include public and privately operated golf courses. The watershed also has designated open space, such as state and county owned land (for example, Monmouth Battle Field, Vallente Park, and others). A total of 2,373 acres of open space was identified within the watershed.

It should be clear that these areas of publically owned open-space are not necessarily protective of water resources. Many of the parks contain impervious surfaces and other development which is not protective of water resources. Thompson Park for example, contains impervious surfaces and a county-run zoo. Other open space areas, including the 1,479 acre Jamesburg Park Conservation Area, are undeveloped and maintained for the purpose of conservation.

Forty-seven percent (47%) of the watershed remains as intact forest, wetlands, floodplains and riparian zones. Within the watershed region, significant acquisition and preservation of open space has been undertaken by both Middlesex and Monmouth County. Middlesex County operates the 1,400 acre Jamesburg Park in Helmetta as a conservation area, James Monroe Memorial Park, and Thompson Park in Monroe Township, which includes several active recreational facilities, a zoo and Manalapan Lake. Monmouth County owns and operates the Charleston Springs Golf Courses and open space in Millstone Township, and the Thompson Park in Manalapan, and Millhurst Park.

Five large public and privately operated golfing and residential communities are present in the watershed. These golf courses include Charleston Springs in Millstone, 36 holes opened in 2002; Pine Brook in Manalapan Township, an 18 hole course; Knob Hill in Manalapan Township, 18 hole opened in 1998; Greenbrier at Whittingham in Jamesburg, 9 hole, built in 1996; and the Rossmoor Club in Monroe Township built in 1966.

Open Space areas within the Manalapan Brook watershed are presented in Map 10 in Appendix A. Further discussion of open space in the watershed is provided in the Water Resources Protection Open Space Criteria Analysis (WRPOS) section of the Identification and Prioritization section of this plan.

Septic:
The number of people on septic and sewer systems was estimated using the NJDEP septic sewer service area GIS dataset. Using this data, a GIS layer was created for areas with septic and sewer systems. This layer was overlain with the 2002 aerials, and the number of houses was counted for each municipality based on the municipality's wastewater treatment system (i.e. septic or sewer). The number of housing units in each municipality was divided by the 2000 census for that municipality in order to find the average number of people per housing unit. The average number of people per housing unit ranged from 2.1 to 3.2 for each municipality (see Table 9). These data were then used to find the total number of people on each wastewater treatment system, as well as an estimated population living within the Manalapan Brook watershed (~36,200). In spite of these numbers, the septic system contribution to the annual nutrient loads in the Manalapan Brook watershed was minor. Septic system leachate accounted for less than 2% of the annual TN load and less than 1% of the annual TP load.

Table 9. Summary of census and septic data.

Municipality	Housing Units	Census	People per Household	Households on Septic	People on Septic	People within Watershed
Monroe	13259	27999	2.1	161	340	10993
Englishtown	643	1764	2.7	0	0	11
Freehold	3821	10976	2.9	19	55	3783
Manalapan	11066	33423	3.0	1065	3217	5270
Millstone	2797	8970	3.2	173	555	564
South Brunswick	13862	37734	2.7	7	19	19
Jamesburg	2240	6025	2.7	2240	6025	6025
East Brunswick	16640	46756	2.8	12	34	3968
Spotswood	3158	7880	2.5	0	0	3740
Helmetta	769	1825	2.4	5	12	1825

Impervious Surfaces:
The most recent (2007) LU/LC data was published by the NJDEP in 2010. This data was used to calculate the impervious cover in the Manalapan Brook watershed. The analysis indicated that the 43 square mile watershed is covered by approximately 12% impervious

coverage. The same impervious coverage analysis was used for the 20 subwatersheds. The results of the subwatershed analysis indicated that the impervious coverage of the 20 subwatersheds ranges from 3.2% (#18) to 24% in the more urbanized sections of the watershed (subwatershed #4). Subwatershed #4 completely encompasses Jamesburg. The results are summarized in Table 10.

Table 10. Subwatershed impervious surface summary.

Subwatershed	Impervious Coverage (%)
1	18
2	21
3	9.3
4	24
5	14
6	7.2
7	4.8
8	6.2
9	3.6
10	19
11	6.8
12	18
13	8.4
14	9.4
15	6.8
16	11
17	4.6
18	3.2
19	4.8
20	4.4

Floodplains:

Manalapan Brook watershed contains a significant amount of land that is mapped by FEMA to be inundated during the one percent annual chance storm event (often referred to as the 100-year storm). The floodplains in the watershed are generally broad with average widths of approximately 600 feet in the watershed. These broad and relatively large floodplain areas are a result of the flat topography and low riparian wetlands areas which are typical of the coastal plain physiographic province. These areas provide critical flood control and water quality functions for the watershed. FEMA flood zones (areas subject to inundation by the one percent annual chance storm) are shown with both the watershed and municipal boundaries in Appendix A.

Stream Visual Assessment Protocol

Introduction:
The AVGWLF model was used to quantify the existing pollutant load; however, the model is only capable of providing pollutant loads on a municipal and sub-watershed basis. The watershed scale model is not intended to be used to identify site-scale sources of pollution. The first element of a Watershed Protection and Restoration Plan includes identification of the causes and sources of pollutant loading; therefore, a detailed field-based survey of the watershed was conducted using a standardized Stream Visual Assessment Protocol.

Although the goal of the watershed protection and restoration plan is to address TSS loads within the Manalapan Brook watershed, the stream visual assessment provided a more comprehensive assessment of the watershed, including channel conditions and bank stability, general ecological conditions, and the presence of stormwater infrastructure and invasive plant species at a series of visual assessment stations distributed throughout the watershed. The project Scope of Work outlined the following three objectives to utilize the findings of the visual assessment work:

1. Develop a detailed and comprehensive description of the health of Manalapan Brook and its tributaries.
2. Identify potential problem areas associated with nonpoint source (NPS) pollution and sediment loading.
3. Identify the nature and extent of NPS impacts, based on visual inspection and photo documentation of the physical characteristics of individual stream reaches or segments.

The Center for Watershed Protection (CWP) also promotes the use of stream visual assessments to evaluate the health of streams and watersheds. Additional goals and objectives outlined by CWP are also relevant to the Manalapan Brook field work and are incorporated into this report (CWP, 2005):

- generate maps and data on existing conditions for stakeholder education and recruitment;
- provide basic data to identify problem sites; and
- provide initial data to choose sites for more detailed analysis or more detailed assessments.

The project team also set a general target of identifying potential mitigation projects within each of the 20 subwatersheds, 10 municipalities and two counties within the watershed study area. Proposed projects include locations for stormwater retrofits, streambank stabilization projects, re-vegetating buffers, among others.

Delineating Assessment Stations:

In consultation with the project committee, staff from Princeton Hydro and the NJWSA identified 100 stream stations within the Manalapan Brook Watershed. Stream stations were identified based on prominent features such as headwater tributaries, the confluence of tributaries, public accessibility, road crossings, and municipality locations. Each station was assessed using an agreed upon Stream Visual Assessment (SVA) protocol which is included in Appendix B. The total number of stream stations assessed was modified based on field conditions, accessibility, safety, and development of headwater areas, and ultimately 94 stations in total were assessed. These stream stations were also identified with GPS technology and placed into the GIS database for the watershed.

Princeton Hydro created a grid of the entire watershed depicting the stream reaches and tributaries, municipal and county boundaries, major roadways, and stream stations. The watershed was divided into nine grids, and each grid was also enlarged as aerial photographs to depict details of land uses and riparian conditions that may impact stream health. Additional watershed mapping was also created to depict wetlands, wildlife habitat areas, land use, and open space. These maps were a valuable resource which was used throughout the visual assessment process. The maps streamlined the visual assessment process by providing field staff with spatial information to assist in the field determination of contributing drainage areas, land use, and other characteristics which are not always apparent at the field scale.

Full scale maps displaying all of the visual assessment stations are provided in the project mapping in Appendix A. For convenience and ease of reference inset maps are provided below in Figure 2 and Figure 3.

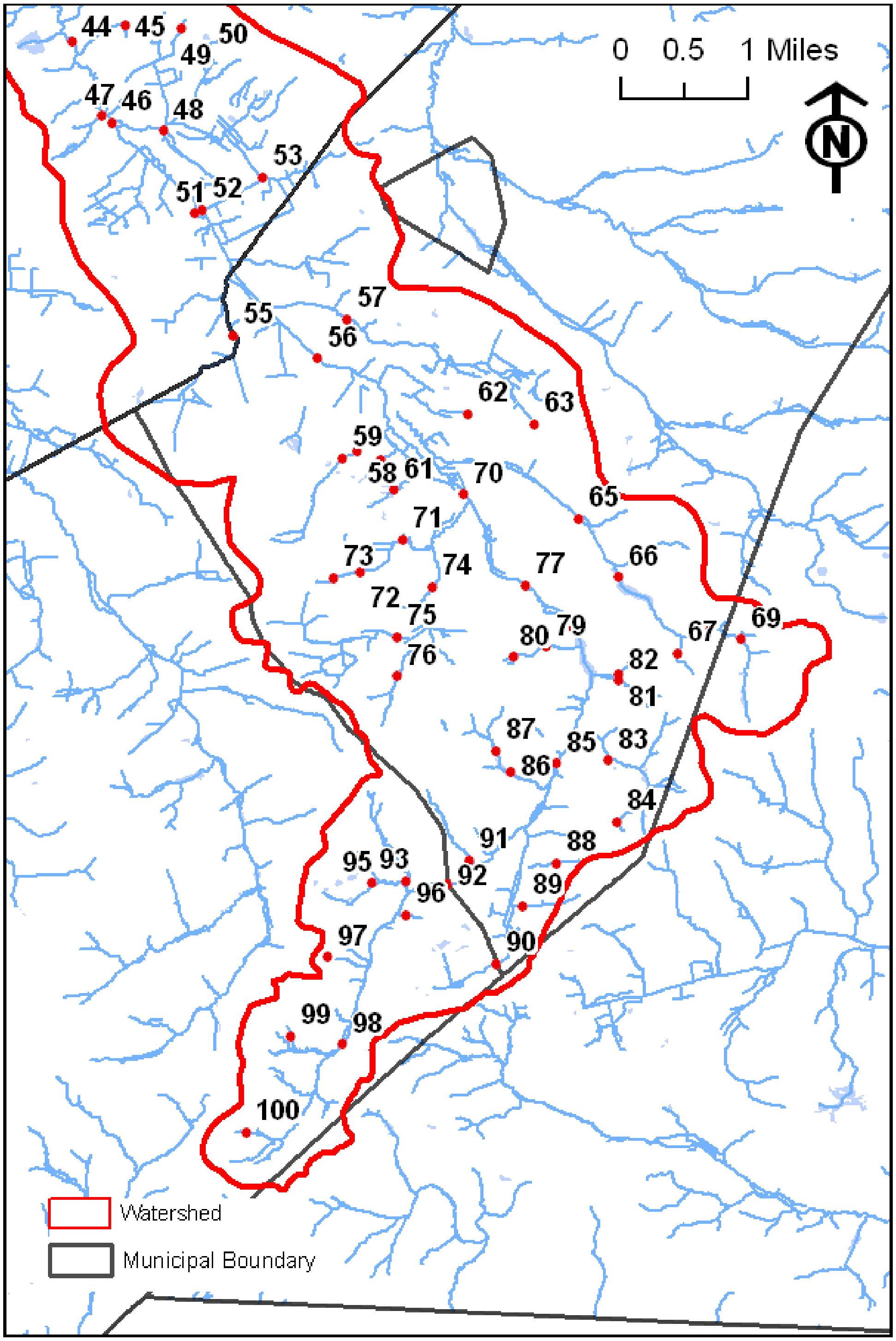

Figure 2. Visual assessment stations in the upstream (southern) section of Manalapan Brook watershed.

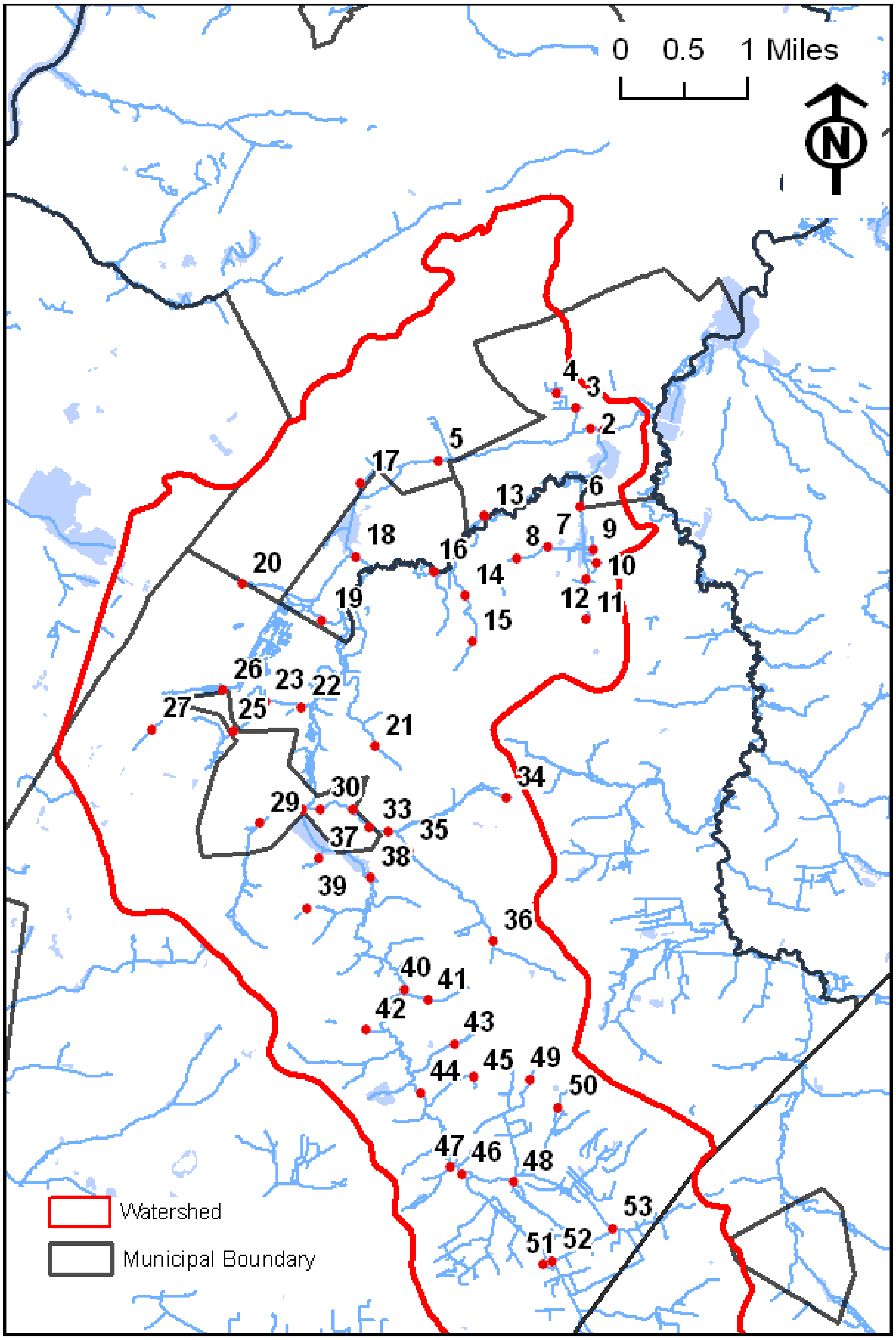

Figure 3. Visual assessment stations in the downstream (northern) section of Manalapan Brook watershed.

Visual Assessment Protocol:
A modified version of the state's protocol for performing stream visual assessments (SVAs) was used for the Manalapan Brook Watershed project. This SVA is largely based on the NRCS Stream Visual Assessment protocol, with additional protocols provided from the NJDEP, USEPA, and CWP protocols. The SVA reporting forms were also re-organized in order to expedite the recording of field notes. A copy of the SVA protocol data form used for this project is provided in Appendix B. The SVA field work was completed by staff from both Princeton Hydro and the NJWSA such that both organizations could obtain "hands on" understanding of the Manalapan Brook watershed.

The components of the SVA protocol include:

1. **Visual Assessment Scoring Survey of Stream Attributes:** A semi-quantitative visual assessment protocol was developed to evaluate fifteen distinct stream attributes that were assessed on a scale of 1 through 10 (higher scores reflect higher ecological integrity / fewer negative impacts). The assessment included features such as riparian buffer width, buffer condition, forest canopy cover, stream bank stability, stream channel condition, infrastructure hydrologic alterations, floodplain encroachment, aquatic plant community, invertebrate habitat and fish cover, barriers to fish movement, stream velocity and depth variability, pool variability, and manure presence. Stream width, depth, water appearance, stream substrate, and GPS coordinates were also recorded, and photographs were also taken at each station.

2. **Streamside Land Use Survey**: Various land uses within 100 feet of the stream were assessed to determine whether they were clearly impacting the stream. The land use form highlighted agricultural lands, residential housing, industrial or commercial developments, construction areas, and utility lines.

3. **Stormwater Outfall / Drainage Ditch Survey**: The stormwater outfall survey recorded locations (including GPS coordinates) and conditions of each stormwater outfall observed, including pipe diameter, material, type, and flow description. The stations were selected at stream road crossings, but drainage ditches were not frequently noted in this watershed.

4. **Invasive Plant Survey**: Common invasive plant species such as multi-flora rose, knotweed, phragmites, and honeysuckle vines were recorded and their presence was identified as either L ("local"), S ("scattered"), or W ("widespread"), in order to determine their potential impact on the stream corridor.

Streambank erosion can be a significant contributor to downstream sediment loadings in a watershed. This is further discussed in the detailed description of the AVGWLF model application for Manalapan Brook in this plan. The Stream Assessment Manual published by the Center for Watershed Protection (CWP) quotes a study by Trimble (1997) that more than half of the sediment loads from highly urban watersheds are derived from eroded banks (CWP, 2005). The model results in this application generally agree with these findings. The SVA team assessed the stability of the streambanks by ranking the stream stations from 1 to 10 regarding the presence of actively eroding outside bends, overhanging vegetation, falling trees, or slope failures. Assessments of streambank erosion were made as a part of the first component of the SVA protocol as listed above.

The conditions of a riparian corridor, including a healthy forest canopy along the streambank, can reduce the erosion of streambanks and reduce the potential runoff of fertilizers, herbicides, manure, and other NPS loads from impacting in-stream water quality. The SVA team assessed the health of the riparian corridor by evaluating the vegetative buffer width, canopy cover, and the presence of invasive plant species. Other encroachments in the floodplain and buffer were also assessed separately. Assessments of the riparian corridor were made as a part of the first component of the SVA protocol as listed above.

The SVA scoring form enabled the field staff to evaluate the typical stream attributes and the potential problems that generally occur in many watersheds in order to assess individual reaches, compare subwatershed areas, and identify potential best management practices (BMPs) that could be considered. A summary of these stream attributes, problems and BMPs are outlined in Appendix B; the detailed evaluations are also provided in the scoring forms supplied in Appendix B.

Example parameters from the SVA scoring form are summarized below in Table 11.

Table 11. SVA scoring survey of stream attributes.

Stream Attributes	Potential Problems Assessed	Potential Best Management Practices (BMPs)
Vegetated Buffer Width and Condition, Canopy cover, and Invasive Plant Survey Form	• Poor stream corridor habitat • Encroachment in buffer and floodplain • Impact on stream by increasing water temperatures • Degradation of vegetation buffer from the dominance of invasive plant species	• Active reforestation • Natural regeneration of forest • Greenway Connections
Bank Stability	• Areas of scour, erosion, down cutting, slope failures, bank widening, and the severity • Disconnection from floodplain • Potential impacts to property or infrastructure • Exposed glauconitic sands and clay that produce high iron and acids that reduce water quality	• Bank stabilization • Grade control • Improvements to stormwater controls • Minimize exposure of acid producing soils
Channel Condition	• Location and length of altered streams • Habitat degradation • Impacts to property or infrastructure	• Improve maintenance or repair • Re-design of a natural channel

Hydrologic Alterations	• Impacts of dams and water withdrawals on stream flow and habitats	• Re-design of a natural channel • Sampling stations • Detailed hydrologic investigations
Floodplain Encroachment	• Impacts to property or infrastructure • Frequency of flooding • Impacts on flood storage potential	• Active reforestation • Natural regeneration • Greenway Connections • Improvements to stormwater controls
Aquatic Plant Community	• Excessive nutrients or sediment loadings causing an overabundance of algal blooms or macrophytes (pond lilies) • Impacts to water quality and aquatic habitats from excessive growth and eutrophic conditions	• Investigate potential nutrient or sediment sources (NPS) • Reduce NPS sources • Enhance riparian corridor plantings • Dredge/remove sediments • Herbicide management
Invertebrate Habitat and Fish Cover	• Impacts to aquatic diversity from the physical conditions of the stream bank and stream bed	• Re-design of a natural channel • Improvements to stormwater controls
Stream velocity/ depth variability and pool variability	• Impacts to aquatic diversity from the physical conditions of the stream bank and stream bed	• Re-design of a natural channel • Improvements to stormwater controls
Barriers to Fish	• Impediments to fish movement by dams, outfalls, culverts, or utilities	• Improve infrastructure or barriers • Re-design of a natural channel
Manure Presence	• Sources of fecal coliform that have impaired the entire length of Manalapan Brook • Identify livestock sources • Identify geese populations • Identify sewer utility line crossings and conditions	• Promote BMPs for horse and cow farms • Promote reducing geese populations on local lakes • Investigate condition of utility lines
Outfall and Drainage Ditch Survey Forms	• Poor conditions of outfalls and infrastructure • Maintenance concerns • Areas of scour, erosion, down cutting, and their severity • Trash, debris and floatables impeding flow or water quality • Impacts to property and infrastructure	• Outfall stabilization or improve infrastructure • Improve maintenance • Improve stormwater controls • Cleanup sites for trash, debris and floatables • Re-design of a natural channel

Visual Assessment Data Management:
Based on initial field efforts, the scoring sheets were modified in order to better facilitate the site evaluation and scoring process. These modifications included moving similar categories together on the forms, and modifying the layout to reduce the forms from 8 to

6 pages. During the transfer of the field data to Excel spread sheets, the information and scores were evaluated to ensure a uniform method of scoring each criterion.

The scoring sheets were uniformly scored for the sixteen criteria, ten of which evaluated buffer conditions and/or habitat conditions for macroinvertebrates and fish. Therefore, the overall score was then weighted towards habitat and buffer conditions and not the potential for NPS or sediment loadings or stream bank stability. The result is that some stations scored relatively high based on the project protocols (greater than 6) but potential mitigation at these stations could reduce sediment loading to the stream and improve water quality. For this reason, the stations selected for further consideration were based on a combination of the SVA protocol scores, AVGWLF model results, visual observations, professional expertise, and the potential to reduce sediment loading to the watershed. This process is further explained in the Watershed Protection and Restoration Implementation Strategy section of this document.

Visual Assessment Results:

Field assessments of each station were conducted by walking approximately 500 feet upstream and downstream of the road crossing where conditions permitted access. At each station throughout the watershed, field conditions were documented, the resulting assessment scores for each stream station are summarized in data tables in Appendix B. It should be noted that no water sampling or water chemistry measurements were conducted as part of the visual assessment process.

The data collected include 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, presence of drainage ditches, and exceptional resources. 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 criterion assessed.

Following scoring, each stream segment was ranked among 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. The general scoring distribution is summarized below in Table 12.

Table 12. General SVA scores within the watershed.

SVA Score	General Health	No. of Stations	% of Stations
>7.5	Good or Excellent	41	44%
6-7.5	Fair	29	31%
4-6	Some Impairment	18	17%
<4	Serious Impairment	8	8%

Based solely on the SVA scores, forty-one stations out of 94 (44%) received a final score of greater than 7.5 and are considered in good condition or better, and these stations are listed below in Table 13. Twenty-nine stations (31%) with scores between 6 and 7.5 were considered in fair condition. Sixteen stations (17%) within the entire watershed received scores of 4-6 as listed in Table 14. Eight stations (8%) received scores less than 4 and are listed in Table 15 as having serious impairments. Based solely on the SVA score, 75% of the stations were determined to be in fair health or better, with 25% of the stations with observed impairments. Additionally, there are sixty-three (63) stations upstream of Manalapan Lake and based on this SVA scoring protocol, thirty-one (31) of these stations or nearly half were considered in good condition.

It should be noted that several of the criteria in the visual assessment protocol are related to the stream ecological and habitat conditions for invertebrates and fish, and are not directly related to the main concerns impacting Manalapan Brook, such as the high sediment loadings, fecal coliform and high nutrients. Therefore, some stations with high scores may still have unstable bank conditions and may be recommended for some form of mitigation.

Table 13. Stations with scores >7.5, good to excellent.

Station	Stream	Municipality	Overall Score
4	Cedar Brook trib	Spotswood	8.89
13	South River Wetland	Spotswood	7.50
5	Cedar Brook	East Brunswick	7.57
16	MB Mainstem	Helmetta	8.64
28	MB Mainstem	Jamesburg	8.86
11	South River Wetland	Monroe	9.43
20	Tributary to MB	Monroe	7.86
22B	MB Mainstem	Monroe	8.14
23	ditched wetland	Monroe	9.00
27	Tributary to MB	Monroe	9.38
33	Barclay Brook	Monroe	7.93
38	MB entering Manalapan Lake	Monroe	7.64
40	MB Mainstem	Monroe	9.23
41	MB Mainstem	Monroe	8.15
43	Tributary to MB	Monroe	7.80
44	MB Mainstem	Monroe	9.08
46	MB Mainstem	Monroe	8.64
48	Tributary to MB	Monroe	8.43
49	Tributary to MB	Monroe	7.50
50	Tributary to MB	Monroe	8.29
51	Tributary to MB	Monroe	8.71
52	MB Mainstem	Monroe	8.07
54	MB Mainstem	Manalapan	8.29

56	MB Mainstem	Manalapan	8.14
57	North Brook	Manalapan	9.21
58	Tributary to MB	Manalapan	8.73
62	MB Mainstem	Manalapan	8.29
63	Tributary to MB	Manalapan	7.71
64	Tributary to MB	Manalapan	8.21
74	MB Mainstem	Manalapan	8.07
75	Tributary to MB	Manalapan	8.71
76	Gander Brook	Manalapan	9.07
77	MB Mainstem	Manalapan	8.71
78	MB Mainstem	Manalapan	8.43
82	Tributary to MB	Manalapan	7.71
83	Pond	Manalapan	7.93
85	MB Mainstem	Manalapan	9.14
87	Tributary to MB	Manalapan	8.07
90	Tributary to MB	Manalapan	7.86
93	Tributary to MB	Millstone	7.79
96	Tributary to MB	Millstone	7.64
98	MB Mainstem	Millstone	8.00

Table 14. Stations with scores 4-6, some impairment.

Station	Stream	Municipality	Overall Score
2	DeVoe Lake / Cedar Brook	Spotswood	5.50
3	Cedar Brook	Spotswood	4.21
30	Barclay Brook	Jamesburg	5.93
31	Barclay Brook	Jamesburg	6.07
32	Barclay Brook	Jamesburg	5.57
7	South River Tributary	Monroe	5.71
8	South River Tributary	Monroe	5.14
10	South River Wetland	Monroe	5.86
24	ROW Ditched Wetlands	Monroe	4.50
26	Ditched Wetlands	Monroe	5.71
53	Tributary to MB	Monroe	5.50
67	Tributary to MB	Manalapan	5.93
86	Lake/Wetland	Manalapan	4.07
92	MB Mainstem, Pond	Manalapan	5.43
94	Tributary to MB	Millstone	4.67
95	Tributary to MB	Millstone	6.00

Table 15. Stations with scores <4, serious impairments.

Location	Stream	Municipality	Overall Score
19	Tributary to MB	Helmetta	3.79
29	Wigwam Brook	Jamesburg	2.93
15	Tributary to MB	Monroe	3.07
37	Manalapan Lake	Monroe	2.86
45	Tributary to MB	Monroe	2.86
71	Tributary to MB	Manalapan	2.36
80	Tributary Running Thru Ponds	Manalapan	3.64
84	Tributary Within Detention Basin	Manalapan	2.21

The findings of the SVA are summarized in the above tables; the site-specific problems and results are provided below with more details provided in Appendix B.

Upper Watershed Region
Millstone and Manalapan Townships, Monmouth County
Stations #100-#51

Millstone Township contains the headwaters and small tributaries to the Manalapan Brook. Land use was predominately farming, including horse farms, stables and training tracks until the 1990s, when significant residential development occurred in this area. Several horse training facilities were developed into residential homes. The NJDEP aerials and land use data indicate that these headwater areas are approximately 50% developed as residential housing, 30% wetlands and forest and less than 20% agriculture. The remaining agriculture is predominately commercial nursery operations. Within Millstone Township the residential developments preserved the floodplain and wetland areas; therefore, the riparian buffers are predominately intact forested wetland areas.

Within Millstone Township, significantly eroded streambanks were observed at station #98, eroded streambanks (2-3 feet) on the Manalapan Brook mainstem, downstream of the bridge on Harmony Road. At station #98 Manalapan Brook crosses under Harmony Road via two 48-inch culverts. Significant sediment deposition and vegetative growth are blocking flow for one of the culvert crossings.

The glauconitic soils are present in this region; however, the stream buffers in these areas are well preserved and the field staff did not observe significant detrimental impacts due to exposed acid producing soils.

The Charleston Springs Golf Course is located within the upstream segment, and is owned by Monmouth County. Monmouth County has implemented several BMPs at the golf course including the preservation of wetlands and riparian corridors, eradicating invasive plants, planting of native grasses along fairways and buffers, maintaining vegetative buffers along all ponds, and minimal herbicide use. Additionally, the county currently allows winter deer hunting to reduce the deer herd, which according to Monmouth County personnel was identified at approximately 160 deer utilizing this one square mile golf course. The NJ Division of Fish and Wildlife suggests managing for approximately 20 deer per square mile in order to maintain an intact forest. Managing the deer herd can assist in conserving vegetated buffers on the golf course.

Although the county has implemented these BMPs, conditions such as the shallow water depth, high algal growth, and overabundance of lilies in the pond on the Charleston Springs Golf Course suggest that an increased sediment deposition and/or nutrient loading may have or may be actively occurring at station #92. Aerial photographs identify that the pond lilies were minimally present at the pond prior to the golf course construction in 2002. In 2002 the lilies were present in 40% of the pond in the upper segment of the pond above the pedestrian bridge. The 2005 aerials show the lilies spreading to 75% or more of the pond. This may indicate that a significant sediment and/or nutrient load to the pond may have occurred as a result of the golf course's construction in 2002.

Manalapan Township contains the mainstem of Manalapan Brook. Significant floodplains and wetlands exist in this area, and have been preserved as intact forests. The 2002 NJDEP aerial photograph and land use data indicate that the lands in this township include approximately 30% wetlands; 20% forests; 25% residential and commercial development; and 25% agricultural land.

In general, the stream segments have natural channel conditions with unimpeded access to the floodplain. The majority of the stream stations were characterized by slow and shallow flows, with shallow pools more prevalent than deep pools. The banks and stream beds are stable, with what appeared to be suitable aquatic habitat for fish and macroinvertebrates. Sediment bars were present at stations #75 and #79. Barriers to fish movement greater than one foot high, primarily associated with road crossing culverts, were present at stations: #89, #88, #87, #84, #82, #78, #68, and #67.

Poor maintenance of stormwater basins, outlets, outfalls, and culverts was noted in many of the stations in Manalapan Township. Specifically the following stations are noted:

- stations #91, #90, #84, #82, #79, #57 and #55: had evidence of poor maintenance practices;
- station #80: stormwater is directed to ponds at station #80, and the dam and outfall for the second pond appears to have collapsed. The ponds lack sufficient riparian plantings and buffers which could improve the water quality benefit of the ponds;
- station #84: a stormwater detention basin was constructed with a small tributary flowing through the concrete channel of the basin. The channelized nature of the stream impacts water quality by increasing water temperature, increasing algal growth, and degrading aquatic habitats; and,

- stations #83, #78, and #57: significant accumulations of litter and floatables (primarily bottles and cans).

Acid producing soils underlie the majority of the subwatershed regions in Manalapan Township. The stream visual assessment stations in Manalapan Township were mapped with current USDA soils data and were determined to be likely to contain glauconitic soils. The maps indicate that stations near Stillhouse Brook and Gander Brook were located near the high level acid producing soils (stations #72, #73, #74, #75, and #76); however, while some iron (orange) discoloration was noted in the water appearance, these stations were not as severely impacted as other areas. This is likely a result of the fact that the riparian corridors of these streams were mostly intact, forested areas.

At stations #82, #67, and #71 the construction of stormwater culverts caused the exposure of acid producing soils. At the time of the assessment (summer 2008) some mitigation measures had been implemented which included:

- partially lining the stream bank and stream bed with silt matting material to reduce soil exposure;
- covering the matting with 6-12 inches of soil and a grass cover; and
- new riparian plantings along a re-aligned tributary at station #71.

At station #82 these measures appear somewhat successful; however, the grass cover is nearly entirely Japanese stilt grass, an invasive plant, and the matting prevents shade trees from re-generating in the area to protect the stream and streambank.

Station #67 has several problem areas including: the high storm flows from this outfall are actively eroding the stream bank by 3-4 feet; acid seeps are present along the streambanks; and there is widespread growth of Japanese stilt grass over the matting and into the wooded area.

Within Manalapan Township there were a significant number of eroded streambanks that were observed during the stream visual assessment, including:

- station #78: eroded streambanks (>6 feet) on the Manalapan Brook mainstem, downstream of the former mill and pond on Route 527;
- station #67: eroded streambanks (3-4 feet) on an unnamed tributary, downstream of the outfall at Kinney Road;
- station #58: eroded streambanks (3-5 feet) on a tributary, downstream of the outfall at Daum Road;
- station #52: eroded streambanks (>6 feet) on the mainstem, downstream of the bridge on Federal Road; and
- station #51: minimal riparian vegetation was noted and frequent riparian mowing appeared to be present.

Within Manalapan Township land uses that may be impacting the riparian corridor and water quality include: several horse farms and training facilities, garden nurseries, and lakeside residential developments. The following stations were of specific note:

- station #86: there was minimal riparian vegetation and frequent riparian mowing along the lake shore;
- station #80: there were minimal amounts of riparian vegetation and the riparian vegetation was frequently mown along both ponds at this station;
- stations #60, #55, #54, #53, and #51: at these stations there were minimal amounts of riparian vegetation and the riparian vegetation was frequently mown along the streambanks, these conditions increase NPS and runoff and do not prevent stream access by livestock which was observed in the mainstem of Manalapan Brook in the vicinity of station #52 as shown below in Figure 4.

Figure 4. Livestock fence enclosure located within Manalapan Brook near station #52.

Central Watershed Region
Monroe Township, Middlesex County
Stations #50-#34

This section focuses on the health of the central portion of Manalapan Brook, within Monroe Township and Middlesex County, from station #53 downstream to and including station #37 at Manalapan Lake. The 2002 NJDEP aerials and land use data indicate that the watershed lands in this township include approximately 50% wetlands; 20% forests; 25% residential and commercial development; and 25% remain as agriculture.

In general, the stream segments have natural channel conditions with some access to the floodplain during major storm events. The majority of the stream stations were characterized by slow and shallow flows, with some shallow pools. The streambanks on the mainstem of Manalapan Brook are generally downcut by 3-4 feet throughout the lower segment. The stream beds are stable, with suitable aquatic habitats for fish and macroinvertebrates. Barriers to fish movement greater than one foot high were present at stations: #47, #42, and #37. These barriers primarily consisted of culverts at road crossings.

Monroe Township is responsible for maintaining some of the stormwater basins in this subwatershed. During the visual assessment (Summer 2008) significant sediment deposition of 6-12 inches was being removed from the low flow channels at station #15. Poor maintenance practices were observed at the following stations:

- stations #50, #49, #47, #45, #43, #42, and #41: displayed poor maintenance of stormwater facilities; and,
- station #37: large amounts of "uncontrolled"[1] impervious surfaces and exposed soils were observed.

At Station #41, at a railroad bridge overpass, a large tree had fallen into the mainstem of Manalapan Brook. This fallen tree and debris were blocking stream flow at the time of inspection (spring 2008).

Station #37 is located on Manalapan Lake in Thompson Park, which is owned and operated by Middlesex County. The county operates a zoo within Thompson Park that houses over 50 geese and fowl, goats, and approximately 90 deer in a fenced enclosure, according to a zoo staff member. Foraging by the zoo inhabitants has removed most ground cover. The bare soil condition and the presence of manure contribute sediment, nutrient and pathogen loading to the lake, further reducing water quality. It is not known whether the zoo is subject to any specific animal waste or other rules which regulate zoos. In addition, visual observations indicate that over 500 Canada geese and seagulls routinely utilize Manalapan Lake in the winter, contributing additional pollutant loading. Over fifty resident geese were utilizing the lake during the spring 2008.

Within Monroe Township, eroded streambanks were observed at:

- station #48: eroded streambanks (3-4 feet) on an unnamed tributary, downstream of the culvert crossing at Monroe Boulevard;

[1] The term "uncontrolled" refers to impervious surfaces that generate runoff that is not controlled or managed in any fashion, whether it be a detention basin or other stormwater control. Runoff from these is often directly connected via pipe networks to receiving water bodies including lakes, and streams. The construction of these uncontrolled impervious surfaces may not have been subject to stormwater requirements or the construction may have pre-dated stormwater management regulations.

- station #36: eroded stream banks were observed at station #36, and towards the end of Louise Lane. There were approximately 100 yards of eroded streambanks (3-4 feet high) which were noted along the mainstem of Manalapan Brook.

Significant impairments to the riparian corridor were noted in this section of the watershed. Specifically, station #44 was noted to have insufficient riparian vegetation.

Lower Watershed Region Downstream of Manalapan Lake
Jamesburg, Helmetta, and Spotswood Boroughs and East Brunswick Township, Middlesex County
Stations #33-#1
This section focuses on the health of the lower portion of Manalapan Brook, within Jamesburg, Helmetta, and Spotswood Boroughs and East Brunswick Township, Middlesex County, from downstream of Manalapan Lake from station #33 to station #1. The 2002 NJDEP aerials and land use data indicate that the watershed lands in this township include approximately 15% wetlands; 20% forests; 50% residential and commercial development; and 15% remains as agriculture.

The lower portion of Manalapan Brook contains significant floodplains and wetland areas, which were preserved as intact forests. In general, the stream segments on the mainstem of Manalapan Brook and Barclay Brook have a natural channel condition with some access to the floodplain during periods of high flow conditions. The streambanks on the mainstem of Manalapan Brook and Barclay Brook are generally down cut by 3-4 feet throughout the lower segment. The majority of the stream stations were characterized by slow and shallow flows with some shallow pools. The stream beds are somewhat stable, with aquatic habitat that appeared to be suitable to support fish and macroinvertebrates. Significant sediment accumulation was observed throughout DeVoe Lake, and at stations #3, #31, and #32. Culvert crossings creating barriers to fish movement were present at stations #28, #3 and #1.

There were notable problems resulting from poor maintenance practices at several stormwater facilities throughout this section of the watershed including:

- station #32: poor sediment removal practices have exposed large portions of the basin bottom. The unnamed tributary has severe streambank erosion at this station and has severely impacted a property. The resident at this property has constructed a large gabion wall in an attempt to prevent additional property loss. The erosion is also undercutting trees, a storm sewer outfall, and the roadway;
- station #29: there is a severely eroded ravine in this location with large amounts of exposed and actively eroding soil. This erosion is further aggravated by several stormwater outfalls (from Beaver Brook apartments) along the west side of Wigwam Brook;
- station #26: large sediment accumulations were noted in culverts and other drainage ways; and,

- stations #19 and #3: sediment accumulation was impacting the capacity of road culverts at these locations.

Significantly eroded streambanks were observed at the following locations:

- stations #32, #31, #30, #29, and #28: these stations had severely eroded streambanks that included the exposure of acid producing soils at stations #29 and #28; and,
- station #29: the eroded ravine is nearly 50 yards long and 10-15 feet high on Wigwam Lane. Based on a visual assessment this erosion was the most egregious in the watershed. The streambanks appeared to be actively eroding with numerous trees whose roots have been undermined and have either previously fallen into or are currently in the process of falling into the eroding stream.

Wetlands are present at stations #20, #22, #23 and #24 but these wetlands were impacted from previous ditching efforts to drain them, and overhead power lines which cross the area. All-terrain vehicle (ATV) use is also prevalent within the right of way (ROW) for the power lines, this activity frequently leads to exposed soil and consequent TSS loading. These areas are adjacent to highly populated areas, and, based on personal communication with county personnel, the wetland areas are routinely sprayed by the county for mosquito control.

Barriers to fish movement greater than one foot high were present at stations: #21, #15, and #7. These barriers consisted of culverts at road crossings. Depositional sediment bars were noted in the upper sections of DeVoe Lake, and at stations #7, #11.

Station #5 on Cedar Brook in the Village Trailer Park in East Brunswick Township, had a high level of algae and macrophyte growth, which could be indicative of high nutrient loading. Wastewater conveyance systems or septic systems could be the potential source of these nutrients.

Throughout the lower segments of Manalapan Brook, Barclay Brook and the South River, dense urban development, limited stormwater detention controls and significant floodplain development and encroachments reduce the width of the riparian forested corridor, increase stream flows, and aggravate streambank erosion. In many areas the riparian buffers are less than 25 feet. The frequent encroachments from street storm sewers, road crossings, private fencing, yards, sheds and development have led to degraded water quality conditions and degraded channel conditions throughout these areas. Based on visual observations the use of ATVs was also prevalent in the lower segment of Manalapan Brook.

Water Quality Data

Introduction:
Selected water quality and ecological data were collected on Manalapan Lake to determine if the NJDEP's TMDL modeled TP concentrations based on the Reckhow Model reasonably agree with existing in-lake concentrations. While the Manalapan Lake dataset was limited in size and scope (five sampling events over the course of 2004 and 2005 growing seasons and four sampling events over the 2008 growing season), existing TP concentrations diverged significantly from modeled concentrations. Based on the limited amount of water quality sampling that was conducted at Manalapan Lake, the mean surface water TP concentration was 0.032 mg/l for the 2004-05 database. If the 2008 TP concentrations are included in that database, the mean TP concentration is 0.047 mg/l. In contrast, based on the Reckhow model, the mean in-lake TP concentration is 0.132 mg/l. Thus, the Reckhow model severely overestimates the mean TP concentration.

Furthermore, using the Carlson's trophic state models for total phosphorus, Secchi depth and chlorophyll *a*, deviations from standard phosphorus – algal relationships can be identified. Based on this deviation analysis, there tends to be a surplus of phosphorus associated with non-algal particles. These non-algal particles are also frequently responsible for the low water clarity. Based on some inter-relationships among various in-lake trophic parameters (TP, chlorophyll *a* and Secchi depth), the highly turbid conditions experienced in Manalapan Lake tended to be the result of inorganic particulate material and not algal blooms (Carlson and Havens, 2005); however, it should be emphasized that while algal blooms can still periodically create nuisance conditions in Manalapan Lake, the majority of the turbidity problems impacting the lake and associated waterways are elevated concentrations of inorganic particles.

The empirical data collected in 2004 and 2005 were extremely valuable, since they revealed that focusing on TP as the primary pollutant of concern for Manalapan Lake may not be the most effective means of managing this watershed. For convenience, the entire Interim Water Quality Report is included in Appendix C. As will be described below, additional data were collected during the 2008 growing season that provided additional support for this suggestion.

Since the amount of in-lake water quality data collected in 2004 and 2005 was limited, it was recommended that additional in-lake data be collected to develop a larger, inter-annual database on Manalapan Lake. A larger database will aid in verifying the alternative approach that is now being taken for the management of the Manalapan Brook watershed. Thus, four additional in-lake, water quality monitoring events were conducted during the 2008 growing season. This section of the Manalapan Brook Watershed Restoration Plan discusses the 2004 and 2005 data, as well as the water quality data collected during the 2008 growing season.

In addition to collecting an additional year of water quality data, another monitoring task was included during the 2008 program, to satisfy one of NJDEP's requirements in the development of a state-approved lake characterization plan. Specifically, consecutive monitoring of Manalapan Lake over a *minimum* of two days for dissolved oxygen, temperature, and pH was conducted. Four readings of the *in-situ* data were collected per hour over the course of the monitoring period, during the height of the late summer season (early September). An YSI 6920 multi-parameter system was installed in the lake adjacent to the dam in Jamesburg. These data were valuable in assessing diurnal fluctuations in Manalapan Lake through the late summer season and identifing potential violations of state water quality criteria. Comprehensive monitoring data summary tables for all measured parameters are provided in Appendix D.

Sampling Protocol:
In order to comply with NJDEP's protocol for lake characterizations, it was recommended that Manalapan Lake be sampled four times over the course of the 2008 growing season. These monitoring events were conducted on 2 May 2008, 19 June 2008, 1 August 2008 and 19 August 2008. This proposed sampling program was smaller in scale than the first one conducted in 2004-05 (11 August 2004, 18 October 2004, 18 April 2005, 14 July 2005 and 16 August 2005); however, the 2008 monitoring of Manalapan Lake included a nine (9) consecutive day diurnal monitoring event of dissolved oxygen, temperature, and pH. At least one reading was recorded every 15 minutes throughout the day (as per the state's recommended methodology for lake characterization plans) over the course of nine days during September 2008. An YSI 6920 multi-parameter system was installed in Manalapan Lake adjacent to the dam in Jamesburg.

Prior to sampling the lake, an addendum to the existing Quality Assurance Project Plan (QAPP) was prepared. All protocols and methodologies associated with collecting these field data and conducting all necessary analyses were identified in the amended QAPP. The QAPP was submitted to NJDEP prior to initiating the monitoring program. No sampling or monitoring occurred until the amended QAPP was approved by NJDEP.

During each sampling event, *in-situ* data were collected from two in-lake sampling stations (see Figure 5): a mid-lake sampling station located near the dam/outflow of the lake (ST-1) and a near-inlet sampling station located in the shallower, southeastern section of the lake (ST-2). In addition, *in-situ* data were also collected from the Manalapan Brook inlet. A calibrated Eureka or Hydrolab Quanta data sonde was used to collect the *in-situ* data. These data were collected in profile, from surface to bottom at 0.5 to 1.0 meter intervals. The measured parameters included temperature, dissolved oxygen (DO), pH and conductivity. Water clarity was also measured with a Secchi disk at each in-lake sampling station. The raw *in-situ* data are provided in a following section.

Figure 5. Sampling stations in Manalapan Lake (yellow circles).

In addition to the *in-situ* data, sub-surface (0.5 m below the water's surface) discrete water samples were collected during each sampling event with a Van Dorn sampling device at ST-1 and ST-2. The discrete samples collected from ST-1 were analyzed for TP, TSS, soluble reactive phosphorus (SRP), and chlorophyll *a*. The discrete samples from ST-2 were analyzed for TP and TSS. These samples were appropriately preserved and transported to a state-certified laboratory for analysis. These discrete data provided the information needed to conduct the Carlson Trophic State Index deviation analysis, which was used to determine that inorganic suspended material was the primary cause for low water clarity in Manalapan Lake. Finally, a bottom water sample (approximately 0.5 meters above the sediments) was collected at ST-1 during each sampling event and analyzed for TP to provide an estimate of the lake's internal phosphorus load. Also, zooplankton and phytoplankton samples were collected during each monitoring event at ST-1. These biological samples were to taken to Princeton Hydro biological laboratory where they were identified and enumerated. All water quality data are provided in Appendix D.

In addition to the in-lake and inlet sampling, discrete stormwater samples were collected at ST-2 on 28 April 2008, 23 July 2008, and 14 November 2008. These stormwater samples were analyzed for TP and TSS; the resulting data were used to calculate pollutant loading to Manalapan Lake during storm events.

In-situ Data:

Temperature:
Temperature affects a number of physical, chemical, and biological processes in natural waters. It is controlled primarily by climatic conditions, but human activity can also have an influence. The temperature regime of a lake is a function of ambient air temperatures, as well as the morphometry and setting of the lake. One of the most biologically important impacts of temperature is the decrease in oxygen solubility with increasing temperature. In other words, the higher the water temperature, the less DO that water can hold. Another important ecosystem-based impact of temperature in lakes is the duration and strength of thermal stratification. The temperature difference between the surface and bottom waters of a lake can be large enough to essentially separate the bottom waters from atmospheric exchange. In productive waterbodies, this can result in a depletion of DO in the bottom waters and a substantial increase in the release of phosphorus from the sediments. Such conditions depend on the morphometry of a lake and its level of productivity.

Thermal stratification is typically defined as occurring when the water temperature declines by more than one degree (Celsius) over a depth of one meter. In Manalapan Lake, thermal stratification was detected on 11 August 2004 (Appendix C); on that date, from 1.5 m to 2.0 meters there was a 4-degree decline in water temperature. By October 2004, the lake was well mixed, which was also the case in April 2005. By mid-July 2005, the lake was once again thermally stratified. Such stratification was also detected during the mid-August 2005 sampling event. Thus, in spite of its relative shallow depth, Manalapan Lake does thermally stratify, at least in the area adjacent to the dam during the summer season. Such conditions are very typical of relatively shallow, highly productive, temperate waterbodies. During the summer months, the surface waters warm to a temperature sufficient to produce a density difference between the surface and bottom waters strong enough to result in thermal stratification. The impacts of such conditions during the summer months are explained below in detail.

Temperatures in Manalapan Lake coincided with seasonal variation in temperature and varied from 14.7°C on 2 May 2008 to 26.2°C on 19 August 2008. Thermal stratification at ST-1 was weak during the May and June sampling events; however, during the August sampling event thermal stratification was slightly stronger with temperatures varying approximately 4-5°C from surface to bottom. Temperatures at ST-2 followed a pattern similar to ST-1 with the exception of the May and June sampling events, where stratification was slightly stronger at ST-2 than at ST-1 (see Figure 6 and Figure 7). Overall, thermal stratification at both stations was strong enough to result in a reduction of bottom water DO concentrations during the mid-to-late summer season.

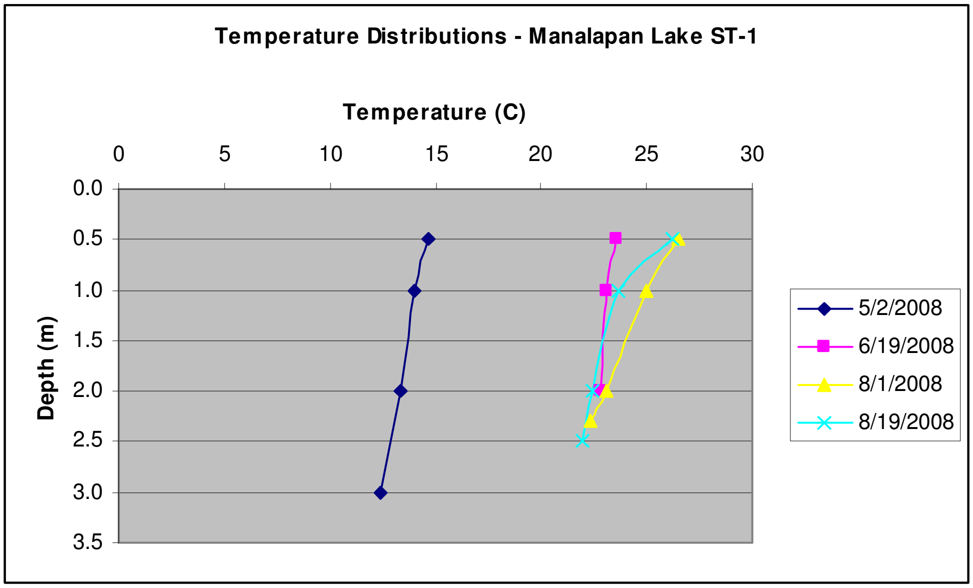

Figure 6. Manalapan Lake ST-1 temperature distributions.

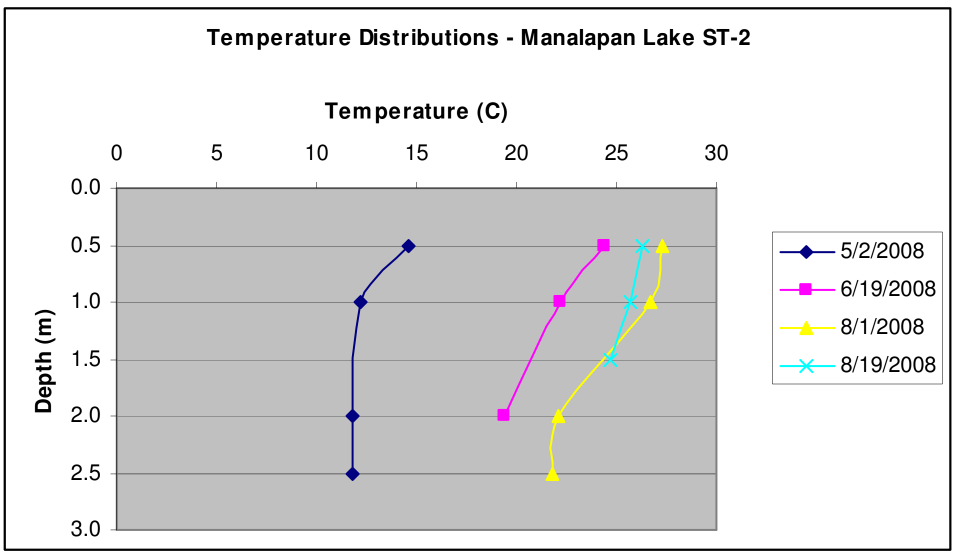

Figure 7. Manalapan Lake ST-2 temperature distributions.

Dissolved Oxygen:
The amount of oxygen that dissolves in water is subject to fluctuations caused in part by variations in temperature, photosynthetic activity, flow, vertical mixing and surface water agitation. Respiratory processes, oxidation of inorganic wastes and the decomposition of organic matter deplete DO, while photosynthesis and re-aeration by contact with the atmosphere increase DO concentrations in water. DO concentrations are important because it is essential for the survival of fish and the majority of other aquatic organisms. Most sensitive aquatic organisms (i.e. trout) require a minimum DO concentration of 4.0 mg/l or greater for long-term survival. According to the New Jersey State Surface Water

Quality Standards criteria, surface water DO concentrations of 5.0 mg/l or greater are indicative of a healthy aquatic ecosystem. The DO concentration of a lake is an important indicator of its overall "health". A large amount of information can be obtained on a lake ecosystem solely through the analysis of this parameter. DO concentrations are related to the photosynthetic activity of algae and aquatic plants; therefore, they provide insight into lake productivity. Vertical DO gradients (i.e., through the water column) provide an indication of mixing patterns and the effectiveness of mixing processes in a lake.

Manalapan Lake was well oxygenated (> 6.8 mg/l DO) from the surface to 1.5 meters during the mid-August 2004 sampling event (Appendix C). At the point where thermal stratification separated the surface waters from the bottom waters, DO concentrations were low (< 5 mg/l), and immediately over the sediments DO was anoxic (< 1 mg/l). Under anoxic conditions, the sediments liberate or “leak” substantially large amounts of phosphorus into the overlying waters relative to the oxygenated waters. This phosphorus, which originates from the sediments, can account for a large portion of the phosphorus available for algal growth, particularly during the dry summer months. This source of phosphorus is defined as internal loading.

Since Manalapan Lake was well mixed during the October 2004 and April 2005 sampling events, the lake was well oxygenated from surface to bottom, with DO concentrations typically greater than 10 mg/l (Appendix C). In addition to being well mixed, cooler water holds more DO relative to the warmer waters of the summer season.

While Manalapan Lake was thermally stratified by mid-July 2005, the bottom waters were not anoxic; however, the waters immediately over the sediments were below the 5 mg/l threshold (Appendix C). In contrast, the lake waters immediately over the sediments were anoxic (< 1 mg/l) during the mid-August 2005 sampling event (Appendix C).

In general, Manalapan Lake and its main inlet, Manalapan Brook, were well oxygenated during all five sampling events. During the summer months, depressed (< 5 mg/l) DO concentrations were detected in the bottom waters and anoxic conditions (< 1 mg/l) were detected in the waters immediately over the sediments. Such seasonal conditions are typical of shallow, productive waterbodies in the Mid-Atlantic region of the United States.

DO concentrations in the surface waters of Manalapan Lake were generally acceptable (>5 mg/l) throughout the growing season in 2008; however, deeper waters displayed reduced DO concentrations (<5 mg/l) at various times during the growing season, usually but not always, coinciding with thermal stratification. DO concentrations at the inlet to Manalapan Lake remained above 6 mg/l throughout the study period.

During the 2 May 2008 sampling event, ST-1 was well oxygenated from surface to bottom and varied between 9.9 mg/l at the surface and 6.2 mg/l near the sediments;

however, while the surface waters at ST-2 were well oxygenated, DO concentrations below 1 meter dropped significantly to 2 mg/l. This could have been the result of a bloom of the diatom *Melosira* and the resulting microbial decomposition. During the 19 June 2008 sampling event surface DO concentrations were the lowest observed during the study. ST-1 surface DO concentrations were 5.63 mg/l and declined to 3.9 mg/l near the sediment. ST-2 surface DO concentrations were 6.8 mg/l and declined to 5.4 mg/l near the sediment.

During the 1 August 2008 monitoring event, DO concentrations were similar at both ST-1 and ST-2. Surface waters were very well oxygenated (>10 mg/l); however, below 1 meter, DO concentrations declined rapidly to near-anoxic conditions (1.08 mg/l) at both stations. This is probably the result of the hot, dry weather which occurred prior to this sampling date. Such weather results in thermal stratification and associated anoxic conditions in the bottom waters. During the 19 August 2008 monitoring event, ST-1 followed a pattern similar to previous monitoring date. Surface waters at both stations were well oxygenated while bottom waters were near-anoxic (1.57 mg/l); however, ST-2 was well oxygenated from the surface to a depth of 1.5 meters (>9 mg/l). Several rain events prior to this sampling date may have weakened thermal stratification and mixed the waters at ST-2, thereby resulting in oxygenated waters at deeper depths. The dissolved oxygen distributions are summarized below in Figure 8 and Figure 9.

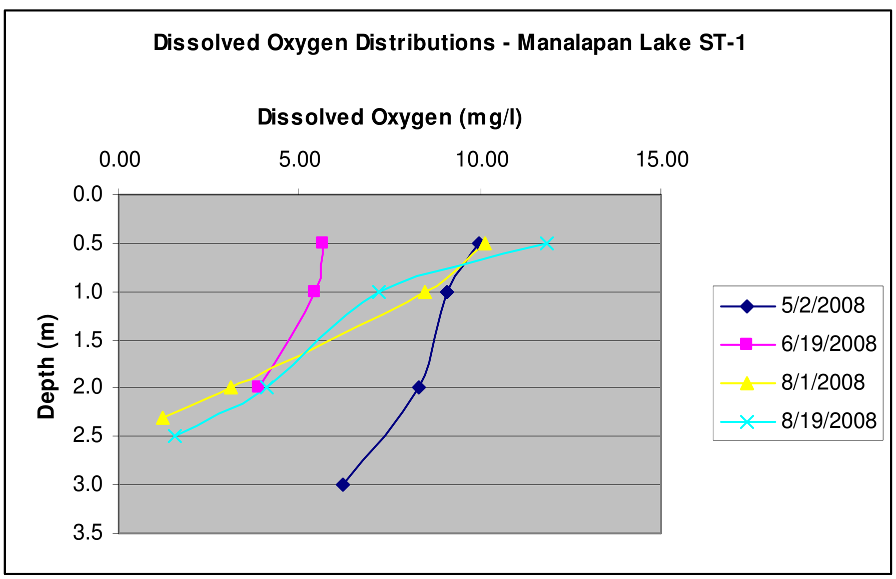

Figure 8. Manalapan Lake ST-1 dissolved oxygen distributions.

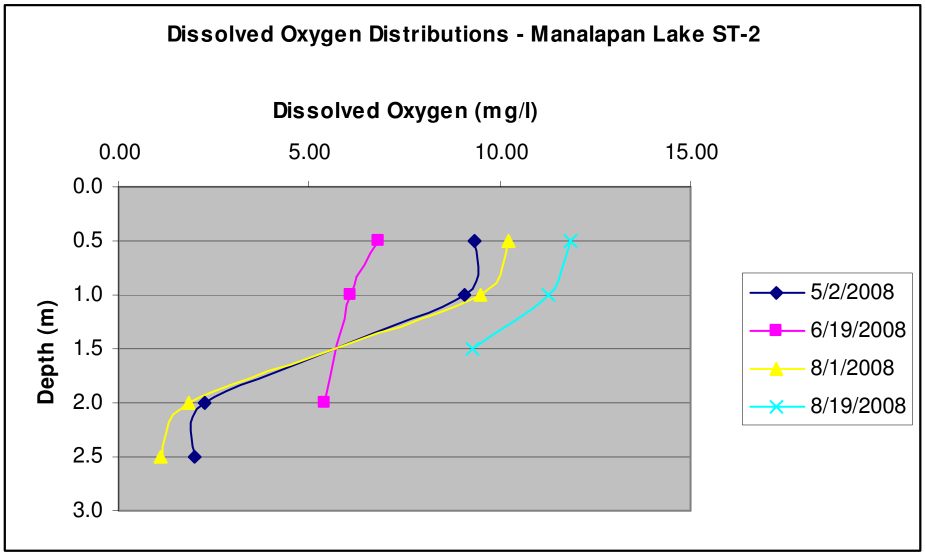

Figure 9. Manalapan Lake ST-2 dissolved oxygen distributions.

pH:
The hydrogen ion activity in water provides an indication of the balance between acids and bases in solution. Hydrogen ion activity in water is usually reported as its negative logarithm, or pH. The pH scale ranges from 1 to 14 standard units. A pH of 7 indicates neutral conditions, while waters with a pH less than 7 are acidic and those with pH values greater than 7 are considered basic. Since pH is expressed on a logarithmic scale, each 1 unit change in pH represents a ten-fold increase or decrease in the hydrogen ion concentration. Therefore, a pH of 6 is ten times more acidic than a pH of 7 and 100 times more acidic than a pH of 8. The pH of normal rainwater (containing no pollutants) is about 5.6. As the rainwater travels over and through rocks and soil, chemical reactions with minerals affect the pH and buffering capacity of the water. In addition, pH is an important water quality indicator since it impacts most chemical and biological reactions. For most aquatic organisms, the optimal pH range is between 6.0 and 9.0; however, some organisms are adapted to unusually low pH values (such as in the New Jersey Pinelands, where the pH is typically in the 4.0 to 5.0 range).

The pH at Manalapan Lake during the 2004 to 2005 sampling program was typically acidic, varying between 6.1 and 6.9; the exception to this was in mid-October 2004, when in-lake pH values varied between 5.8 and 5.9 (Appendix C). As algae and aquatic plants photosynthesize, the pH of the surrounding waters will increase. Thus, the lower pH values in mid-October 2004 were most likely associated with minimal amounts of algal / aquatic plant photosynthesis. At ST-2, the pH was slightly acidic varying between 5.77 and 6.83 among the five sampling events.

Generally speaking, during each sampling event at Manalapan Lake pH readings during the 2008 monitoring program were within the acceptable limit of 6 to 9. In fact, the majority of pH values were between 7 and 8; however, during the 19 August 2008 monitoring event, pH values near the surface were above the acceptable limit of 9. This was due to the presence of a late-summer phytoplankton bloom and was only temporary in nature. Elevated rates of photosynthesis result in an increase in pH by removing carbon dioxide from the water, thereby making the water temporarily more basic. In addition, pH values for the inlet to Manalapan Lake were within acceptable state limits.

Conductivity:
Conductivity is a measurement of the capacity of water to carry an electrical current. It can also serve as an indirect way of measuring the amount of dissolved substances in the water; the more dissolved substances, the higher the conductivity. Highly productive (eutrophic) waterbodies tend to have conductivity values greater than 0.5 mmhos/cm, while waterbodies with low levels of productivity (oligotrophic) tend to have conductivity values less than 0.1 mmhos/cm.

During the 2004-05 monitoring events, the conductivity of Manalapan Lake generally varied between 0.18 and 0.20 mmhos/cm, which is indicative of a moderate level of productivity (mesotrophic). During the 2008 monitoring program, conductivity values for Manalapan Lake and the inlet to Manalapan Lake were moderate and varied from 0.166 mmhos/cm to 0.271 mmhos/cm.

Water Clarity:
Water clarity is primarily a function of the amount of particulate matter in the water column; the more particulate matter the lower the clarity. Algal biomass and/or suspended sediments are primarily responsible for the water clarity observed in lakes. Water clarity, or transparency, is most often measured with a Secchi disk. Based on Princeton Hydro's database of Mid-Atlantic waterbodies, Secchi depths less than 1.0 meter are usually considered undesirable for recreational lake uses.

Secchi depths were generally acceptable in Manalapan Lake during the 2004-05 sampling program. Secchi depths were greater than or equal to 1.0 meter during four of the five events. The only sampling event when the Secchi depth was less than the 1.0 meter threshold was 14 July 2005, when the value was 0.5 meters (1.6 feet). As described below, this condition was attributed to a nuisance algal bloom. Such nuisance conditions, in terms of water clarity, were no longer present in Manalapan Lake by mid-August 2005 when the Secchi depth was 1.25 meters.

In contrast to 2004-05 dataset, Secchi depths in 2008 varied from 0.5 to 0.75 metes at ST-1, with a mean value of 0.66 meters. Thus, while the water clarity at Manalapan Lake was lower in 2008 relative to 2004-05, the data were skewed toward such conditions since three of the four 2008 monitoring events occurred during the summer season; two were conducted in August 2008.

Discrete Parameters:

Total Phosphorus:
Phosphorus has been identified as the primary limiting nutrient for algae and aquatic plants in most freshwater lakes. Total phosphorus (TP) is a measure of all fractions of phosphorus found within the lake water which includes organic, inorganic, dissolved, and particulate forms. Based on Princeton Hydro's in-house Mid-Atlantic database, TP concentrations >0.06 mg/l typically result in nuisance algal blooms. Due to high turnover rates of phosphorus within the algal community, TP can also serve as an excellent predictor of algal biomass and nuisance algal blooms. Moreover, the state has an established criterion for TP when no site-specific criterion (i.e. TMDL) is applied. Specifically, based on N.J.A.C. 7:9B-1.5(g) 3, TP concentrations in the surface waters of a lake or a tributary at the point where it enters the lake shall not exceed 0.05 mg/l.

Surface water TP concentrations in Manalapan Lake during the 2004-05 sampling events varied from 0.02 mg/l in October 2004 to 0.04 mg/l in August 2004 and August 2005. The mean TP concentration of the five surface water samples collected at Manalapan Lake was 0.032 mg/l.

In contrast to surface water TP concentrations, deep water TP concentrations during the 2004-05 sampling events were excessive, varying between 0.06 mg/l in August 2005 to 0.250 mg/l in July 2005, with a mean of 0.120 mg/l. Such high TP concentrations in the deep waters, immediately above the sediments, are very common in temperate waterbodies. During the growing season, even a small difference between the surface and bottom water temperatures can result in weak stratification and a depletion of DO over the sediments. As shown in the *in-situ* data, DO concentrations immediately over the sediments were anoxic (< 1 mg/l of DO) during two of the five sampling events, which were August 2004 and August 2005. Such conditions result in chemical reactions which liberate substantially large amounts of phosphorus into the overlaying water. A storm or wind event can then easily transport this phosphorus-rich water to the surface and stimulate algal growth. This source of phosphorus is called internal loading.

In 2008, surface water TP concentrations at ST-1 varied between 0.04 and 0.09 mg/l with a mean value of 0.065 mg/l. Although this represents an increase in surface TP from 2004 to 2005, this concentration remains far below the Reckhow-predicted TP concentration of 0.132 mg/l. In addition, using all of the surface water ST-1 TP data from 2004-05 and 2008, the total mean TP concentration was 0.047 mg/l.

At least one of the reasons for the discrepancy between the 2004-05 and 2008 data sets is the low phosphorus retention capacity of Manalapan Lake (11%). Most of the TP that enters Manalapan Lake is bound to particulate material and is either flushed out of the system or settles to the lake bottom. In addition, the 2008 mean inlet TP concentration was 0.15 mg/l, far above the average surface TP concentration of 0.065 mg/l, which is another indication that TP from the Manalapan Lake inlet is either being flushed out of the lake or settling to the bottom. In addition, elevated levels of TP were detected in the anoxic bottom waters of ST-1 starting in June. This is indicative of high internal sediment loading of TP in Manalapan Lake during periods of thermal stratification and subsequent depletion of DO.

Soluble Reactive Phosphorus (SRP):
Typically, only inorganic orthophosphates are available for uptake by phytoplankton and plants, except cyanobacteria (blue-green algae) which can utilize organic forms of phosphorus and tend to thrive in extremely elevated TP environments. Soluble reactive phosphorus (SRP) is a basic measure of those phosphorus species which are readily assimilated by phytoplankton. SRP is generally found in very small quantities in natural lake systems because it is so biologically active. Elevated concentrations are capable of predicting and causing algae blooms. In unproductive lake systems, SRP is usually less than 0.005 mg/l. In general, Princeton Hydro recommends SRP concentrations not to exceed 0.005 mg/l in order to avoid nuisance algal blooms.

During the 2004-05 sampling events, SRP concentrations varied between 0.003 and 0.015 mg/l, with three of the five concentrations being above the 0.005 mg/l threshold.

During the 2 May 2008, 19 June 2008, and 1 August 2008 monitoring events SRP concentrations exceeded the recommended threshold of 0.005 mg/l. The highest SRP concentration was 0.043 mg/l and was recorded during the May sampling event. This elevated concentration may have been the result of spring fertilizer applications on agricultural and/or residential lands; however, the SRP concentrations declined throughout the course of the growing season whereby SRP was non-detectable by 19 August 2008. This is an indication that SRP was being assimilated by phytoplankton as they became more numerous towards late summer.

Total Suspended Solids (TSS):
Elevated total suspended solids (TSS) concentrations in a waterbody will result in turbid or “muddy” conditions; such elevated concentrations are often a useful indicator of sediment erosion and stormwater inputs into a waterbody. Since TSS within the water column reduces 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 toward a “muddy” appearance at values over 25 mg/l. TSS measures include suspended inorganic sediment, algal particles, and zooplankton particles.

In addition, as phosphorus molecules are often times tightly bound to soil particles, elevated TSS concentrations may serve as an indicator of not only excessive sediment inputs but also excessive phosphorus inputs to a waterbody.

During the five 2004-05 in-lake sampling events, TSS concentrations in Manalapan Lake varied from < 3 to 6 mg/l, well below the 40 mg/l State standard. The inlet TSS concentrations were also generally low, varying between < 3 and 4 mg/l. The exception to this was on 14 July 2005 when the inlet TSS concentration approached the 25 mg/l threshold, being 22 mg/l (Appendix C). It should be noted that the elevated inlet TSS concentration in July 2005 correlated with the highest inlet TP concentration of 0.19 mg/l (Appendix C).

In 2008, TSS concentrations in Manalapan Lake were moderately low and varied from non-detectable (<3 mg/l) on 1 August 2008 to 11 mg/l on 19 August 2008; however, on 19 August 2008, the inlet TSS concentration was 189 mg/l. This sample might have been contaminated and should be viewed as an outlier; therefore this data point was not used in any subsequent analysis. It should also be noted that these four 2008 in-lake and inlet samples were collected during baseline (non-storm event) conditions.

Chlorophyll a:
An important biological parameter in assessing in-lake water quality conditions is chlorophyll *a*, which is a photosynthetic pigment possessed by all algal groups. Since all algae contain chlorophyll *a*, measuring its concentration in lake water is an excellent means of quantifying the relative biomass of the phytoplankton within the open waters of a lake. Concentrations of chlorophyll *a* are also used to gauge the in-lake productivity associated with phytoplankton. In turn, this information can be used to quantify the trophic state of a waterbody, as well as measure the relative effectiveness of an implemented in-lake restoration technique. Chlorophyll *a* concentrations greater than 30 mg/m^3 produce algal blooms and surface scums that are considered unpleasant for recreational waterbodies.

With the exception of 14 July 2005, chlorophyll *a* concentrations during the 2004 to 2005 sampling events were well below the 30 mg/m^3 threshold, varying between 4 and 15.8 mg/m^3 (Appendix C). In contrast, an algal bloom occurred on 14 July 2005, when the chlorophyll *a* concentration was 86.4 mg/m^3; however, this algal bloom was "flushed out" of the lake four days later by a storm which produced upwards of six inches of rainfall in the area[2]. By 16 August 2005, a month after the severe storm event, the chlorophyll *a* concentration was 10.4 mg/m^3. These data indicate that Manalapan Lake has the potential to generate nuisance algal blooms; however, such blooms are limited to seasons or periods of time that receive little or no precipitation. Due to the large watershed size to lake volume ratio, storm events quickly flush algal blooms out of the lake. Such conditions were observed from July to August 2005, a direct result of the large 7-8 inch early July 2005 storm event.

During the 2008 spring and early-summer sampling events, chlorophyll *a* concentrations were moderate and below the 30 mg/m^3 threshold. The chlorophyll *a* concentration during the May 2008 sampling was 19.1 mg/m^3 and declined to 6.9 mg/m^3 during the June 2008 sampling event. The higher concentration in May 2008 was probably the result of a spring diatom bloom (Appendix D) which had receded by June 2008; however, by

[2] Daily precipitation data from radar rainfall estimates taken from the NOAA National Weather Service, Advanced Hydrologic Prediction Service, available online at http://water.weather.gov/precip/.

the 1 August 2008 monitoring event, chlorophyll *a* concentrations had exceeded the 30 mg/m^3 threshold and by 19 August 2008 the chlorophyll *a* concentration attained a severe nuisance bloom condition of 84.9 mg/m^3. This extremely high chlorophyll *a* concentration coincided with a nuisance bloom of blue-green algae, namely *Anabaena*, *Microcystis*, and *Aphanizomenon*.

Plankton and Fish Sampling:

Phytoplankton:
Phytoplankton are algae that are freely floating in the open waters of a lake or pond. These algae are vital to supporting a healthy ecosystem, since they are the base of the aquatic food web; however, elevated densities of phytoplankton can produce nuisance conditions. The majority of nuisance algal blooms in freshwater ecosystems are the result of cyanobacteria, also known as blue-green algae. Some of the more common water quality problems created by blue-green algae include bright green surface scums, taste and odor problems and cyanotoxins. Phytoplankton samples were collected during each sampling event and were subsequently identified and enumerated; the resulting data are provided at the end of this document.

During the May 2008 spring sampling event, the filamentous diatom *Melosira* was the dominant genus of phytoplankton, accounting for 98% of the biomass. *Melosira* is often a major constituent of the spring phytoplankton assemblage as it prefers cooler water temperatures; however, the June 2008 phytoplankton sample was dominated by the blue-green alga *Anabaena*, which accounted for >90% of biomass. The 1 August 2008 sample was diverse in terms of different types of phytoplankton; however, biomass was relatively low. Only a small amount of blue-green algae was present. This may be attributable to below average temperatures preceding the sampling event. Nevertheless, by 19 August 2008 the phytoplankton assemblage was dominated by a nuisance bloom of blue-green algae which consisted mainly of *Anabaena*. As stated earlier, this large amount of blue-green algae coincided with extremely high chlorophyll *a* concentrations and shallow Secchi depths during this summer sampling event, thereby confirming the presence of a nuisance bloom.

Zooplankton:
Zooplankton 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. Many cladocerans are typically characterized as large, highly herbivorous zooplankters, capable of keeping algal densities naturally in check through grazing pressure. Some species of copepods are also herbivorous and can also help maintain algal densities. Aside from algae, many copepods also feed on other small aquatic animals and 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.

During the 2 May 2008 sampling event, rotifers were the dominant zooplankton in terms of numbers and biomass; however, zooplankton community composition changed as of the June 2008 sampling event. During this period, cladocerans became more numerous and dominated the community in both numbers and biomass. The herbivorous cladocerans *Daphnia* and *Ceriodaphnia* were both present in the sample. This is a normal occurrence when adequate amounts of edible phytoplankton are available this time of year. During the late summer season, zooplankton abundance and biomass declined. Although some herbivorous zooplankters were still present, their numbers and biomass were lower relative to the mid-summer zooplankton community. This decrease may be a result of the late-summer bloom of blue-green algae which is generally not consumed by herbivorous zooplankton.

Fishery Survey:
Fishery surveys and their associated analyses provide critical information in assessing a lake ecosystem. Fish are generally the top predators of most temperate aquatic ecosystems, excluding raptors and various wading birds. As such, they fulfill varied roles in the ecological function of a lake. Fish can have a direct impact on water quality. For example, benthic dwelling species feeding off the bottom can increase turbidity in the water column. Fish also have the potential to effectively control varied invertebrate taxa, and in biomanipulation strategies are used to alter phytoplankton and zooplankton densities to avoid nuisance algae blooms. From a recreational perspective, fish are the most familiar aquatic organisms to the public, and are prized for their recreational value by anglers. In order to assess how the fishery community impacts the water quality of Manalapan Lake, a one day electroshocking fishery survey was conducted on 18 April 2005.

The electroshocking system employed during the fishery survey is a Coffelt VVP (variable voltage pulsator) Electroshocking Unit and associated probes powered by a 5 horsepower Honda generator mounted on a 16 foot Boston Whaler. The electrofishing component of the fishery survey was conducted during daylight hours on 18 April 2005. Electrofishing focused primarily on the littoral sections of the lake. In total, six (6) transects were surveyed with the electrofishing equipment for 15 - 30 minute periods along each transect. The shoreline survey focused on areas with favorable fish habitat and structure including fallen trees, submerged structures, rocks, and aquatic / wetland vegetation. Given the relatively small surface area of Manalapan Lake, the transects crossed over many of the lake's open water habitats.

A total of 11 species were identified during the spring 2005 fishery survey of Manalapan Lake with the total catch being 351. Of the 351 fish caught, 76% were yellow bullhead, with the majority of these fish being within the size ranges of 3-6" and 6-9". Other species of fish caught included American eel (26), pumpkinseed (23), bluegill (19), white sucker (5), yellow perch (5), largemouth bass (2), chain pickerel (1), common carp (1), golden shiner (1) and black crappie (1). The complete fishery survey results are provided in Appendix J.

The yellow bullhead is a benthivorous species, feeding on organisms on and in the sediments. The feeding activities of benthivorous species similar to the yellow bullhead tend to maintain and re-suspend sediment in lake systems.

Trophic State Analyses:

The productivity or "trophic" status of a lake is of special concern in relating the overall degree of production (algal / weed growth) to ecological health and user satisfaction. The trophic status of any waterbody pertains to the productivity of that waterbody, specifically the rate or degree or algal and aquatic weed productivity.

While the trophic concept is often misunderstood it represents a continuum from a nutrient poor state (oligotrophic) to a nutrient rich state (eutrophic). When classifying lakes based on their trophic character, questions frequently arise as to exactly which parameters (chlorophyll *a*, total phosphorus, Secchi depth) accurately reflect the true trophic status of that waterbody and at what limits a lake switches from one category of production to another. Despite these questions humans naturally desire a simple scheme in order to classify lake productivity and therefore make educated decisions as to their use and management. Given this desire, a simple trophic state index derived by Dr. Robert Carlson was utilized to classify the productivity status of a lake.

The trophic state index (TSI) of Carlson (1977) uses a log-based, single variable transformation for an easy method to calculate an index of trophic status. The basis of this index is derived from chlorophyll *a* concentrations, which serve as a proxy indicator for algal biomass, although growing season total phosphorus concentrations and Secchi disk values may be substituted using modified regression equations derived by Carlson. Based on a scale of 0 to 100, Carlson's TSI provides an easy-to-understand index of lake productivity that may be used by limnologists or volunteers to accurately gauge a lake's state of productivity.

The basic underlying assumptions of this model are that particulate matter is the sole source influencing Secchi disk depth while algal matter is the sole contributor to suspended particulate matter. Often times the basic model assumptions are not true and systematic deviations may be determined through TSI residual analysis. Princeton Hydro calculated the trophic state index of Manalapan Lake using both the data collected during the 2004-05 and 2008 monitoring events. A residual analysis was performed of all the data in order to assess whether there were any systematic deviations from the basic model assumptions (see Figure 10 below).

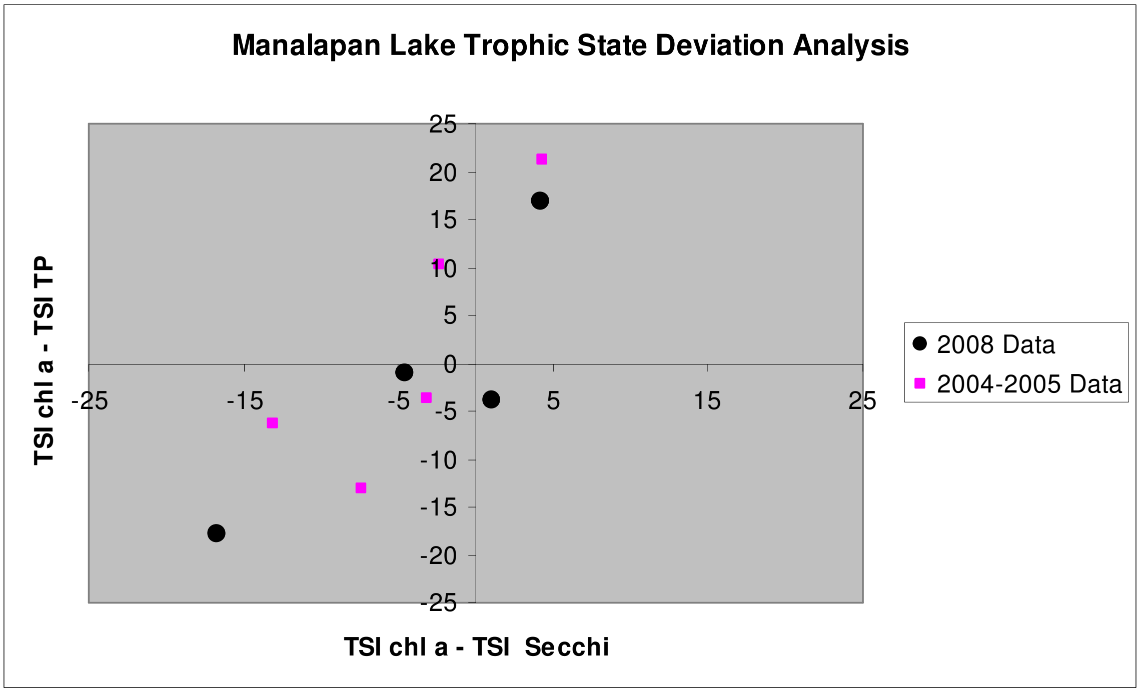

Figure 10. Manalapan Lake Trophic State Deviation Analysis.

Five of the nine deviation data points are located in the lower, left hand quadrant. As per Carlson's interpretation, non-algal turbidity and a surplus of phosphorus indicates that algal blooms were not the cause of the low water clarity under these conditions. In contrast, the two points in the upper right hand quadrants were directly attributed to nuisance algal densities (chlorophyll *a* > 80 mg/m^3 in both cases) and lower concentrations of TP; however, based on these data and the lake's high flushing rate, the lake is typically turbid as a result of non-algal particles (soils; re-suspended sediments). The cause of these turbid conditions is primarily through the heavy sediment load entering the lake through Manalapan Brook; however, another potentially substantial source of elevated TSS concentrations could be the lack of submerged, rooted vegetation and the fishery community being composed primarily of yellow bullhead catfish. While the relative contribution of "external" relative to "internal" TSS loading has not been quantified, given the size of the watershed relative to the size of Manalapan Lake and the existing land use, it is more than likely that watershed-based sources account for the majority of TSS problems experienced in the lake.

In conclusion, the 2004 to 2005 and 2008 water quality data validated the conclusions drawn in 2006 to modify the Manalapan Lake / Brook Management strategy to address TSS and not TP. Thus, instead of focusing on the original TP TMDL for Manalapan Lake, this Restoration Plan now focuses on addressing the impacts of elevated TSS loading for the entire stretch of Manalapan Brook.

Consecutive In-Situ Monitoring at Manalapan Lake:
As part of New Jersey's requirements for a lake characterization plan, at least two consecutive days of *in-situ* monitoring (DO, temperature and pH) must be conducted of the surface waters. This was the only part of the Manalapan Lake monitoring that was not also conducted during the 2004-05 monitoring program; this monitoring was only conducted in 2008.

In order to maximize the amount of relevant data collected and minimize the associated costs, Princeton Hydro placed a field probe into Manalapan Lake, anchored and buoyed just off the dam. The probe was programmed to consistently collect *in-situ* measurements of the surface waters (0.5 meters) once every 15 minutes over the course of seven days for a total of 671 readings. Unlike the state requirement, the probe collected data 24 hours a day, once every 15 minutes. This monitoring occurred during the late summer season, from 3-10 September 2008.

Over the seven day monitoring period, surface water temperatures varied from 22.21 to 27.61^{o}C, which was below the state's rolling seven day average daily maximum of 28^{o}C for FW2-NT waters (N.J.A.C. 7:9b-1.14(d)). An examination of the entire temperature database shows that surface water temperatures exhibited diel variations in addition to an overall seasonal decline through the seven days (Figure 11).

DO concentrations in the surface waters of Manalapan Lake varied from 3.84 to 10.09 over the course of the seven day monitoring period. For FW2-NT waters such as Manalapan Lake, DO concentrations cannot have a 24-hour average less than 5.0 mg/l and not be less than 4.0 mg/l at any one time (N.J.A.C. 7:9b-1.14(d)). Only eight of the over 670 readings of DO were less than 5 mg/l so Manalapan Lake was in compliance with the 24 hour criteria. Of the 670 readings only one was less than 4 mg/l. The DO exhibited a typical diel pattern where DO concentrations increased through the morning and afternoon hours and decreased through the evening hours into dawn. Over the first three days of monitoring DO varied between the upper 7's and the mid-9's mg/l. A rain event on 6-7 September resulted in over four inches (CLIMOD Station: NEW BRUNSWICK 3 SE; ID: 286055) of rain; at the on-set of this storm the DO declined from 9 mg/l to slightly less than 6 mg/l (Figure 12). After the four-inch storm event and for the rest of the monitoring period, the degree of variation between the daily minimum and maximum DO readings substantially increased. Over the last three days of monitoring DO concentrations varied from slightly less than 4 mg/l (one reading) to greater than 10 mg/l. Based on these results, the large storm experienced in early September had a substantial impact on the DO concentrations of the surface waters at Manalapan Lake.

The optimal range of pH for most aquatic organisms, excluding those found in the Pinelands, is between 6.0 and 9.0. In addition, for FW2-NT waters such as Manalapan Lake, the optimal range in pH is between 6.5 and 8.5. The range of pH actually measured at Manalapan Lake varied between 6.28 and 8.71. Of the over 670 readings, 41 were below 6.5 and 4 were greater than 8.5. The elevated pH values were attributed to high rates of algal photosynthesis, which increases both the pH and DO concentrations in the surrounding waters. The lower pH values (less than 6.5) all occurred after the four-inch storm event. Thus, the increase in the hydrologic and pollutant loads entering Manalapan Lake, as a result of the large storm, contributed to the temporary decline in pH.

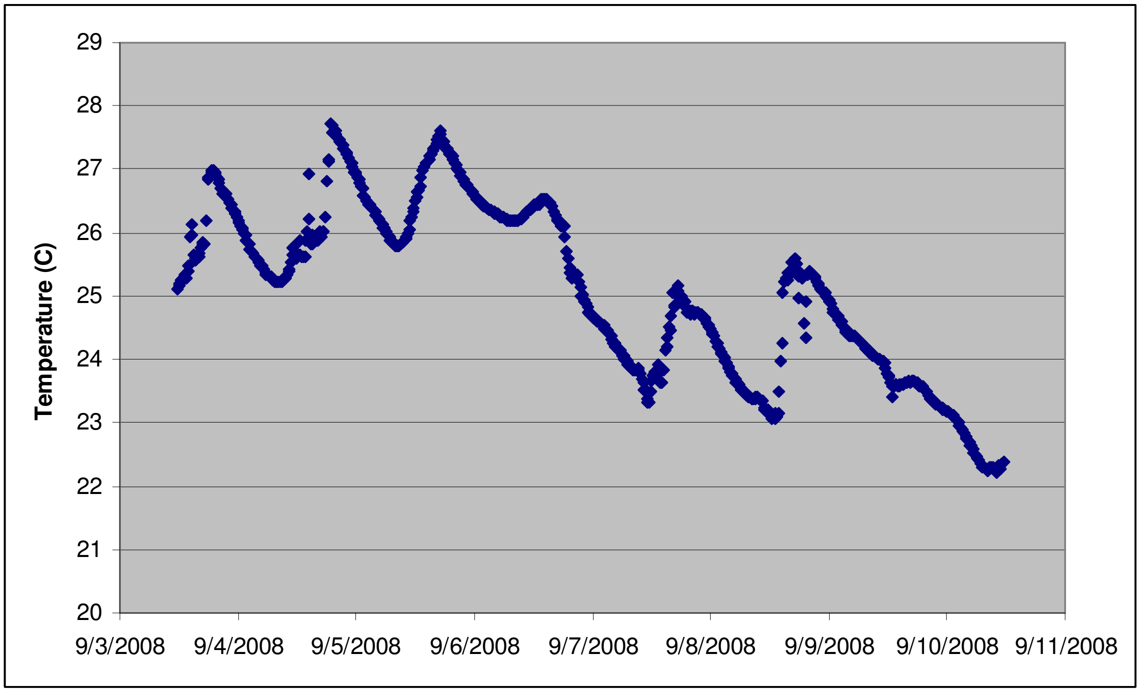

Figure 11. Manalapan Lake temperature data 3-10 September 2008.

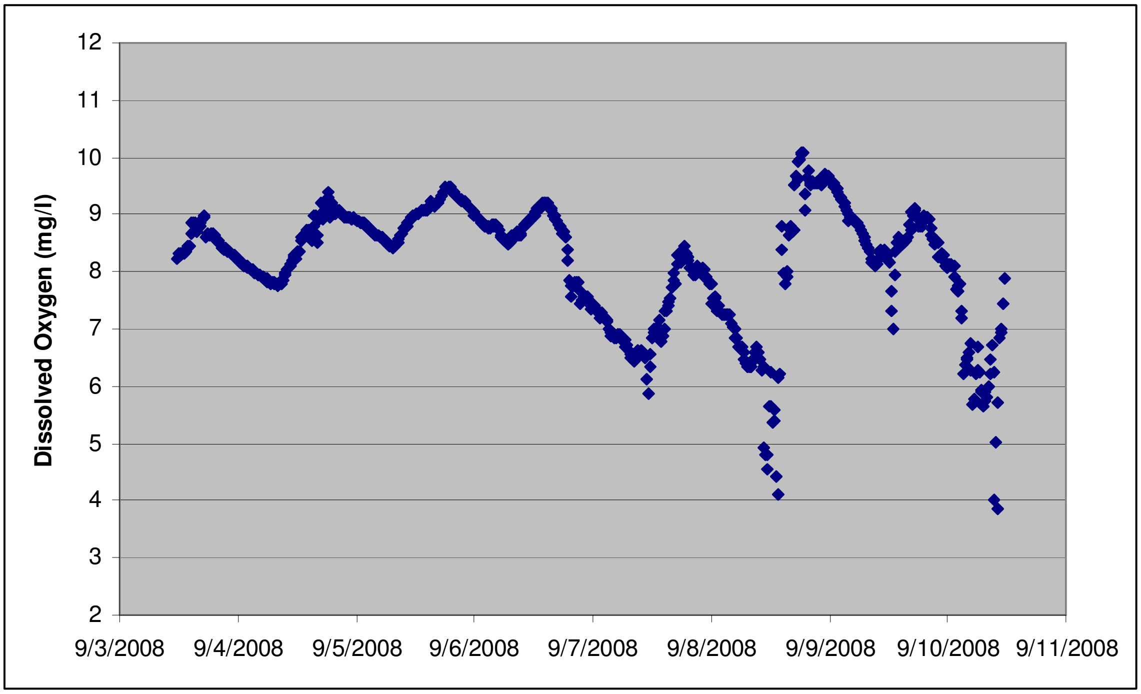

Figure 12. Manalapan Lake dissolved oxygen data 3-10 September 2008.

Discussion:
Simply based on the water quality data, particularly the TP and TSS concentrations measured during the 2008 growing season, it may not initially appear that TSS should be the primary pollutant of concern for the Manalapan Brook watershed; however, it should be emphasized that the 2004-05 and 2008 water quality database is small in size, representing less than 10 baseline sampling events and only three storm events. All monitoring events during the 2008 growing season were conducted under baseline conditions. This further skews the water quality data, particularly the TSS data, potentially indicating that elevated turbidity is not a concern in Manalapan Lake or Manalapan Brook. Thus, the limited size and scope of water quality database is one of the reasons other methods of assessment and analysis had to be taken into account, which are described below.

First, based on the results of the Carlson trophic state residual analysis discussed above, the turbidity experienced in Manalapan Lake tends to be the result of non-organic material (e.g. suspended sediments) and not algal cells. Second, the fishery survey revealed that benthic fish species dominate the fishery community of Manalapan Lake. Such a fishery community can exert a negative impact on the clarity of a shallow waterbody through their feeding activities in the bottom sediment.

The most telling evidence that the primary pollutant of concern for the entire Manalapan Brook watershed should be TSS are the photographs of severely eroded streambanks, filled in detention basins and ponds and large gravel / sediment bars identified throughout the watershed. As is discussed in the description of the application of the AVGWLF model, the actual sediment load conveyed during and immediately after a storm event can be underestimated since a lot of the larger particles do not stay in suspension for long periods of time following a storm event. In contrast to fine particulate material that can be transported considerable distances downstream during a storm event, larger particles drop out of the water column fairly quickly as the velocity of the storm flows decline. This plan provides visual evidence of this in the field photographs.

While measuring pollutant concentrations in the lake and brook, particularly under baseline conditions, can be useful as a means of assessing current water quality conditions, it certain does not exemplify or identify all of the impacts associated with storm-based flows. This is particularly the case for developed lands where impervious cover increases the magnitude and velocity of the hydrologic loads entering a receiving waterway. Such hydrologic loads result in eroding streambank and transporting material deposited in the streambed further downstream. Therefore, given the all of the data collected and observations made of Manalapan Brook and Lake, TSS should be the primary pollutant of concern.

Applying AVGWLF Model to Manalapan Brook Watershed

Introduction:
Task 2 addresses the first element of a comprehensive watershed restoration plan. Specifically, a hydrologic and water quality model was used to identify and quantify the causes and sources of NPS pollution. In the case of Manalapan Brook the primary pollutant of concern is total suspended solids (TSS). The model was used to quantify the sources from both municipal and sub-watershed perspectives. Additionally, the model separated TSS loads originating from streambank erosion from that of surface runoff. In turn, the results of this modeling analysis were used as the foundation for the comprehensive watershed plan, which included identifying a desirable water quality endpoint for TSS in for Manalapan Brook.

The ArcView Generalized Watershed Loading Function (AVGWLF) model is one of the few hydrologic/water quality models which can incorporate large quantities of diverse spatial data and provide pollutant loading estimates based on continuous hydrologic simulation. Furthermore, the model has recently been improved to provide estimates for sediment loads originating from streambank erosion. Therefore, the model was ideally suited for application to the Manalapan Brook.

The GWLF model provides a means of simulating runoff and sediment and nutrient (nitrogen and phosphorus) loads from watersheds with a mosaic of land types (i.e., agricultural, forested, developed lands) (Haith et al., 1992). The model also has the capability to account for septic system loads, point source discharges, surface and ground water withdrawals and streambank erosion. The GWLF model has recently been linked to ArcView GIS software by researchers at Penn State to parameterize the input data needed to run the model (Evans et al., 2006). The AVGWLF software (Version 7.2.0) is a preprocessor for the original GWLF model. The software comes packaged with a slightly revised version of the GWLF model. The AVGWLF preprocessor and GWLF model have been applied to predict the sediment loads throughout the Manalapan Brook watershed. The AVGWLF has been widely applied to model sediment and nutrient loads in watersheds throughout Pennsylvania and the Northeast. The model has been successfully applied to watersheds that are dominated by a combination of land uses including agricultural and developed areas. Similar conditions can be used to describe the Manalapan Brook watershed, where over 40% of the land is agricultural and urban in nature.

The AVGWLF model is a continuous simulation model that uses daily time steps for weather data and hydrologic calculations. Hydrologic calculations in GWLF are based on a lump parameter linear reservoir representation of groundwater and stream flow. GWLF uses the Curve Number methodology to calculate runoff. AVGWLF calculates Curve Numbers based on the provided LU/LC data and the soils data (soil HSG). Runoff is routed directly to the stream and the remainder of the precipitation is routed to the unsaturated zone, as defined by the soil database. Water in the unsaturated zone can either be lost to evapotranspiration or flow into the shallow saturated zone. The shallow saturated zone is the only groundwater component that can contribute to stream flow; water in the shallow saturated zone can also contribute to the deep saturated zone where it is no longer available for stream flow. This hydrologic simulation is parameterized by spatial data from the AVGWLF preprocessor or through direct entry of empirical coefficients as is further explained in the Model Calibration section and the original GWLF program documentation (Haith et al., 1992).

Monthly calculations are made for sediment and nutrient loads based on monthly summaries of the daily hydrologic calculations. Sediment loads are calculated for both land surface sources (runoff) and streambank erosion.

The GWLF model uses the widely accepted Universal Soil Loss Equation (USLE) to calculate sediment loads originating from surface runoff and erosion. The general formulation of the daily erosion calculation implemented in the model is summarized as follows:

$$E = 0.132 \times RE \times K \times LS \times C \times P$$

Where:	E = daily erosion	[tons/acre]
	0.132 = unit conversion for SI units	[-]
	RE = rainfall erosivity factor	[MJ mm/ha hr]
	K = soil erosion factor	[MJ mm/ha hr]
	LS = slope length gradient factor	[-]
	C = crop/vegetation management factor	[-]
	P = erosion control practice	[-]

$$RE = 64.6 \times a_t \times R_t^{1.81}$$

Where:	a_t = seasonal and geographic coefficient	[-]
	R_t = daily rainfall total	[-]

The AVGWLF model uses the spatial data and daily weather data to calculate the parameters in the above formula. The coefficients which describe the condition of the land surface are calculated from the land use data. The erosion is then converted to an actual sediment load using an empirical sediment delivery ratio based on watershed size.

$$SDR = 0.451 \times b^{-0.298}$$

Where:	SDR = sediment delivery ratio	[-]
	b = watershed area	[km^2]

A streambank erosion routine is included in the AVGWLF model (Evans et al. 2003). The AVGWLF manual explains the calculation of the streambank erosion as follows:

$$LER = a \times q^{.6}$$

Where: LER = lateral erosion rate [m/month]
q = monthly stream flow [m^3/s]

$$a = (4.67 * 10^{-3} \times PD) + (8.63 * 10^{-4} \times AD) + (1.0 * 10^{-6} \times CN) + (4.25 * 10^{-4} \times KF) + (1.0 * 10^{-6} \times MS) - 3.6 * 10^{-5}$$

Where: PD = percent of developed land
AD = animal density
CN = average curve number
KF = average soil 'k' factor
MS = mean topographic slope

It should be noted that agricultural lands accounted for less than 12% of the total watershed area, with the majority of this land being row crops. Due to the lack of concentrated animal farming or other similar operations in the watershed, it is anticipated that these operations have a very small contribution to nutrient loading in the Manalapan Brook watershed. This input is optional in the AVGWLF model and therefore was not used.

This is an empirical formulation of a commonly applied sediment transport relationship. The development of the empirical coefficients and original formulation are further detailed in the AVGWLF manual and other supporting documentation (Evans et al. 2003). The lateral erosion rate (into the streambank) is then converted into a mass sediment load by multiplying the calculated lateral erosion rate by the total length of streams in the watershed and representative values for stream height and bulk density.

In developed watersheds such as Manalapan Brook, streambank erosion often is the main source for sediment load generation. For this reason it is critical to attempt to differentiate the streambank erosion sediment load from sediment loads originating from surface water runoff. In turn, this data can aid in the selection and prioritization of structural and non-structural BMP implementation including streambank stabilization projects.

The program manuals can be consulted for a more in depth description of the mathematical representations of the physical processes simulation within the GWLF model (Haith et al., 1992; Evans et al., 2008). The AVGWLF model has been run on an inter-annual basis over a seven (7) year period (2001 to 2007). This time period was chosen because it is sufficiently large to include a variety of climatological conditions.

Data Requirements:
A data repository for properly formatted input data for the AVGWLF model does not currently exist for New Jersey. Therefore Princeton Hydro acquired and compiled the necessary data and properly formatted it for input into the AVGWLF system. The authors of the AVGWLF model provide a data format guide and documentation which provides instructions on how to properly format data for input into the AVGWLF model (Evans and Corradini, 2006). The input data can be categorized into three main categories: Weather (daily precipitation and temperature records), Transport (basin size, land use/land cover, evapotranspiration cover coefficients, daylight hours per month, etc.) and Nutrients (land use, loading coefficients, point sources, background concentrations, population on septic systems, etc.).

The required data included spatial representations of the analysis areas (entire watershed (1), HUC-14 watersheds (3), and analysis subwatersheds (20)). The Digital Elevation Model (DEM) of the watershed was also necessary input for various calculations in the model, including slope calculations. The DEM was obtained and subsequently clipped from the original 100 meter DEM acquired from the NJDEP (NJDEP, 2009). The model also requires a digital representation of the locations of the streams, roads and weather stations. The soil data was obtained from the USDA NRCS as described in the previous section. The 2002 LULC data were manually updated using 2005 aerial imagery available through Google Earth in an effort to better represent the current land use conditions in the watershed. The LU/LC were converted to a grid (raster) dataset. The dataset was then reclassified such that the model would properly interpret the NJDEP LU/LC data. A complete summary of the reclassification process is provided in Table 16.

Table 16. Summary of LU/LC classifications for AVGWLF input.

NJ LU/LC	NJDEP Land Use	AVGWLF Description
Agriculture	Confined Feeding Operations	Hay/ Pasture
	Cropland and Pastures	Hay/ Pasture
	Orchards/Vineyards/ Nurseries/ Horticultural Areas	Row Crops
	Other Agricultures	Hay/ Pasture
Barren Land	Altered Lands	Transitional
	Extractive Mining	Quarries
	Transitional Areas	Transitional
	Undifferentiated Barren Lands	Transitional
Forest	Coniferous Brush/ Shrublands	Coniferous Forest
	Coniferous Forests (>50% Crown Closure)	Coniferous Forest
	Coniferous Forests (10 - 50% Crown Closure)	Coniferous Forest
	Deciduous Brush/ Shrublands	Deciduous Forest
	Deciduous Forests (>50% Crown Closure)	Deciduous Forest
	Deciduous Forests (10 - 50% Crown Closure)	Deciduous Forest
	Mixed Deciduous/ Coniferous/ Brush/Shrublands	Mixed Forest
	Mixed Forests (>50% Coniferous with >50% Crown Closure)	Mixed Forest
	Mixed Forests (>50% Coniferous with 10 - 50% Crown Closure)	Mixed Forest
	Mixed Forests (>50% Deciduous with >50% Crown Closure)	Mixed Forest
	Mixed Forests (>50% Deciduous with 10 - 50% Crown Closure)	Mixed Forest
	Old Fields (<25% brush cover)	Mixed Forest
	Plantation	Coniferous Forest
Urban	Athletic Fields	Low-Density Development
	Cemeteries	Low-Density Development
	Commercial/ Services	High-Density Development
	Industrial	High-Density Development
	Industrial/ Commercial Complexes	High-Density Development
	Major Roadways	High-Density Development
	Other Urban or Built-up Lands	Low-Density Development
	Recreational Lands*	Low-Density Development
	Residential, High density, or Multiple Dwellings	High-Density Residential
	Residential, Rural, Single Units	Low-Density Residential
	Residential, Single Units, Low Density	Low-Density Residential
	Residential, Single Units, Medium Density	Low-Density Residential
	Stormbasins	Low-Density Development
	Transportation/ Communication/ Utilities	High-Density Development
	Upland Right-of-Ways Developed	Low-Density Development
	Upland Right-of-Ways Undeveloped	Low-Density Development
Water	Artificial Lakes	Water
	Bridge Over Water	Water
	Natural Lakes	Water
	Streams/ Canals	Water

Wetlands	Agricultural Wetlands (modified)	Woody Wetland
	Coniferous Scrub/Shrub Wetlands	Woody Wetland
	Coniferous Wooded Wetlands	Woody Wetland
	Deciduous Scrub/Shrub Wetlands	Woody Wetland
	Deciduous Wooded Wetlands	Woody Wetland
	Disturbed Wetlands (modified)	Woody Wetland
	Former Agricultural Wetlands	Woody Wetland
	Herbaceous Wetlands	Emergent Wetland
	Managed Wetland in Built-up Maintained Rec. Area	Woody Wetland
	Managed Wetland in Maintained Lawn Green Space	Woody Wetland
	Mixed Scrub/Shrub Wetland (Coniferous Dom.)	Woody Wetland
	Mixed Scrub/Shrub Wetland (Deciduous Dom.)	Woody Wetland
	Mixed Wooded Wetlands (Coniferous Dom.)	Woody Wetland
	Mixed Wooded Wetlands (Deciduous Dom.)	Woody Wetland
	Phragmites Dom. Interior Wetlands	Emergent Wetland
	Wetland Right-of-Ways	Woody Wetland

In addition to the previously mentioned data, road data and sewer service area data were also obtained from the NJDEP. The road data was clipped to the watershed and is part of the optional data for the AVGWLF model. The road data is not used in any of the calculations in AVGWLF, and was used here as a reference layer. The sewer service area data were also clipped to the watershed and municipal boundary data. These data were then added to the sewer service area data in GIS and used as input for the model. Further information on the data formatting requirements and procedures can be found in the model's data format guide (Evans and Corradini, 2006).

Model Calibration:

As previously discussed, the Generalized Watershed Loading Function (GWLF) was applied to the Manalapan Brook watershed. The model results were used to direct further efforts consistent with the Manalapan Brook Watershed Protection and Restoration Plan. Princeton Hydro completed a comprehensive model calibration process for the GWLF model developed for the Manalapan Brook watershed.

GWLF is a hydrologic model which incorporates the capability to simulate water quality and pollutant loading; however, the water quality capabilities of GWLF are largely driven by its hydrologic simulation. The majority of the watershed is tributary to DeVoe Lake. Spotswood Dam at DeVoe Lake is the location of the USGS stream gage on the Manalapan Brook (USGS Station #01405400). This stream gage measures stream flow on a 15-minute interval and the USGS catalogs this data in various formats including monthly average flows. This flow data is an indispensable asset to the calibration process as it represents a continuous direct measurement of the main model output on which all water quality calculations are based on. Numerous sources for water quality data exist for the watershed including these data collected by Princeton Hydro towards the current effort; however, the vast majority of these data are grab samples and do not represent a continuous record for any water quality parameter. During the seven-year period of analysis (2001 to 2007) there were 53 separate suspended sediment measurements made at various locations in the watershed by four different entities. If these measurements were assumed to represent a daily average for suspended sediment concentration (which they do not), this dataset would only represent less than two percent (2%) of the total analysis period. Furthermore, these types of water quality data are expected to be highly variable and without continuous sampling it would not be appropriate to use these data in a calibration process. Instead, this water quality data will be used as a general comparison against the pollutant loading predictions from GWLF. A further explanation of the suspended sediment sampling data is provided in the Establishment of a Targeted Endpoint and Long-Term Goal section of this report.

Since the GWLF model is based on hydrology and a complete, continuous data set of observed stream flow for the period of analysis exists for the watershed, the observed monthly average stream flow was used as the basis for the GWLF model calibration. As was previously mentioned, a small portion of the watershed (~3.3 square miles) is located downstream of the stream gage and was therefore not considered when comparing the GWLF output to the observed stream flow; although this area was used in the final model runs. This small portion encompasses portions of East Brunswick, Spotswood, and Helmetta.

Minimal changes to the default parameters in GWLF were required to attain an appropriate calibration, and none of the GIS-derived spatial data compiled by AVGWLF were changed in an effort to calibrate the GWLF model. The only parameters adjusted were the groundwater recession coefficient and the groundwater seepage coefficient. These are both empirical coefficients related to the lumped groundwater simulation routines of GWLF. The groundwater recession coefficient is used to describe the rate at which water from the shallow saturated groundwater zone will contribute to stream flow, with higher numbers indicating a faster transition from groundwater to stream flow. The value used here (0.01 day^{-1}) is within the range recommended by the AVGWLF model documentation. Similarly, the groundwater seepage coefficient describes the rate that water in the shallow saturated zone transitions to the deep saturated zone. The only distinction between the deep and shallow groundwater zones is that water in the shallow saturated zone can contribute to stream flow and the deep zone cannot. The seepage coefficient used in this analysis is 0.003 day^{-1}, which results in about 4 in/yr of deep recharge.

Four indices were used to measure the model calibration, the background information and results of these calibration indices are summarized below and provided in graphical format as figures. The first index is a simple graphical time series comparison of the observed monthly flows from the stream gage and the corresponding monthly stream flow predicted by GWLF (see Figure 13). The purpose of this calibration metric is to determine (by eye) how well the model generally predicts monthly stream flow; specifically this is useful in determining how well the model predicts the seasonal aspect of stream flow. The time-series plot indicates that the GWLF model generally follows the observed data. This is especially obvious during the first two years when the observed flow was less variable. Also noteworthy is the fact that the seasonality predicted by the model is similar in magnitude to that in the observed data. Although the model seems to over predict months with significant high flows (three months), overall the model is shown to reasonably predict the observed stream flow.

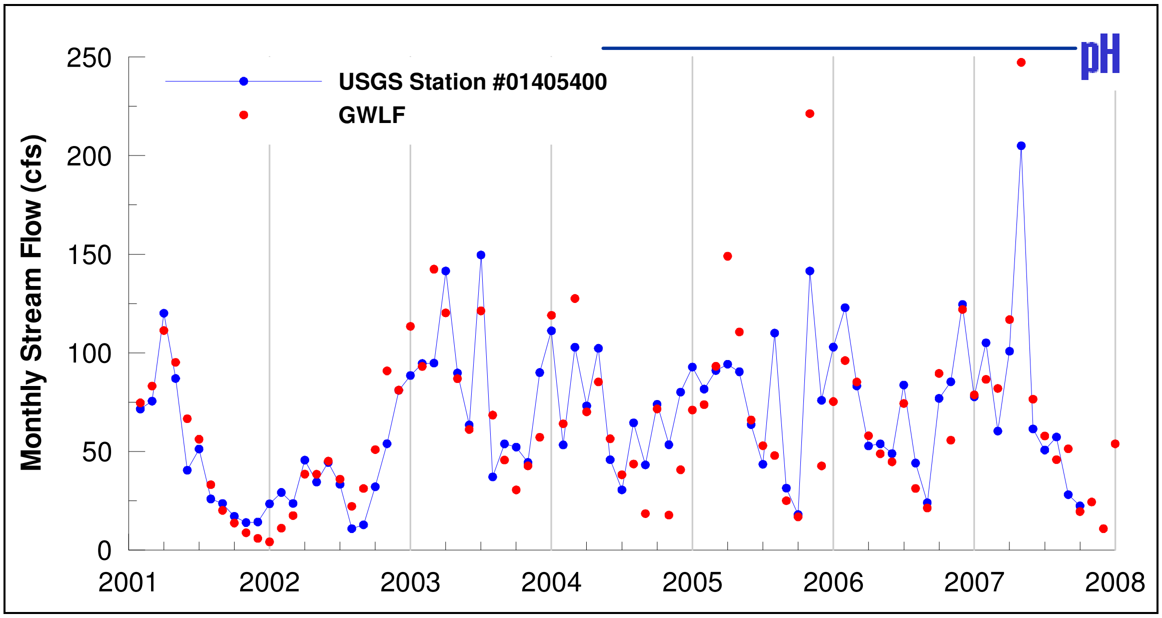

Figure 13. Time series comparison of observed and simulated stream flow.

The second calibration metric is a single statistical value that has been widely applied as a calibration metric for continuous simulation hydrologic models. This statistic is called the Nash-Sutcliffe coefficient and it has been recommended by the American Society of Civil Engineers for similar applications (ASCE, 1993). The coefficient is calculated as follows:

$$NS = 1 - \frac{\sum_{t_1}^{t_2}\left(Q_{observed} - Q_{GWLF}\right)^2}{\sum_{t_1}^{t_2}\left(Q_{observed} - \overline{Q}_{observed}\right)^2}$$

Where Q is stream flow and $\overline{Q}$ is the average observed stream flow over the period of analysis. This statistic can only be less than or equal to one. Negative values indicate that the average observed stream flow provides a better prediction than the GWLF model (unsatisfactory model results), while a value of 1 indicates that the model is a perfect prediction of the observed flow. In similar studies using monthly stream flows from GWLF, the New England Interstate Water Pollution Control Commission has considered simulations which result in a Nash-Sutcliffe value greater than 0.1 to be sufficiently calibrated (NEIWPCC 2005). In this application a resulting Nash-Sutcliffe statistic of 0.65 is determined from the data presented in Figure 9.

The third measure is a scatter plot comparing the observed monthly flows (x axis) to the predicted flows (y axis) (see Figure 14). A perfect 1:1 comparison between the x and y axes would indicate a perfect match between the observed and modeled flows. A linear regression of the data provides a slope of 1.00, indicating that *on average* the modeled flow provides an accurate prediction of the observed flow. While there is scatter around the 1:1 line, this figure shows that on average the model neither over estimates nor underestimates the stream flow.

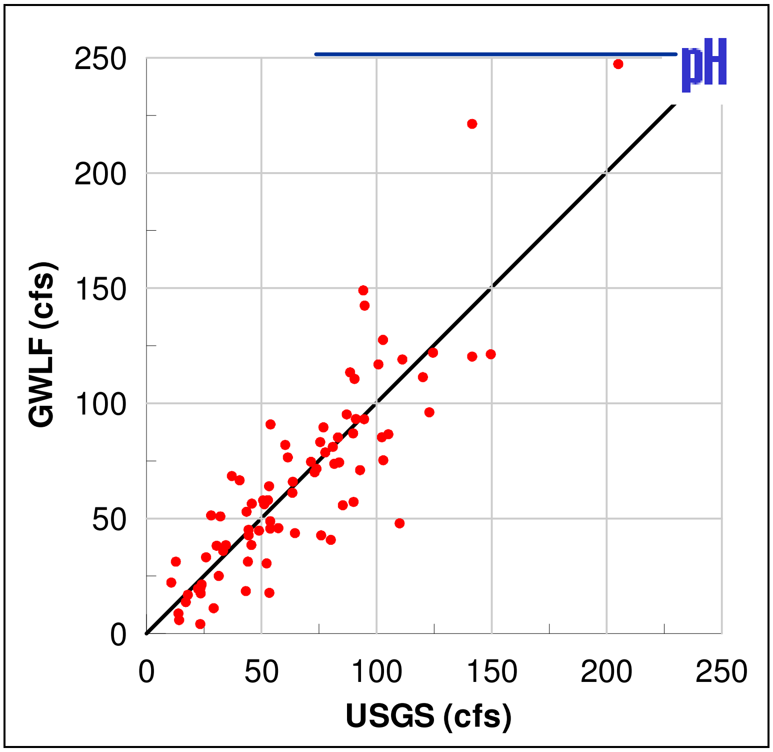

Figure 14. Comparison scatter plot of observed and simulated stream flow.

Finally, the fourth index goes beyond the monthly stream flow output and compares the entire water budget predicted by the model. The purpose of this measure to ensure that the water budget predicted by the model is reasonable and comparable to water budgets estimates reported from other sources. The New Jersey Water Supply Authority (NJWSA) provides a water budget estimate for the Manalapan Brook watershed which is summarized in the September 2000 report entitled "Water Budget in the Raritan Basin" (NJWSA, 2000). The GWLF predicted water budget is not directly comparable to that provided in the report for Manalapan Brook because the annual average precipitation for the analysis period (2001 to 2007, 50 inches) is not the same as the annual precipitation used for the watershed in the report (46 inches). Also the components of recharge are not defined in the same manner; however, many useful comparisons remain between the two water budgets. The NJWSA water budget indicates that on average there are 26 in/yr of evapotranspiration; the GWLF model also predicts 26 in/yr. The NJWSA report indicates 9.0 and 11 in/yr of recharge and runoff respectively. If it is assumed that all of the recharge returns as baseflow to the stream this results in 20 in/yr of total stream flow (baseflow and runoff). For the seven year period the GWLF model also predicts 20 in/yr of stream flow (baseflow and runoff).

In summary, the objective of the calibration procedure was to focus primarily on the hydrology of the watershed, as the hydrology is a primary driver in the water quality routines of the GWLF model. Furthermore, a continuous dataset of stream flow is available, while only minimal grab samples exist for water quality parameters. The GWLF model required minimal adjustments to adequately simulate the stream flow as measured by the USGS stream gage located in Spotswood. This calibration has been demonstrated with the use of various calibration indices including a time-series and scatter plot, Nash-Sutcliffe calibration statistic, and water budget comparisons. Therefore the model is considered to have been adequately calibrated and the calibrated GWLF model has been used to generate pollutant loads for the subwatersheds, HUC14 watersheds, municipalities, and watershed as a whole.

Model Results:
The previously described input data were used in the AVGWLF preprocessor to create the necessary input files for the GWLF model. The model was run on a subwatershed (20), municipality (9), HUC-14 (3), and whole watershed basis. Therefore there were 33 individual model runs completed as each analysis area requires a separate model run. The model was run for a seven-year period of analysis for the years 2001 through 2007. It should be noted that a pollutant load for Englishtown was unattainable since there are no streams in the small Englishtown portion of the watershed.

The model results are summarized as the average annual sediment loads calculated over the seven-year period of analysis. The results from the four separate analysis scales are summarized in Table 17.

On a watershed-wide basis, 22,790 tons of sediment impact Manalapan Brook via loading on an annual basis, with 88% of this load originating from streambank erosion. For the HUC-14, the total sediment load is 13,389 tons, with 75% of it originating from streambank erosion.

Table 17. Summary of annual total sediment loads for all model runs.

	Avg. Area (mi^2)	Streambank (tons)	Land/Runoff (tons)	Percent Stream	Total
Subwatersheds	2.2	3590	3507	51	7097
Municipalities	4.8	9111	3375	73	12487
HUC-14	14	10091	3297	75	13389
Watershed	43	20013	2777	88	22790

The results shown in Table 17 are a summation of all the individual areas (subwatersheds, municipalities etc.). The results indicate that the sediment load calculations are dependent on the average size of the analysis area. The sediment loads from overland sources ('Land') are shown to decrease slightly as the average size of the analysis area increases. This is expected due to the sediment delivery ratio calculated based on basin area. The predicted sediment load associated with streambank erosion ('Stream') is shown to increase with increasing analysis area. This is a result of the formulation of the streambank erosion calculation as summarized in the previous section. Specifically, the lateral erosion rate is a function of the average monthly flow rate (m^3/s), and the flow rate is inherently a function of watershed size.

Municipality Results:
The sediment load results for each of the nine municipalities reveal that the municipalities of Monroe and Manalapan have the highest total sediment load. This is expected since the portions of these two municipalities are by far the largest in the watershed. In an effort to provide an even comparison of sediment loads from the individual municipalities, the sediment loads were normalized. The overland sediment loads were normalized by the area of the municipality and are presented in units of tons/mi^2. The streambank erosion sediment loads are normalized by the total stream length in each municipality, and these results are presented in units of tons/mile. The results are summarized in graphical format in Figure 15 (total load with percentage from streambank indicated) and Figure 16 (normalized sediment load); the raw data is provided in Table 18.

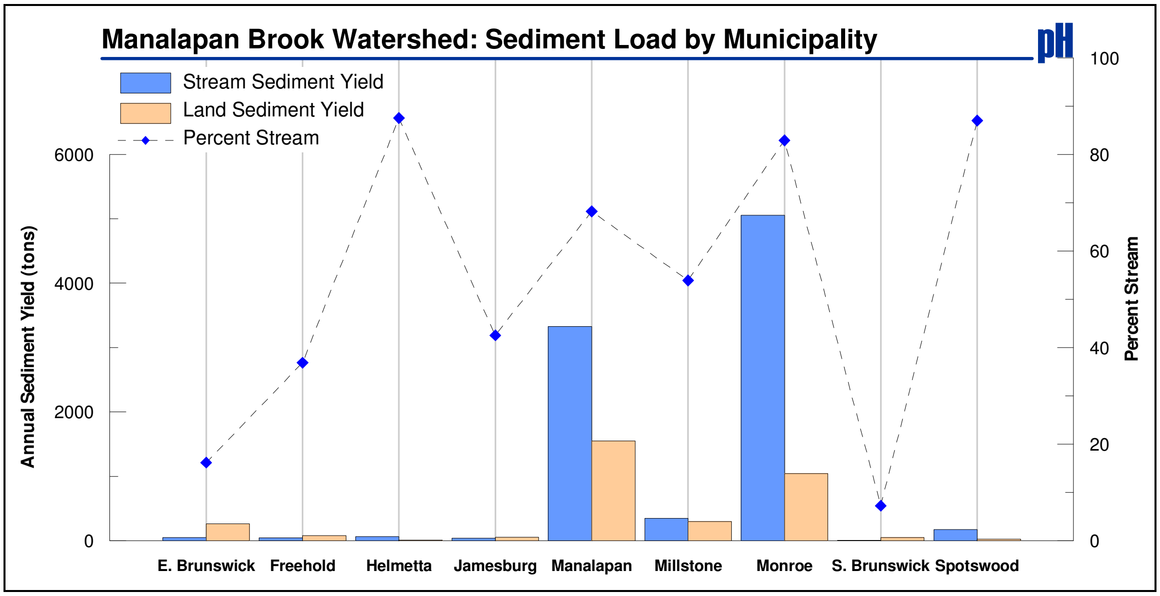

Figure 15. Total sediment load by municipality.

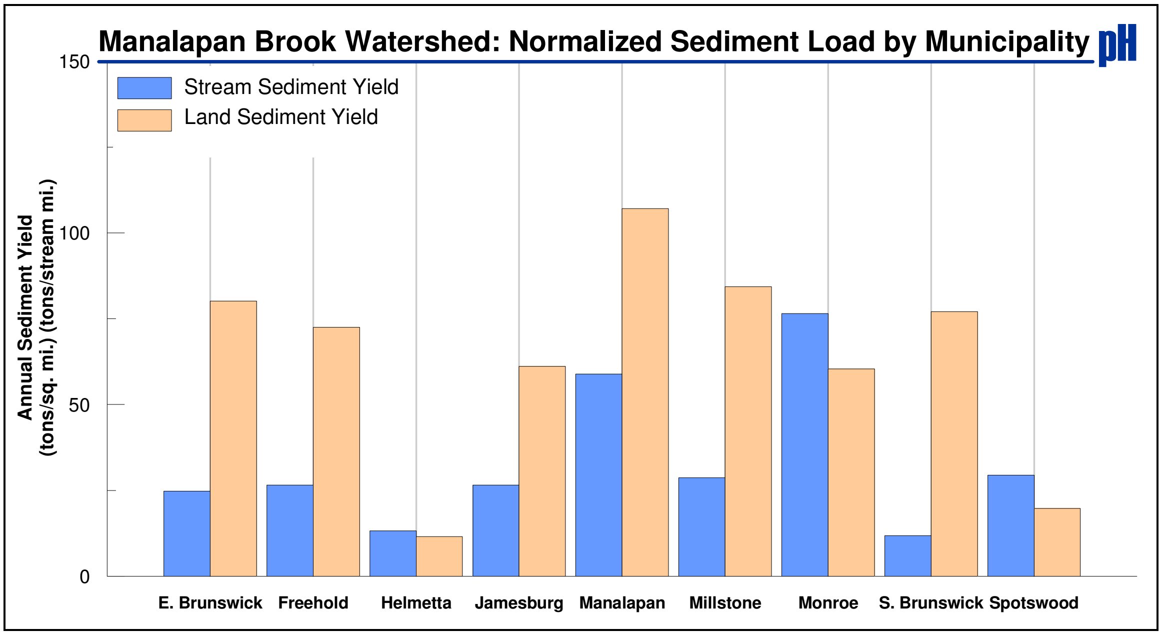

Figure 16. Total normalized sediment load by municipality.

Table 18. Summary of annual total sediment loads for municipalities.

Municipality	Area (mi^2)	Land (tons)	Land ($tons/mi^2$)	Stream (tons)	Stream (tons/mi.)	Total Load (tons)
East Brunswick	3.31	266	80	51	25	317
Freehold	1.07	78	72	45	27	123
Helmetta	0.819	9	12	66	13	76
Jamesburg	0.845	52	61	38	26	90
Manalapan	14.5	1551	107	3327	59	4878
Millstone	3.56	300	84	351	29	651
Monroe	17.3	1043	60	5057	77	6100
South Brunswick	0.656	51	77	4	12	55
Spotswood	1.31	26	20	172	29	198

The normalized loads show that the municipalities of Manalapan and Millstone are the largest contributors of overland sediment loads on a per area basis. The streambank erosion sediment load results show that on a per stream mile basis the townships of Monroe and Manalapan are the highest contributors; however, it should be understood that the main reason these two municipalities have the highest streambank sediment load is because they are the largest areas in the watershed and therefore the results will have a tendency to predict more sediment load due to the increased area and consequently higher average monthly flow rate. The streambank erosion routine does not consider the spatial relationship of each analysis area.

The GWLF model was also used to calculate the nutrient (nitrogen and phosphorus) loads from the watershed on a municipality specific basis. The total average annual nitrogen load is 129,000 lbs/yr (1.0 mg/l) and the total phosphorus load is calculated as 7,640 lbs/yr (0.059 mg/l). A graphical representation of the municipalities' nutrient loads are provided in Figure 17 and a summary table of the nutrient loads for the municipalities is provided in Table 19.

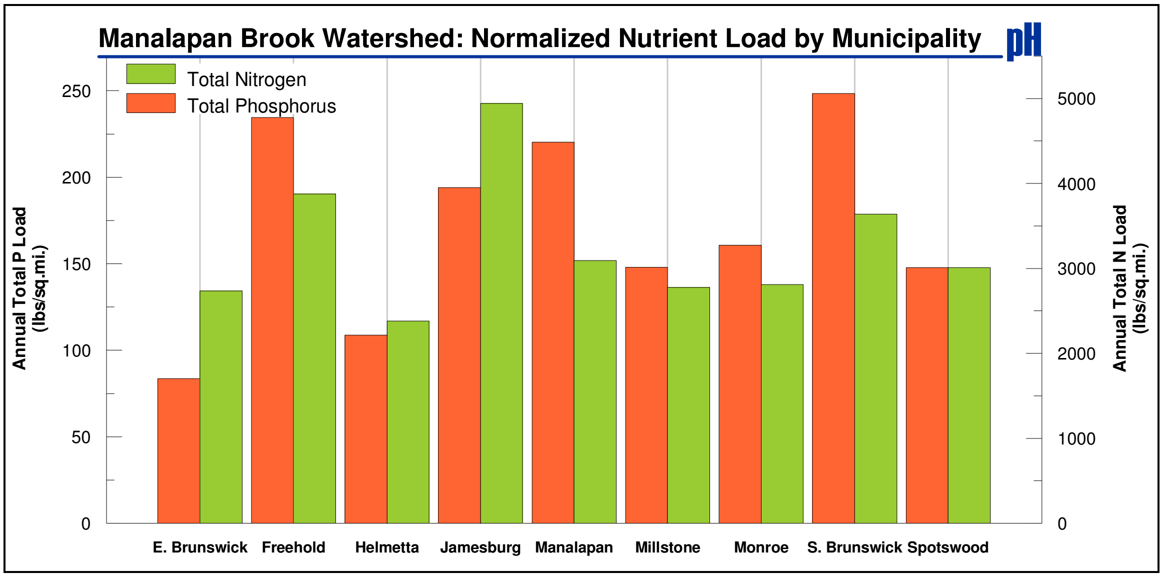

Figure 17. Summary of normalized nutrient loads by municipality.

Table 19. Summary of annual nutrient loads for municipalities.

Municipality	Area (mi^2)	Total P (lbs)	Total P (lbs/mi^2)	Total N (lbs)	Total N (lbs/mi^2)
East Brunswick	3.31	277	84	9066	2737
Freehold	1.07	251	235	4150	3877
Helmetta	0.819	89	109	1950	2382
Jamesburg	0.845	164	194	4179	4943
Manalapan	14.5	3192	220	44815	3094
Millstone	3.56	527	148	9886	2776
Monroe	17.3	2779	161	48645	2813
South Brunswick	0.656	163	248	2390	3641
Spotswood	1.31	193	148	3930	3011

The results for the nutrient loads vary little among the nine municipalities. South Brunswick has the highest total phosphorus load and Jamesburg is shown to have the highest total nitrogen load. Helmetta is shown to have the lowest total nitrogen load and the second lowest total phosphorus load on a per area basis (next to East Brunswick).

Subwatershed Results:

The sediment load results for each of the 20 subwatersheds show that on average the 20 subwatersheds produce 355 tons of sediment from land and streambank erosion sources combined (163.6 tons/mi^2 or 573 kg/ha). The model results for the subwatersheds, like the municipality results, were normalized based on area (land sediment) and stream length (streambank sediment source).

Subwatershed #17 was shown to be the highest sediment producer for land sediment sources with average annual land sediment load of 460 tons/mi^2. This subwatershed has a high proportion of agricultural and urban areas which are responsible for the high ranking indicated by the model results. Subwatershed #5 was found to have the highest streambank erosion sediment load, with an average annual sediment load of 165 tons/mi. Graphical summaries of the AVGWLF model results are provided in Figure 18 (total load with percentage from streambank indicated) and Figure 19 (normalized loads). The numeric results are also provided in Table 20.

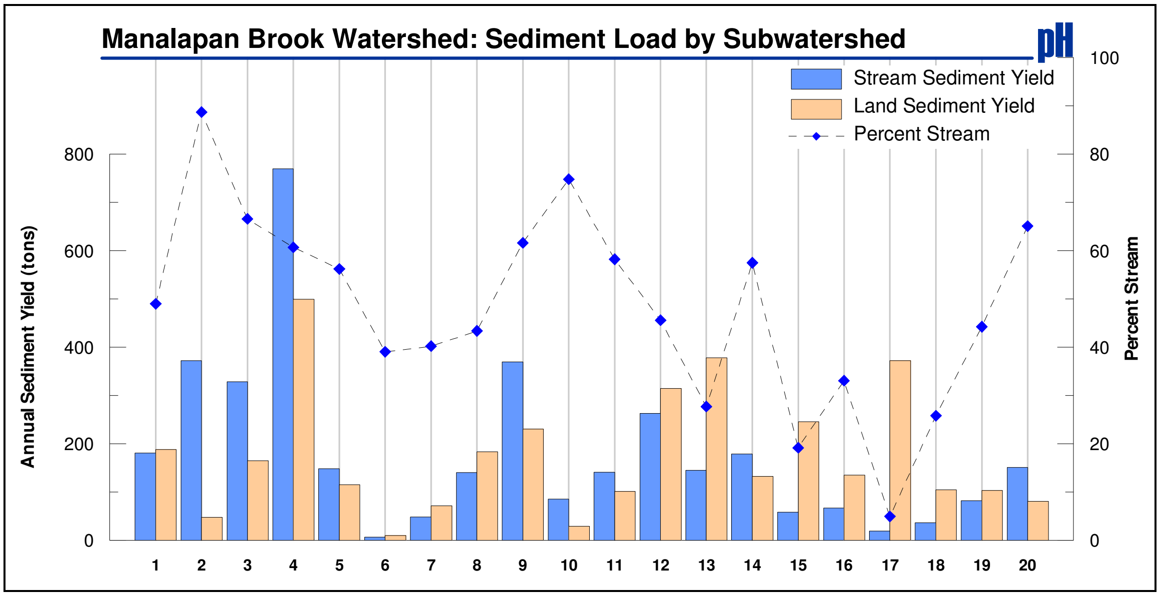

Figure 18. Total sediment load by subwatershed.

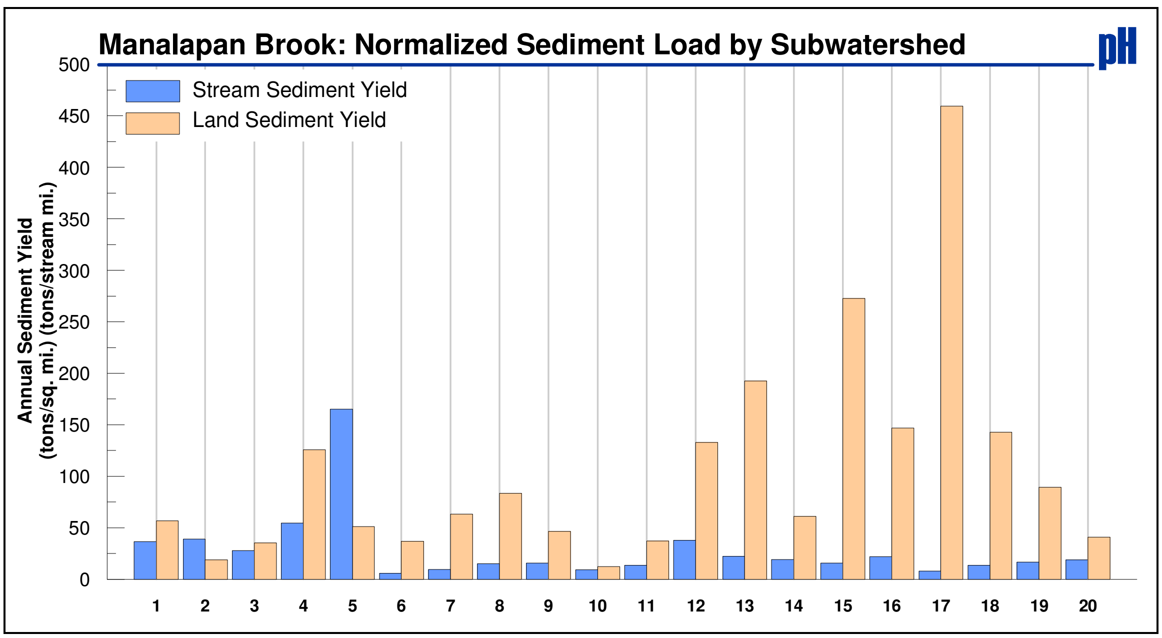

Figure 19. Total normalized sediment load by subwatershed.

Table 20. Summary of annual sediment loads for subwatersheds.

Sub-watershed	Area (mi^2)	Land (tons)	Land (tons/mi^2)	Stream (tons)	Stream (tons/mi.)	Total Load (tons)
1	3.32	188	57	181	37	369
2	2.52	48	19	372	39	420
3	4.65	165	36	328	28	493
4	3.97	499	126	770	54	1269
5	2.26	115	51	148	165	263
6	0.263	10	37	6	6	16
7	1.13	71	63	48	10	119
8	2.20	184	83	141	15	324
9	4.93	230	47	370	16	600
10	2.34	29	12	86	9	115
11	2.73	102	37	141	14	243
12	2.37	314	133	263	38	577
13	1.97	378	192	145	22	523
14	2.17	132	61	179	19	311
15	0.900	245	273	58	16	304
16	0.919	135	147	67	22	202
17	0.811	372	459	19	8	392
18	0.730	104.3	143	36	14	141
19	1.16	103.43	89	82	17	185
20	1.97	80.84	41	151	19	231

In addition to the sediment loads, the AVGWLF model was also used to calculate the nutrient (nitrogen and phosphorus) loads from the watershed at the subwatershed level. The total average annual nitrogen load is 121,000 lbs/yr (0.93 mg/l) and the total phosphorus load is calculated as 6,940 lbs/yr (0.054 mg/l). A graphical representation of the subwatershed nutrient loads are provided in Figure 20 and a summary table of the nutrient loads for the subwatersheds are provided in Table 21.

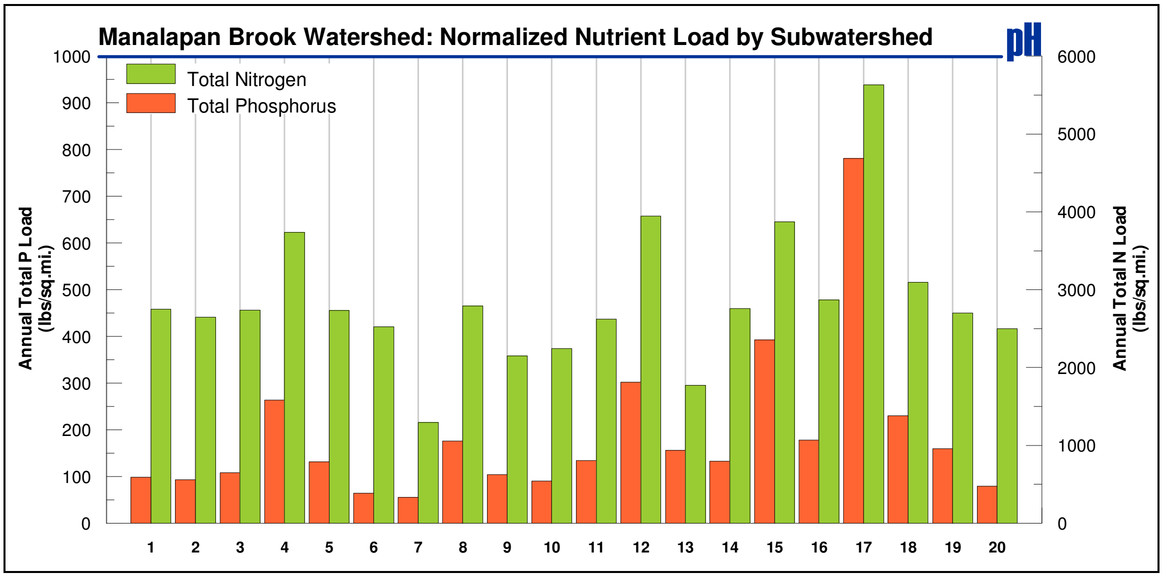

Figure 20. Summary of normalized nutrient loads by subwatershed.

Table 21. Summary of annual nutrient loads for subwatersheds.

Sub-watershed	Area (mi^2)	Total P (lbs)	Total P (lbs/mi^2)	Total N (lbs)	Total N (lbs/mi^2)
1	3.32	328	99	9128	2749
2	2.52	235	93	6678	2649
3	4.65	504	108	12725	2737
4	3.97	1049	264	14852	3738
5	2.26	296	131	6164	2733
6	0.263	17	65	663	2526
7	1.13	63	56	1464	1294
8	2.20	388	176	6138	2789
9	4.93	513	104	10617	2152
10	2.34	212	90	5257	2243
11	2.73	368	135	7168	2622
12	2.37	715	302	9337	3945
13	1.97	307	156	3483	1772
14	2.17	288	133	5974	2758
15	0.900	353	392	3485	3874
16	0.919	164	178	2636	2869
17	0.811	633	781	4566	5632
18	0.730	168	230	2259	3095
19	1.16	185	160	3131	2703
20	1.97	156	79	4923	2500

Establishment of Targeted Endpoint and Long-Term Goal

Introduction:
The original focus of the Manalapan Brook Watershed Protection and Restoration Plan was redirected from a focus on total phosphorus (TP) and the established phosphorus TMDL to a focus on total suspended solids (TSS). This decision was based on an observed poor link between TP and chlorophyll *a* concentrations, turbidity and Secchi depth measurements and other observations in Manalapan Lake and the watershed. A further detailed discussion of this justification is provided in the Project Justification section of this plan. A white paper which originally documented these conditions and observations is provided in Appendix F.

Targeted Endpoint Analysis:
Establishing the endpoint needed to be completed in order to run the ArcView GIS-based Generalized Watershed Loading Function model (AVGWLF) to quantify the desirable (targeted) TSS loads for the watershed. Details on running the AVGWLF model to quantify existing conditions and TSS loads were provided in the previous section of this plan. Based on these modeled results, the existing annual TSS loading budget has been summarized (Table 22).

Table 22. Summary of existing annual TSS loads for Manalapan Brook Watershed.

Source of TSS	Tons per Year	Percent Contribution
Existing Stream Erosion Load	3,590	50.6
Existing Surface Runoff Load	3,507	49.4
Total Annual TSS Load	**7,097**	**100**

Based on existing conditions, as quantified by the AVGWLF model, streambank erosion and surface runoff each account for approximately half of the total annual TSS load entering Manalapan Brook.

With the existing annual TSS load quantified for the Manalapan Brook watershed, the goal then was to establish an acceptable endpoint for mean TSS concentrations within the brook to avoid, or at least minimize, water quality impairments. New Jersey has TSS numeric criteria for its waterways. Manalapan Brook and Lake are both designated, under the state's Surface Water Quality Standards (SWQS), as being FW2-NT waters. For such waterways the TSS concentration should not exceed 40 mg/l (SWQS, N.J.A.C. 7:9b – 1.14(c) 7) under baseline conditions. Since this criterion has already been established by

NJDEP for freshwater, non-trout waterways, a targeted TSS load was quantified, based on a mean endpoint of 40 mg/l.

In order to accommodate varying climatic and hydrologic conditions (i.e. seasonal variations in flow, storm events), the identified endpoint of 40 mg/l is a targeted annual mean value. This endpoint concentration was then used to back calculate the targeted annual TSS load, which was 2,570 tons per year (Table 23).

Based on the AVGWLF model the existing TSS load for Manalapan Brook is 7,097 tons per year, which is an estimated annual TSS concentration of 110.6 mg/l. Given these existing and targeted TSS loads, a reduction of 64% or 4,527 tons is required in order to attain the desirable water quality endpoint of 40 mg/l of TSS.

Table 23. Existing and Targeted (Desired) TSS Loads for Manalapan Brook Watershed.

TMDL Scenario	Tons of TSS per Year
Existing Load	7,097
Targeted Load	2,570
Required Reduction	**4,527**

As described in detail above, the primary pollutant of concern for the Manalapan Brook watershed shifted from TP to TSS. In addition, the AVGWLF model was used to quantify the existing annual TSS loads. The targeted TSS loads were established, based on the state's Surface Water Quality Standard designation for Manalapan Brook and Lake. The difference between the existing and targeted TSS loads is the load reduction expected for the management measures described in Manalapan Brook Watershed Protection and Restoration Plan.

Watershed Protection and Restoration Implementation Strategy

Introduction:
The objective of the Watershed Protection and Restoration Plan is to integrate and synthesize the results of the watershed characterization, AVGWLF modeling, stream visual assessment, water quality monitoring, and TSS targeted endpoint of the Manalapan Brook project. The purpose of this process is to use the results to identify the sources of TSS (based on the SVA and water quality monitoring / modeling), prioritize and rank specific subwatersheds, and target potential site-level implementation projects to achieve the targeted watershed-wide suspended sediment load reductions and desired water quality goals. The Watershed Protection and Restoration Plan uses the nine minimum components approach as required by the NJDEP and detailed in the U.S. Environmental Protection Agency's "Handbook for Developing Watershed Plans to Restore and Protect Our Waters" (USEPA, 2005).

This section addresses the third element of a comprehensive watershed restoration plan. Specifically, the identification and prioritization protocol described below addresses the identification of critical areas component of the third element. This section also provides a detailed description of a list of NPS management measures proposed for implementation to attain the targeted TSS load.

This section outlines the process of prioritization of site specific implementation projects in the watershed in accordance with the Scope of Work and in compliance with the nine minimum components approach. These projects represent the "First Tier" of implementation projects. Additionally, the plan provides a list of "Second Tier" projects based on an analysis of all the SVA station locations. Furthermore, in addition to both the site-specific first and second tier projects several watershed wide initiatives are also proposed. These watershed wide initiatives are not site specific and are therefore not prioritized or directly compared to the individual implementation projects.

The project identification and prioritization processes were used in conjunction with the project committee's oversight to select representative locations for the implementation of a project "kick-off" demonstration project and for the creation of site specific design projects. These items are discussed in the Demonstration Project and Design Projects sections of the plan.

Project Identification and Prioritization:
All efforts were made to assign potential implementation projects across the 43 square mile watershed in an objective and equitable fashion. The project committee required that there be an equitable spatial (subwatershed basis) and political (municipality, and county basis) implementation project distribution. Similarly, the revised project Scope of Work stated that "at least one potential BMP implementation and/or stream restoration project can be identified in each of the 20 subwatersheds, eight municipalities and two counties

within the watershed". Therefore in an effort to determine the most equitable distribution of the implementation projects, the lowest scoring SVA station from each of the 20 subwatersheds was chosen. Due to the spatial characteristics of the subwatersheds this methodology results in good spatial coverage throughout the watershed, and also represents adequate political distribution between the counties and municipalities.

This process involved sediment load calculations on a subwatershed basis and the corresponding ranking of those results to prioritize areas of the watershed with higher annual sediment loading rates. GIS was then used to relate the AVGWLF results to the results from the Stream Visual Assessment (SVA) scoring, the Water Resources Protection Open Space (WRPOS) model, and updated LU/LC data. The following sections further describe the identification and prioritization process.

Subwatershed Ranking:
The watershed was divided into 20 subwatersheds based on topography and natural drainage divides (stream confluences, etc.). The subwatersheds vary slightly in size but are on average approximately 2.2 square miles. Sediment loads were calculated using the AVGWLF hydrologic/water quality model. The AVGWLF model differentiates total watershed sediment loads based on two main sources. These two separate sources include land sources (overland flow and erosion) and streambank erosion. Generally, the sediment loads referenced in the Watershed Protection and Restoration Plan represent the average annual AVGWLF results over the seven year simulation period (2001 to 2007). A complete description of the modeling process is provided in AVGWLF modeling section of this plan. For the purpose of the Watershed Protection and Restoration Plan the model results for each subwatershed were compared and ranked based on their relative sediment load contributions. The following sections summarize the AVGWLF result rankings and prioritization.

Land Sediment Results:
The 20 subwatersheds vary in size (standard deviation of 1.3 square miles); therefore, it would not be equitable to simply compare total sediment loads among the 20 subwatersheds as larger subwatersheds would have an inherent tendency to produce a larger sediment load. The calculated land sediment loads were normalized by the individual total subwatershed areas and have the units of tons per square mile. This normalized sediment load represents the average sediment load per unit area and is a direct reflection of the erosion and sediment loading characteristics of each subwatershed. The normalized sediment loads were then assigned a ranking. Three simplified categories (low, medium, and high) were assigned to characterize the relative loading of each subwatershed. Subwatersheds which had normalized sediment loadings greater than twice the median value (median = 62.1 tons/mi^2) were assigned a "High" ranking, any loadings otherwise greater than the median were assigned a "Medium" ranking, and all loadings less

than the median were assigned a "Low" ranking. The normalized land sediment results for the 20 subwatersheds are shown below in Table 24.

Table 24. Normalized subwatershed land sediment loads.

Subwatershed	Land Sediment (tons/mi^2)	Ranking
1	56.72	Low
2	18.89	Low
3	35.50	Low
4	125.7	High
5	51.11	Low
6	36.76	Low
7	63.14	Medium
8	83.44	Medium
9	46.69	Low
10	12.34	Low
11	37.13	Low
12	132.8	High
13	192.5	High
14	61.05	Low
15	272.8	High
16	147.0	High
17	459.3	High
18	142.9	High
19	89.28	Medium
20	41.05	Low

The average land sediment load for the 20 subwatersheds was 105 tons/mi^2 with a maximum of 459 tons/mi^2 (Subwatershed #17) and a minimum of 12.3 tons/mi^2 (Subwatershed #10). Seven of the subwatersheds were classified as "High" in terms of their land sediment loading characteristics. AVGWLF uses a modification of the Universal Soil Loss Equation (USLE) to calculate land sediment loads. The USLE calculation procedure accounts for numerous GIS-derived land surface conditions; however, one of the main factors is land use. The land use data indicates that 71% of the land use in Subwatershed #10 is composed of wetland and forest areas which tend to produce little sediment loadings, and has only 15% of its total area classified as developed or cropland. Conversely, Subwatershed #17 has only 26% of its total area classified under the wetland and forest land use categories, and 61% classified as developed or cropland areas. A graphical representation of the subwatershed land sediment ranking is provided below in Figure 21.

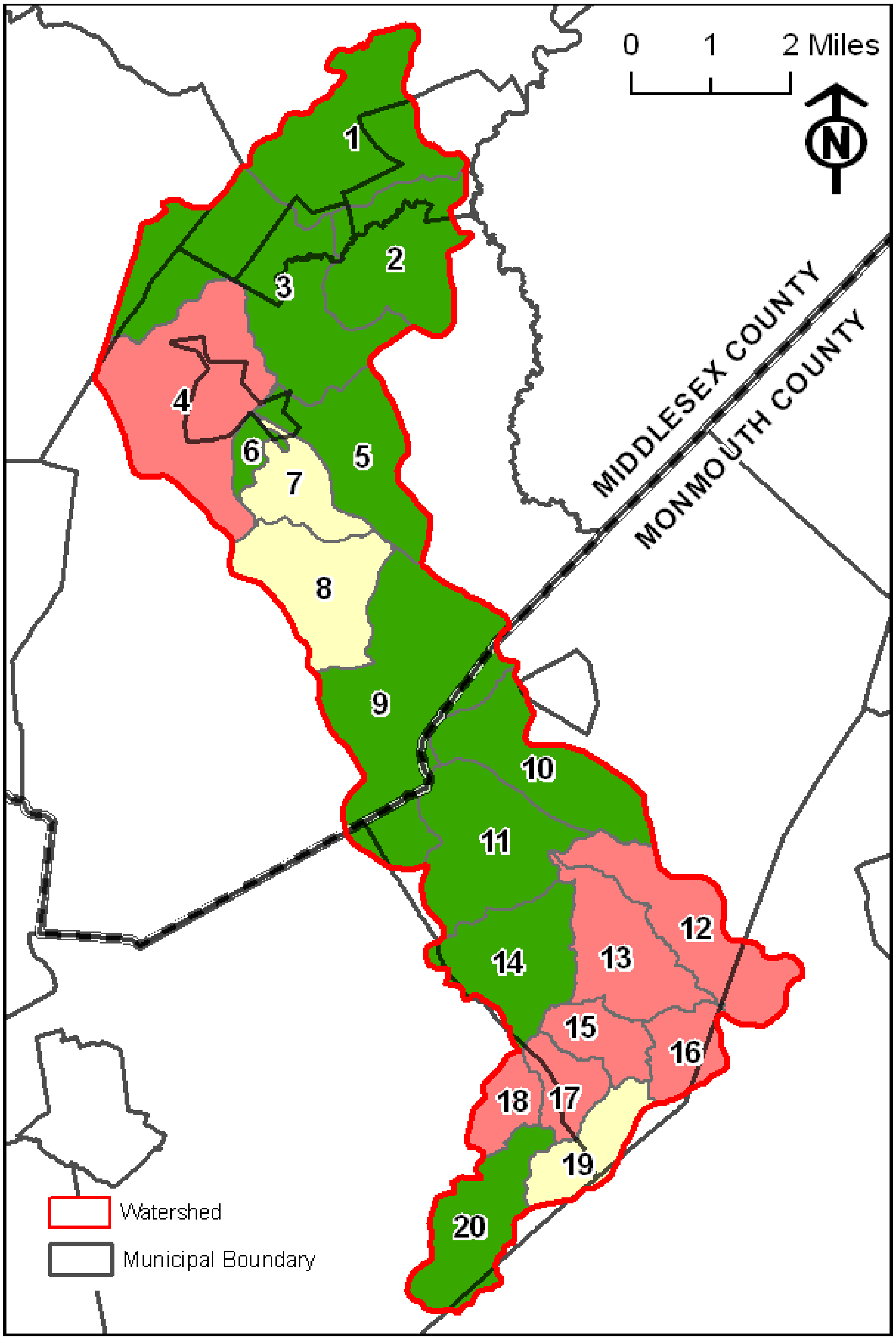

Figure 21. Land sediment loading ranking (red indicates highest ranking, green represents lowest ranking).

Streambank Erosion Results:
Similar to the land sediment loading, the sediment load associated with streambank erosion was normalized to better compare the relative contributions from the subwatersheds. AVGWLF calculates a Lateral Erosion Rate (LER) for each subwatershed. This erosion rate is a function of numerous GIS-derived parameters and the modeled stream flow rate (also a function of GIS-derived parameters such as land use and soil type). In order to calculate a streambank erosion sediment load, the calculated LER is multiplied by default values for average streambank height and soil density and then by the GIS calculated total stream length for each subwatershed. In an effort to normalize the streambank erosion sediment loads, each subwatershed's sediment load was divided by the total stream length in the subwatershed to result in a streambank erosion sediment loads with the units of tons/mile. Three simplified categories (low, medium, and high) were assigned to characterize the relative loading of each subwatershed. The normalized streambank erosion sediment results for the 20 subwatersheds are shown below in Table 25.

Table 25. Normalized subwatershed streambank erosion sediment loads.

Subwatershed	Land Sediment (tons/mi)	Ranking
1	36.6	High
2	39.1	High
3	27.9	Medium
4	54.5	High
5	165	High
6	5.81	Low
7	9.56	Low
8	15.2	Low
9	15.9	Low
10	9.14	Low
11	13.7	Low
12	37.9	High
13	22.3	Medium
14	19.3	Medium
15	15.7	Low
16	21.9	Medium
17	8.25	Low
18	13.5	Low
19	16.7	Low
20	18.8	Medium

The average streambank erosion sediment load for the 20 subwatersheds was determined to be 28.3 tons/mi with a maximum of 165 tons/mi^2 (Subwatershed #5) and a minimum of 5.81 tons/mi (Subwatershed #6). Five of the subwatersheds

(#1, 2, 4, 5, 12) were classified as “High” in terms of their streambank erosion sediment loading characteristics. A graphical representation of the streambank erosion subwatershed rankings is provided in Figure 22.

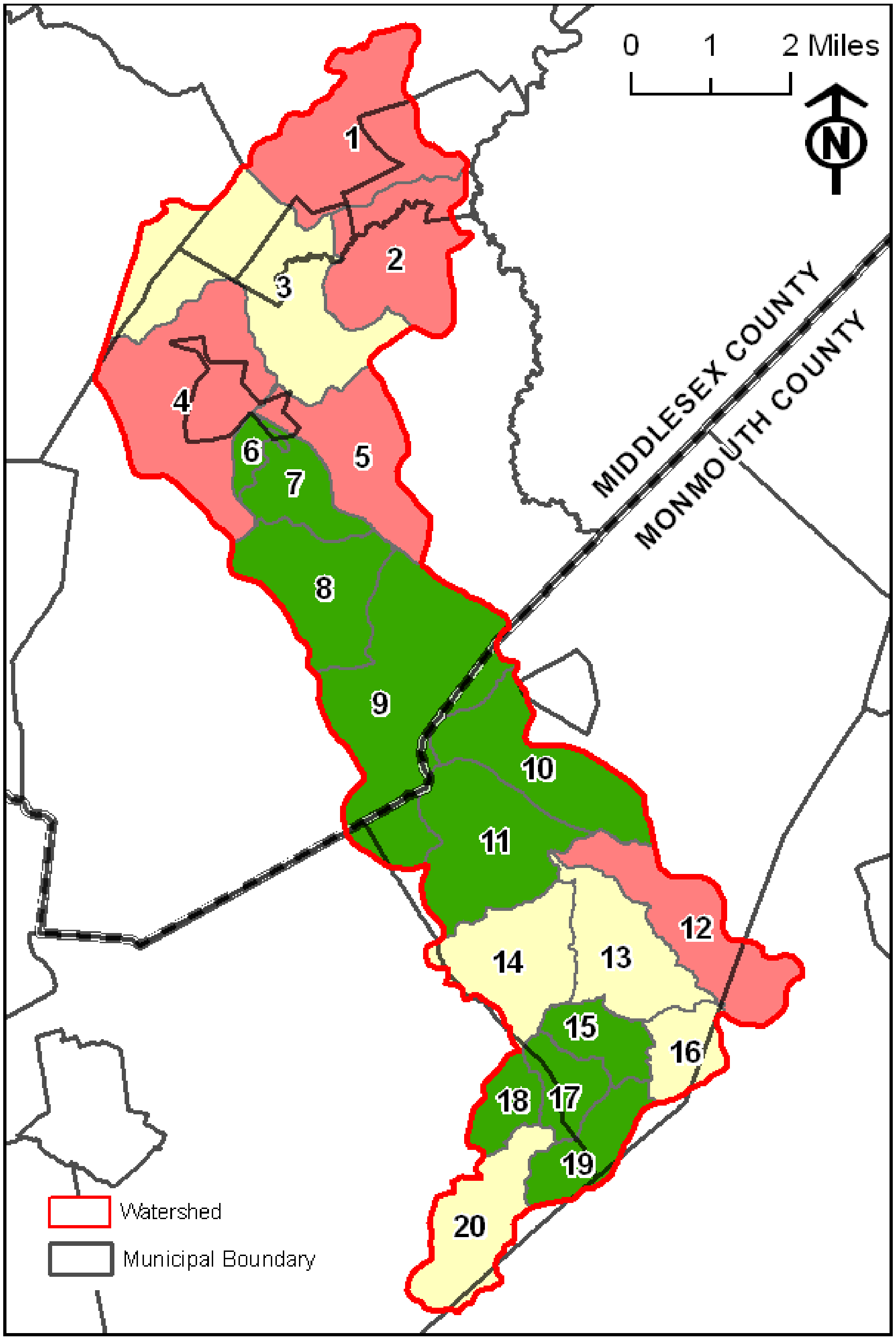

Figure 22. Streambank erosion sediment ranking (red indicates highest ranking, green represents lowest ranking).

Combined Subwatershed Ranking:
The subwatershed rankings determined in the land sediment and streambank erosion were combined to provide an overall ranking of the subwatersheds based on the AVGWLF sediment loads. For this ranking, each subwatershed was assigned a rank (1-20) for both its land and streambank erosion sediment load. The two ranks were summed to produce an overall ranking. This ranking varied from as low as 9 (Subwatershed #4) to 38 (Subwatershed #10). A graphical representation of the combined subwatershed ranking is provided below in Figure 23.

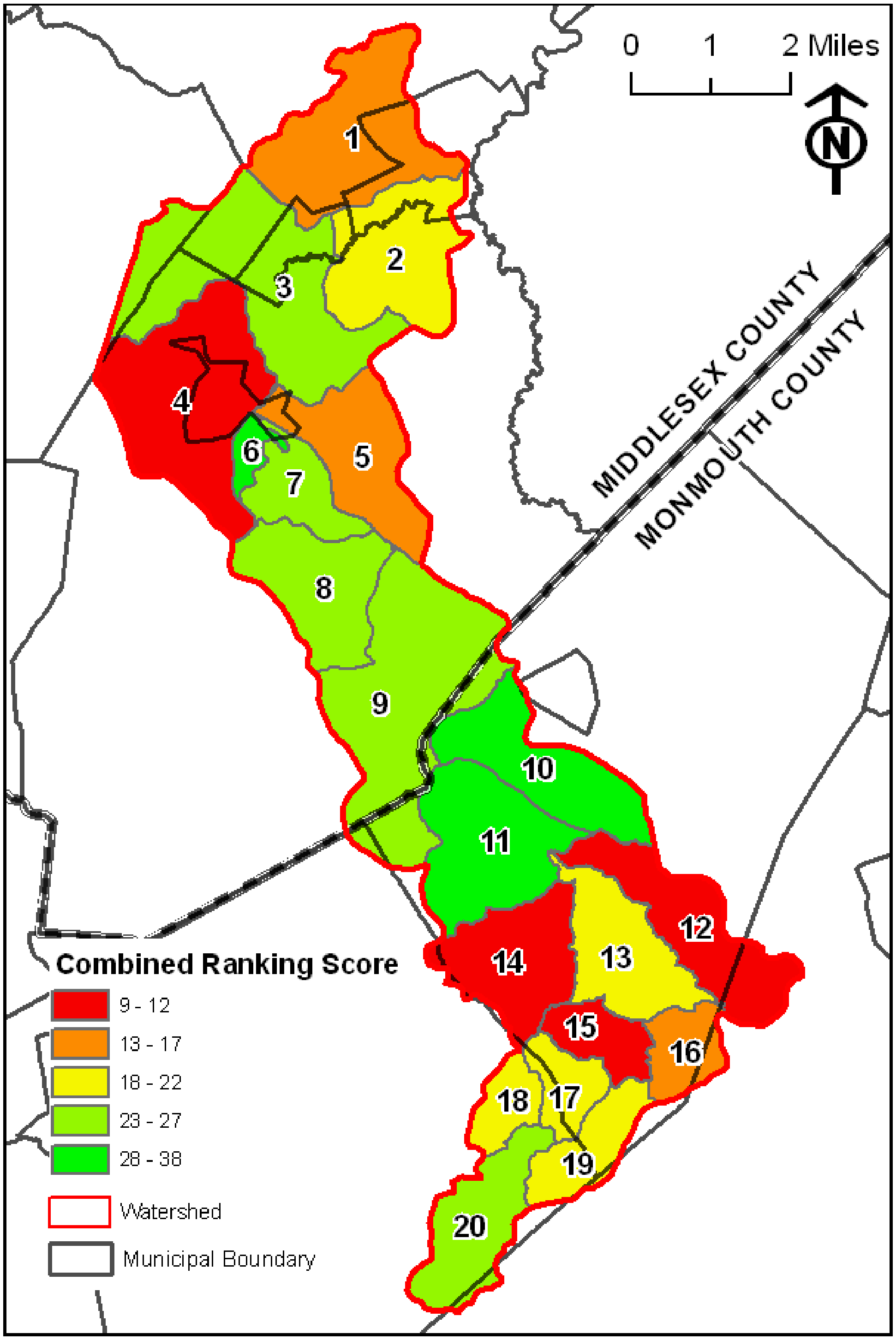

Figure 23. Combined subwatershed ranking (red indicates higher sediment loads, green represents lowest loads).

The combined subwatershed ranking procedure indicates that Subwatersheds #4, #12, #14, and #15 have the lowest ranking and consequently some of the largest overall sediment loads to the Manalapan Brook. Subwatersheds #4 and #12 were the only areas ranked as "High" priority areas for both land sediment and streambank erosion sediment loads.

Stream Visual Assessment:
A field reconnaissance and Stream Visual Assessment (SVA) were conducted in the spring of 2008. Prior to the SVA, 100 stream stations were identified throughout the 43 square mile watershed. The SVA entailed a detailed assessment and scoring of each station (0, lowest to 10, highest). The details and scoring basis used in the SVA are summarized in the Stream Visual Assessment section. A GIS was used to identify which subwatershed each SVA stream station was located in, and assign each SVA station the combined subwatershed ranking score for that subwatershed. This process enabled all the SVA stations to be prioritized and ranked based on the subwatershed's score and the individual SVA station score.

Water Resource Protection Open Space Criteria Model (WRPOS):
Another tool used to identify and screen potential site-specific implementation projects were the results from the previously completed Water Resources Protection Open Space Criteria (WRPOS) model (NJWSA, 2000). The original impetus of the WRPOS model was to promote better management of the water resources of the Raritan River watershed and to protect and preserve those resources for the future. The purpose of the WRPOS model was to identify areas within the Manalapan Brook watershed that are more protective of water resources, and therefore should be targeted for open space preservation or other restoration activities. The model incorporates numerous GIS-based data sources and summarizes them into four main criteria including wellhead protection, riparian area, groundwater recharge, and existing vegetation. The final output of the model identifies the number of water resource protection criteria that each parcel of land possesses (0 to 4) and also identifies whether that parcel is already open space or an urban area. The entire Raritan Basin WRPOS data were clipped to include only those portions within the Manalapan Brook watershed. A GIS was used to identify the final WRPOS criteria score within the area of each SVA site location. The final WRPOS model output for the Manalapan Brook watershed is shown graphically below in Figure 24. Further discussion of the analysis and mapping for the revised WRPOS analysis for the Manalapan Watershed are provided below.

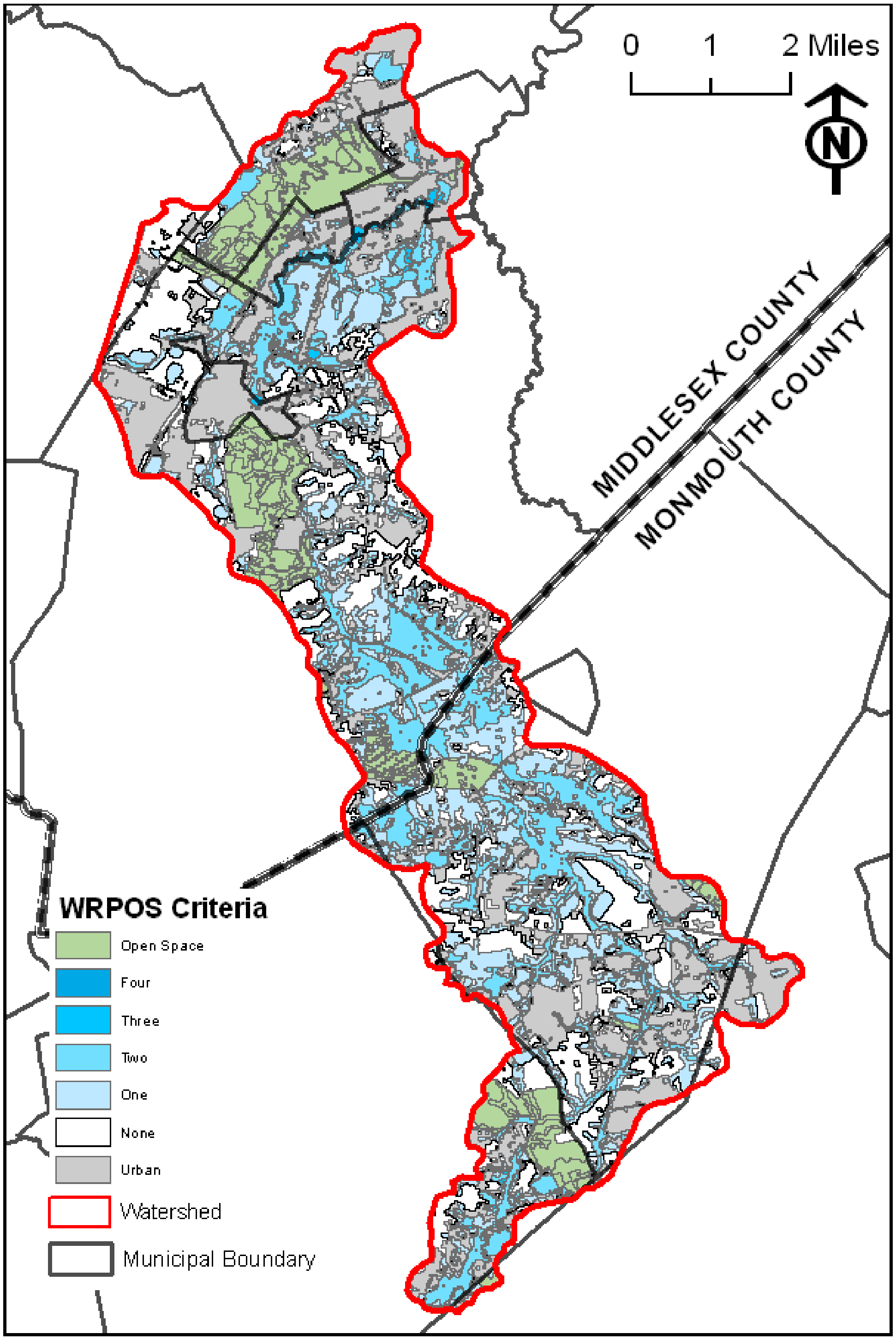

Figure 24. WRPOS model results for Manalapan Brook watershed.

The purpose of performing this analysis was to identify and prioritize areas within the Manalapan Lake watershed where protection from development impacts is most likely to protect water quality. For this task, Princeton Hydro refined the methodology outlined by the Raritan Basin Watershed Management Project's 2002 "Water Resources Protection Open Space Criteria" (WRPOS) report using the updated digital data described below. The WRPOS model is based on several widely-available GIS coverages, each encompassing one or more criteria identified by a subcommittee of the Raritan Basin Council as critical for water resource protection. Open space mapping of the Manalapan Brook watershed is provided in Map 10 of Appendix A.

The following is a description of the refined methodology and criteria Princeton Hydro used to perform this analysis, as compared to the original WRPOS analysis conducted for the Raritan Basin Project.

Wellhead Protection Areas:
The purpose of this criterion is to protect areas where potential ground water pollution could pose a threat to public water supply wells. Similar to the Raritan Basin methodology, Princeton Hydro used data provided by NJDEP. Princeton Hydro also adhered to the WRPOS methodology by including only Tier 1 and Tier 2 Wellhead Protection Areas and public community supply wells rather than non-public supply wells.

Groundwater Recharge:
The purpose of this criterion is to protect areas that contribute the largest amount of groundwater recharge. The WRPOS model is based on groundwater recharge rates calculated from the New Jersey Geological Survey GSR-32 analysis, combined with NJDEP's 1995/97 LU/LC dataset. The Raritan Basin subcommittee determined that areas that contribute 25% of the recharge should be preserved. Consistent with the WRPOS methodology, Princeton Hydro utilized the New Jersey Geological Survey's (NJGS) current GIS dataset that represents the results of the GSR-32 analysis. The digital data ranks each area of ground water recharge as category A, B, C or D, with A representing the highest amount of recharge and Rank D indicating the lowest (recharge estimates are reported in inches/year). The specific quantitative range for each ground water recharge category is: 19 – 23 in/yr (A), 13 – 18 in/yr (B), 10 – 12 in/yr (C), and 1 – 9 in/yr (D). It should be noted that recharge rates were calculated on a by-county basis; recharge rates by rank vary for each county. Taking a more conservative approach than the WRPOS model, which was limited to the area contributing 25% of the watershed's total recharge, Princeton Hydro included all land within the top two ranks (A and B) for the entire watershed.

Riparian Areas:

The purpose of this criterion is to protect undeveloped areas adjacent to streams which provide flood protection, wildlife habitat and/or other water quality benefits. To precisely define riparian boundaries, field verification is essential; however, for an area as large as the Manalapan Lake watershed, physically mapping the riparian areas would be impractical and cost prohibitive. To delineate riparian areas in the watershed as accurately as possible without "ground truthing," the Raritan Basin subcommittee used several existing GIS datasets to create an integrated GIS coverage:

Wetlands:
Consistent with the WRPOS model, Princeton Hydro used NJDEP's wetlands dataset, a subset of the 1995/97 Land Use/Land Cover dataset. Only wetlands adjacent to a stream and over one (1) acre in size were included.

Wildlife Passage Corridors:
Riparian corridors provide safe passage for wildlife from one habitat area to another. These Wildlife Passage Corridors are calculated by delineating a buffer area along all streams within the watershed. First- and second-order streams were buffered 150 feet on each side, and all third-order streams and above were buffered 300 feet on each side.

Floodplains:
For this analysis, the Federal Emergency Management Agency (FEMA) 100-year flood zone was incorporated in the GIS database.

Steep Slopes:
Consistent with the WRPOS methodology, any slope greater than 15% that encroaches on a riparian area as defined by any other parameter listed here (i.e., wetlands) was included. Princeton Hydro used a 10-meter Digital Elevation Model (DEM) to model the topography of the watershed. From the DEM, contours for the entire watershed were interpolated and slopes greater than 15% were identified. Using these contours, steep slopes that flow directly into a riparian area were identified and included in the analysis.

Soils:
All soils classified as hydric and alluvial that are also directly adjacent to a riparian area were included in the analysis. Princeton Hydro used digital soils data obtained from the USDA Natural Resource Conservation Service (NRCS).

The WRPOS methodology included one additional input: a water quality/filter zone. This area was deemed important for maintaining vegetative cover to provide stream shading, maintain cooler water temperatures, and filtering of pollutants (such as suspended solids and nutrients) before they enter the stream and degrade water quality. The WRPOS model defines this area as 100 feet on each side of the streams. Princeton Hydro omitted this analysis because this entire area was already included within the Wildlife Passage Corridors coverage.

Forests and Wildlife Habitat:
The purpose of this criterion is to protect high-quality, vegetated areas that provide wildlife habitat and protect water resources by slowing runoff, retaining sediment, allowing ground water recharge and maintaining cooler surface water temperatures. To develop this coverage, Princeton Hydro refined the WRPOS model with updated digital data. The coverage is comprised of three datasets: “dense forests," "emergent wetlands" and "forested wetlands." All three are part of the NJ Division of Fish and Wildlife’s Landscape Data Program, which has been updated since the Raritan Basin subcommittee first ran the WRPOS analysis. Princeton Hydro utilized the latest version of the Landscape Data for this analysis (2007). The “dense forests" coverage was developed by creating 400-foot buffers for all Forest LU/LC polygons (from NJDEP’s 1995/97 LU/LC dataset). All three inputs were merged together in the GIS.

Preserved Open Space:
The purpose of this criterion is to identify areas of permanently protected open space that could potentially be augmented and/or connected to other open space sites. The 2002 Green Acres Open Space Program data was used in the original WRPOS model. For this analysis, Princeton Hydro combined the updated 2004 Green Acres Open Space data with data from the Department of Agriculture’s Farmland Preservation Program and open space data from the counties and municipalities within the watershed. All data inputs were merged within the GIS.

WRPOS Map:
After all data specified for each criteria above were collected and finalized, all criteria input files were converted to an ESRI GRID format, overlaid on top of one another and combined to create an output that identified areas where all inputs intersected one another. Within the output database, the number of inputs in each particular area was tallied. Map 11 in Appendix A provides a graphic depiction of the number of refined WRPOS criteria found within each identified area for the revised WRPOS analysis.

The resulting WRPOS Map for the Manalapan Lake watershed was used to prioritize land coverage, based on the number of existing criteria that are critical for water resource protection. Therefore, lands that have a higher number of criteria would be prioritized in terms of the need for protection and potential development-related impacts on water quality.

Application of WRPOS Results:
In order to create a prioritized list of critical open space areas within the watershed, a review of the Master Plans of all watershed municipalities was

conducted. Based on this review, a selected list of open space goals and areas targeted for land acquisition was compiled for each municipality (Appendix G). Above and beyond the WRPOS criteria, priority areas were selected based on recreational values and public accessibility, consistent with municipal goals for open space protection/preservation. In some cases, areas outside the watershed boundary were included to provide more information regarding potential links to or extensions of existing or future open space protection efforts.

The resulting WRPOS map and analyses can be used for planning purposes from both a protection and restoration perspective. From a protection perspective, the identification of those lands that have ranked high in terms of the WRPOS criteria should be prioritized over other lands due to their environmental sensitivity. Such prioritization would justify management actions such as the purchase of land through Green Acres and other programs, developing incentives for land owners not to build on forested and/or farmlands within the highly ranked areas, and assist municipalities to publicly recognize their open space priorities. From a pollutant loading perspective (TSS and/or TP), such management actions would prevent an increase in the existing loads.

From a restoration perspective, the WRPOS map and analyses provides an objective means of prioritizing locations in need of restoration. For example, those lands that rank highest in terms of the WRPOS criteria and exhibit watershed / water quality problems (i.e. eroded streambanks, legacy sediments, generation of large NPS pollutant loads from watershed sources and localized flooding) should be prioritized in terms of receiving funds to implement restoration projects. The management actions that would be implemented under such restoration project would depend on the actual source of the problems and would include, but not be limited to, stormwater management, septic management, goose control, streambank stabilization and other in-stream measures. From a pollutant loading perspective (TSS and/or TP), such management actions would reduce the existing loads in order to achieve some targeted or desired pollutant load, more than likely as identified in the TMDL.

Updated Land Use / Land Cover (LU/LC):
The updated (by Princeton Hydro based on 2005 aerials) 2002 Land Use Land Cover (LU/LC) data were also used in the prioritization process, similar to the WRPOS model results. The LU/LC type was identified for each SVA location as this provides valuable information regarding the potential for site-specific project implementation.

First Tier Project Identification and Prioritization:
The 100 SVA site locations within the Manalapan Brook watershed were prioritized as follows. First, the lowest scoring SVA sites in each of the subwatersheds were identified; these projects represent the first tier of project

identification. These results were further ranked based on the combined score resulting from the AVGWLF land and streambank erosion sediment loads. Additionally, the WRPOS results and the updated LU/LC were identified for each priority SVA location. This process results in a list of 20 first tier implementation projects which are summarized with their associated ranking below in Table 26. The purpose of this table is simply to list the first tier projects and document the prioritization process.

Table 26. Prioritization scores of the top 20 projects ranked by their combined score.

Subwatershed	Combined Score	SVA Station	SVA Score	Municipality	WRPOS	LU/LC
4	9	**29**	2.9	Jamesburg	Urban	RESIDENTIAL, SINGLE UNIT, MEDIUM DENSITY
12	10	**67**	5.9	Manalapan	Two	TRANSPORTATION/COMMUNICATION/UTILITIES
13	10	**80**	3.6	Manalapan	One	OTHER URBAN OR BUILT-UP LAND
16	12	**84**	2.2	Manalapan	Urban	TRANSPORTATION/COMMUNICATION/UTILITIES
5	14	**32**	5.6	Jamesburg	Urban	DECIDUOUS WOODED WETLANDS
15	15	**86**	4.1	Manalapan	Two	DECIDUOUS SCRUB/SHRUB WETLANDS
1	17	**3**	4.2	Spotswood	Urban	DECIDUOUS FOREST (>50% CROWN CLOSURE)
19	19	**88**	6.9	Manalapan	One	DECIDUOUS WOODED WETLANDS
14	20	**71**	2.4	Manalapan	One	DECIDUOUS FOREST (>50% CROWN CLOSURE)
17	20	**92**	5.4	Manalapan	One	OTHER AGRICULTURE
18	21	**94**	4.7	Millstone	Open Space	DECIDUOUS WOODED WETLANDS
2	22	**15**	3.1	Monroe	One	CONIFEROUS FOREST (>50% CROWN CLOSURE)
8	23	**45**	2.1	Monroe	Urban	RESIDENTIAL, RURAL, SINGLE UNIT
3	24	**19**	3.8	Helmetta	Urban	RESIDENTIAL, RURAL, SINGLE UNIT
20	25	**96**	7.6	Millstone	Open Space	DECIDUOUS WOODED WETLANDS
9	26	**53**	5.5	Monroe	Urban	RESIDENTIAL, SINGLE UNIT, LOW DENSITY
7	27	**38**	7.6	Monroe	Open Space	STREAMS AND CANALS
11	31	**61**	6.4	Manalapan	One	RECREATIONAL LAND
6	37	**37**	2.9	Monroe	Open Space	RECREATIONAL LAND
10	38	**63**	7.7	Manalapan	Two	DECIDUOUS WOODED WETLANDS

A summary of the general descriptions of the first tier implementation projects is provided below in Table 27. This table also provides calculated TSS load reductions which are based on frequently used methods of pollutant loading and removal in accordance with NJDEP recommended methods. Cost estimates for project implementation are also provided in the table. These cost estimates are preliminary and may vary significantly based on site specific data.

Table 27. Summary of first tier watershed implementation projects in order of priority.

SVA	SVA Score	Municipality	Description of Proposed BMP	TSS Reduction (lbs)	Cost Estimate
84	2.2	Manalapan	Basin retrofits (possible modification into a wetland BMP)	46,224	$50,000
71	2.4	Manalapan	Additional stabilization work	29,983	$7,000
29	2.9	Jamesburg	Installation of 2-4 larger BMPs / MTDs	1,006,586	$1,000,000
29	2.9	Jamesburg	Stabilization of approximately 400 LF of streambank	1,174,350	$75,000
29	2.9	Jamesburg	Stabilize / revegetate approx. 400 LF of streambank	137,424	$40,000
45	2.9	Monroe	The installation of a MTD	18,204	$312,500
37	2.9	Monroe	Wetland BMP or rain garden/bioretention area	99,945	$11,000
37	2.9	Monroe	MTD at zoo	85,667	$312,500
37	2.9	Monroe	Shoreline stabilization	50,000	$20,000
15	3.1	Monroe	Basin retrofits (some additional stabilization and plantings)	17,847	$12,500
80	3.6	Manalapan	Basin retrofits (not including a new outlet structure)	18,561	$50,000
19	3.8	Helmetta	Bioretention / infiltration basin	592,529	$100,000
19	3.8	Helmetta	Streambank stabilization	592,529	$150,000
86	4.1	Manalapan	Shoreline Stabilization work around the pond, approx 10,000 LF	217,380	$312,500
3	4.2	Spotswood	Streambank stabilization and re-vegetation, 200 LF	230,230	$33,000
94	4.7	Millstone	Shoreline stabilization on golf course	19,239	$55,000
92	5.4	Manalapan	Dredging and some additional mitigation measures	696,044	$870,000
53	5.5	Monroe	Expansion of riparian habitat	278,752	$9,400
53	5.5	Monroe	Installation of a MTD	238,930	$187,500
32	5.6	Monroe	Streambank stabilization work	16,063	$65,000
32	5.6	Monroe	Basin retrofits (not including a new outlet structure)	10,708	$50,000
67	5.9	Manalapan	Installation of a BMP / MTD	58,896	$125,000
67	5.9	Manalapan	Stabilization of approximately 150 LF of streambank	68,712	$40,000
61	6.4	Manalapan	Stabilize disturbed areas	82,454	$25,000
88	6.9	Manalapan	Stabilization of approximately 400 LF of streambank	37,479	$12,500
96	7.6	Millstone	Wetland enhancement	6,853	$36,000
38	7.6	Monroe	Maintenance dredging of upper section of lake	3,898,953	$4,260,000
			Totals:	***9,730,544***	***$8,221,400***

The following sections describe each of the 20 first tier SVA locations and provide specific restoration measures to address the sediment load sources originating at each of the SVA locations. These descriptions also include rough cost estimates for each project. These cost estimates may vary significantly from actual implementation costs due to individual project specific details. These first tier projects are presented in descending order of priority.

Station #29:

The streambank erosion observed at station #29 was identified as being the worst in the entire watershed. This station is also within Subwatershed #4 which has the lowest combined score of all 20 subwatersheds. Station #29 is located on Wigwam Brook, the reach in question is approximately 400 feet long and originates at the outlet of Wigwam Pond and flows through a wooded parcel near the residential area located at the end of Prospect Street in Jamesburg. Wigwam Pond Lane parallels the reach to the west. The streambanks in this area are actively eroding and are five to 15 feet high along the entire reach. Numerous trees have been undermined and have fallen into the stream along the entire stream reach. There is also one stormwater outfall from the nearby apartment complex on the west side of the reach. Several acid seeps were observed along the base of the reach. Glauconitic soils (surficial) are not mapped in this portion of the watershed; however, due to the extent of the apparent channel down cutting, acid producing soils have been exposed at various locations along the entire reach. The extent of the erosion is shown below in Figure 25.

Figure 25. Station #29 looking downstream.

Historically, there was a concrete dam structure in the channel which was removed following the 2005 flood. The 2005 storm caused significant local erosion in this area. This former obstruction may partially explain the severe erosion observed in this reach due to significant changes in the flow conditions experienced in the reach.

Potential sediment loading mitigation measures at this location include channel stabilization and retrofits to upstream stormwater management facilities for the residential areas along the eastern side of Half Acre Road. These upstream retrofits may include modifications to increase storage and detention in existing facilities. Ideally, upstream stormwater retrofits should focus on reducing the total volume of stormwater runoff generated. This could include small scale infiltration

BMPs, impervious area disconnections, rainwater harvesting among other methods.

As mentioned above, station #29 has been identified as one of the worst sites within the entire Manalapan Brook watershed relative to the magnitude of its generated sediment load. Thus, in addition to addressing the upstream sources the following restoration activities are recommended:

- installation of 2-4 large manufactured treatment devices (MTDs) within the neighborhood and/or upstream; examples of some of these MTDs are provided in Appendix E;
- stabilization and re-vegetation of approximately 400 linear feet of streambank.

Combined, this series of restoration projects is estimated to remove approximately 2.32 million pounds of sediment from the watershed's annual load (Table 24). The implementation of these projects is estimated to cost between $578,000 and $1,115,000.

If the upstream sources of the surface runoff sediment load and the large, storm-based hydrologic loads are addressed, long-term maintenance activities will be reduced; however, there will be some degree of maintenance requirements. For the MTDs, these large structures typically need to be cleaned out 1-2 times per year. For most MTDs, conventional Vac-All or similar equipment / machinery can be used to remove accumulated material (i.e. sediments and leaf litter). For the stabilized streambanks, monitoring and control of invasive species and addressing the potential formation of erosional gullies will need to be addressed.

Station #67:
Station #67 is located in a headwater area of Subwatershed #12. At this station a small tributary which originates in a residential area flows under Kinney Road in Manalapan Township. There appear to have been recent culvert upgrades to the road crossing. Geotextile matting was placed to a distance of approximately 75 feet downstream of the two culverts. For approximately 150 feet downstream of the road crossing there are 3-4 foot eroded streambanks with numerous acid seeps present, as shown in Figure 26.

Figure 26. Station #67 looking downstream.

Potential retrofit and mitigation measures at station #67 include streambank restoration and upstream stormwater retrofits in the adjacent residential area. The headwater area for this tributary is relatively small (~55 acres) and is primarily composed of 15-20 residential house lots with no apparent stormwater control measures. Retrofits in this area could include impervious area disconnection and small scale infiltration practices to reduce the stormwater runoff generated from the small catchment.

Specific recommendations for the site include the stabilization of approximately 150 linear feet of streambank and the installation of some type of MTD (Appendix E). The estimated annual sediment removal rate for these projects is approximately 127,600 pounds. The cost to implement such projects is estimated to cost between $105,000 and $165,000.

Station #80:
Station #80 is located in Subwatershed #13 in Manalapan Township. At this location a small tributary is impounded in two small ponds on either side of Michael Lane at the intersection with Monmouth County Route 527. The ponds have little to no vegetated buffers and are mowed to the water's edge in many locations. This condition has made the ponds appealing habitat for Canada Geese, as were observed during the May 29, 2008 site visit. There is also a relatively large (~1.1 acre) detention basin at station #80 which appears to collect stormwater runoff from the low density residential lots in the adjacent

subdivision. The detention basin has two inlets and a series of three concrete low flow channels which route inflow from small storms directly to the outlet structure and into the adjacent tributary, as shown in Figure 27.

Figure 27. Large stormwater detention basin at station #80.

No significant direct sources of sediment loading were observed at station #80, and there did not appear to be a significant accumulation of sediment in the detention basin. In addition to improving the pond buffers, mitigation measures at this station could include a detention basin retrofit to enhance the basin's sediment removal and hydraulic performance. Such a retrofit would focus on the disconnection/removal of the concrete low flow channels, minor re-grading, possible outlet structure modification, and a natural landscaping renovation of the current turf grass vegetation. These modifications would reduce the sediment loading of the basin's immediate drainage area, and drastically improve the runoff volume and rate reductions currently provided by the basin. This retrofit would reduce the streambank erosion potential of flows exiting the basin.

Retrofitting the existing basin is estimated to remove approximately 18,500 pounds of sediments on an annual basis. Such a retrofit is estimated to cost between $40,000 and $50,000, not including a new outlet structure. This project was chosen as one of the five design projects as part of this plan.

Station #84:
Station #84 is located along Thompson Grove Road in Manalapan Township. Located at the headwaters of Subwatershed #16, this portion of the watershed has experienced significant recent development primarily involving the conversion of agricultural areas to low density residential housing developments. At station #84 a large detention basin (~1.1 acres) was constructed to control runoff from the adjacent low density residential housing development (Figure 28). The site is located in the headwaters of Subwatershed #16, and it appears that the basin was built as an in-stream basin with a small tributary flowing through the basin in a concrete low flow channel. Flow was observed in the tributary during all site visits to station #84. The portion of the basin surrounding the tributary is well vegetated and contains typical wetland vegetation. The basin has a second inlet whose flow is also conveyed via a concrete low flow channel. This portion of the basin appears to be mown on a semi-regular basis.

Figure 28. Stormwater detention basin located at station #84.

This basin is another good candidate for a naturalized basin retrofit. Based on field observations, the basin could be converted to a wetland meadow, which would provide enhanced sediment removal and increased flow attenuation thereby alleviating downstream channel erosion; however, some additional field investigations would be required. Such a retrofit could also include minor modifications to the outlet structure.

Retrofitting the existing basin into a possible wetland BMP is estimated to remove approximately 46,000 pounds of sediments on an annual basis. This proposed retrofit is estimated to cost between $40,000 and $50,000. This project was chosen as one of the five design projects as part of this plan.

Station #32:
Station #32 is located on the border between Jamesburg Borough and Monroe Township near State Street and Oakwood Terrace along the downstream reaches of Subwatershed #5. The station is approximately 0.4 miles upstream of the unnamed tributary's confluence with the mainstem of Manalapan Brook (just below Manalapan Lake). The stream has significant erosion and sedimentation along this section. The streambank is severely undercut in areas and a gabion wall has been installed in an effort to protect an adjacent property from further erosion (see Figure 29).

Figure 29. Station #32 looking upstream at street outfall and gabion wall.

The streambank erosion at this station is a result of both a change in the stream flow regime resulting from changes in the contributory area hydrology, *and* also a result of the multiple local obstructions and encroachments into and near the stream channel. These include the upstream road crossing, gabion wall, riparian fill, and multiple outfalls.

The specific recommendation for the site includes some minor streambank stabilization work. The estimated annual sediment removal rate for this station

#32 site is approximately 16,000 pounds. The cost to implement this project is estimated to be between $50,000 and $65,000.

At this location the stream receives runoff from both the adjacent street (William Street) and the outflow from a large detention basin located just off the right side of the tributary. At the time of inspection (summer 2008), the relatively large (~1.1 acre) detention basin appeared to have been recently serviced to remove accumulated sediment as is shown in Figure 30.

Figure 30. Detention basin outlet structure and recently disturbed vegetation.

The basin was designed with a concrete low flow channel and a perforated pipe underdrain. Even with the underdrain and low flow channel the basin is still supporting volunteer wetland vegetation.

Retrofits at this station could include stream stabilization measures in the channel. These measures could include energy dissipation modifications to the two outfalls located in this section. The large detention basin provides additional retrofit opportunities at the station. The basin could be modified to create a sediment forebay at the north end of the basin. In addition to improving the sediment removal capabilities of the basin, this would make sediment removal operations easier and less expensive. It would also ensure that future maintenance procedures would not disrupt large portions of the basin, which may inadvertently provide an additional sediment source. This basin is also a good candidate for a naturalized basin retrofit. The concrete low flow channel and underdrain could be removed.

Minor regrading of the basin and planting would greatly enhance the sediment removal and hydrologic performance of the basin. This would provide a direct improvement in the sediment removal capacity of the basin and decrease the erosive energy of basin outflows in the stream at the basin outfall.

The specific recommendation for the site includes retrofitting an existing detention basin. The estimated annual sediment removal rate for this project is approximately 10,700 pounds. Retrofitting this existing basin is estimated to cost between $40,000 and $50,000, not including a new outlet structure. This project was chosen as one of the five design projects as part of this plan.

Station #86:
Station #86 is located on Highland Ridge Road in Manalapan Township and in Subwatershed #15. The station is also near a private pond. At the time of inspection (summer 2008) the shoreline of this pond consisted mainly of mowed grass (Figure 31). In addition, several waterfowl were present including over 20 geese.

This area could benefit from lakeshore riparian plantings that would reduce erosion, discourage geese and help remove nutrients and sediment from runoff. In addition, signs discouraging the feeding of waterfowl and mowing grass could be installed at this location.

Figure 31. Shoreline located at station #86.

Approximately 10,000 linear feet of shoreline stabilization work is recommended for the pond. The amount of sediments that would be removed through this project is estimated to be approximately 217,000 pounds. The estimated cost for the proposed project is between $200,000 and $312,500.

Station #3:
Station #3 is located on Adirondack Avenue in Spotswood Borough, Middlesex County, along Cedar Brook in Subwatershed #1 (Figure 32). This area received significant flood damage in 2005 and at the time of the site visit (summer 2008) the twin culverts under Adirondack Avenue were nearly filled with sediment. This station would benefit from cleaning sediment out of the culverts and initiating a better maintenance and sediment removal program (Figure 33).

Figure 32. Station #3 near Cedar Brook.

Due to minor erosion in the area approximately 200 linear feet of minor streambank stabilization with re-vegetation and buffer planting is recommended for this site. The amount of sediments that would be removed through this project is estimated to be approximately 230,000 pounds. The estimated cost for the proposed project is between $25,000 and $33,000.

Figure 33. Sediment-clogged culverts at station #3.

Station #88:

Station #88 is located on Nottingham Court in Manalapan Township, Monmouth County in Subwatershed #19. The station is on an unnamed tributary that runs through a housing development. During the site visit, high amounts of iron staining, iron floc, and iron bacteria were observed. These conditions caused a bright orange discoloration of the water (Figure 34). Acid seeps were also observed in this area. Actions should be taken to minimize the exposure of the acid producing soils in this area. This may include the placement of a suitable soil cover to help establish stable, vegetated cover.

Figure 34. Iron staining at station #88.

The placement of cover soil and the implementation of soil erosion control measures including temporary stabilization techniques and permanent stabilization through the use of native seed mixes are recommended here. The amount of TSS that would be removed under stabilized conditions through this project is estimated to be approximately 37,500 pounds. The estimated cost for the proposed project is between $8,000 and $12,500.

Station #71:

Station #71 is located on Woodward Road in Manalapan Township, Monmouth County in Subwatershed #14. The station is situated on a tributary near a culvert. The culvert was recently upgraded at the time of inspection (summer 2008) and the tributary was slightly re-aligned. As evidenced in Figure 31, these activities may have disturbed some acid producing soils at this station; however, erosion control measures including riparian plantings, were implemented (Figure 36). These plantings seem to have been mostly successful.

Sediment loads from this station could be further reduced by the planting of supplemental vegetation or the installation of other erosion control practices. The channels created during the construction operation may also need to be stabilized due to streamflow changes resulting from upstream developments in the area.

Figure 35. Construction prior to riparian planting at station #71.

Some supplemental re-vegetation and buffer planting work, focusing primarily on planting additional vegetation, is recommended for this site. No additional permitting is anticipated. The amount of sediment that would be removed by conducting this supplemental stabilization work is estimated to be approximately 30,000 pounds. The estimated cost for the proposed project is between $5,000 and $7,000.

Figure 36. Station #71 after riparian plantings and partial stabilization.

Station #92:
Station #92 is located off of Route 527 at the Charleston Springs Golf Club, Manalapan Township, Monmouth County in Subwatershed #17. The golf course was constructed in 1997 on lands that consisted mainly of farms and nurseries. The property is owned by Monmouth County and is managed by the Monmouth County Park System.

This pond serves as the primary irrigation water source for the golf course. Monmouth County owns the golf course and has implemented several BMPs; however, evidence from aerial photographs suggests that sedimentation and nutrient loading have occurred in the pond on the golf course. This is evidenced by shallow depth to sediments and the growth of nuisance algae and water lilies (Figure 37). This sediment and nutrient loading may be a result of previous (agricultural) land uses at the site.

Mitigation measures for this pond should focus on removing some of the accumulated material from the pond to increase depth, thereby reducing growth of nuisance algae and water lilies and increasing its ability to capture suspended sediment. Some additional restoration and stabilization measures would be integrated into such a project to maximize the assimilation of nutrients and solids by littoral vegetation.

The proposed project would also increase the recreational opportunities provided by the pond (fishing and boating). If the pond is not deepened then it will likely become completely covered in water lilies. Nutrient management, such as the use of non-phosphorus fertilizers, should also be considered for use at this station.

While there are some positive water quality benefits to the proposed project; the golf course may want to implement the project to enhance the general aesthetics of the golf course. Thus, the golf course may be willing to assist in the removal of this accumulated material, particularly if some financial assistance (funding) is secured for project implementation. Obviously, such a project would be conducted sometime between the late fall and early spring when the golf course is not being used. Some restoration measures associated with the turf and associated landscaping would need to be taken into consideration when conducting this project.

Figure 37. Station #92 pond at Charleston Springs Golf Course.

The removal of approximately three feet of accumulated material from the pond is estimated to cost between $580,000 and $870,000; this price includes feasibility study, permitting, engineering, actual implementation and restoration of site. Such a project would also include additional restoration or stabilization measures that would maximize the pond’s littoral fringe of vegetation to enhance pollutant uptake; however, it should be emphasized that a bathymetric study would be required to quantify how much unconsolidated material is in the pond to develop a more detailed cost estimate. The amount of sediment anticipated to be removed with the completion of such a project, through settling of solids in both the open water and littoral sections of the pond is estimated to be approximately 700,000 pounds per year.

Depending on the magnitude of the annual TSS load, the pond may need to be periodically cleaned out once every 10 to 25 years. Including a forebay area in the upper end of the pond, which is easily accessible with construction equipment, would minimize the costs associated with permitting and long-term maintenance.

Station #94:
Station #94 is located adjacent to an unnamed tributary of Manalapan Brook at the Charleston Springs Golf Course in the municipality of Millstone, Monmouth County, and Subwatershed #18. There are several ponds located at the northern end of the golf course which are used for irrigation purposes. The county is actively trying to reduce the area of invasive species by planting native grasses during the winter. Due to the irrigation use of the ponds, Monmouth County Park System has observed that the ponds typically do not overflow during the growing season. Outflow is limited to winter months. Based on the onsite observations, this site is expected to contribute a minimal TSS load; however, increasing the width of the pond's riparian buffers would help further reduce the overflow potential and TSS load originating from the ponds.

Figure 38. Station #94 at Charleston Springs Golf Course.

Expanding the existing shoreline buffers and replacing any existing invasive species with native species would provide water quality, ecological, recreational and economic benefits to the golf course. Expanding these shoreline buffers is estimated to cost between $35,000 and $55,000, and is anticipated to remove approximately 19,000 pounds of TSS per year.

Station #15:
Station #15 is located on McKinley Road in Monroe Township, Middlesex County and in Subwatershed #2. This station is on an unnamed tributary to Manalapan Brook and was dry at the time of the site evaluation; however, this tributary receives stormwater runoff from a detention basin and a wet pond. At the time of the site inspection (summer 2008) Monroe Township recently removed 1 foot of sediment from the flow channel of the detention basin and spread the sediment around the basin (Figure 39).

The TSS removal capabilities provided by the detention basin would be drastically improved with the implementation of revised operation and maintenance practices in the basin. Such practices would not expose the entire basin bottom soils and remove established vegetation within the basin. The basin should have permanent vegetation established to minimize sediment suspension and transport from the basin. This vegetation will also encourage the removal of incoming sediment loads from the basin's contributory drainage area.

Figure 39. Recently cleared detention basin at station #15.

Specific recommendations for the site include some additional stabilization and planting efforts for the existing detention basin. The estimated annual sediment removal rate for this retrofit project is approximately 17,800 pounds. The cost to implement the proposed project is estimated to be between $8,000 and $12,500.

Station #45:
Station #45 is located near the intersection of Dancer Court and Hoffman Station in Monroe Township, Middlesex County (Figure 40). The station is in a residential area of Subwatershed #8. At the time of the assessment there was very low flow in the tributary. This area of the subwatershed has experienced recent and ongoing local development. The area has a substantial number of culverts and outfalls. In addition, there are limited riparian buffers around the tributary. These inlets may provide opportunities for stormwater management retrofits through the installation of manufactured treatment devices. These devices have the potential to provide TSS removal of 80%.

Figure 40. Tributary and culvert at station #45.

As mentioned above, some type of MTD could be installed either adjacent to or under the existing roadway to provide a means of removing suspended sediments from stormwater before it flows into Manalapan Brook. Examples of some MTDs that could be used at this site are provided in Appendix E. The design and installation of a MTD at this site is estimated to cost between $200,000 and $312,500, with approximately 18,000 pounds of sediment being removed on an annual basis. As with any installed MTD or BMP, the structure would need to be cleaned out on a routine basis with conventional equipment; at least 1-2 times per year.

Station #19:
Station #19 is located in a residential area in Helmetta Borough, Middlesex County and is within Subwatershed #3. Flooding is a concern in this area as an apartment building is located within 30 feet of the unnamed tributary (Figure 41). High flows are common in this area as indicated by the culverts being fortified with concrete headwalls. The downstream culvert is clogged with sediment and needs to be cleaned out. Mitigation in this area should focus on BMPs that can reduce the flow volumes during storm events. If sufficient space is available, structural BMPs such as bioretention systems and infiltration basins should be considered.

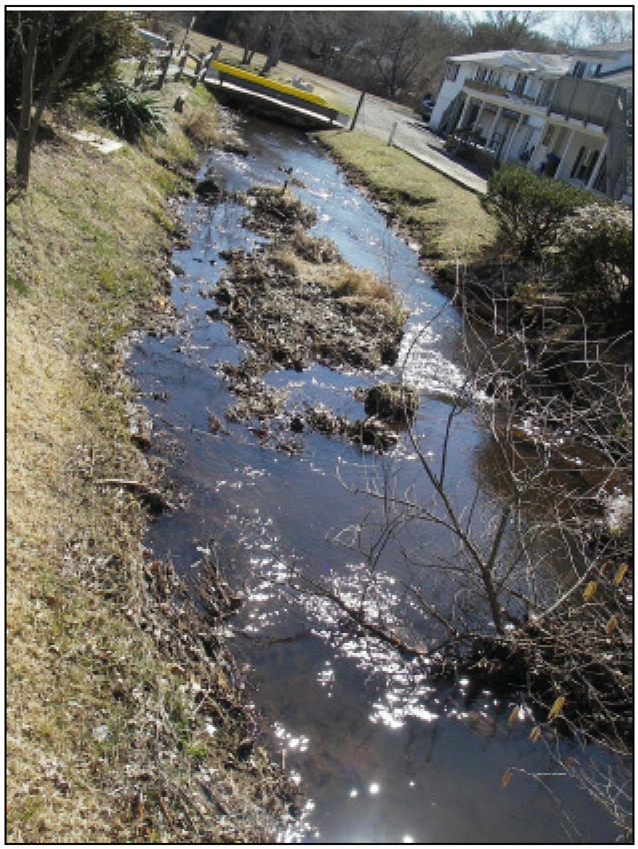

Figure 41. Tributary at station #19.

The installation of a bioretention or infiltration basin, coupled with some extensive streambank stabilization is recommended for this site to reduce the TSS loads entering Manalapan Brook, as well as contribute toward reducing the magnitude of the volume of flood water that impacts this area. This project has the potential to remove approximately 1.2 million pounds of TSS and is estimated to cost between $120,000 and $150,000; however, some issues associated with land ownership, easements and right-of-ways would need to be investigated prior to design. Also, such restoration projects will require routine maintenance, such as monitoring or removal of invasive species and periodically cleaning out the basin at least once a year, as do all of the listed projects.

Station #96:
Station #96 is located on an unnamed tributary at the south course of Charleston Springs Golf Course in Millstone Township, Monmouth Township, and Subwatershed 20. The station is located near a bridge that spans the tributary. The area consists of a wetland with a small tributary (Figure 42). Mitigation for this site should consist of preserving and improving the wetland. Wetlands are capable of removing as much as 90% of suspended solids that enter via stormwater runoff.

Figure 42. Tributary at station #96

Protecting and further wetland enhancement is recommended for this site and is expected to remove an additional 6,800 pounds of sediments. Such work would also foster and enhance the ecological, wildlife and aesthetic value of the site. It is anticipated that this work will not require a significant permitting effort. The estimated cost of protecting and enhancing these wetlands potentially through additional plantings and fencing is between $23,000 and $36,000.

Station #53:
Station #53 is located in Subwatershed #9 on an unnamed tributary to Manalapan Brook near the intersection of Federal Road and Monroe Boulevard in Monroe Township, Middlesex County. The area consists of a housing development and

several horse farms. The tributary is piped to a new swale and flows along Federal Road (Figure 43). Mitigation in this area should involve the encouragement of preservation of riparian areas and the planting of riparian vegetation. In addition, energy dissipation modifications should be considered where the tributary is piped into the swale. Depending on the magnitude of the storm loads that enters this tributary, a manufactured treatment device may also be considered for this site.

Figure 43. Culvert and swale along Federal Road at station #53.

The restoration recommendations for this site include the installation of a MTD and expansion of existing riparian habitat. If implemented, these projects are estimated to remove approximately 518,000 pounds of TSS on an annual basis. The estimated cost to implement these projects is between $126,000 and $197,000.

Station #38:

Station #38 is located on Rues Road in Monroe Township, Middlesex County where Manalapan Brook enters Manalapan Lake (Figure 44). The station is located in Subwatershed #7. Manalapan Brook meanders through several wetland areas before reaching Manalapan Lake.

This upstream portion of Manalapan Lake is an area where suspended sediment is deposited during periods of high flow and elevated TSS loading. This area of Manalapan Brook is characterized by a transition from in-channel flows with high velocities to an area with increasingly large cross sectional area and decreasing flows as the water surface elevation of Manalapan Brook comes under the influence of the dam in Jamesburg.

Removing some of this accumulated material and rehabilitating this section of the lake to function as a forebay settling basin for the main body of the lake and the downstream sections of the Manalapan Brook will provide significant TSS load reductions and restore the sediment removal capacity of the area.

Figure 44. Manalapan Brook at station #38.

Based on the modeled annual TSS load entering Manalapan Lake and the expected NJDEP approved load reduction, it is estimated that the forebay of Manalapan Lake has the capacity to remove approximately 3.9 million pounds of suspended sediments per year. A preliminary estimate of the cost of removing this unconsolidated sediment and providing some additional restoration measures (see below) is estimated to cost between $2.8 and $4.3 million. Such sediment removing activities are expected to be required approximately once every 20 to 50 years; however, the actual frequency will depend on the degree of soil stabilization measures that are implemented upstream of the lake.

It should be noted that instead of simply removing all of the unconsolidated sediment from the upper lake, some additional rehabilitation measures would enhance the water quality, ecological and recreational value of the lake in general. For example, the upper portion of the lake should be designed as a forebay for the main body, which requires some degree of maintenance every 20 to 50 years.

Access to the forebay area should be planned and designed to be relatively easy for conventional construction equipment. In addition, creating an extensive littoral fringe of wetland vegetation along the shoreline of the forebay would provide additional value as described above.

Station #61:

Station #61 is located in Subwatershed #11 on an unnamed tributary of Manalapan Brook near Daum Drive in Manalapan Township, Monmouth County and. The tributary meanders through several healthy wetlands and then meets a road swale by the Knob Hill Golf Course housing development. Where the tributary meets the swale, the water appears heavily stained by iron, iron floc, and iron bacteria (Figure 45). This iron staining may be indicative of upstream soil erosion.

Mitigation for this site should be to investigate residential and golf course sites for areas of soil disturbance and acid seeps. If soil disturbance is causing the iron staining, then mitigation of that site should occur; however, it should be emphasized that additional investigations as to the specific cause of the soil disturbance need to be conducted before any site-specific course of action is taken.

Figure 45. Iron floc accumulation at Station #61.

Some additional upstream stabilization measures would contribute toward reducing the exposure of the natural glauconite soils, which in turn would reduce erosion. Such generalized upstream stabilization measures, with the use of a combination of rip-rap and/or native vegetation, is estimated to reduce the TSS load by approximately 82,500 pounds of sediments per year, at an estimated cost of between $20,000 and $25,000.

Station #37:
Station #37 is located at Thompson Park, Monroe Township, Middlesex County and is adjacent to Manalapan Lake. Middlesex County owns Thompson Park (Figure 46) and operates a zoo within the park. The zoo houses waterfowl, goats, and deer and has a large parking lot and large areas of exposed soil (Figure 43). Runoff from the zoo and parking lot enters Manalapan Lake, thereby contributing sediment, pathogens and nutrients to the lake.

As a result of this area contributing significant sediment loads directly to Manalapan Lake, mitigation measures that reduce the park's and zoo's sediment load to the lake should be considered. Several stretches of the shoreline, especially along the southwestern side, are in need of stabilization to reduce erosion from wave action. In addition to shoreline stabilization, riparian planting should be established in areas surrounding the shoreline to intercept runoff and provide sediment and nutrient removal. Furthermore, runoff from the zoo and parking lots should be directed to BMPs such as a bioretention basin to filter out sediment and nutrient loads. The area also contains numerous stormwater inlets that could be retrofit with manufactured treatment devices to remove sediment from stormwater inflow to the lake.

Figure 46. Exposed soil in heavily trafficked areas at station #37.

Figure 47. Pond located within the Thompson Park Zoo.

A series of restoration projects have been recommended for this site, which include the installation of rain garden at the County Park parking lot (similar to the demonstration project completed as part of this plan), shoreline stabilization/re-vegetation and the installation of a MTD at the zoo. Combined, these restoration measures are expected to remove approximately 236,000 pounds of TSS annually. The costs for the design and implementation of these projects are estimated to be between $217,000 and $343,500.

It should be noted that a rain garden project (demonstration project) in the parking lot was completed in the spring of 2010 and that some shoreline re-vegetation and buffer planting work with goose deterrent was also implemented along a 150 foot stretch of shoreline in the fall of 2010. Furthermore, a more substantial shoreline stabilization at Manalapan Lake was also chosen as one of the five design projects as part of this plan. The cost estimate for this portion of work at station #37 is between $15,000 and $25,000.

Station #63:
Station #63 is located on an unnamed tributary of Manalapan Brook on Woodward Road (Figure 48) in Manalapan Township, Monmouth County and in Subwatershed #10. The main water quality concern at this station is the ongoing development of housing, basins and culverts. The construction is causing minor sediment deposition in the tributary. This area should be monitored for future sediment deposition.

Figure 48. Construction of culvert crossing upgrade at station #63.

Since the recommendation for this site is to monitor the potential impacts of the existing and/or recently completed construction, no specific restoration project is recommended.

Second Tier Project Identification:
The projects which were identified during the stream visual assessment process and were not included in the first tier of project identification and prioritization are listed in the following two tables. With the exception of station #48, none of these second tier projects were selected for the five design projects completed as part of this plan.

Table 28 and Table 29 list the second tier implementation projects by municipality. The tables also summarizes each project's SVA score, location, receiving water body, and provides specific mitigation recommendations at each location. The predicted annual TSS reductions and cost estimates are preliminary and will be highly dependant on individual site specific conditions.

Table 28. Second tier project implementation sites in alphabetical order by municipality, part one of two.

SVA	SVA Score	Municipality	Recommendations	TSS Reduction (lbs/yr)	Cost Estimate
5	7.6	E Brunswick	Priority sample location for nutrients and bacteria	NA	$2,000
25	NA	Jamesburg	Litter removal	NA	$1,000
28	8.9	Jamesburg	Remove dumpster and litter, Consider plantings and/or bank stabilization, Minimize exposure of acid soils	60,000	$90,000
30	5.9	Jamesburg	Evaluate potential drainage improvements, Remove litter, Consider plantings and/or bank stabilization	50,000	$70,000
31	6.1	Jamesburg	Consider plantings and/or bank stabilization	50,000	$70,000
54	8.3	Manalapan	Encourage riparian preservation and plantings	1,000	$4,000
55	7.2	Manalapan	Consider additional rip rap by swale and 12" outfall Encourage riparian preservation and plantings	5,000	$10,000
57	9.2	Manalapan	Remove sediment and litter	1,000	$2,000
58	8.7	Manalapan	Streambank stabilization	50,000	$70,000
60	7.2	Manalapan	Encourage riparian preservation and plantings	1000	$4,000
64	8.2	Manalapan	Monitor and maintain mitigation measures	NA	$1,000
65	6.6	Manalapan	Monitor and maintain mitigation measures	NA	$1,000
66	6.9	Manalapan	Minor streambank stabilization	20,000	$40,000
68	6.6	Manalapan	Control invasive plants in pond and wetlands	NA	$3,000
69	7.4	Manalapan	Control invasive plants in wetlands	NA	$3,000
72	7.1	Manalapan	Reduce exposure of acid producing soils	5,000	$5,000
73	6.2	Manalapan	Reduce exposure of acid producing soils	5,000	$5,000
77	8.7	Manalapan	Reduce exposure of acid producing soils	5,000	$5,000
78	8.4	Manalapan	Streambank stabilization, Enhance public access for fishing and boating	50,000	$90,000
79	7.3	Manalapan	Remove sediment	2,000	$2,000
82	7.7	Manalapan	Plant woody veg to provide stabilization and monitor and maintain mitigation measures	1,000	$5,000
83	7.9	Manalapan	Litter removal, Control invasive plants in wetlands	NA	$3,000
87	8.1	Manalapan	Monitor water quality	NA	$2,000
89	7.4	Manalapan	Reduce exposure of acid producing soils	5,000	$5,000

Table 29. Second tier project implementation sites in alphabetical order by municipality, part two of two.

SVA	SVA Score	Municipality	Recommendations	TSS Reduction (lbs/yr)	Cost Estimate
90	7.9	Manalapan	Detention basin needs repair to outlet structure, and >6" sediment removal from channels	10,000	$10,000
91	7.1	Manalapan	6" orifice on basin outlet is clogged, Maintenance needed to remove vegetation from basin outlet	5,000	$3,000
95	6.0	Millstone	ROW repair culvert, Remove invasives from wetlands	NA	$3,000
98	8.0	Millstone	Remove sediment bar from culvert	2,000	$2,000
7	5.7	Monroe	Monitor sediment deposition	NA	$1,000
8	5.1	Monroe	Dissipate SW flow from outfall, provide additional stabilization at outfall	10,000	$15,000
10	5.9	Monroe	Litter removal	NA	$1,000
11	9.4	Monroe	Trash cleanup needed	NA	$1,000
14	7.8	Monroe	ATV education	unknown	$2,000
15	3.1	Monroe	Improve basin maintenance	5,000	$3,000
20	7.9	Monroe	Middlesex County Park needs signage at trail head, ATV education	unknown	$2,000
26	5.7	Monroe	Remove sediment from culverts, Evaluate potential drainage improvements, Remove litter	10,000	$15,000
36	6.5	Monroe	Streambank stabilization	60,000	$90,000
41	8.2	Monroe	Remove tree and debris from RR bridge	NA	$2,000
42	6.5	Monroe	Remove leaves and debris from clogged culvert/ inlet	NA	$2,000
43	7.8	Monroe	Repair wooden headwall for 3' RR culvert	NA	$5,000
44	9.1	Monroe	Streambank plantings	1,000	$4,000
47	7.4	Monroe	Mitigate culvert drop and scour pool	10,000	$20,000
48	8.4	Monroe	Streambank stabilization/floodplain reconnection, Cover exposed acid producing soils	50,000	$70,000
49	7.5	Monroe	Upstream culvert needs sediment removal	10,000	$15,000
50	8.3	Monroe	Address erosion at culvert	5,000	$10,000
51	8.7	Monroe	Encourage riparian preservation and plantings	1,000	$4,000
52	5.5	Monroe	Streambank stabilization, Prevent livestock access to stream, Encourage riparian and plantings	400,000	$100,000
22A	7.1	Monroe	Additional planting along utility ROW	1,000	$3,000
22B	8.1	Monroe	Streambank stabilization	50,000	$70,000
1	7.4	Spotswood	Improve public access, fishing and boating area, repair fishing dock	NA	$20,000
2	5.5	Spotswood	Dredge sediments in lake, Control pond lilies	40,000	$150,000
4	8.9	Spotswood	ATV Education	unknown	$2,000
6	7.1	Spotswood	ATV Education	unknown	$2,000

Watershed Initiatives:

In addition to the specific implementation projects there are other opportunities in the watershed which can address nonpoint source pollution and specifically TSS loading in the watershed. A Rain Garden Initiative for the Manalapan Brook watershed will help spur interest and implementation in rain gardens throughout the watershed. Additionally, the River-Friendly suite of programs is discussed due to its potential applicability in the watershed. Other recommended watershed wide program initiatives include riparian buffer improvements, stormwater infrastructure maintenance, and education and outreach. These programs are outlined in the following sections.

Manalapan Brook Rain Garden Initiative:

The implementation of a Manalapan Brook Rain Garden Initiative (RGI) will be an important component of watershed plan implementation. Rain gardens provide water quality treatment and infiltration of stormwater runoff. They capture and treat many types of nonpoint source pollution including TSS. Additionally, they decrease the volume of runoff that reaches surface waterways.

Volume reduction occurs through direct infiltration of captured runoff with some additional benefit from evapotranspiration. The volume control provided by rain gardens decreases the total volume, peak flow rate, and erosive flow durations experienced in receiving streams and other waterways. These hydrologic benefits can translate into decreases in the amount of streambank erosion and decreases in the corresponding TSS load.

The Manalapan Brook RGI should build on programs provided by Rutgers Cooperative Extension-Water Resources Program. More information on this program can be found here:

http://water.rutgers.edu/Rain_Gardens/RGWebsite/raingardens.html

The Rutgers Cooperative Extension provides workshops for professionals, landscapers and residents interested in constructing rain gardens. Their rain garden manual and other brochures and factsheets can be used for education of various stakeholder groups.

The Manalapan Brook RGI should provide education to various stakeholder groups in the watershed through the form of informative brochures/mailings, presentations and informative displays at public events, hands-on workshops, and other potential outlets. This information should stress both the disconnection of impervious surfaces in various landscapes and the need for proper design, construction and maintenance of rain gardens. The rain garden at Thompson Park can serve as an “in the ground” example of a rain garden somewhat similar to those that could be implemented throughout the watershed.

The RGI should be promoted throughout the watershed; however, the upper sections of the watershed could serve as a specific initial focus of the RGI. Residential development in the upper section of the watershed tends to be lower density where more opportunities for retrofit may be available. Furthermore, due to the upstream location of these areas more in-stream benefit will be realized throughout the watershed through decreased erosive flow durations, volume and peak flow rates.

The ability to create widespread public interest and "buy-in" to the RGI has the potential to provide improvements to the water quality and hydrology of the Manalapan Brook watershed.

Rain gardens can be constructed in various shapes, sizes and styles. The RGI should promote the widespread application of rain gardens; from residential to corporate and commercial settings.

The example rain garden shown below is especially adaptable to a residential setting where more variety and color are desired. This rain garden has a single downspout for inflow. Relatively intensely planted rain gardens similar to this one may require periodic supplemental irrigation during summer months.

Figure 49. Rain garden photo credit: USDA.

The large scale rain garden shown in the following example photo is maintained in a meadow condition and was planted with a native meadow and wildflower seed mix. The photo was taken during the first growing season only approximately three months after construction and seeding.

Figure 50. Rain garden photo credit: Princeton Hydro, LLC.

Maintenance Requirements:
The maintenance requirements for rain gardens vary greatly depending on the desired look for the rain garden. The desired vegetation will be a major factor in determining the level of maintenance required for the implementation. Some rain gardens are maintained as would a typical decorative garden, with frequent weeding, pruning, and supplemental irrigation. Other applications may require only minimal maintenance from year to year depending on the desired appearance. In general, maintenance measures may include the following:

- periodic inspection is necessary to determine what maintenance measures may become necessary. Early detection and attention will minimize overall maintenance;
- removal of accumulated sediment may be necessary on an infrequent basis depending on the nature of the drainage area;

- supplemental irrigation and weeding may be necessary while the vegetation is first becoming established;
- mowing is typically not desired, unless a turf grass appearance is required; and,
- minor erosion features may need attention including mulch or stone replacement.

River-Friendly Programs:
The New Jersey Water Supply Authority (NJWSA, www.njwsa.org) implements a suite of River-Friendly programs, including those for Golf Courses, Businesses and Residents. These programs are based on those developed by the Stony Brook-Millstone Watershed Association. Through these programs, NJWSA works with landowners to improve water quality by implementing actions in four categories: Water Quality Management & Nonpoint Source Pollution Management, Water Conservation, Native Habitat & Wildlife Enhancement, and Education & Outreach. These programs could be implemented by an appropriate entity within the Manalapan Brook watershed.

The voluntary River-Friendly Golf Course and Business programs are a cooperative effort between the participants and NJWSA (or appropriate entity). They provide an opportunity for landowners to become local stewards, to showcase positive environmental actions they have already taken and to work with NJWSA to implement new practices. Participating landowners receive ongoing technical information, support and guidance for implementing environmental actions tailored to their unique location, resources and needs.

Example accomplishments at one business facility include establishing a buffer along the Peter's Brook; expanding no-mow areas by 10 acres and thereby reducing lawn areas by 17%; and reducing irrigated areas by 33%.

As discussed in the Characterization and Assessment of the Watershed, there are currently five large public and privately operated golfing and residential communities in the watershed. These golf courses include Charleston Springs in Millstone, Pine Brook in Manalapan Township, Knob Hill in Manalapan Township, Greenbrier at Whittingham in Jamesburg, and the Rossmoor Club in Monroe Township.

These programs are mutually beneficial and they often reduce the operational cost of the golf course, improve water quality conditions, and provide good public relation opportunities for the course.

Residents can fill out a self-certification questionnaire to receive recognition as a River-Friendly Resident. The questionnaire includes questions about lawn management practices, water conservation and septic system management, and represents a resident's pledge to manage their property in a responsible manner to help protect our drinking water resources and the environment.

The River-Friendly Farm program, administered by North Jersey Resource Conservation and Development Council (www.njriverfriendlyfarm.org) and the Raritan Watershed Agricultural Committee in the North & South Branch Watershed, uses a set of five criteria, including nutrient management, pest management, riparian buffers, soil loss and irrigation water management.

For more information on any of these programs, visit:

www.njwsa.org/wpu www.njriverfriendly.org.

Acid Producing Soil Exposure:
Acid producing soils are a result of the geology and geologic history of the watershed. These soils are widespread throughout the watershed. See Appendix A for a map displaying all of the acid producing soils present in the watershed.

The exposure of these soils has a direct impact on the pH of the streams; however, vegetation is especially difficult to establish on these exposed soils. These areas tend to remain exposed for long periods of time. During this time the soils are exposed to additional erosion from raindrop impact and stream flow shear stresses. The presence of these soils in the watershed has a direct link to water quality and specifically TSS loading in the Manalapan Brook watershed.

Since 1999, the New Jersey Soil Standards for Erosion and Sediment Controls (N.J.A.C. 2-90) have required construction projects to:

- minimize the disturbance of acid producing soils;
- stabilize these soils by covering with lime and a layer of non-acid producing soil sufficient to facilitate the growth of vegetation; and
- prevent acid producing soils from washing into any nearby water.

These erosion control requirements are administered by the County Soil Conservation Districts; however, observations of water quality impacts were recorded and photographed at stations #89, #88, #82, #78, #77, #73, #72, #71, #67, #65, #64, #63, and #61 within Manalapan Township, and stations #52, #48, #29, and #28 located in Monroe and Jamesburg. Some of the impacts included streams with high iron content and heavy iron bacteria that caused a bright orange discoloration of the stream. Acid producing seeps on eroded streambanks were also observed. These disturbances may have occurred from the construction of residential communities, golf courses (Knob Hill), roadways, and stormwater culverts. Photographs of stations #89, #88 and #61 depict bright orange streams, with high concentrations of iron bacteria, where local development has disturbed these soils. The NJDEP previously restricted stream encroachments within 25 feet of freshwater streams, but the 2007 Flood Hazard Rules (N.J.A.C. 7:13.4-1) now restrict future disturbances within a riparian zone of 150 feet to reduce the potential disturbance of these soils. Local planning and zoning boards and environmental commissions need to be aware of these requirements, in order to ensure compliance.

Table 30 includes all stations within the entire Manalapan Brook watershed where impacts from acid producing soils were observed. Long term monitoring, maintenance and mitigation should be conducted on these sites.

Table 30. Observed glauconitic soil exposure at stations.

Station	Municipality	Soil Series Glauconitic Soil	Observations
96-92	Millstone	Moderate	Tea colored water, slight orange discoloration
90	Millstone	Moderate	Tea colored water, slight orange discoloration
89	Manalapan	High	Bright orange discolored water, high iron bacteria
88	Manalapan	Moderate	Bright orange discolored water, high iron bacteria
84	Manalapan	Moderate	Bright orange discolored water, high iron bacteria
82	Manalapan	Moderate	Tea colored water, slight orange discoloration
78	Manalapan	Low	Tea colored water, acid seeps on streambanks
77	Manalapan	Moderate	Mainstem is clear and tea colored water, slight orange discoloration in swale
73	Manalapan	Moderate	Tea colored water, slight orange discoloration
72	Manalapan	Moderate	Mainstem is clear and tea colored water, slight orange discoloration in swale
71	Manalapan	Moderate	Tea colored water, slight orange discoloration
67	Manalapan	Low	Tea colored water, slight orange discoloration, several acid seeps present
65, 64, 63	Manalapan	Low- Moderate	Tea colored water, slight orange discoloration
61	Manalapan	Moderate	Bright orange discolored water, high iron bacteria
52	Monroe	Moderate	Tea colored water, few acid seeps on streambanks
48	Monroe	Non-listed	Tea colored water, acid seep on streambanks
29	Jamesburg	Non-listed	Tea colored water, several major acid seep on streambanks
28	Jamesburg	Non-listed	Bright orange discolored water, high iron bacteria

Open Space Acquisition:
A concerted effort should be made to acquire additional open space in the watershed. The focus of these acquisitions should be on areas that are inherently protective of water quality and the hydrology of the Manalapan Brook. The various input criteria and the resulting mapping from the Manalapan Brook WRPOS analysis should be used as a guidance document for any potential open space acquisitions.

Once acquired the open space should be managed in a manner that promotes water quality. A good example of this type of protective open space management is the 1,479 acre Jamesburg Park Conservation Area. This area is undeveloped and maintained for the purpose of conservation and passive recreation.

Riparian Buffer Improvements:
As discussed in the watershed characterization sections of this plan, the Manalapan Brook watershed contains an extensive stream network with numerous first order streams. Many of the streams throughout the wetlands still have riparian wetland areas that provide critical water quality functions for the stream. Protection of these existing areas is of upmost importance.

The main three municipalities in the watershed include Millstone, Manalapan, and Monroe Townships. Each of these municipalities have ordinances that contain verbiage designed to protect riparian areas. The municipalities should consider revisiting these sections of their ordinances to further improve riparian buffer protection. The NJDEP offers guidance on the development of municipal ordinances for the protection of riparian areas including a sample model ordinance[3].

The importance of riparian buffers in the watershed cannot be overstated. The unique soil conditions in the watershed make these areas highly sensitive to disturbance. An intensive watershed wide effort to protect, improve and expand riparian buffers in the Manalapan Brook watershed should be undertaken. These efforts should focus on the stabilization and re-vegetation of riparian areas. Such efforts will minimize the sediment load originating from some of the existing riparian areas and also restore the water quality and water quantity benefits of these areas.

Stormwater Infrastructure Maintenance:
Maintenance of stormwater infrastructure is required as part of the municipal stormwater permits for each of the municipalities in the Manalapan Brook watershed. However, the results of the stream visual assessment indicated that maintenance in the watershed was a significant issue.

These maintenance concerns included excessive sediment deposition in and around various stormwater infrastructure. Some of the maintenance methods observed during the

[3] NJDEP sample Riparian Zone Model Ordinance, available online at: http://www.state.nj.us/dep/watershedmgt/DOCS/WQMP/riparian_model_ordinance.pdf

visual assessment were inadequate. In many cases the maintenance methods inadvertently increased the sediment load from the structures.

Each municipality should re-examine the funding mechanisms for maintenance. Municipal ordinances should also be improved to enforce maintenance on all structures that may be privately owned.

Education and Outreach:
Education and outreach will occur through various mechanisms described in this plan. The implementation of these efforts will be managed primarily by Monmouth County, Middlesex County Planning Department, and the Freehold Conservation Service.

Specific education and outreach methods to stakeholders and the general public in the watershed may include informative brochures/mailings, presentations and informative displays at public events, hands-on workshops, among other potential outlets.The demonstration projects (rain garden and shoreline re-vegetation) implemented at Thompson Park can serve as a vehicle for hands-on education.

Demonstration Project

Background Information:

Thompson Park in Monroe Township (Middlesex County; Station #37) was identified as the ideal location for the demonstration project. Project stakeholders provided unanimous support for the implementation of a demonstration project in Thompson Park. The heavily used park was selected due to its high visibility, potential public outreach and educational opportunities.

Project Description:

The park offers numerous opportunities for sediment and stormwater retrofit controls. These include multiple parking areas and other impervious surfaces that lack significant stormwater quantity or quality control measures. Additionally, the shoreline of Manalapan Lake is highly eroded due to wind-driven wave action and goose activity. Therefore a small scale re-vegetation along the shoreline was also desired.

The main design option considered for the park was the creation of a rain garden to capture and infiltrate runoff from the park’s impervious surfaces. Generally speaking, the construction of a rain garden entails re-grading in the form of shallow (6-18 inch) depressions. Additional soil amendments or other flow control devices are often required. The rain garden can be planted or seeded with native vegetation. A wide variety of vegetation can be used depending on the desired appearance of the rain garden.

Shoreline stabilization along relatively low-energy shorelines such as Manalapan Lake can often be stabilized without the need for extensive earth work and therefore permitting issues can often be avoided. While portions of the Manalapan Lake shoreline are severely eroded and will require more aggressive stabilization measures, a 150 foot section of shoreline buffer was chosen for a re-vegetation project. The demonstration section is more typical of the majority of the shoreline in Thompson Park.

The rain garden and shoreline buffer re-vegetation provide both a functional and aesthetically pleasing addition to Thompson Park. The demonstration project also included the creation of educational signage to inform the public and promote the implementation of similar practices throughout the watershed.

Implementation of Demonstration Project at Thompson Park:

As described above, Thompson Park was identified as a priority site during the stream visual assessment. Manalapan Lake is one of the main attractions at the park. Thompson Park contains significant amounts of unmanaged impervious surfaces, unstabilized soil, and eroding shorelines. Due to the park’s high visibility within the watershed and community, and the sediment load sources and unmanaged stormwater runoff present at the park, the project stakeholders identified the park (Station #37) as the best location for the implementation of the project kick-off demonstration project.

The demonstration project was designed as a two-phase project. The first phase entailed the design and construction of a rain garden. The rain garden was a retrofit design which made use of a large curbed traffic island within one of the park's parking areas. Soil and infiltration tests conducted in the area indicated that the stormwater retrofit would not be able to rely solely on infiltration due to compacted nature of the soils. Therefore the rain garden was designed with an 18-inch thick planting soil replacement underlain with a clean sand layer containing a fabric encapsulated perforated pipe. The underdrain was connected to an existing underdrain flowing into the adjacent roadway inlet.

Inflow to the rain garden occurs via a curb cut out along the upstream side of the garden and overflow is provided via a cut out in the roadside berm which flows into the existing roadway inlet. The inflow and outflow points are protected with stone. The rain garden was planted with vegetation well suited for the unique hydrologic conditions experienced in the rain garden. These plants include purple coneflower, joe pye weed, black-eyed susan, bee balm, and soft rush, with woody vegetation including groundsel tree, red chokeberry, and sweet pepperbush (Figure 51).

Figure 51. Completed rain garden in August 2010, photo by Rick Lear.

Princeton Hydro designed the rain garden, with input from the project team. The Middlesex County Department of Parks and Recreation, with oversight from Princeton Hydro, performed the earth-moving and site-preparation activities associated with the installation of the rain garden. Volunteers from the Rutgers Cooperative Extension Rain Garden Specialist Certification Workshop planted the vegetation in April 2010 (Figure 52). The County Department of Parks and Recreation watered the rain garden during the extremely dry conditions of the mid- and late summer of 2010 to ensure the survival of the newly planted vegetation. Middlesex County Master Gardeners will work with the Parks staff to maintain the garden.

Figure 52. Planting in April of 2010 with assistance provided by the Rutgers Rain Garden Workshop Certification class. Photo by NJWSA

The completed rain garden provides TSS removal and other water quality functions for stormwater runoff collected from approximately 13,000 square feet of impervious area. On an average year the rain garden will treat approximately 300,000 gallons of runoff. The retrofit also slows and reduces the total volume of stormwater runoff. This provides downstream benefits including flood relief and decreased streambank erosion.

Streambank and shoreline erosion have been identified as a major source of sediment loading within the watershed. The second phase of the demonstration project involved the re-vegetation of a portion of the Manalapan Lake shoreline buffer. In order to complete the project without permitting requirements, no topography changes were proposed and no permanent structures were installed (coir logs, stone, etc). A section of the shoreline buffer was chosen which was eroding and unstabilized but not to the extent of requiring grading or permanent stabilization structures.

A 150 foot by 10 foot section of the shoreline buffer was fenced and flagged to temporarily protect the plantings from the heavy winter usage of the lake by Canada geese. The vegetation planted along the shoreline included pickerel weed, duck potato, and soft stem bulrush, with woody vegetation including river birch, red chokeberry, groundsel tree, sweet pepperbush and northern bayberry.

Design Projects

Five design projects were selected from *all* of the identified projects. Four of these five selected design projects are included in the top 20 prioritized site specific implementation projects. These four projects represent the projects ranked first, fifth, seventh, and fourteenth in the top 20 first tier project list. Station #48 was not one of the first tier projects; however, the project was identified in the second tier project list and selected by the project committee for design.

The design of these projects was incorporated into the creation of the Manalapan Brook Watershed Protection and Restoration Plan. The purpose of this section is to outline and summarize the five design projects. The projects were selected through a voting process which incorporated the entire project committee. This process evaluated the projects based on many characteristics including TSS load reduction, implementation cost, project visibility, and variety among others.

A more thorough summary of each design project, including permitting and other considerations, is provided in Appendix K.

Station #37: Manalapan Lake Shoreline Stabilization at Thompson Park

The Manalapan Lake Shoreline Stabilization project is located in Thompson Park along the southern shoreline of Manalapan Lake. The stabilization measures are distributed along a total of approximately 600 linear feet of eroded shoreline. The stabilization measures include the establishment of native vegetation, regrading, erosion control blankets and the installation of coir logs. The objective of these design measures is to reduce Total Suspended Solids (TSS) loading originating from the continued erosion and degradation of the Manalapan Lake shoreline. The persistent erosion along this area is a result of numerous factors including wind-driven wave action erosion and exposed soil conditions related to extensive Canada geese herbivory of shoreline vegetation.

The proposed design features will provide a shoreline that can dissipate and resist the wind-driven wave action along the shoreline. The design will also create a shoreline that will deter the Canada geese which frequent the lake. The proposed aquatic vegetation will reduce the wind-driven wave energy associated with the long fetch of Manalapan Lake. The additional native shoreline vegetation will stabilize the shoreline. In sections of shoreline where the erosion has resulted in steeper eroded conditions, coir logs have been proposed. The coir logs will be planted with native wetland vegetation ideally suited for the riparian location. In addition to stabilizing the shoreline and preventing further erosion of the lake shoreline, the project will also provide ecological, recreational and aesthetic benefits to Thompson Park. The material quantities and associated labor for the proposed design plans for station #37 were used to calculate a construction cost estimate of $20,000 for the project.

Figure 53. Project section along southern Manalapan Lake shoreline, photo taken facing west, photo taken in January 2010.

Station #32: Wetland Water Quality Basin Retrofit

The Wetland Water Quality Retrofit project is located in an existing “dry” detention basin in Monroe Township. The design objective of the retrofit is to enhance the water quality benefits of the basin by improving the basin’s removal of Total Suspended Solids (TSS).

The existing basin has a single inlet and a series of concrete low flow channels which convey flow directly to the outlet structure. The current configuration of the basin does not provide substantial TSS removal due to the lack of vegetation and the directly connected concrete low flow channels. The proposed design features include the removal of concrete low flow channels, the creation of a forebay and stone filter berm, the elongation of the flow path, and a complete re-vegetation of the basin.

Under proposed conditions, the flow from smaller, more frequent storm events will have access to the entire basin. The flow path during these smaller events will be substantially lengthened under proposed conditions. This will maximize the runoff contact time with vegetation, decrease flow velocity and therefore promote the removal of TSS.

The basin was evaluated to determine if the retrofit could be designed to provide infiltration of incoming stormwater runoff; however, it was determined that the close proximity of the groundwater table would be prohibitive to the design of an infiltration system. The proposed retrofit will likely increase the volume control of runoff to some extent due to the removal of the concrete low flow channels and the minor regrading proposed in the basin; however, no infiltration is explicitly accounted for in the design of this retrofit. The proposed design plans also provide provisions to improve the operation and maintenance of the basin to facilitate sediment and debris removal from the basin.

Ancillary benefits of the project include aesthetic improvements to the basin; largely due to the proposed addition of native vegetation in the basin. The project will also greatly increase the ecological value of the basin. The proposed condition of the basin will minimize the need for periodic mowing of the basin which is currently conducted by the township. The design plans also propose a location for potential educational signage. The material quantities and associated labor for the proposed design plans for station #32 were used to calculate a construction cost estimate of $44,000 for the project.

Figure 54. Detention basin at station #32 showing outlet control structure and concrete low flow channel, photo taken in summer 2008.

Station #80: Dry Detention Basin Retrofit

The Dry Detention Basin Retrofit project is located in an existing detention basin in Manalapan Township. The design objective of this design project is to improve the water quality benefits of the basin by providing infiltration of stormwater runoff and also by improving the basin’s removal of Total Suspended Solids (TSS).

The existing basin has two main inlets and three main concrete low flow channels which convey flow from the inlets directly to the outlet structure. The current configuration of the basin does not provide substantial TSS removal due to the lack of vegetation over the majority of the basin, and the directly connected concrete low flow channels.

The proposed design features include the removal of all of the concrete low flow channels, the creation of a forebays and stone filter berms at both inlets, the elongation of the flow path, a complete re-vegetation of the basin, and the creation of a large designated infiltration area within the basin.

Under the proposed conditions flows from smaller, more frequent storm events will have access to the entire basin, instead of being routed directly to the outlet structure. The flow path during these smaller events will be substantially lengthened under proposed conditions. This will maximize the runoff contact time with vegetation, decrease flow velocity and therefore promote the removal of TSS. Furthermore, the creation of a large designated infiltration area will provide direct infiltration of incoming stormwater runoff from the basin's main inlet. This infiltration will result in direct TSS removal and decrease downstream flow rates and durations which will decrease potential streambank erosion in downstream stream segments.

Infiltration is possible at this location based on the adequate separation from the groundwater table that was observed at the basin and the coarse-grained soils and acceptable hydraulic conductivity measurements made during an initial site investigation.

Ancillary benefits of the project include aesthetic improvements to the basin, largely due to the proposed addition of native vegetation in the basin. The proposed condition of the basin will minimize the need for the periodic mowing of the basin. The project will also greatly increase the ecological value of the basin. The design plans also propose a location for potential educational signage. The material quantities and associated labor for the proposed design plans for station #80 were used to calculate a construction cost estimate of $41,000 for the project.

Figure 55. Dry detention basin at station #80, showing turf grass vegetation and concrete low-flow channels, photo taken in summer 2009.

Station #84: Dry Detention Basin Retrofit

The Dry Detention Basin Retrofit project is located in an existing detention basin in Manalapan Township. The purpose of this design project is to improve the water quality benefits of the basin by improving the basin's removal of Total Suspended Solids (TSS).

The existing basin has two main inlets and two main concrete low flow channels which convey flow from the inlets directly to the outlet structure. The current configuration of the basin does not provide substantial TSS removal due to the lack of vegetation over the majority of the basin, the directly connected concrete low flow channels, and the large low-flow orifice on the basin's outlet structure.

The proposed design features include the removal of a large section of the concrete low flow channels, the creation of a forebays and stone filter berms at both inlet, the elongation of the flow path, the modification of the outlet structure, and a complete re-vegetation of the basin.

The existing concrete low flow channel along the south side of the basin is not proposed to be removed. This area has become established with vegetation which primarily includes various species of sedges and rushes. The vegetation has grown over the concrete low flow channels as can be seen in the photo below which was taken during the summer of 2009. Due to the stabilized nature of this area and establishment of desirable plant species, the proposed plans do not propose any disturbance in this portion of the basin; however, proposed grading near the inlet structure on this side of the basin has been designed to divert storm flows into the larger portion of the basin for additional treatment.

Figure 56. Photo of station #84 facing west along the southern concrete low flow channel.

Under the proposed conditions flows from smaller, more frequent storm events will have access to the entire basin. The flow path during these smaller events will be substantially lengthened under proposed conditions. This will maximize the runoff contact time with vegetation, decrease flow velocity and therefore promote the removal of TSS. Furthermore, the proposed modifications to the outlet control structure will increase the detention time of the basin without compromising its peak flow attenuation performance for the larger infrequent design storm events.

The basin was evaluated to determine if the retrofit could be designed to provide infiltration of incoming stormwater runoff; however, the close proximity of the groundwater table was determined to be prohibitive to the design of an infiltration system. The proposed retrofit will provide some volume control due to the removal of portions of the concrete low flow channels and the minor regrading proposed within the basin; however, no infiltration is explicitly accounted for in the design of this retrofit. The proposed design plans also provide provisions to improve the operation and maintenance of the basin to facilitate sediment and debris removal from the basin.

In addition to the retrofits proposed within the basin, an area of exposed soil along the north side embankment is proposed to be covered with topsoil and seeded to stabilize this area and prevent the continued supply of sediment from this source.

Ancillary benefits of the project include aesthetic improvements to the basin, largely due to the proposed addition of native vegetation in the basin. The proposed condition of the basin will minimize the need for the periodic mowing of the basin. The project will also greatly increase the ecological value of the basin. The design plans also propose a location for potential educational signage. The material quantities and associated labor for the proposed design plans for station #84 were used to calculate a construction cost estimate of $47,000 for the project.

Figure 57. Dry detention basin at station #80, showing turf grass vegetation and concrete low-flow channels, photo taken in summer 2009.

Station #48: Streambank Stabilization and Floodplain Restoration

The Streambank Stabilization and Floodplain Restoration project is located along an unnamed tributary of Manalapan Brook at station #48. The channel in this location has steep eroding banks and is significantly entrenched. The project entails the creation of a stable stream channel through the use of various soil bioengineering techniques. The project also creates a functional floodplain to reduce velocity and resulting shear stress in the channel. The proposed bioengineering techniques used by the project include the implementation of live fascines, live stakes, boulder toe protection and additional vegetation.

The material quantities and associated labor for the proposed design plans for station #48 were used to calculate a construction cost estimate of $74,000 for the project. Project permitting fees are also discussed later in this document.

At the time of the creation of the design plans for station #48, the existing corrugated metal pipe culvert under Monroe Boulevard (upstream of the project reach) was in the design stage for replacement. The culvert is showing signs of distress and the asphalt along Monroe Boulevard was showing distress due to the condition of the culvert. The culvert is dedicated as #5C81 by Middlesex County. Based on correspondence with Middlesex County, the culvert is being designed by Delaware Raritan Engineering. An attempt was made to coordinate the design of the station #48 project with the replacement of the culvert. A written information request was sent to the Middlesex County Engineering Department on October 4th 2010. The request asked for any additional topographic or design information which may become available. It is assumed that the design of the culvert replacement was still ongoing, as no information was received. Therefore, these design plans were not available from the county at the completion of the design plans (February, 2011) for the streambank stabilization. The implementation of these plans should be coordinated such that it does not interfere with the culvert replacement. If the culvert replacement occurs prior to the implementation of this project, the current plans should be reevaluated to ensure that any potential topographic changes resulting from the culvert replacement do not interfere with the design project plans. Furthermore, the ownership/usage of the utility pole on the north side of the stream should be determined. Upon inspection, the pole appeared to only partially support abandoned phone or cable lines.

Figure 58. Stream reach at station #48, photo taken facing downstream of the road crossing, photo taken in June 2009.

Summary and Comprehensive Watershed Management Plan Compliance

As previously described, the specific implementation projects previously described, would contribute toward attaining the targeted TSS load and mean TSS concentration, thus complying with the state Surface Water Quality Standard. The primary or initial source of technical assistance for any of these projects would start with the property owner, which may include private landowners or municipal, county, or state entities. Wherever possible for convenience, the land owners were specifically identified under each project's description.

Table 27 is a summary of the proposed watershed projects that are designed to attain the targeted TSS load and comply with the Water Quality Standard. This section of the plan specifically addresses the second element of the Comprehensive Watershed Management Plan. Details on how these projects were selected were provided in previous sections of this plan. Note that some of these projects are also included in the five design projects completed as part of this Watershed Protection and Restoration Plan.

A schedule for the implementation of the projects identified in Table 27 over the course of a 10 to 20 year period is provided below in Table 31.

Table 31. Proposed timeline of first tier project implementation.

SVA Station	BMP	Municipality	Estimated Implementation Date
37	Installation of a rain garden in Thompson Park	Monroe	2010
Attain first milestone by completing the first BMP project identified in the Watershed Plan			
37	Shoreline stabilization project along Thompson Park	Monroe	2011
32	Basin retrofits	Jamesburg	2012
80	Basin retrofits	Manalapan	2012
84	Basin retrofits (possible modification into a wetland BMP)	Manalapan	2012
29	Stabilize / revegetate 400 l.ft. of streambank	Jamesburg	2014
67	Stabilize approx. 150 l.ft of streambank	Manalapan	2014
Attain second milestone by completing approximately 25% of the BMPs identified in the Watershed Plan			
29	Stabilize approx. 400 l.ft. of streambank	Jamesburg	2016
32	Minor streambank stabilization work	Jamesburg	2016
67	Installation of a BMP or Manufactured Treatment Device	Manalapan	2016
3	Streambank stabilization	Spotswood	2016
29	Installation of 2-4 large Manufactured Treatment Devices	Jamesburg	2018
86	Shoreline stabilization around 10,000 l.ft of pondshore	Manalapan	2018
Attain third milestone by completing approximately 50% of the BMPs identified in the Watershed Plan			
71	Some additional / supplemental streambank stabilization work	Manalapan	2019
88	Stabilize approx. 400 l.ft. of streambank	Manalapan	2020
92	Dredging and additional mitigation / stabilization measures	Manalapan	2020
94	Shoreline stabilization on golf course	Millstone	2020
15	Basin retrofits (some additional stabilization and plantings)	Monroe	2021
45	Installation of a Manufactured Treatment Device	Monroe	2021
Attain fourth milestone by completing approximately 75% of the BMPs identified in the Watershed Plan			
19	Bioretention / infiltration basin with some streambank stabilization	Helmetta	2024
96	Wetland enhancement	Millstone	2024
53	Expansion of riparian habitat	Monroe	2024
61	Stabilization of disturbed areas	Manalapan	2024
53	Installation of a Manufactured Treatment Device	Monroe	2026
Attain fifth milestone by completing approximately 100% of the BMPs identified in the Watershed Plan			
37	Installation of a Manufactured Treatment Device at County zoo	Monroe	2028
61	Maintenance dredging the upper section of Manalapan Lake	Monroe	2028

Technical / Financial Assistance

Initiating this implementation plan will require an organization or agency to serve as the "steward" for the Manalapan Brook watershed. It is not recommended to create a new agency to serve this capacity. Instead, if possible, an existing organization or organizations serve as the steward(s) for the watershed and overseeing the implementation of the plan. Since the watershed covers two counties and 10 municipalities, it is recommended that the project committee which represents the municipalities in the watershed, the Monmouth and Middlesex County Planning Departments, and the Freehold Soil Conservation District continue to meet. It is also recommended that Monmouth County, Middlesex County Planning Department, and the Freehold Conservation Service serve as partners responsible for coordinating implementation of the watershed restoration plan.

In terms of financial assistance for the design and implementation of the recommended projects, a number of potential avenues of funding should be considered and possibly pursued such as:

- federal and/or state grants, loans or technical assistance. Example programs include the state's Non-Point Source 319(h) program, federal and state environmental education grants and other sources such as US EPA, US Army Corp of Engineers and possibly United States Department of Agriculture;
- small-scale county or municipal grants or projects that fund the planting of native vegetation;
- establishment of unique agreements such as the creation of wetlands as part of a mitigation bank to compensate for the loss of wetlands associated with development within the watershed;
- integrating required MS4 permit actions into the plan; many of the basin retrofit projects could be addressed through such municipal – county – state agreements;
- cooperative agreements between private property owners (i.e. residential developments, golf courses) and local / county agencies to implement stabilization and/or vegetation-based projects; and,
- other modes of funding such as private, non-profit sources, land or tax credit incentives and municipal agreements for future development or establishment of open space lands.

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

Potential State Sources of Funding for Watershed Restoration Projects:

More details on the potential sources of funding through the programs listed below can be found at www.nj.gov/dep/grantandloanprograms.

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

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

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

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

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

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

Potential Federal Sources of Funding for Watershed Restoration Projects:

- *Landowner Incentive Program* (funds provided through the National Landowner Incentive Program administered by the U.S. Fish and Wildlife Service) can be used toward the enhancement, protection or restoration of habitats that benefit federal and state listed, proposed, or candidate species, or other at-risk species on private lands. More information can be found at:

  www.nj.gov/dep/grantandloanprograms.

- *Environmental Education Grants* (funds provided by U.S. EPA) can be used to support environmental programs through education and public outreach. More information can be found at:

www.epa/gov/enviroed/grants.

- *Aquatic Ecosystem Restoration Grants* (funds provide 50% federal cost share from the U.S. Army Corp of Engineers) can be used to conduct remedial or restoration actions on aquatic ecosystems. More information can be found at:

  www.lrl.usace.army.mil

- *Five-Star Restoration Program* (funds provided by U.S. EPA and the National Fish and Wildlife Foundation) provides funds to implement a wide variety of watershed-based restoration projects. More information can be found at:

  www.epa.gov/owow/wetlands/restore/5star

- *North American Wetlands Conservation Act Grants Program* (funds provide a cost-share match of 1:1 from the U.S. Fish and Wildlife Service and North American Waterfowl and Wetland Office) provides funds to implement a wide variety of watershed-based restoration projects. More information can be found at www.cfda.gov.

- *Partners for Fish and Wildlife Program* (funds provide 50% federal cost share from the U.S. Department of the Interior; local 50% share can be money or in-kind and the specific amount is negotiable) can be used to implement a wide variety of watershed-based restoration projects. More information can be found at www.fws.gov/partners

- *State Wildlife Grant Program (Non-Tribal)* (funds provided through the U.S. Fish and Wildlife Service, Wildlife and Sport Fish Restoration Program; 25% match required for non-federal planning activities and a 50% match for all other non-federal activities) can be used to implement a wide variety of watershed-based, riparian and aquatic restoration projects. More information can be found at:

  www.wsfrprograms.fws.gov

- *Targeted Watershed Grants Program* (funds provided through the U.S. EPA and require a non-federal match of 25% which can be money or in-kind activities) can be used to implement a wide variety of watershed-based restoration activities that focus primarily on reducing point and non-point source pollutant loading to receiving waterways. More information can be found at:

  www.epa.gov/owow/watershed/initiative

- *Watershed Rehabilitation Program* (funds provided through the Natural Resources Conservation Service and does require a non-specific match) can be used implement land-based, watershed restoration projects that focus on reducing non-point source pollution. More information can be found at:

  www.nrcs.usda.gov/programs/WSRehab

- *Wetlands Program Development Grants* (funds provided through the regional office [Region II] of U.S. EPA and require a 25% match) can be used to implement a wide variety of watershed-based restoration projects. More information can be found at:

  www.epa.gov/owow/wetlands/grantguidelines

- *Wetlands Reserve Program* (funds provided through local or state NRCS office / Conservation District office; matches are not typically applicable except for some cost-share agreement projects) can be used to implement a wide-variety of land-based, watershed restoration projects. More information can be found at:

  www.nrcs.usda.gov.

Public Information and Outreach:

At least one specific project was identified within each municipality in the Manalapan Brook watershed in order to garner public support for plan implementation. Public information and outreach should focus on conveying information to the stakeholders through the municipalities, since the local communities have a vested interest in protecting the water quality of their local resources, as well as addressing and complying with their MS4 permits.

The Manalapan Brook Watershed Restoration and Protection Plan Project Committee meetings have provided participants with updates since this project was initiated in 2007. These meetings were held between 2-4 times per year and have been critically important in providing stakeholders with progress reports on the development of the plan and communicating to each other activities within the watershed. Thus, it is recommended that these meetings continue as the plan moves into the implementation phase. Specifically, meetings should be held approximately twice a year, once every six months, to provide stakeholders with the following information:

- what watershed-based activities or updates have occurred since the last meeting;
- what projects are currently under review or being implemented;

- what projects are scheduled for implementation in the near future (up to a year), particularly within the context of securing sources of funding;
- other issues, including the long-term implementation of projects, progress on complying with the TMDL and future sources of funding.

The participating stakeholders who attend the meeting can then go to their constituents and provide information and outreach material on how to proceed with implementing the identified management measures.

Participants at these committee meetings have included representatives from state agencies (i.e. NJWSA and NJDEP), the counties (Middlesex and Monmouth Counties) and associated agencies (i.e. Parks and Recreation), the local municipalities and other stakeholders/landowners. While all representatives will continue to participate in these meetings and contribute toward the implementation of the Manalapan Brook Watershed Restoration and Protection Plan, a key stakeholder must be identified that will manage the overall implementation of the plan and oversee these project meetings.

Schedule and Milestones

As previously cited, the projects identified in this plan could be conducted over the course of 10 to 20 years (Table 29). A series of long-term project milestones have been integrated into the implementation schedule (Table 29). Interim milestones are based on a number of criteria including the percent of projects completed and the percent of the TSS load targeted for reduction that has been addressed. Thus, while the implementation schedule sets out the proposed timeline in completing the identified projects, the interim milestones will be proposed as follows:

- Completion and estimation of the amount of TSS removed by the Thompson Park Rain Garden Bioretention BMP.
- Completion of some or all five projects that were identified for design work in this plan.
- Completion of all of the projects that were identified for design work in the plan; the completion of the Thompson Park BMP and the five additional BMPs identified and designed in the plan would represent approximately 25% of the management measures listed in Table 29. At this point a revised assessment of the exiting TSS loads should be conducted.
- Completion of approximately six more management measures, representing approximately half of the listed projects. At this point a revised assessment of the existing TSS loads should be conducted.
- Completion of approximately five more management measures, representing most of the remaining half of the listed projects. At this point a revised assessment of the existing TSS loads should be conducted.
- The final project should be the removal of the unconsolidated material in the upper portion of Manalapan Lake and its associated rehabilitation as a regional BMP. With the majority of the watershed projects completed it may be possible to request the use of 319 funds to implement this proposed restoration project for the upper portion of the lake.
- Final revised assessment and confirmation that the watershed is in compliance with the targeted TSS loads and mean concentration, as per the State Water Quality Standard.

Criteria to Determine Whether Loading Reductions are being Achieved Over Time:

The criteria that will be used to determine if loading reductions associated with the implementation of the recommended projects will be three-fold. First, tributary and in-stream water quality sampling will be conducted, specifically for TSS to determine if the state's Water Quality Standard designated for Manalapan Brook and Lake is being met. Specifically, the mean TSS concentration should be less than or equal to 40 mg/l. Such monitoring will require the development of a statistically sound and state-approved (e.g. NJDEP) Quality Assurance plan (for more details see the ninth element below).

Second, site-specific stormwater sampling will be conducted at each project site as funds allow. Sampling would be conducted both prior to and after a specific project is installed to quantify how it contributes toward reducing the TSS loads. Typically post-installation stormwater monitoring would entail collecting samples immediately up gradient and down gradient of the installed project to calculate its pollutant removal efficiency.

Third, given the costs associated with the collection and analysis of samples for TSS, some watershed-based models should be utilized to quantify the project-related, estimated TSS reductions. In order to maximize the potential for obtaining funding for the implementation of the recommended watershed projects, it is recommended that the Spreadsheet Tool for Estimating Pollutant Load (STEPL) model be utilized to quantify TSS reductions associated with the implemented BMPs.

The STEPL model uses simple algorithms to calculate pollutant loads, in this case TSS, similar to the AVGWLF; however, the model also uses known BMP pollutant reduction efficiencies to quantify the reductions associated with the implementation of various watershed management measures. Since the STEPL model is approved for use by both NJDEP and US EPA, it should be utilized to quantify the TSS reductions associated with any implemented BMPs. The resulting reductions will provide a means of documenting the progress made in attaining the goals of the plan (eighth element) as well as attaining the desired mean TSS concentration. It should be noted that while many of the Manufactured Treatment Devices may not have STEPL designed TSS reduction efficiencies, project-specific stormwater sampling (the second method) should provide the information need to develop such efficiencies.

Thus, these three methods, baseline TSS monitoring, stormwater sampling to quantify project specific reduction efficiencies, and the use of the STEPL model, will be used to determine if the plan needs to be revised or document the progress being made in both reducing the TSS loads and attaining the desired mean TSS concentration.

Monitoring to Evaluate the Effectiveness of the Implementation Efforts:

This last element of the plan outlines the specific monitoring methodology that should be used to determine if the load and concentration reductions are being achieved over time. While at this point no stable source of funding exists to develop such a long-term monitoring program, the following recommendations are being made to identify the bare minimum that should be done to provide some means of monitoring the effectiveness of the implementation efforts. More data would be preferred to conduct more rigorous statistical analysis in evaluating project progress, particularly relative to storm-based sampling; however, at a minimum:

- Six monitoring stations should be established throughout the watershed; four of these stations should be the same locations used for the NJDEP AMNET program with the remaining two to be located above and below Manalapan Lake;
- At least six samples should be collected at each station per year, three during baseline (non-storm) and three during storm event conditions for the analysis of TSS. This would generate a total of 36 data points per year;
- If possible, in-situ data should also be collected at the sites, at least during the baseline (non-storm event) conditions.

The proposed monitoring plan should generate a sufficient amount of TSS data to develop a long-term and statistically sound inter-annual database for the 43 square miles Manalapan Brook watershed. As previously mentioned, the TSS data collected under this proposed monitoring program could be used to determine if watershed management efforts are contributing toward long-term, inter-annual reductions in TSS.

Summary and Conclusions

The Manalapan Brook watershed is a unique watershed with a wide range of historic land use and development. The hydrologic changes experienced by the watershed are a result of historic and ongoing shifts in land use which have resulted in a watershed that is covered by approximately 12% impervious surfaces. These changes have increased non-point source pollution and lead to a general destabilization of many of the stream reaches within the watershed. These impacts have led to decreased water quality in the Manalapan Brook and specifically in Manalapan Lake; the largest impoundment and a major focal point of the watershed.

This watershed protection and restoration plan was developed to address these specific water quality impairments. Numerous methods were used quantify existing TSS loads within the watershed and to identify specific sources of non-point source pollution. This included a comprehensive visual assessment, water quality and biological sampling and watershed scale hydrologic and water quality modeling.

This plan identified watershed initiatives and specific recommended and prioritized projects. Additionally the development of this plan has gone beyond recommendations and included the design of five additional projects and the implementation of two demonstration projects. The plan outlines the means and methods to address the water quality impairments of the watershed and will be used a guidance document for the continued protection and restoration of the watershed.

References

ASCE Task Committee on Definition of Criteria for Evaluation of Watershed Models of the Watershed Management Committee, Irrigation and Drainage Division (1993). Criteria for Evaluation of Watershed Models. Journal of Irrigation and Drainage Engineering, Vol. 199, No 3.

Center for Watershed Protection, Anne Kitchell and Tom Schueler, February 2005, Unified Stream Assessment: A User's Manual 10, Version 2, Ellicott City, MD

Evans, B.M., S.A. Sheeder, D.W. Lehning, (2003) A spatial technique for estimating streambank erosion based on watershed characteristics. J. Spatial Hydrology 3(2).

Evans, B.M., D.W. Lehning, K.J. Corradini, G.W. Petersen, E. Nizeyimana, J.M. Hamlett, P.D. Robillard, R.L. Day, (2002) A comprehensive GIS-based modelling approach for predicting nutrient loads in watersheds. J. Spatial Hydrology 2(2).

Evans, B.M., Corradini, K.J. (2006) AVGWLF Version 7.2 A Guide to Creating Software-Compatable Data Sets (Revised August 2008), Penn State Institutes of Energy and the Environment, The Pennsylvania State University

Evans, B.M., D.W. Lehning, K.J. Corradini (2008) AVGWLF Version 7.1 Users Guide, Penn State Institutes of Energy and the Environment, The Pennsylvania State University.

Haith, D.R., R. Mandel, and R.S. Wu, (1992) GWLF: Generalized Watershed Loading Functions User's Manual, Vers. 2.0. Cornell University, Ithaca, NY.

New England Interstate Water Pollution Control Commission (NEIWPCC) (2005) Calibration and Validation of the AVGWLF Model for New England and New York State.

New Jersey Department of Environmental Protection (NJDEP) (1983) *New Jersey Lakes Management Program Lakes Classification Study: Manalapan Lake.* Bureau of Monitoring and Data Management in Association with Princeton Aqua Science.

New Jersey Department of Environmental Protection (NJDEP) (2003) Total Maximum Daily Loads for Phosphorus To Address 6 Eutrophic Lakes in the Raritan Water Region, Division of Watershed Management. Trenton, New Jersey.

New Jersey Department of Environmental Protection (NJDEP) (2005) Total Maximum Daily Loads for Fecal Coliform to Address 3 Streams in the Raritan Water Region, Division of Watershed Management. Trenton, New Jersey.

New Jersey Department of Environmental Protection (NJDEP) (2006) *New Jersey Integrated Water Quality Monitoring and Assessment Report*. Water Monitoring and Standards. Trenton, New Jersey.

New Jersey Department of Environmental Protection (NJDEP) (2008) NJDEP Digital Data Downloads, Bureau of Geographic Information Systems. http://www.state.nj.us/dep/gis/, accessed June 2008.

New Jersey Department of Environmental Protection (NJDEP) (2008) Ambient Biomonitoring Report for the Raritan Region, Trenton, New Jersey.

New Jersey Geological Survey (NJGS) (1993) Geological Survey Report GSR-32, A Method for Evaluating Ground Water Recharge Areas in New Jersey.

New Jersey Water Supply Authority (NJWSA) (2000) Water Budget in the Raritan River Basin: A Technical Report for the Raritan Basin Watershed Management Project.

Haith, D.R., R. Mandel, and R.S. Wu, (1992). GWLF: Generalized Watershed Loading Functions User's Manual, Vers. 2.0. Cornell University, Ithaca, NY.

New Jersey Department of Environmental Protection (NJDEP) (1983) New Jersey Lakes Management Program Lakes Classification Study: Manalapan Lake. Bureau of Monitoring and Data Management in Association with Princeton Aqua Science.

New Jersey Department of Environmental Protection (NJDEP) (2003) Total Maximum Daily Loads for Phosphorus to Address 5 Eutrophic Lakes in the Raritan Water Region, Division of Watershed Management. Trenton, New Jersey.

New Jersey Department of Environmental Protection (NJDEP) (2006) New Jersey Integrated Water Quality Monitoring and Assessment Report. Water Monitoring and Standards. Trenton, New Jersey.

New Jersey Department of Environmental Protection (NJDEP) (2007) Flood Hazard Area Control Regulations (N.J.A.C.7:13)

New Jersey Department of Environmental Protection (NJDEP) (2008) Wildlife Species of Special Concern in New Jersey. http://www.state.nj.us/dep/fgw//spclspp.htm, accessed June 2008.

New Jersey Department of Environmental Protection (NJDEP) (2008) *Ambient Biomonitoring Network Report for the Raritan Region, Watershed Management Areas 7, 8, 9 and 10, Round 3 Benthic Macroinvertebrate Data*. Trenton, New Jersey.

New Jersey Water Supply Authority (NJWSA) (2000) Raritan Basin Watershed Management Project, Water Resources Protection Open Space Criteria.

New Jersey Water Supply Authority. (2007) Manalapan Lake Watershed Restoration / Implementation Plan – Interim Report. Somerville, New Jersey. In Association with Princeton Hydro, LLC

Natural Resource Conservation Service (NRCS) (1998) Soil Quality Information Sheet, Available Water Capacity, January 1998.

Natural Resource Conservation Service (NRCS) (2008) Web Soil Survey, http://websoilsurvey.nrcs.usda.gov/, accessed June 2008.

Natural Resource Conservation Service (NRCS) (2008) Soil Survey Geographic (SSURGO) Database, http://soils.usda.gov/survey/geography/ssurgo/, accessed June 2008.

Natural Resource Conservation Service (NRCS) (2008) Key to Glauconitic Soils in Coastal Plains of New Jersey, ttp://www.nj.nrcs.usda.gov/technical/soils/glauconitic.html

Natural Resource Conservation Service (NRCS) (2009) Key to Glauconitic Soils in Coastal Plains of New Jersey, http://websoilsurvey.nrcs.usda.gov/, accessed March 2009.

US Census Bureau - Census 2000 Data for the State of New Jersey http://www.census.gov/census2000/states/nj.html

United States Environmental Protection Agency (USEPA) (2005) "Handbook for Developing Watershed Plans to Restore and Protect Our Water" EPA 841-B-08-002