TENAKILL BROOK WATERSHED RESTORATION & PROTECTION PLAN

Developed by the Rutgers Cooperative Extension Water Resources Program
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RP 07-001

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Table of Contents

List of Figures

List of Tables

I. Acknowledgements

The *Tenakill Brook Watershed Restoration and Protection Plan* has been produced by the **Rutgers Cooperative Extension (RCE) Water Resources Program** (more information at www.water.rutgers.edu). Principal authors were **Steven Yergeau, Ph.D.**, Post-Doctoral Associate, **Lisa Galloway Evrard**, Senior Program Coordinator, and **Christopher Obropta, Ph.D., P.E.**, Associate Extension Specialist. Additional material was prepared by **Craig Phelps, Ph.D.**, Department of Environmental Sciences, **Sean Walsh**, Program Associate, **Robert Miskewitz, Ph.D.**, Department of Environmental Sciences, and **Katie Giacalone**, Program Associate.

Marion McClary, Jr., Ph.D., Associate Professor and Co-Director, School of Natural Sciences at Fairleigh Dickenson University collected and analyzed benthic macroinvertebrate data in the Tenakill Brook Watershed. The **Bergen County Department of Health Services** and **Bergen County Utilities Authority** assisted with sampling events and analyzed samples for all the parameters except bacteria and microbial source tracking.

Funding for this project was provided by the **New Jersey Department of Environmental Protection (NJDEP)** through the 319(h) Grants for Nonpoint Source Pollution Control. The *Tenakill Brook Watershed Restoration and Protection Plan* maps were developed using NJDEP Geographic Information System (GIS) digital data, but this secondary product has not been verified by NJDEP and is not State-authorized.

II. Executive Summary

The *Tenakill Brook Watershed Restoration and Protection Plan* assesses the health of this watershed and provides insight into potential problems facing the water quality of Tenakill Brook. In addition, this plan presents potential solutions targeted at the problems determined to affect the Tenakill Brook and its watershed. The Tenakill Brook is an important natural resource as a tributary of the Oradell Reservoir, which provides drinking water for an estimated 800,000 residents of Bergen and Hudson Counties.

The watershed area is predominantly urbanized. This intensive land use has caused degradation of stream health through polluted stormwater runoff and increased flows through the streams and brooks in the watershed, threatening the Category One waters to which the Tenakill

Brook flows. Pollutants of concern for the Tenakill Brook Watershed include bacteria (fecal coliform & *E. coli*) and phosphorus. With the introduction of enhanced stormwater management, this watershed can continue these land use practices while achieving sustainability and improved water quality. Management measures that will minimize the amount of and reduce pollutants in stormwater runoff will be essential for reducing contaminants that now impair the designated uses of the surface waters within the Tenakill Brook Watershed.

Working with the Bergen County Department of Health Services, Bergen County Utilities Authority and Fairleigh Dickenson University, the RCE Water Resources Program has created this plan to recommended implementation projects, measureable milestones and suggestions for technical assistance and funding to improve water quality and enhance the water resources of the Tenakill Brook Watershed. Along with site specific projects, combining watershed-wide educational components with building stormwater controls will be essential for achieving sustainable goals for the future of this region.

III. Introduction

A. Project Background

The purpose of developing a Watershed Restoration and Protection Plan for the Tenakill Brook Watershed is to ensure that the valuable uses that this freshwater system has provided the area in the past continues into the future. These uses include recreational activities and drinking water supplies, along with the ability of the river to provide a healthy ecosystem for aquatic species and surrounding wildlife. The RCE Water Resources Program has undertaken the task of performing water quality testing, land surveillance and geographic information system (GIS) analyses to provide stakeholders within the Tenakill Brook Watershed with a Watershed Restoration and Protection Plan to ensure the quality of the watershed for the future.

To properly manage water quality a total maximum daily load (TMDL) was developed, based on data collected in the Tenakill Brook at the U.S. Geological Survey (USGS) monitoring station (USGS 01378387) at Cedar Lane in Closter, to address the fecal coliform impairment. TMDLs are developed by the NJDEP, and approval is given by the U.S. Environmental Protection Agency (USEPA). In accordance with Section 305(b) of the Clean Water Act, New Jersey assesses the overall water quality of the State's waters and identifies impaired waterbodies through the development of a document referred to as the *Integrated List of Waterbodies*

(NJDEP, 2006). Within this document are lists that indicate the presence and level of impairment for each waterbody monitored. The lists are defined as follows:

- **Sublist 1** suggests that the waterbody is meeting water quality standards.
- **Sublist 2** states that a waterbody is attaining some of the designated uses, and no use is threatened. Furthermore, Sublist 2 suggests that data are insufficient to declare if other uses are being met.
- **Sublist 3** maintains a list of waterbodies where no data or information are available to support an attainment determination.
- **Sublist 4** lists waterbodies where use attainment is threatened and/or a waterbody is impaired; however, a TMDL will not be required to restore the waterbody to meet its use designation.
  - **Sublist 4a** includes waterbodies that have a TMDL developed and approved by the USEPA, that when implemented, will result in the waterbody reaching its designated use.
  - **Sublist 4b** establishes that the impaired reach will require pollutant control measurements taken by local, state, or federal authorities that will result in full attainment of designated use.
  - **Sublist 4c** states that the impairment is not caused by a pollutant, but is due to factors such as instream channel condition and so forth. It is recommended by the USEPA that this list be a guideline for water quality management actions that will address the cause of impairment.
- **Sublist 5** clearly states that the water quality standard is not being attained and a TMDL is required.

According to the 2006 *Integrated List of Waterbodies* (NJDEP, 2006), the Tenakill Brook at Cedar Lane was listed (according to surface water use) on Sublist 5 for aquatic life impairments and drinking water supply; Sublist 4a for primary and secondary contact recreation; Sublist 3 for fish consumption; and Sublist 2 for agricultural and industrial water supply. Fecal coliform impairment has been addressed through the New Jersey TMDL process; therefore, this parameter has been moved to Sublist 4a. The 2008 *New Jersey Integrated Water Quality Monitoring and Assessment Report* (NJDEP, 2009a) lists the Tenakill Brook on Sublist 5 for aquatic life impairments and drinking water supply; Sublist 4a for primary and secondary contact recreation; Sublist 3 for fish consumption; and Sublist 2 for agricultural and industrial water supply. In the 2010 *New Jersey Integrated Water Quality Monitoring and Assessment Report* (NJDEP, 2011a), reporting requirements changed to providing information on the attainment of designated uses rather than putting uses into various sublists. The Tenakill Brook was reported as not supporting attainment for aquatic life uses due to dissolved oxygen, pH, total phosphorus, and total suspended solids (NJDEP, 2011a). Primary contact recreation use was not attained due to fecal coliform (NJDEP, 2011a). A 96% reduction in fecal coliform loading to the Tenakill Brook is needed to achieve water quality standards (NJDEP, 2003). The TMDL was developed based on summer monitoring results from 2001 and 2002.

Data collected on the Tenakill Brook at the USGS monitoring station for the 2006 and 2008 *Integrated List of Waterbodies* was insufficient to declare the impairment status of total phosphorus (TP). Additional data were collected as part of this study to further examine the possibility of TP impairment. These data are discussed later in this plan and in detail in the *Tenakill Brook Watershed Restoration and Protection Plan: Data Report* (RCE Water Resources Program, 2011).

B. Purpose of This Plan

The purpose of this restoration and protection plan is to synthesize environmental data on the Tenakill Brook Watershed, including previous studies and the work of the RCE Water Resources Program, to evaluate the water quality of Tenakill Brook and its tributaries, as well as overall watershed health. Water quality problems and their potential sources will be evaluated so that potential solutions to these problems can be determined. Examples of such solutions for specific areas within the watershed are highlighted to improve the water quality within the Tenakill Brook Watershed.

IV. Tenakill Brook Watershed Description

A. Physical Characteristics

1. Geography and Topography

Located entirely in Bergen County in northeastern New Jersey, the Tenakill Brook Watershed includes portions of Demarest, Closter, Alpine, Haworth, Cresskill, and Tenafly Boroughs in Bergen County (Figure 1). Small portions of Dumont Borough and Englewood City also lie within the watershed area (Figure 1). There are approximately 11 miles of rivers and streams within the watershed; these include the mainstem Tenakill Brook and tributaries Cresskill Brook, Demarest Brook, and Charlie's Creek (Figure 1). The headwaters of Tenakill Brook are in Tenafly Borough. The largest surface waterbody in the drainage area is Demarest Pond, though several other lakes exist within the watershed on private and public lands and golf courses. The Tenakill Brook Watershed is located in Watershed Management Area (WMA) 5 (Figure 1).

The Tenakill Brook Watershed is approximately 8.8 square miles (5,673.2 acres) and is dominated by urban land uses (Figure 2). Approximately 48% of the watershed is comprised of single unit, medium density residential properties (Figure 3). Residential single unit, low density development comprises approximately 17%, and deciduous forested areas are approximately 11% of the watershed (Figure 3). Single residential, medium density has been defined by the NJDEP as residential urban/suburban neighborhoods greater than 1/8 acre and up to and including 1/2 acre lots (Anderson *et al.*, 1976). These areas generally contain impervious surface areas of ~30-35%. Urban land use also includes land used for commercial, industrial and transportation purposes including residential (Figure 3).

The elevations found within the Tenakill Brook Watershed range from approximately 29 feet above mean sea level (AMSL) to 500 feet AMSL (Figure 4). The highest elevations are found within Alpine Borough in the eastern part of the watershed (Figure 4). This area contains the headwaters for Cresskill Brook and Demarest Brook.

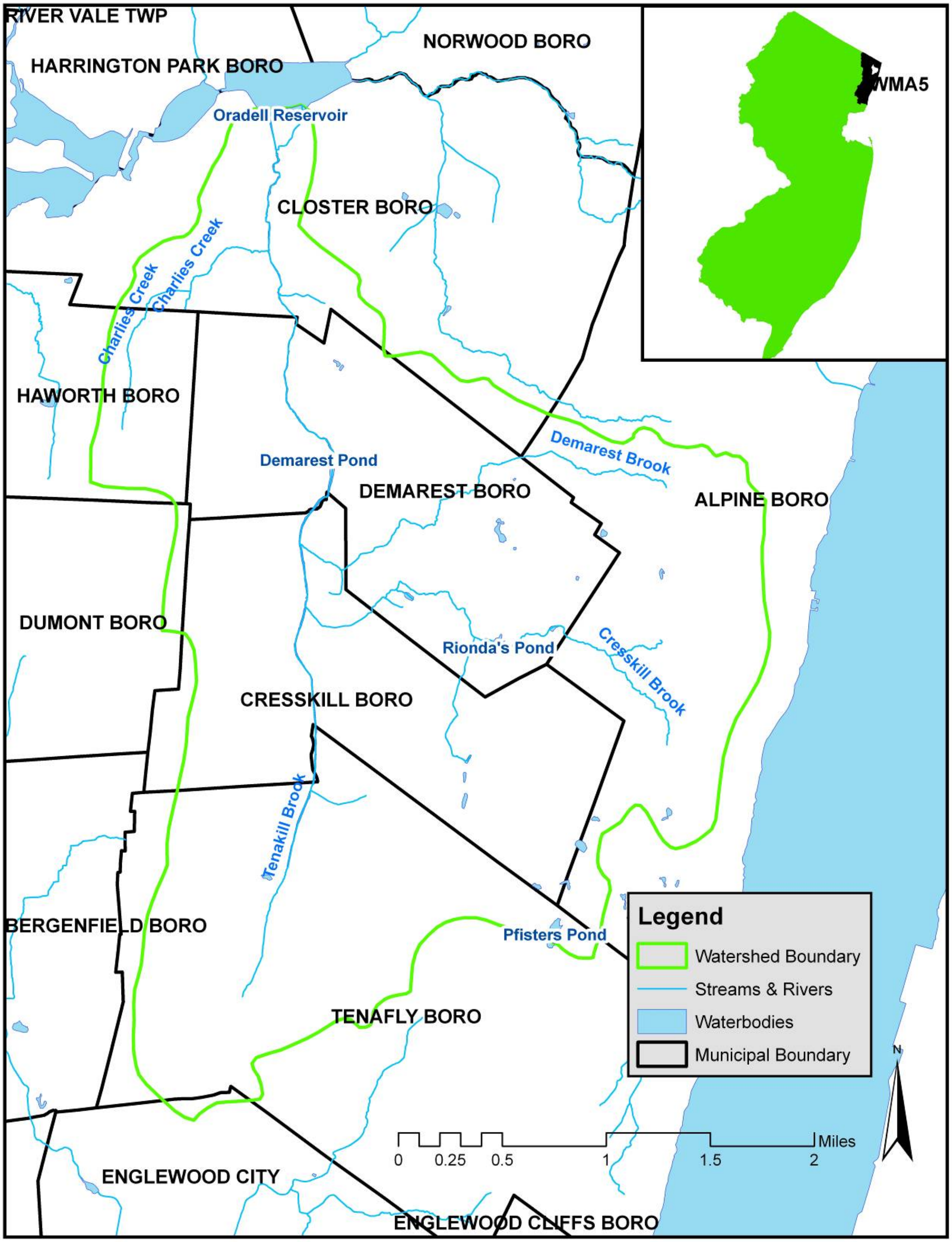


Figure 1: The Tenakill Brook Watershed.

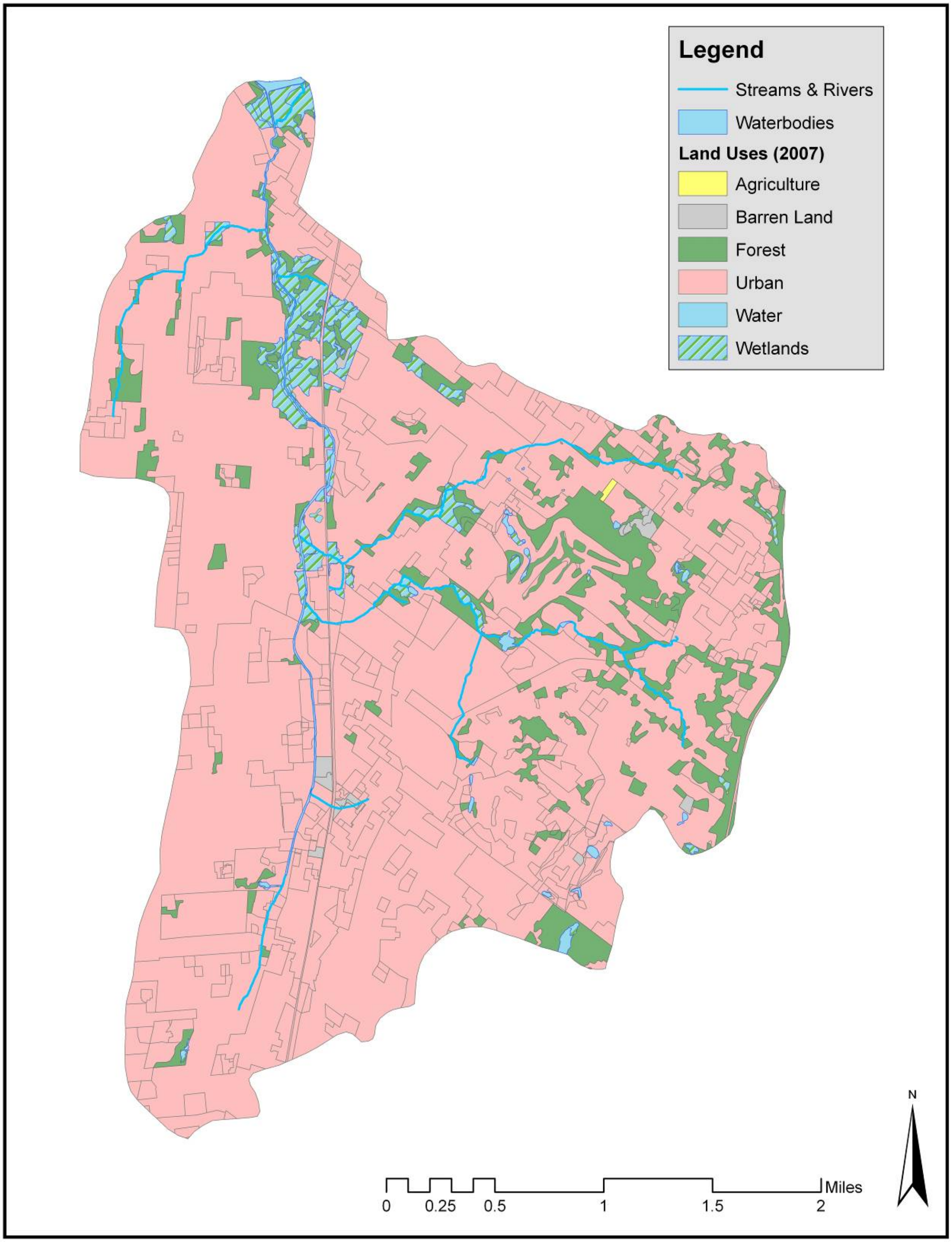
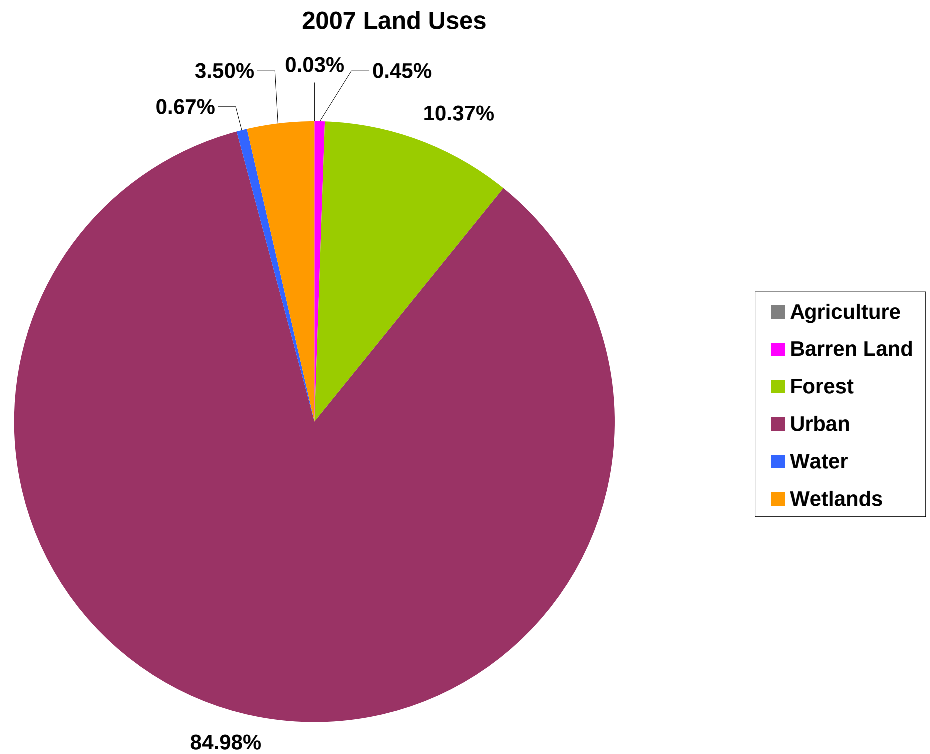


Figure 2: 2007 Land uses in the Tenakill Brook Watershed.



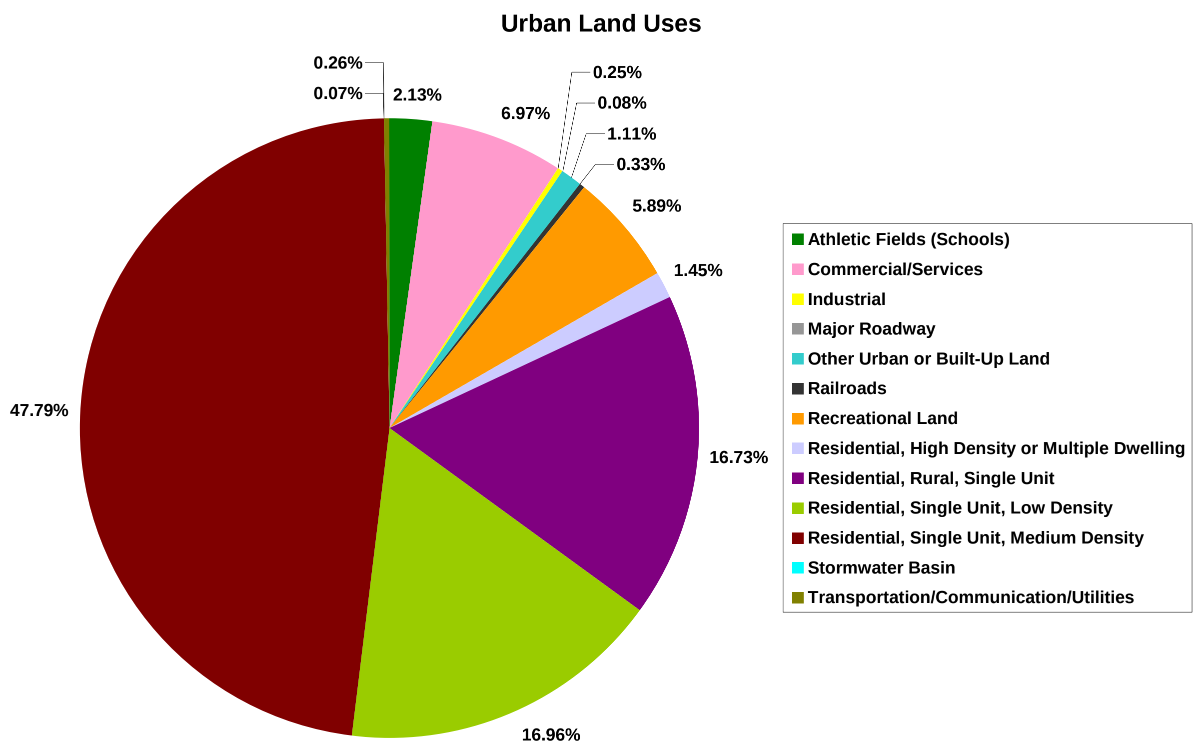


Figure 3: 2007 Land cover types in the Tenakill Brook Watershed

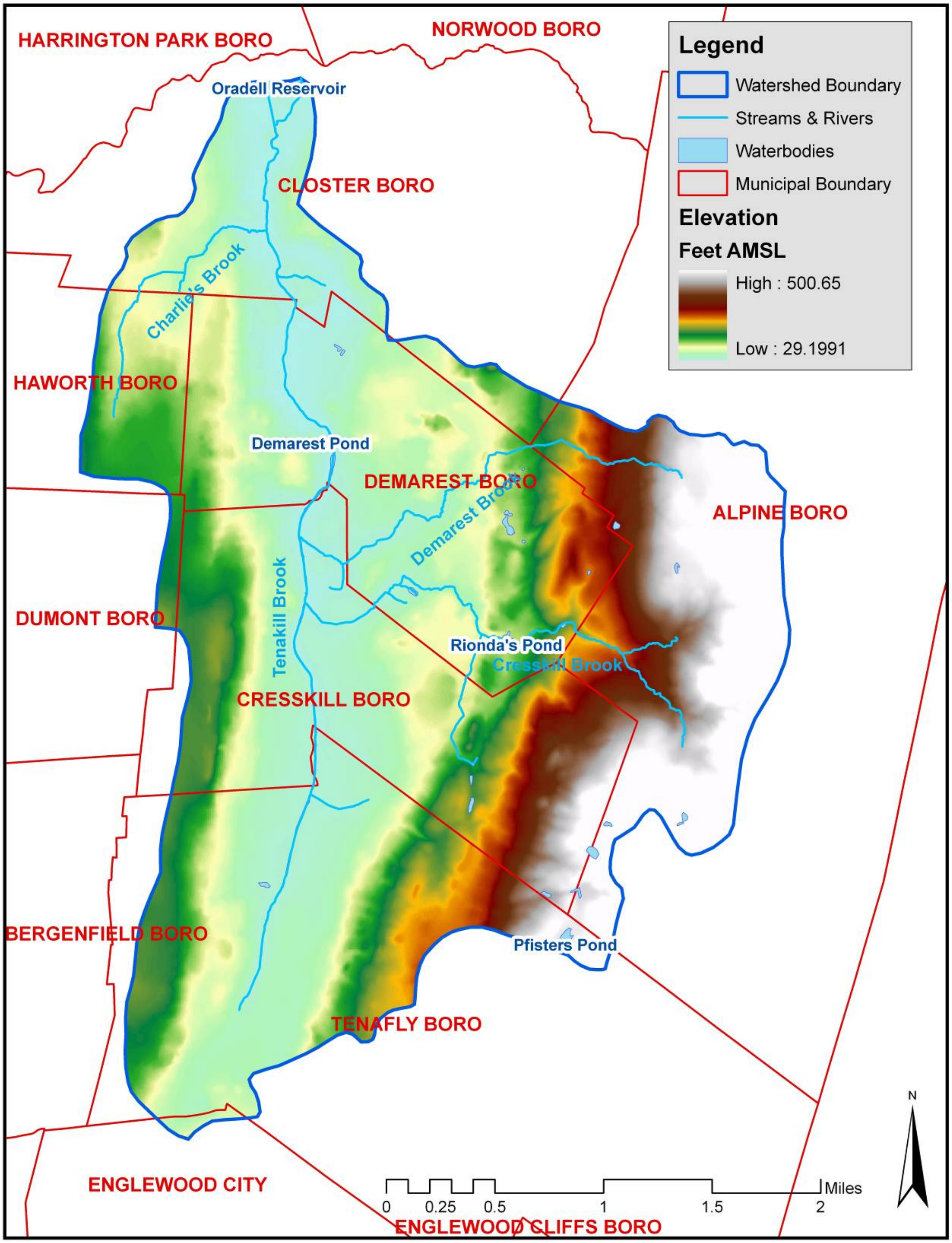


Figure 4: Topography of the Tenakill Brook Watershed.

2. Streams and Groundwater

The NJDEP classifies waters within the state to properly manage their uses and quality. Water quality criteria are developed according to a waterbody's designated uses. Almost all waters within the Tenakill Brook Watershed are classified as FW2-NT/C1, except the upstream half of Cresskill Brook, which is classified as FW2-TP/C1 (Figure 5). FW2-NT/C1 waters are freshwater (FW) systems that are not used for either the production or maintenance of trout populations (NT), but the Category One (C1) status protects the water from "measureable or calculable changes in water quality" based upon its significance for water supply, recreation, fisheries sustainability, or ecologically (NJDEP, 2011b). FW2-TP/C1 waters have the same protection from "measureable or calculable changes" in water quality but the water is also considered suitable for trout production (TP).

FW2 refers to waterbodies that are used for primary and secondary contact recreation; industrial and agricultural water supply; maintenance, migration, and propagation of natural and established biota; public potable water supply after conventional filtration treatment and disinfection; and any other reasonable uses. NT waters are not suitable for trout due to physical, chemical, or biological characteristics, but NT waters can support other fish species (NJDEP, 2011b). Furthermore, the Tenakill Brook is a C1 antidegradation waterbody due to its discharge to the Oradell Reservoir, which is a potable water supply.

There were six New Jersey Pollution Discharge Elimination System (NJPDES) permits allowing discharges in the project watershed (Figure 6). Five of the six permits have been revoked or terminated as the discharge pipe is no longer there (Figure 6). Revoked dischargers no longer possess a valid NJPDES permit, for consolidated permits this means all discharge categories have ceased and the submission of Monitoring Report Forms is no longer required. The last existing permit belongs to the Penetone Corporation (NJPDES Permit No. NJ0109878.001A), a cleaning product manufacturer (Figure 6). This discharger releases water to the Tenakill Brook via an outfall 100 feet away from the treatment building. This permit is to discharge water used for general remediation clean-up. The permit requires monitoring and reporting for flow, petroleum hydrocarbons, total organic carbon, pH, total iron, chloroethane, 1,1-dichloroethane, 1,1-dichloroethylene, 1,1,1-tricholorethane, tetrachloroethylene and chronic whole effluent toxicity. A review of the USEPA Permit Compliance System (http://www.epa.gov/enviro/facts/pcs-icis/search.html) indicated that the Penetone Corporation

(NJPDES Permit No. NJ0109878.001A) has been in compliance for all required monitoring parameters. There are no permitted discharges to groundwater in the Tenakill Brook Watershed.

The Ambient Ground-Water Quality Monitoring Network (AGWQMN) is an NJDEP and U.S. Geological Survey (USGS) cooperative project. The goals of the AGWQMN are to determine the status and trends of shallow groundwater quality as a function of land use related nonpoint source pollution in New Jersey. This network consists of 150 wells and is managed by the New Jersey Geological Survey (NJGS). Chemical and physical parameters analyzed at each well include: field parameters such as pH, specific conductance, dissolved oxygen, water temperature and alkalinity; major ions, trace elements (metals), gross-alpha particle activity (radionuclides), volatile organic compounds, nutrients, and pesticides. One groundwater monitoring well is located within the Tenakill Brook Watershed (Figure 6). Additional investigations into groundwater and drinking water quality in the Tenakill Brook Watershed are in order, but are beyond the scope of work outlined for this planning effort.

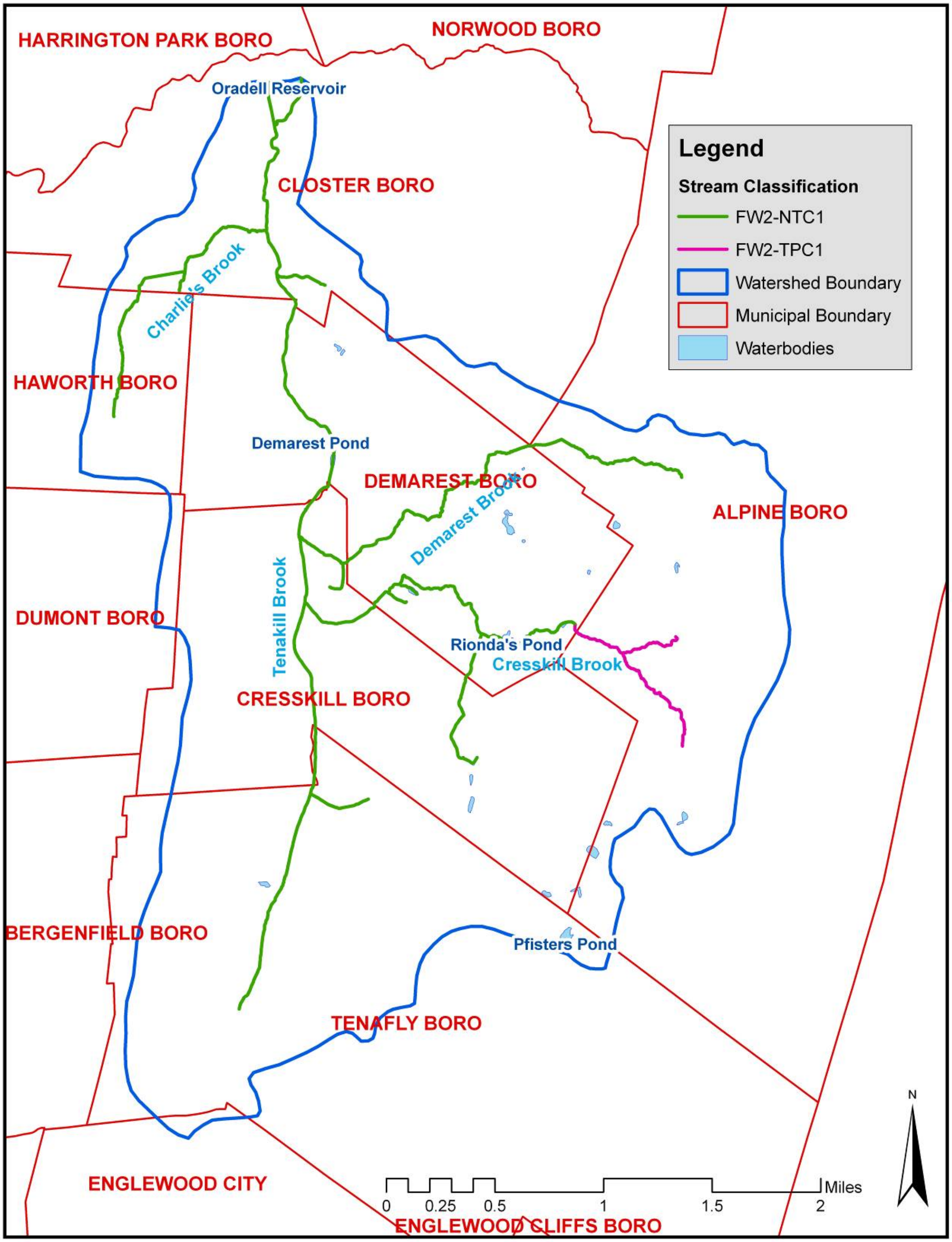


Figure 5: NJDEP stream classification for the Tenakill Brook Watershed.

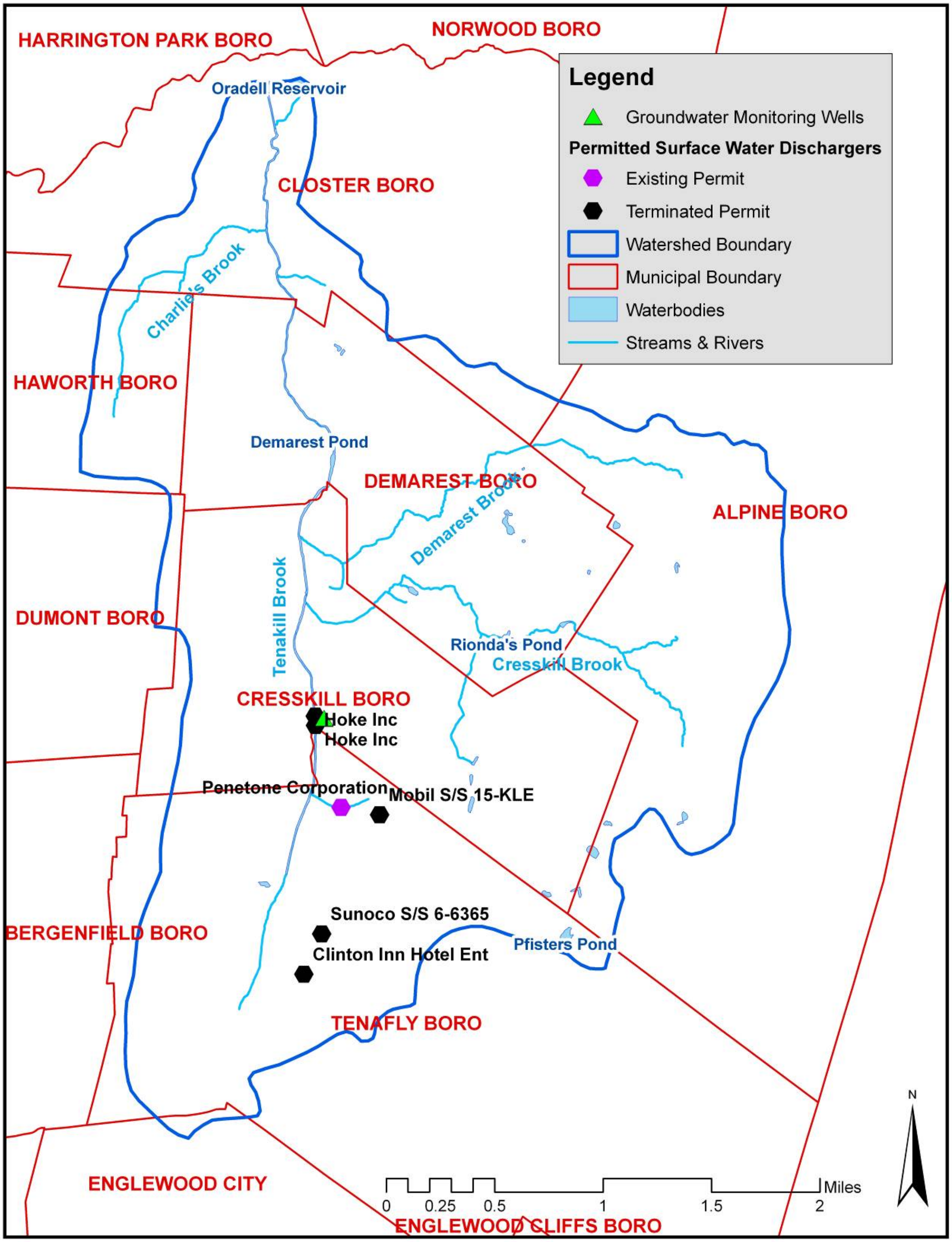


Figure 6: Surface water dischargers and groundwater monitoring wells in the Tenakill Brook Watershed.

3. Critical Source Areas

a) Wetlands

Wetlands are dynamic ecosystems that are characterized by factors that affect their structure and function. The United States Army Corps of Engineers (USACOE) defines wetlands as "areas inundated or saturated by surface water or groundwater at a frequency and duration sufficient to support, and that under normal circumstances do support, a prevalence of vegetation typically adapted for life in saturated soil conditions (USACOE, 1987)." The National Research Council (1995) defines a wetland as an "ecosystem that depends on constant or recurrent, shallow inundation or saturation at or near the surface of the substrate. The minimum essential characteristics of a wetland are recurrent, sustained inundation or saturation at or near the surface and the presence of physical, chemical and biological features reflective of recurrent, sustained inundation or saturation." Hydrology plays a critical role in wetland development and ecosystem structure and function. Wetland functions include the ability to provide critical habitat for many species of plants and animals, flood control through storage and retention of floodwaters, water quality protection, trap anthropogenic contaminants and recreational opportunities for surrounding residents (Ehrenfeld *et al.*, 2003). Wetland functions can be impaired, however, if the surrounding watershed is highly urbanized (Ehrenfeld, 2000).

The NJDEP Land Use Regulation Program primarily regulates wetlands in New Jersey. The NJDEP has adopted the federal wetlands program, and thus is the lead regulating agency. USACOE and NJDEP both have jurisdiction over tidal wetlands, navigable waters and wetlands located within a 1,000 feet of navigable waterways. The NJDEP developed and maintains two types of wetlands information for general planning and regulatory purposes. The first is the delineated wetlands in the NJDEP land use/cover change databases. The second is the linear wetlands database derived from the freshwater wetlands data generated under the New Jersey Freshwater Wetlands Mapping Program (Figure 7). The Tenakill Brook Watershed contains approximately 10.0 miles of linear wetlands and 193 acres of delineated wetlands (Figure 7). Approximately 80% of delineated wetlands are categorized as deciduous wooded wetlands (Figure 7).

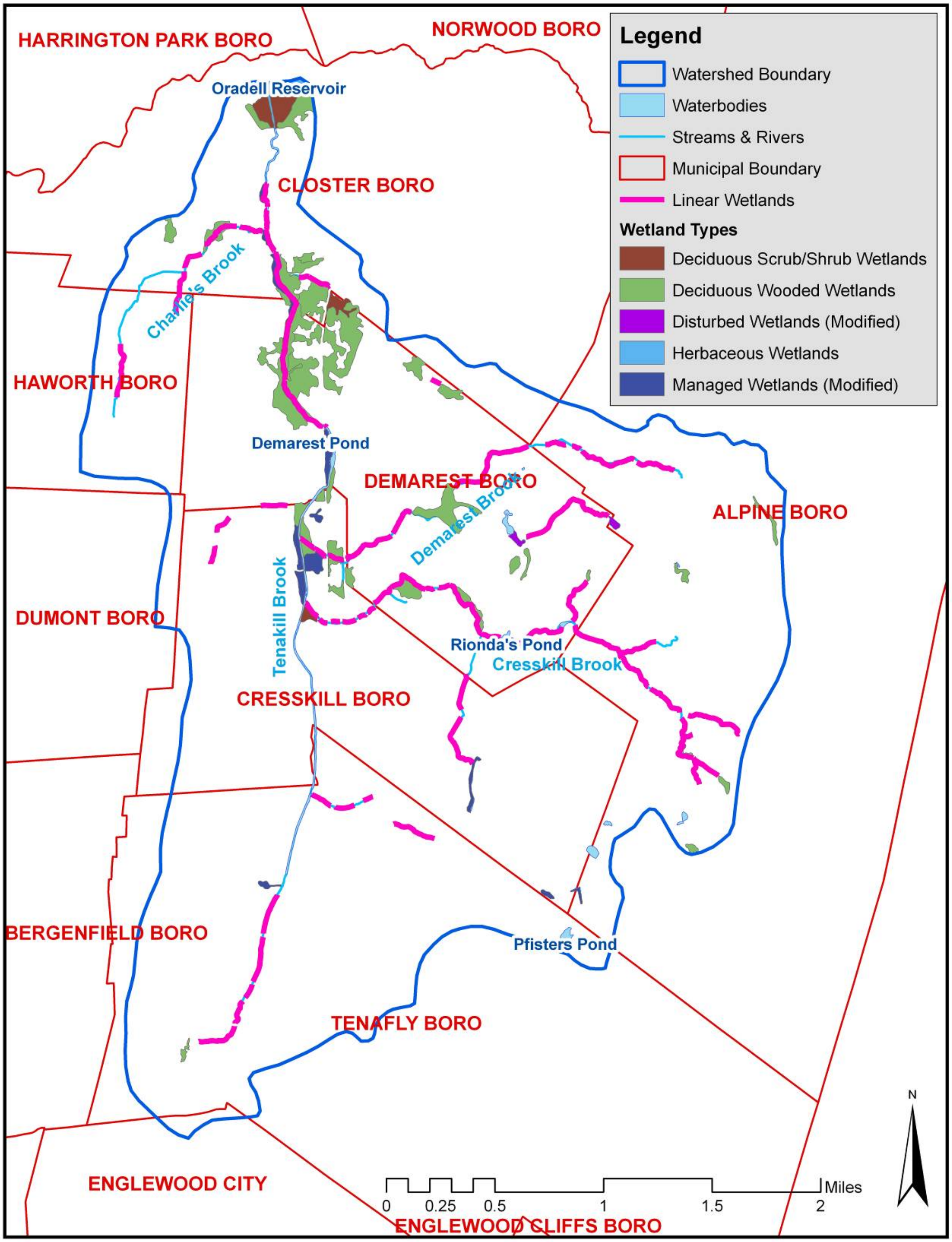


Figure 7: Wetlands within the Tenakill Brook Watershed

b) Riparian Areas

The New Jersey Water Supply Authority (NJWSA) defines riparian areas as undeveloped areas adjacent to streams that are either within the 100-year floodplain, contain hydric soils, contain streamside wetlands and associated transition areas, or are within a 150-foot or 300-foot wildlife passage corridor on both sides of a stream or other waterbody (NJWSA, 2002). Riparian zones are important natural filters of stormwater runoff, protecting aquatic environments from excessive sedimentation, pollutants, and erosion. They supply shelter and food for many aquatic animals and also provide shade, an important part of stream temperature regulation. Disturbances, such as development within the riparian zone or invasive species encroachment, can impact the functions of healthy riparian areas.

The extent of riparian areas within the Tenakill Brook Watershed is depicted in Figure 8. As the waters within the Tenakill Brook Watershed are designated C1, development is restricted within a 300-foot buffer adjacent to streams and rivers. Riparian zones are instrumental in water quality improvement for both surface runoff and water flowing into streams through subsurface or groundwater flow. A decrease in riparian areas in the Tenakill Brook Watershed due to urbanization may contribute to poor surface water quality conditions and increased streambank erosion.

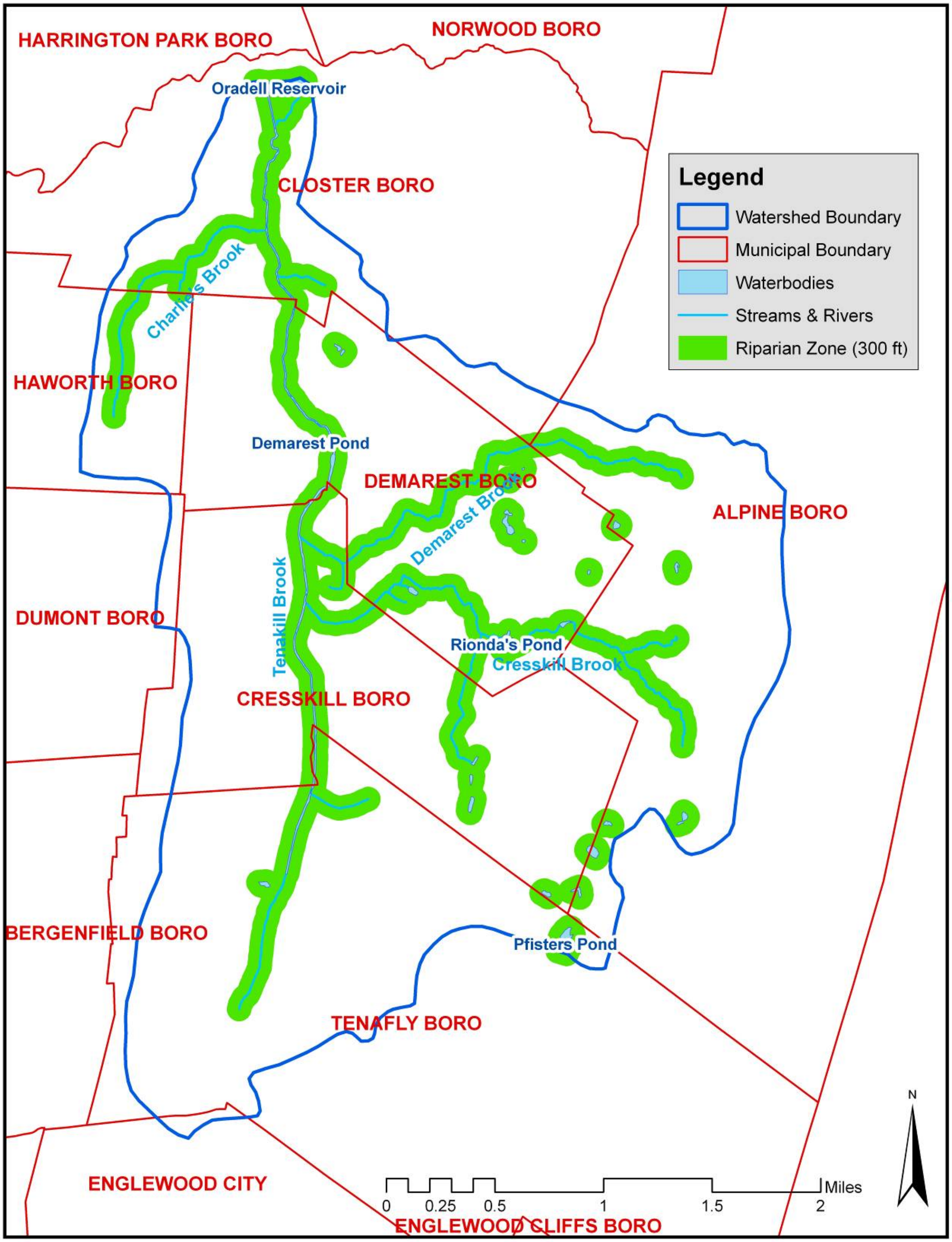


Figure 8: Riparian areas extending out 300 feet from waterbodies within the Tenakill Brook Watershed.

V. Causes and Sources of Pollution

This report contains summaries and analyses of water quality data, stream assessments, and macroinvertebrate sampling conducted in the Tenakill Brook Watershed. For a complete description of sampling programs and methods, see the *Tenakill Brook Watershed Restoration and Protection Plan: Data Report* (RCE Water Resources Program, 2011).

A. Hydrologic Alteration

The loss of natural lands, including wetlands and riparian areas, to development has resulted in significant hydrological alterations in the Tenakill Brook Watershed. Urbanization alters watersheds by clearing vegetation, changing land uses, and fragmenting the landscape with development. The resulting altered hydrology affects runoff quantity and water quality at the watershed outlet (Ehrenfeld, 2000). Shaw (1994) identified five major effects on hydrology due to urbanization: 1) a higher percentage of precipitation is converted to surface runoff; 2) precipitation is converted to runoff at a faster rate; 3) peak flows in streams are elevated; 4) low flow in streams is decreased due to reduced inputs from groundwater storage; and 5) stream water quality is degraded. These effects are echoed by Ehrenfeld (2000) as likely to occur in wetlands, with direct hydrological changes in wetlands commonly occurring by filling, ditching, diking, draining, and damming.

Increasing impervious surfaces associated with urbanization account for many of the alterations to watershed hydrology. Urbanization converts natural habitats to land uses with impervious surfaces (such as asphalt and concrete) that reduce or prevent soil infiltration of precipitation. Impervious surfaces create surface runoff with greater velocities, larger volumes, and shorter times to flow concentration (Brun and Band, 2000). Increased impervious surfaces contribute to decreased groundwater recharge by reducing available groundwater recharge area (Rose and Peters, 2001). The rapid routing of water to urban streams reduces surface and shallow subsurface storage, which results in lower long-term groundwater recharge, and subsequently, reduced groundwater discharge during the period of baseflow (Rose and Peters, 2001). Reductions in baseflow can: 1) cause a decline in water quality as pollutants become more concentrated; 2) degrade riparian habitats as water levels decrease; and 3) interfere with navigable waterways (Brun and Band, 2000). Large amounts of impervious surfaces have negative impacts by increasing the amount of water and associated contaminants and sediments that flow through the watershed. This runoff, when managed improperly, is a major pathway for the transportation of pollutants such as debris, fertilizer, bacteria, and/or petroleum products. These pollutants are washed directly into the Tenakill Brook and its tributaries, ultimately degrading the surface water quality and necessitating the development of the established TMDLs. Stormwater runoff also causes recurrent flooding problems in many municipalities in northeastern New Jersey, the destruction of habitat along the streambank, and may contribute to manhole discharges.

B. Surface Water Quality

1. Designated Uses and Impairments

To evaluate the health of the Tenakill Brook at the RCE monitoring stations, the monitoring results were compared to the designated water quality criteria. Water quality criteria are developed according to a waterbody's designated uses. As mentioned previously, the Tenakill Brook is classified as FW2-NT, or freshwater (FW) non trout (NT). FW2 refers to waterbodies that are used for primary and secondary contact recreation; industrial and agricultural water supply; maintenance, migration, and propagation of natural and established biota; public potable water supply after conventional filtration treatment and disinfection; and any other reasonable uses. NT describes those freshwaters that have not been designated as trout production or trout maintenance. NT waters are not suitable for trout due to physical, chemical, or biological characteristics, but NT waters can support other fish species (NJDEP, 2011b). Furthermore, the Tenakill Brook is a C1 antidegradation waterbody due to its discharge to the Oradell Reservoir, which is a potable water supply. The applicable water quality criteria for this project are detailed in Table 1. As per the NJDEP water quality criteria, the phosphorus standard is different for streams (0.1 mg/L) than in lakes (0.05 mg/L) (Table 1). The lake standard also applies to the tributary discharging to a lake at the point where it enters such bodies of water. Therefore, TB1 (Table 2; Figure 9) is being held to the more stringent standard since this point represents the location where the Tenakill Brook enters the Oradell Reservoir (Table 1).

Table 1: Water quality criteria according to N.J.A.C. 7:9B (NJDEP, 2011b).

Substance	Surface Water Classification	Criteria
pH (S.U.)	FW2	6.5 - 8.5
TP (mg/L)	FW2 Streams	Except as necessary to satisfy the more stringent criteria in accordance with "Lakes" (above) or where watershed or site-specific criteria are developed pursuant to N.J.A.C. 7:9B-1.5(g)3, phosphorus as total P shall not exceed 0.1 in any stream, unless it can be demonstrated that total P is not a limiting nutrient and will not otherwise render the waters unsuitable for the designated uses.
	FW2 Lakes	Phosphorus as total P shall not exceed 0.05 in any lake, pond, or reservoir, or in a tributary at the point where it enters such bodies of water, except where watershed or site-specific criteria are developed pursuant to N.J.A.C. 7:9B-1.5(g)3.
Suspended Solids (mg/L)	FW2-NT	Non-filterable residue/suspended solids shall not exceed 40.
Bacterial Quality (counts/100 mL): Fecal Coliform – former criterion for Bacterial Quality	FW2	Shall not exceed geometric average of 200/100 mL, nor should more than 10% of the total samples taken during any 30-day period exceed 400/100 mL.
Bacterial Quality (counts/100 mL): *E. coli*	FW2	Shall not exceed a geometric mean of 126/100 mL or a single sample maximum of 235/100 mL.

According to the 2006 *Integrated List of Waterbodies* (NJDEP, 2006), the Tenakill Brook at Cedar Lane was listed (according to surface water use) on Sublist 5 for aquatic life impairments and drinking water supply; Sublist 4a for primary and secondary contact recreation; Sublist 3 for fish consumption; and Sublist 2 for agricultural and industrial water supply. Fecal coliform impairment has been addressed through the New Jersey TMDL process; therefore, this parameter has been moved to Sublist 4a. A 96% reduction in fecal coliform loading to the

Tenakill Brook is needed to achieve water quality criteria (NJDEP, 2003). The TMDL was developed based on summer monitoring results from 2001 and 2002.

Data collected on the Tenakill Brook at the USGS monitoring station for the 2006 Integrated List was insufficient to declare the impairment status of total phosphorus (TP). Additional data were collected as part of this study to further examine the possibility of a TP impairment. These data will be discussed later in this report.

2. Monitoring Stations

Surface water samples from six water quality monitoring stations were regularly collected over the six-month sampling time frame (Table 2; Figure 9). Three stations were located on the mainstem Tenakill Brook, and three stations were located on tributaries to the Tenakill Brook. Beginning on July 17, 2007, an additional station was monitored. This adaptive monitoring station was added to the water quality testing to aid the pathogen source track down process. This station is identified as TB6 (Table 2; Figure 9).

Table 2: Water quality monitoring locations and descriptions.

Site ID	Site Description/Location	Longitude	Latitude
TB1	Tenakill Brook at USGS 01378387 at Cedar Lane, Closter (also AN0209)	-73°58'2.48"	40°58'42.93"
TB2	Tenakill Brook at Wakelee Field, Wakelee Drive, Demarest	-73°57'48.16"	40°57'31.84"
DB1	Demarest Brook at Maple Avenue, Demarest	-73°57'29.21"	40°57'3.83"
CB1	Cresskill Brook at Morningside Avenue, Cresskill	-73°57'37.37"	40°56'45.64"
TB3	Unnamed Tributary to the Tenakill Brook at Grove Street, Tenafly	-73°57'46.59"	40°56'0.16"
TB4	Tenakill Brook at Tenafly Road, Tenafly	-73°58'0.59"	40°55'42.81"
TB6	Unnamed Tributary to the Tenakill Brook below Roosevelt Commons Pond, Riveredge Road, Tenafly	-73°58'39.39"	40°55'40.82"

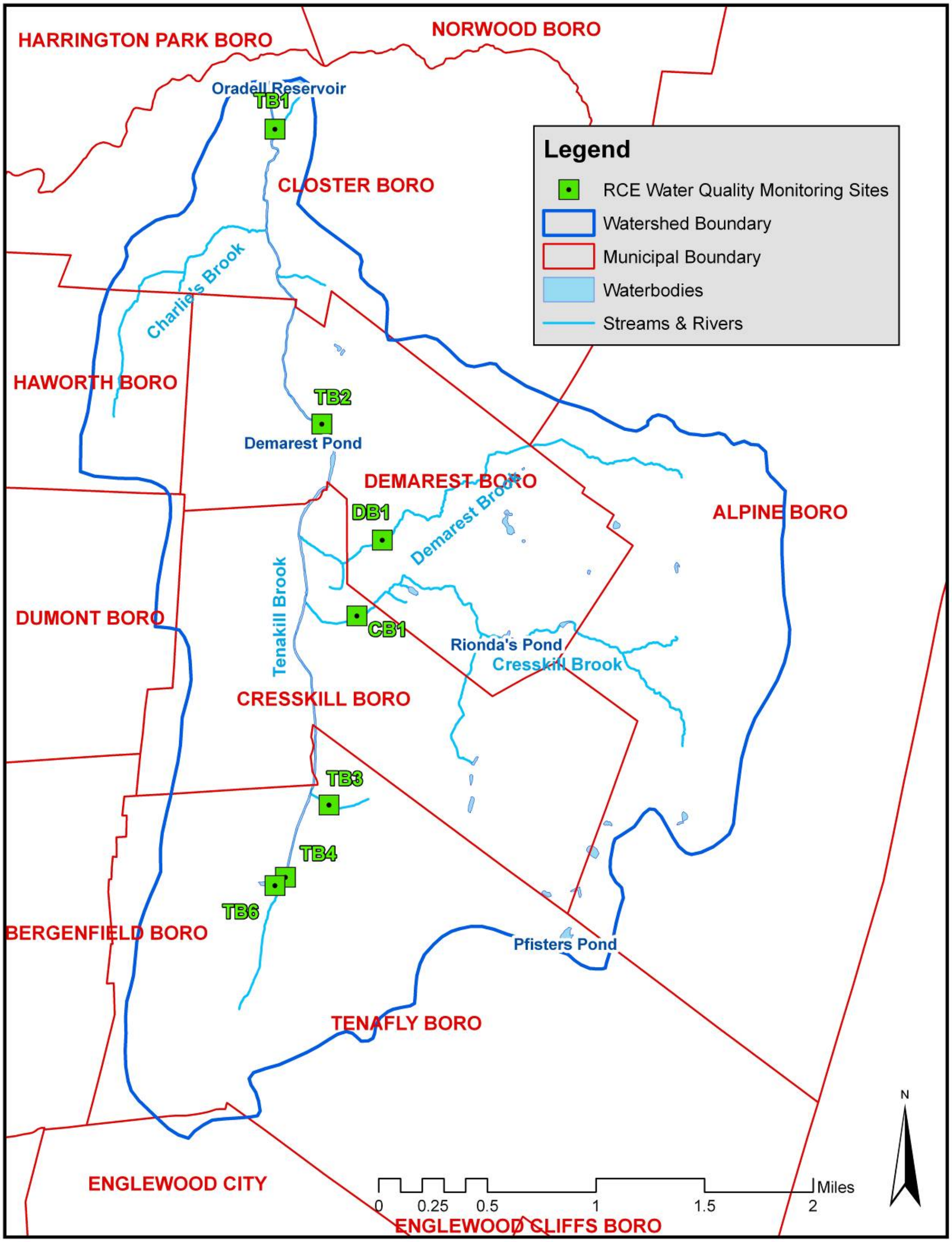


Figure 9: Surface water quality sampling locations in Tenakill Brook Watershed.

3. Monitoring Events

Project partners, including NJDEP, the RCE Water Resources Program, and the Bergen County Department of Health Services, began water quality monitoring on May 22, 2007. As per the NJDEP-approved Quality Assurance Project Plan (QAPP), *in situ* measurements of pH, dissolved oxygen (DO), and temperature were collected. Stream velocity and depth were measured across transects at each sampling station. Using this information, flow (Q) was calculated for each event where access to the stream was deemed safe. Surface water quality samples were collected and analyzed by two separate laboratories. The Bergen County Utilities Authority conducted analyses for TP, dissolved orthophosphate phosphorus, ammonia-nitrogen, Total Kjeldahl Nitrogen (TKN), nitrate-nitrogen, nitrite-nitrogen, total suspended solids (TSS), and fecal coliform. Garden State Laboratories conducted analyses for *Escherichia coli* (*E. coli*).

Water quality monitoring included two different types of sampling events, regular and bacteria only. Regular monitoring, which included analysis for all parameters, occurred from May 22, 2007 through October 24, 2007. During these events, samples were collected and then analyzed for TP, dissolved orthophosphate phosphorus, ammonia-nitrogen, TKN, nitrate-nitrogen, nitrite-nitrogen, TSS, fecal coliform, and *E. coli* and had no specific weather conditions directing the sample collection. Bacteria-only monitoring was conducted in the summer months of June, July, and August 2007, again without conditions set by the weather. The bacteria-only sampling entailed collecting three additional samples in each of those months. Flow was measured and *in situ* samples were collected during these events. Dates and types of monitoring events are given in Table 3.

To more accurately determine which monitoring events were collected under wet conditions when the stream velocities exceeded baseflow conditions, the HYSEP model equations were used. HYSEP is a computer-simulation program developed by the USGS to split the hydrograph to separate baseflow from storm-flow conditions (Sloto and Crouse, 1996). Normally, the equations in this model would be applied to a daily discharge monitoring station within the watershed; however, daily discharge is not recorded by the USGS in the Tenakill Brook Watershed. Instead, USGS monitoring station 01377500, Pascack Brook at Westwood, which is 1.8 miles from the USGS station on the Tenakill Brook, was chosen. This surface water body also discharges to the Oradell Reservoir, and the drainage areas share many similarities. The equations were generated to determine baseflow and storm-related flow for the Pascack

Brook from January 1, 2006 through March 31, 2008. A 10% error bar was also applied to the baseflow since these data were collected in a watershed other than the Tenakill Brook. When flow was more than 10% greater than baseflow and rain occurred on the day of or the day preceding sampling, the event was considered as storm-related flow and assigned the term "wet" in Table 3.

Table 3: Water quality monitoring events.

Date	Weather	Regular Monitoring for all Parameters	Bacteria Only Monitoring
5/22/2007	Dry	X	
5/29/2007	Dry	X	
6/5/2007	Wet	X	
6/12/2007	Dry		X
6/19/2007	Dry	X	
6/26/2007	Dry		X
6/27/2007	Wet		X
7/3/2007	Dry	X	
7/10/2007	Dry		X
7/17/2007	Dry	X	
7/24/2007	Wet		X
7/31/2007	Dry		X
8/7/2007	Dry	X	
8/14/2007	Dry		X
8/16/2007	Dry		X
8/21/2007	Wet	X	
8/28/2007	Dry		X
9/11/2007	Wet	X	
9/25/2007	Dry	X	
10/9/2007	Wet	X	
10/24/2007	Dry	X	

Storm event samples were originally planned to be collected as part of this effort. Due to uncooperative weather patterns during the six months of monitoring, no storm samples were collected that would meet the requirements of the state-approved QAPP overseeing this monitoring task. Fortunately, samples were collected under both dry and wet conditions in the watershed, which will improve the understanding of the impact of stormwater on pollutant concentrations.

4. Summary of Water Quality Data

Monitoring results were compared to the designated water quality criteria as a means to determine surface water quality within the Tenakill Brook Watershed. The NJDEP's *Integrated Water Quality Monitoring and Assessment Methods* advises that if the frequency of water quality results exceeds the water quality criteria twice within a five-year period, then the waterway's quality may be compromised (NJDEP, 2004a). The NJDEP has further stated that a minimum of eight samples collected quarterly over a two-year period are required to confirm the quality of waters (NJDEP, 2004a). Therefore, if a waterbody has a minimum of eight samples collected quarterly over a two-year period and samples exceed the water quality criteria for a certain parameter twice, the waterbody is considered "impaired" for that parameter. By applying this rule to the Tenakill Brook Watershed water quality data, it is possible to identify which stations are impaired for each parameter that has been identified as a concern for this project (i.e., pH, TP, *E. coli* and fecal coliform). The number of samples exceeding these standards is given in Table 4. Due to low pH values recorded in the field, pH has also been identified as a potential water quality concern in some regions of the watershed. At the time of this project's initiation, fecal coliform was the accepted measure indicating pathogen pollution for New Jersey freshwaters. Since then, the fecal coliform standard has been replaced by the count of *E. coli* bacteria. Since the TMDL established by the State of New Jersey refers to fecal coliform, both fecal coliform and *E. coli* were measured.

Table 4: Number of samples that exceed water quality criteria for the Tenakill Brook Watershed.

Station	Selected Monitoring Parameters			
	TP	**Fecal coliform***	***E. coli*****	**pH**
TB1	12 out of 12	19 out of 20	20 out of 20	1 out of 19
TB2	6 out of 12	17 out of 19	20 out of 20	4 out of 19
DB1	2 out of 12	19 out of 20	19 out of 20	1 out of 19
CB1	2 out of 12	17 out of 20	19 out of 20	1 out of 19
TB3	4 out of 12	20 out of 20	20 out of 20	3 out of 19
TB4	2 out of 12	20 out of 20	20 out of 20	3 out of 19
TB6	n/a	10 out of 10	7 out of 7	1 out of 10

**Number of samples higher than 400 counts/100ml*
*** Number of samples higher than 235 counts/100ml*

C. Biological Monitoring Data

Biological monitoring data is available for the Tenakill Brook Watershed as part of the Ambient Biological Monitoring Network (AMNET), which is administered by the New Jersey Department of Environmental Protection (NJDEP). The NJDEP has been monitoring the biological communities of the State's waterways since the early 1970's, specifically the benthic macroinvertebrate communities. Benthic macroinvertebrates are primarily bottom-dwelling (benthic) organisms that are generally ubiquitous in freshwater and are macroscopic. Due to their important role in the food web, macroinvertebrate communities reflect current perturbations in the environment. There are several advantages to using macroinvertebrates to gauge the health of a stream. Macroinvertebrates have limited mobility, and thus, are good indicators of site-specific water conditions. Macroinvertebrates are sensitive to pollution, both point and nonpoint sources; they can be impacted by short-term environmental impacts such as intermittent discharges and contaminated spills. In addition to indicating chemical impacts to stream quality, macroinvertebrates can gauge non-chemical issues of a stream such as turbidity and siltation, eutrophication, and thermal stresses. Macroinvertebrate communities are a holistic overall indicator of water quality health, which is consistent with the goals of the Clean Water Act (NJDEP, 2007). Finally, these organisms are normally abundant in New Jersey freshwaters and are relatively inexpensive to sample.

1. New Jersey Impairment Score (NJIS)

The AMNET program began in 1992 and is currently comprised of more than 800 stream sites with approximately 200 monitoring locations in each of the five major drainage basins of New Jersey (i.e., Upper and Lower Delaware, Northeast, Raritan, and Atlantic). These sites are sampled once every five years using a modified version of the USEPA Rapid Bioassessment Protocol (RBP) II (NJDEP, 2007). To evaluate the biological condition of the sampling locations, several community measures have been calculated by the NJDEP from the data collected and include the following:

1. Taxa Richness: Taxa richness is a measure of the total number of benthic macroinvertebrate families identified. A reduction in taxa richness typically indicates the presence of organic enrichment, toxics, sedimentation, or other factors.
2. EPT (Ephemeroptera, Plecoptera, Trichoptera) Index: The EPT Index is a measure of the total number of Ephemeroptera, Plecoptera, and Trichoptera families (i.e., mayflies,

stoneflies, and caddisflies) in a sample. These organisms typically require clear moving water habitats.

3. % EPT: Percent EPT measures the numeric abundance of the mayflies, stoneflies, and caddisflies within a sample. A high percentage of EPT taxa is associated with good water quality.
4. % CDF (percent contribution of the dominant family): Percent CDF measures the relative balance within the benthic macroinvertebrate community. A healthy community is characterized by a diverse number of taxa that have abundances somewhat proportional to each other.
5. Family Biotic Index: The Family Biotic Index measures the relative tolerances of benthic macroinvertebrates to organic enrichment based on tolerance scores assigned to families ranging from 0 (intolerant) to 10 (tolerant).

This analysis integrates several community parameters into one easily comprehended evaluation of biological integrity referred to as the New Jersey Impairment Score (NJIS). The NJIS was established for three categories of water quality bioassessment for New Jersey streams: non-impaired, moderately impaired, and severely impaired. A non-impaired site has a benthic community comparable to other high quality “reference” streams within the region. The community is characterized by maximum taxa richness, balanced taxa groups, and a good representation of intolerant individuals. A moderately impaired site is characterized by reduced macroinvertebrate taxa richness, in particular the EPT taxa. Changes in taxa composition result in reduced community balance and intolerant taxa become absent. A severely impaired site is one in which the benthic community is significantly different from that of the reference streams. The macroinvertebrates are dominated by a few taxa which are often very abundant. Tolerant taxa are typically the only taxa present. The scoring criteria used by the NJDEP are as follows:

- non-impaired sites have total scores ranging from 24 to 30,
- moderately impaired sites have total scores ranging from 9 to 21, and
- severely impaired sites have total scores ranging from 0 to 6.

It is important to note that the entire scoring system is based on comparisons with reference streams and a historical database consisting of 200 benthic macroinvertebrate samples collected from New Jersey streams. While a low score indicates “impairment,” the score may actually be a consequence of habitat or other natural differences between the subject stream and the reference stream.

Starting with the second round of sampling under the AMNET program in 1998 for the Northeast Basin, habitat assessments were conducted in conjunction with the biological assessments. The first round of sampling under the AMNET program did not include habitat assessments. The habitat assessment, which was designed to provide a measure of habitat quality, involves a visually based technique for assessing stream habitat structure. The habitat assessment is designed to provide an estimate of habitat quality based upon qualitative estimates of selected habitat attributes. The assessment involves the numerical scoring of ten habitat parameters to evaluate instream substrate, channel morphology, bank structural features, and riparian vegetation. Each parameter is scored and summed to produce a total score which is assigned a habitat quality category of optimal, suboptimal, marginal, or poor. Sites with optimal/excellent habitat conditions have total scores ranging from 160 to 200; sites with suboptimal/good habitat conditions have total scores ranging from 110 to 159; sites with marginal/fair habitat conditions have total scores ranging from 60 to 109, and sites with poor habitat conditions have total scores less than 60. The findings from the habitat assessment are used to interpret survey results and identify obvious constraints on the attainable biological potential within the study area.

The NJDEP Bureau of Freshwater & Biological Monitoring maintains one AMNET station within the project area (i.e., Station AN0209 – Tenakill Brook, Cedar Lane, Closter Borough, Bergen County; Figure 10). This station corresponds with the water quality monitoring station TB1 (Figure 10). Station AN0209 was sampled by NJDEP in 1993 (Round 1), 1998 (Round 2), and 2003 (Round 3) under the AMNET program. Findings from the AMNET program are summarized in Table 5. The biological condition over the years has been assessed as being severely to moderately impaired, and the habitat has been assessed as suboptimal within the Tenakill Brook Watershed.

Table 5: Summary of NJDEP Ambient Biological Monitoring Network results (NJDEP, 1994; NJDEP, 2000; NJDEP, 2008).

Station	Date	Biological Condition (Score)	Habitat Assessment (Score)
AN0209	7/6/1993	Severely Impaired (6)	~
AN0209	7/9/1998	Severely Impaired (6)	Suboptimal (121)
AN0209	7/1/2003	Moderately Impaired (12)	Suboptimal (111)

Given these aquatic life impairments, an additional biological assessment was conducted as part of the data collection needed to prepare a comprehensive watershed restoration and protection plan for the Tenakill Brook Watershed. A biological assessment was conducted by Marion McClary, Jr., Ph.D., Associate Director of Biological Sciences at Fairleigh Dickinson University and project partner, in the late summer of 2007 at CB1 (Cresskill Brook at Morningside Avenue, Cresskill), DB1 (Demarest Brook at Maple Avenue, Demarest), TB1 (AMNET Station AN0209 - Tenakill Brook at Cedar Lane, Closter), and at TB4 (Tenakill Brook at Tenafly Road, Tenafly) (Figure 10). The 2007 biological assessment conducted by Dr. McClary is summarized in the *Tenakill Brook Watershed Restoration and Protection Plan: Data Report* (RCE Water Resources Program, 2011). The 2007 assessment revealed that the biological condition within the Tenakill Brook Watershed is severely impaired. Marginal/suboptimal habitat conditions were found at the Demarest Brook site; suboptimal habitat conditions were found at the two Tenakill Brook sites, and optimal habitat conditions were found at the Cresskill Brook site.

Unfortunately, there was such a paucity of benthic organisms found that less than 100 specimens were collected from the four sampling locations combined, prohibiting the calculation of the various metrics needed for the NJIS score.

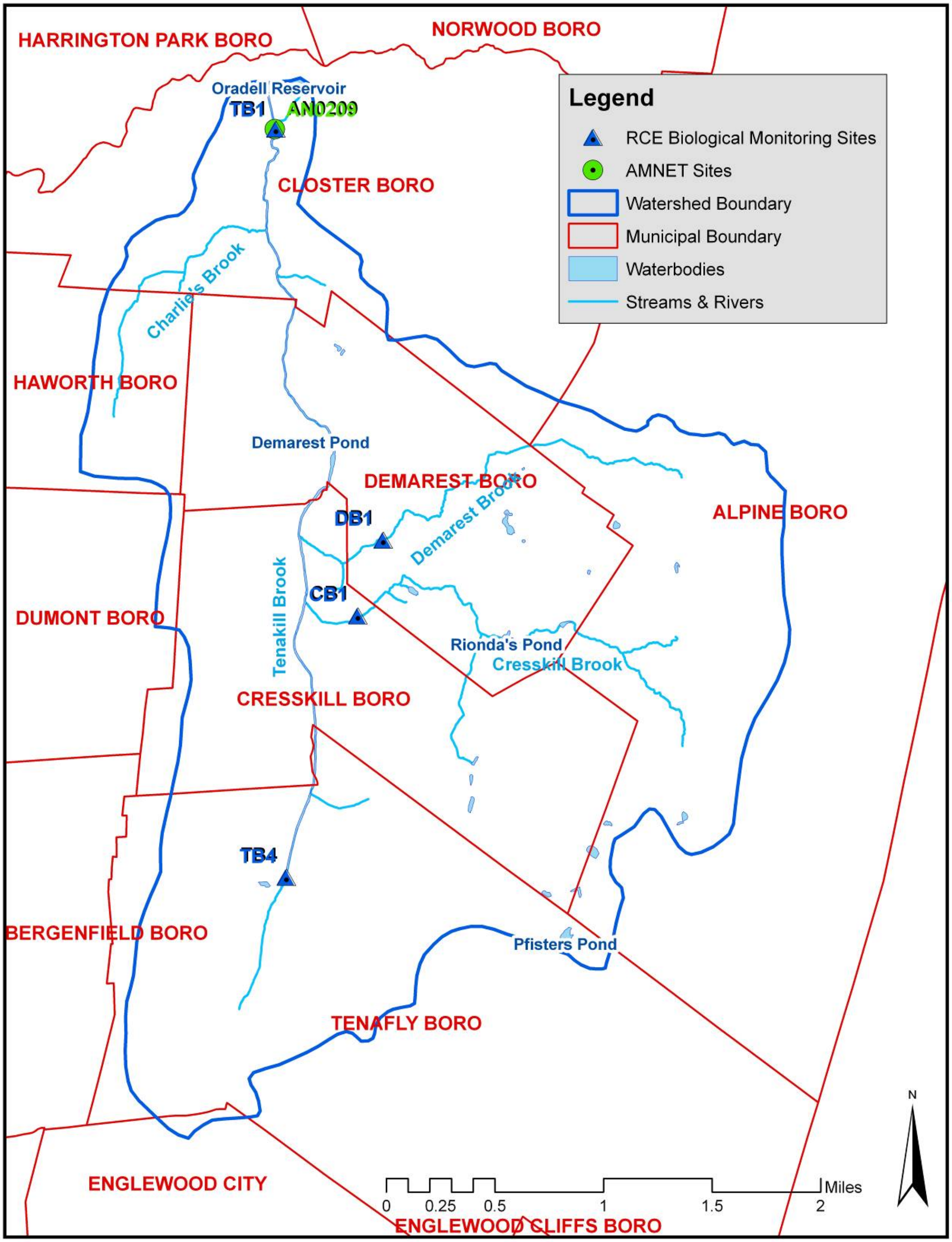


Figure 10: NJDEP and RCE Water Resources Program biological monitoring sites in the Tenakill Brook Watershed.

2. High Gradient Macroinvertebrate Index (HGMI)

New Jersey's benthic macroinvertebrate communities can be grouped into three distinct categories based on geographical regions: high gradient (above the Fall Line), low gradient (Coastal Plain excluding the Pinelands), and Pinelands. A multimetric index has been developed, using genus level taxonomic identifications, for each distinct region. The NJIS described and presented above is a single index used statewide that is based on family level taxonomic identifications. The NJDEP, in 2009, began using the multimetric indices for each distinct region. The index appropriate to use within the Tenakill Brook Watershed is the High Gradient Macroinvertebrate Index (HGMI). The HGMI is comprised of the following metrics: total number of genera, percent genera that are not insects, percent sensitive EPT genera, number of scraper genera, Hilsenhoff Biotic Index, number of New Jersey TALU (tiered aquatic life use) attribute 2 genera, and number of New Jersey TALU attribute 3 genera. Excellent sites have total scores greater than or equal to 63 and are characterized as having minimal changes in the structure of biological community and having minimal changes in ecosystem function. Good sites have total scores ranging from 42-63 and are characterized as having some evident changes in the structure of the biological community and having minimal changes in ecosystem function. Fair sites have total scores ranging from 21-42 and are characterized as having moderate to major changes in the structure of the biological community and having moderate changes in ecosystem function. Poor sites have total scores of <21 and are characterized by extreme changes in the structure of the biological community and a major loss of ecosystem function.

HGMI scores for Station AN0209 (TB1) were reported as 13.29 for the July 2003 AMNET sampling (Round 3) and 36.05 for the 2008 AMNET sampling (Round 4) by NJDEP (NJDEP, 2009b; NJDEP, 2010). These scores correspond to a poor assessment and a fair assessment, respectively. Poor to fair assessments under the HGMI fall below the acceptable regulatory range, and a site assessed as poor or fair using the HGMI would be considered impaired from a Federal Clean Water Act perspective and not attaining the aquatic life use. Given the paucity of organisms collected, the HGMI could not be calculated from the data collected as part of the 2007 assessment conducted by Dr. McClary. Based on the calculation of the HGMI for Round 3 and Round 4 at AMNET Station AN0209 (TB1), an impaired biological condition has persisted since the 2007 assessment, and the aquatic life uses within the Tenakill Brook Watershed have not been attained.

3. Stressor Identification

Biological assessments have become an important tool for managing water quality to meet the goal of the Clean Water Act (i.e., to maintain the chemical, physical, and biological integrity of the nation's water). However, although biological assessments are a critical tool for detecting impairment, they do not identify the cause or causes of the impairment. The USEPA developed a process, known as the Stressor Identification (SI) process, to accurately identify any type of stressor or combination of stressors that might cause biological impairment (USEPA, 2000). The SI process involves the critical review of available information, the formation of possible stressor scenarios that may explain the observed impairment, the analysis of these possible scenarios, and the formation of conclusions about which stressor or combination of stressors are causing the impairment. The SI process is iterative, and in some cases additional data may be needed to identify the stressor(s). In addition, the SI process provides a structure or a method for assembling the scientific evidence needed to support any conclusions made about the stressor(s). When the cause of a biological impairment is identified, stakeholders are then in a better position to locate the source(s) of the stressor(s) and are better prepared to implement the appropriate management actions to improve the biological condition of the impaired waterway.

The benthic macroinvertebrate community occurring within the Tenakill Brook Watershed is apparently under some type of stress as evidenced by the extremely low numbers of organisms collected and by sensitive taxa (i.e., EPT taxa) being markedly diminished. Also, the types of organisms found within the study area are indicative of some organic pollution (Hilsenhoff, 1988). In addition, the habitat assessment revealed marginal to suboptimal habitat conditions at three of the four monitoring sites which may also account for the impaired condition of the community within the study area.

Candidate causes of impairment within the Tenakill Brook Watershed include:

1. Elevated nutrient levels (i.e., total phosphorus)
2. Elevated bacteria levels (i.e., fecal coliform and *E. coli*)
3. Degraded instream habitat
4. Altered hydrology
5. Toxicants

Analysis/Evaluation of Candidate Causes:

Elevated nutrient levels and elevated bacteria levels: The role of elevated nutrients and elevated bacteria levels in impairing the biological community was indicated by continual and persistent exceedances of the surface water quality criteria for phosphorus and bacteria throughout the watershed during the surface water quality monitoring portion of this study. Surface water quality samples were collected from stations within the Tenakill Brook Watershed over a six month sampling time frame from May 2007 through October 2007, demonstrating a co-occurrence of these candidate causes within the watershed. Approximately 87% of the designated land use within the watershed is urban and comprised of residential (medium and low density), commercial, industrial, and transportation land use/land cover types. Stormwater runoff from these land uses is a likely source of elevated nutrients. In addition, microbial source tracking (MST) was conducted within the watershed as part of this study. Human related *Bacteroides* were detected at several locations within the watershed. Aging/leaking/failing infrastructure may be a likely source of the elevated bacteria levels observed within the watershed.

Degraded habitat: The role of degraded habitat in impairing the biological community within the watershed was indicated by the assessed marginal to suboptimal habitat conditions within the watershed. Also, out of the 50 stream reaches evaluated using SVAP, 24 were rated as only fair and 26 were rated as poor. A likely source observed within the watershed for degraded habitat conditions includes channelization, which reduces channel diversity and promotes a uniform flow regime and ultimately reduces habitat diversity. Another likely source is stormwater outfalls which can increase erosion and scour leading to reduced channel diversity, homogenous flow regime, and unstable habitat. An additional source observed within the watershed includes decreased riparian vegetative zone (i.e., riparian buffer) which leads to increased stream temperatures, depressed dissolved oxygen levels, unstable banks, and an overall reduction in habitat complexity.

Altered hydrology: The role of altered hydrology in impairing the biological community within the watershed was indicated by reduced channel and habitat diversity, a slow and homogenous flow regime, and a potential reduction in baseflow. A likely source for altered hydrology observed within the watershed includes channelization, which reduces channel diversity and therefore promotes a uniform flow regime. Another likely source for altered hydrology within the watershed would include stormwater outfalls. Stormwater outfalls can increase erosion and scour leading to reduced channel diversity and homogenous flow regime.

Toxicants: The role of toxicants in impairing the biological community was indicated by the observation of very few macroinvertebrates at each sampling station. Less than 100 organisms were collected from the four sampling locations combined during the 2007 assessment by Dr. McClary. Monitoring for pesticides and herbicides as possible toxicants is warranted given the urban nature of the watershed.

D. Microbial Source Tracking

Microbial source tracking (MST) techniques have recently been developed that identify the origin of fecal pollution. MST is the concept of applying microbiological, genotypic (molecular), phenotypic (biochemical), and chemical methods to identify the origin of fecal pollution (USEPA, 2005). MST techniques typically report fecal contamination source as a percentage of targeted bacteria. One of the most promising targets for MST is group *Bacteroides,* a genus of obligately anaerobic, gram negative bacteria that are found in all mammals and birds. *Bacteroides* comprise up to 40% of the amount of bacteria in feces and 10% of the fecal mass. Due to the large quantity of *Bacteroides* in feces, they are an ideal target organism for identifying fecal contamination (Layton *et al.*, 2006). In addition, *Bacteroides* have been recognized as having broad geographic stability and distribution in target host animals and are a promising microbial species for differentiating fecal sources (USEPA, 2005; Dick *et al.*, 2005; Layton *et al.*, 2006).

Three sets of PCR primers (targets) were used to quantify *Bacteroides* from 1) all sources of *Bacteroides* ("AllBac"), 2) human sources ("HuBac"), and 3) bovine sources of *Bacteroides* ("BoBac"). This assay is based on published results from a study sponsored by the Tennessee Department of Environmental Conservation (Layton *et al*., 2006).

1. Methods

Samples were collected on two dates (July 18, 2008 and August 27, 2008) in sterile bottles at all seven water quality monitoring sites (Figure 9). A 100 mL aliquot of each sample was filtered aseptically onto a membrane filter and held at 4˚C until processing. DNA was extracted from total filtered biomass using a DNeasy® tissue kit (Qiagen, 2004). The protocol used is a modification of the procedure found in the DNeasy® Tissue Handbook (Qiagen, 2004).

After extraction, all DNA samples were quantified by spectroscopy (Beckman DU 640) at 260 and 280 ηm and then diluted in sterile water to a concentration of 1 μg/mL. This diluted DNA was used as the template for quantitative, real-time PCR reactions to measure the number of *Bacteroides* present. All other procedures that were followed are outlined by Layton *et al.* (2006).

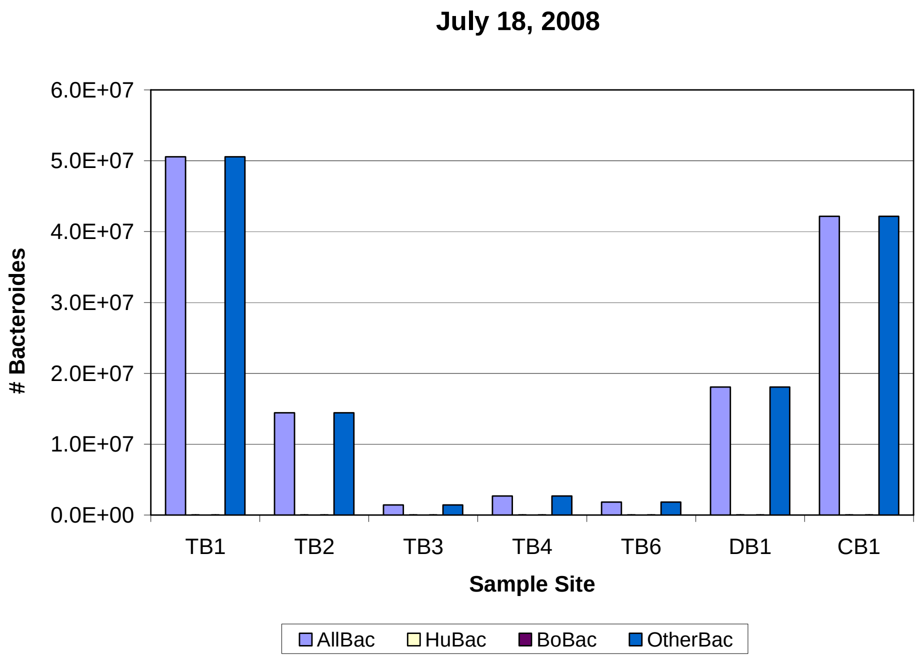
2. Results of MST

The Tenakill Brook Watershed is a highly-urbanized watershed with no agriculture within its boundaries (Figure 2). The MST confirmed this with no detections of agriculturally-derived bovine *Bacteroides* (BoBac) in any sample (Figures 11A-11B). *Bacteroides* from human-related sources (HuBac) could be readily detected at four stations on August 27, 2008 (Figure 11B), but none were detected during the July 18, 2008 sampling event. Station TB4 had the highest levels of human-related *Bacteroides* (HuBac) in August 2008 (Figure 11B).

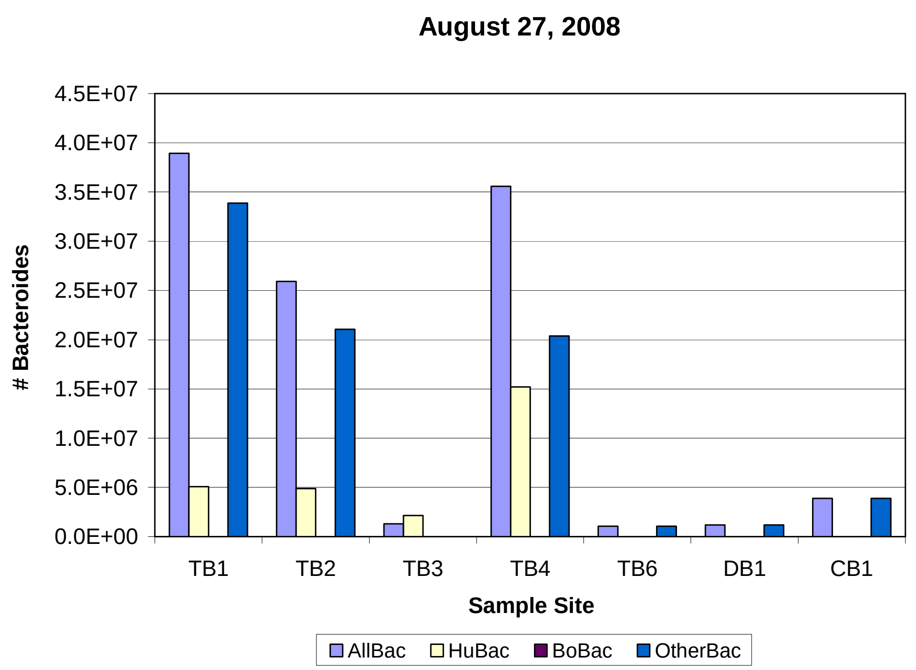
The numbers of *Bacteroides* present in individual samples was also compared to the other indicators of water quality including fecal coliform. Despite the lack of obvious correlations between total *Bacteroides* and fecal coliform, or any of the other water quality measurements, MST provides useful data in regard to the sources and extent of fecal contamination in the watershed. These data show the highly variable nature of all of the water quality measures used.

3. Source Identification

While it is difficult to pinpoint sources of pollution based upon two sampling events, sources could be estimated by the frequency of detection of specific markers at particular stations over these two summer events (Figures 11A-11B). Due to the presence of HuBac detected at many of the sites, potential sources could include failing septic and/or sewer systems or improperly treated human waste as potential sources of fecal contamination. All of the municipalities within the Tenakill Brook Watershed are on sewer systems, except of Alpine Borough which is on septic systems (Figure 12). None of the RCE Water Resources Program sampling locations are within Alpine Borough (Figure 9). Therefore, confirmation of leaking septic systems as a potential source cannot be made at this time. Future MST work should be focused in Alpine Borough waterways to determine if septic systems are a source of bacterial contamination.



(A)



(B)

Figure 11: MST data showing the numbers of *Bacteroides* detected on July 18, 2008 (A) and August 27, 2008 (B).

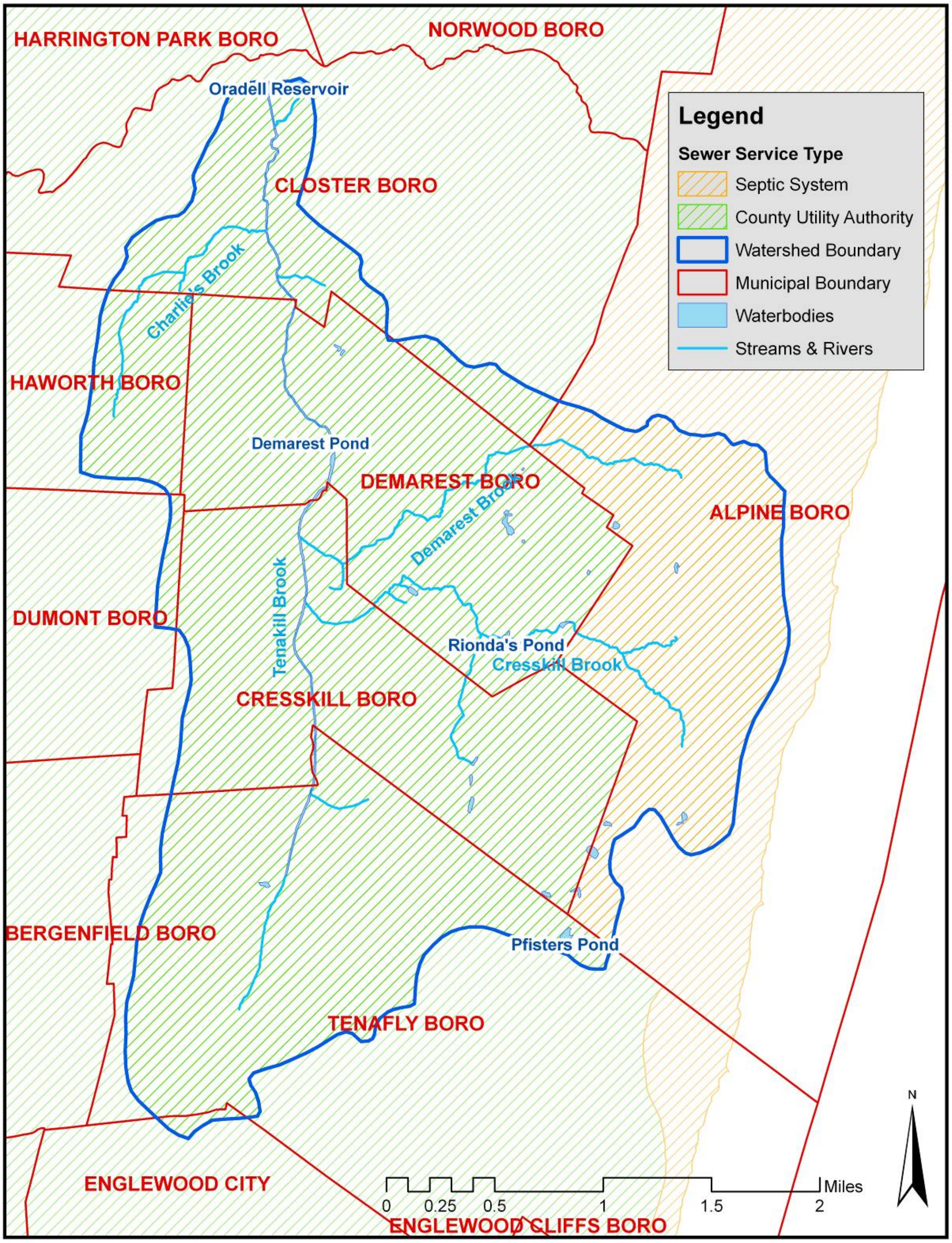


Figure 12: Sewer service areas in the Tenakill Brook Watershed.

E. Nonpoint Sources

Nonpoint sources of water pollution are derived from many different contaminants and landscapes. The extent and locations of these contaminant sources cannot be easily identified due to their diffuse nature, making them difficult to regulate and even more difficult to rectify. The Tenakill Brook Watershed is highly urbanized, with very little agricultural land use. Nonpoint source pollution is therefore largely associated with roads, buildings, pavement, and generally compacted landscapes with impaired drainage. Pollutants of concern include: sediment; oil, grease and toxic chemicals from motor vehicles; pesticides and nutrients from lawns and gardens; bacteria and nutrients from wildlife or pet waste; road salts; heavy metals from roof shingles, motor vehicles and other sources; and thermal pollution from dark impervious surfaces such as streets and rooftops are all pollutant concerns within the watershed. As these pollutants, generated by urban development and wildlife, accumulate on the land surface, hydrological processes such as runoff and percolation during a storm event will eventually transport these contaminants into nearby streams and groundwater. The urban land use has caused significant hydrological alteration and thus accelerated the speed and extent of pollutant transportation from sources to stream. The aggregate contribution of all nonpoint sources of water pollution to the Tenakill Brook has severely degraded surface water quality over time.

Specifically, sources of fecal contamination most likely include failing infrastructure or septic systems, incorrect disposal of domestic pet waste, leaking dumpsters, and waste from waterfowl populations. Phosphorus impairments may be due to excessive fertilizer applications in residential neighborhoods, resulting in stormwater runoff with high nutrient concentrations. Highway runoff during storm events may also contribute to phosphorus loads (Flint and Davis, 2007). Atmospheric deposition of phosphorus and nitrogen and other airborne pollutants onto impervious surfaces may also contribute largely to stormwater runoff loadings.

F. Point Sources

Point sources generally include municipal wastewater (sewage), industrial wastewater discharges, municipal separate storm sewer systems (MS4) and industrial stormwater discharges (Public Law 100-4, 1987). These facilities are required to obtain National Pollution Discharge Elimination System (NPDES) permits or state/local permits. All municipalities within the Tenakill Brook Watershed have MS4s and state permits for stormwater discharges.

There is only one active NJPDES-permitted surface water discharger within the Tenakill Brook Watershed: the Penetone Corporation (Figure 6). This permit is a minor industrial permit to discharge water used for general remediation clean-up. There are no permitted discharges to groundwater in the Tenakill Brook Watershed.

In addition, there are 32 known contaminated sites in the Tenakill Brook Watershed (Table 6). Many of these sites have groundwater contamination associated with them, and some have soil or other media contaminated by a substance release (Table 6). While the specifics of the source and type of contaminants from these sites are regulated by the NJDEP, they are included here as a possible reason for some of water quality issues not explained by monitoring conducted by the RCE Water Resources Program as part of this restoration planning effort. Confirmation of these known contaminated sites as potential sources of water quality impairments cannot be made at this time. However, future monitoring could be focused on determining the impact of these sites.

Table 6: Known contaminated sites (2009) located within the Tenakill Brook Watershed.

Site Name	Site Address	Status	Remedial Level	Municipality
59 Burlington Road	59 Burlington Road	Active	C1: No Formal Design - Source Known or Identified-Potential GW Contamination	Tenafly Borough
Clinton Inn Hotel	145 Dean Dive	Active	C2: Formal Design - Known Source or Release with GW Contamination	Tenafly Borough
Nissans Amoco Service	20 County Road	Active	C2: Formal Design - Known Source or Release with GW Contamination	Tenafly Borough
Mobil Station 15LE6	343 Tenafly Road	Active	C2: Formal Design - Known Source or Release with GW Contamination	Tenafly Borough
Marcos Tenafly Service Station I	21 County Road	Active	C2: Formal Design - Known Source or Release with GW Contamination	Tenafly Borough
Exxon R/S 32156	29 County Road	Active	C2: Formal Design - Known Source or Release with GW Contamination	Tenafly Borough
Seoul Auto Service - Former	71 County Road	Active	C2: Formal Design - Known Source or Release with GW Contamination	Tenafly Borough
Municipal Center	401 Tenafly Road	NFA-A (Limited Restricted Use)	C2: Formal Design - Known Source or Release with GW Contamination	Tenafly Borough
Super Value Service Station	34 Riveredge Road	Active	C2: Formal Design - Known Source or Release with GW Contamination	Tenafly Borough
C&E Service Station Inc.	36 Central Avenue	Active	C2: Formal Design - Known Source or Release with GW Contamination	Tenafly Borough
56032 Getty Petroleum Corp.	25 Central Avenue	NFA-A (Limited Restricted Use)	C2: Formal Design - Known Source or Release with GW Contamination	Tenafly Borough
Grove Street @ Tenafly LLC	80 W Railroad Avenue	Active	C2: Formal Design - Known Source or Release with GW Contamination	Tenafly Borough
Beucler Tree Expert Company Inc.	48 Harold Street	NFA-A (Restricted Use)	C1: No Formal Design - Source Known or Identified-Potential GW Contamination	Tenafly Borough
Harry C. Fichter Trust	100 Grove Street	Active	C1: No Formal Design - Source Known or Identified-Potential GW Contamination	Tenafly Borough
Lukoil #57319	268 County Road	Active	C2: Formal Design - Known Source or Release with GW Contamination	Tenafly Borough
Penetone Corp.	74 Hudson Avenue	Active	D: Multi-Phased RA - Multiple Source/Release to Multi-Media Including GW	Tenafly Borough
County Road Service Center	269 County Road	Active	C1: No Formal Design - Source Known or Identified-Potential GW Contamination	Tenafly Borough
125 Piermont Road LLC	125 Piermont Road	Active	C2: Formal Design - Known Source or Release with GW Contamination	Tenafly Borough
Hillcorp Inc.	111 N Summit Street	Active	C2: Formal Design - Known Source or Release with GW Contamination	Tenafly Borough
Joe DiRese & Sons Inc.	18 Piermont Road	Active	C2: Formal Design - Known Source or Release with GW Contamination	Cresskill Borough
Hoke Inc.	1 Tenakill Road	Active	D: Multi-Phased RA - Multiple Source/Release to Multi-Media Including GW	Cresskill Borough
Cresskill Pyramid	108 Piermont Road	Active	C2: Formal Design - Known Source or Release with GW Contamination	Cresskill Borough
70 Union Avenue	70 Union Avenue	Active	C2: Formal Design - Known Source or Release with GW Contamination	Cresskill Borough
Cresskill Commons	5 Tenakill Road	Active	C3: Multi-Phased RA - Unknown or Uncontrolled Discharge to Soil or GW	Cresskill Borough
42 Park Way	42 Park Way	Active	C1: No Formal Design - Source Known or Identified-Potential GW Contamination	Rochelle Park
116 Tenakill Road	116 Tenakill Road	Active	C1: No Formal Design - Source Known or Identified-Potential GW Contamination	Cresskill Borough
Exxon R/S 35109	480 Knickerbocker Road	Active	C2: Formal Design - Known Source or Release with GW Contamination	Cresskill Borough
Alpine Citgo Inc.	1016 Closter Dock Road	Active	C2: Formal Design - Known Source or Release with GW Contamination	Alpine Borough
Alpine Texaco Service Station Inc.	962 Closter Dock Road & Church Street	Active	C2: Formal Design - Known Source or Release with GW Contamination	Alpine Borough
Lukoil #57310	170 Schraalenburgh Road S	Active	C2: Formal Design - Known Source or Release with GW Contamination	Haworth Borough
DTR Automotive Service Center Inc.	422 Demerest Avenue	Active	C2: Formal Design - Known Source or Release with GW Contamination	Closter Borough
Hotel Research Labs	48 Perry Street	Active	D: Multi-Phased RA - Multiple Source/Release to Multi-Media Including GW	Closter Borough
A&P Shopping Plaza	400 Demarest Avenue	Active	C2: Formal Design - Known Source or Release with GW Contamination	Closter Borough

G. Erosion and Sedimentation

Understanding the geomorphic processes of a stream can help to define past and present watershed dynamics, develop integrated solutions, and assess the consequences of restoration efforts. A geomorphic assessment of a stream is an essential first step in the design process, whether planning the treatment of a single stream reach or attempting to develop a comprehensive plan for an entire watershed. These assessments typically require the collection of data, field investigations and channel stability assessments. A geomorphic assessment examines the processes of bank erosion and channel sedimentation, meander evolution, sediment budgets and connectivity as a means of understanding how water and sediment are related to channel form and function. This assessment provides for an evaluation of the stage of channel evolution to determine stream equilibrium characteristics and to determine how restoration activities can achieve a higher level of stream stability.

One way to understand the complex relationships between streams and their watersheds is through the application of a stream classification system. Stream classification systems provide a means to interpret the channel-forming or dominant processes active at a stream site, providing the basis for restoration activities. One frequently used classification system is the Rosgen System.

The Rosgen Stream Classification System uses six morphological measurements for classifying a stream reach – entrenchment, width/depth ratio, sinuosity, number of channels, slope and bed material particle size. These criteria are used to define eight major stream classes with approximately 100 individual stream types (Figure 13). The Rosgen System uses bankfull discharge to represent the stream-forming flow and relates all the morphological characteristics to bankfull conditions. For the Tenakill Brook Watershed, the Rosgen Stream Classification System was used to determine the stream types of various reaches within the watershed (Natural Resource Conservation Services [NRCS], 2007).

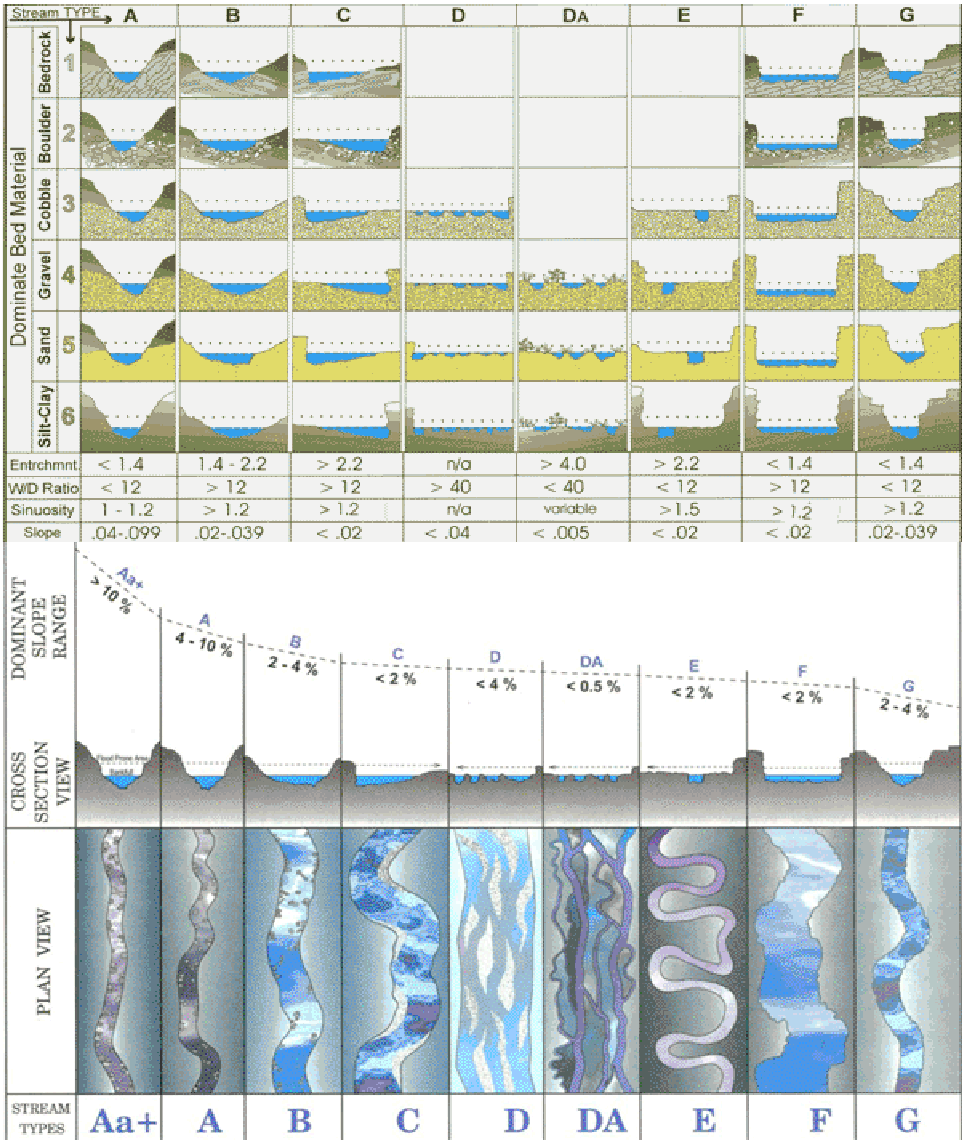


Figure 13: Rosgen stream classification cross section, plan and profile views (Rosgen, 1994).

Another method to evaluate the geomorphic conditions of a stream is through a Channel Evolution Model. This model describes the changes in a stream due to various disturbances. These changes can include an increase or decrease in width/depth ratio of a channel or alterations to a floodplain. These models help establish the direction of current trends in disturbed or constructed channels. Channel Evolution Models are also very useful in prioritizing restoration activities by identifying the current stage of evolution that a channel is experiencing (Figure 14). Simon's (1989) Channel Evolution Model was used for evaluating the Tenakill Brook Watershed.

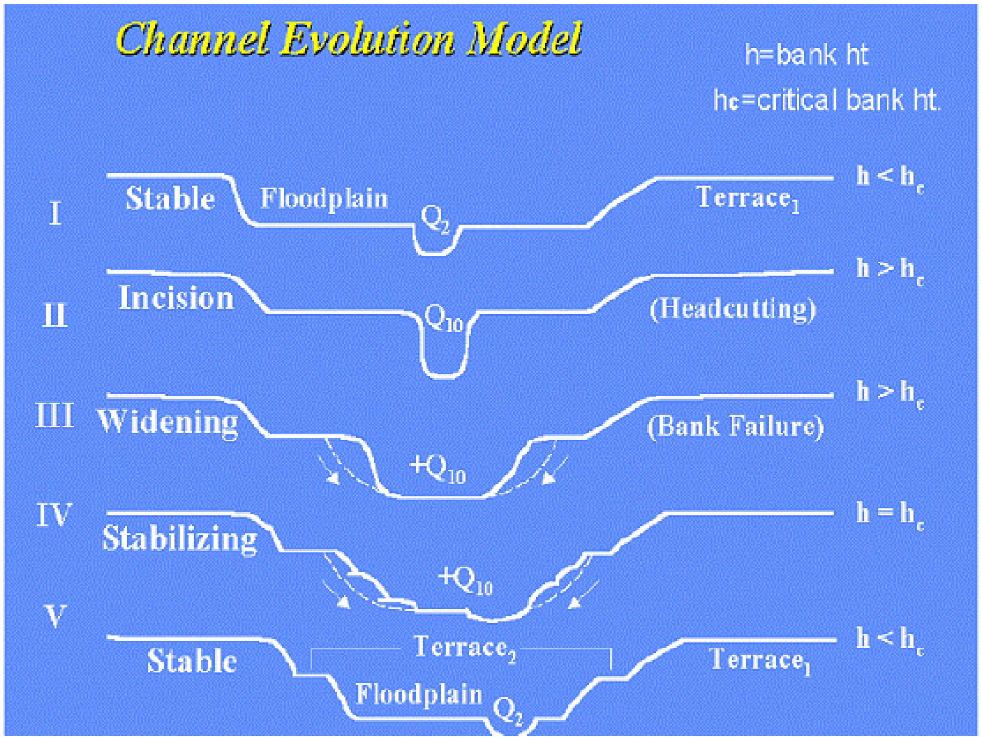


Figure 14: Simon's Channel Evolution Model classification system.

1. Rosgen Analysis Method

There are several levels of detail in the Rosgen Stream Classification System. The first level is a broad morphological characterization used to describe generalized fluvial features using remote sensing and existing inventories of geology, landform evaluations, valley morphology, depositional history and associated river slopes and patterns. The second level of classification is a more detailed morphological description delineating homogeneous stream types based upon channel patterns, entrenchment ratios, width/depth ratios, sinuosity, channel material and slope. The third level further describes stream "state" or condition. The fourth level involves the direct measurement/observation of sediment transport, bank erosion rates, aggradation/degradation processes, hydraulic geometry, biological data, and riparian vegetation evaluations.

Though data were limited and insufficient resources were available to complete a full Rosgen Level 2 assessment, a modified Level 1 Rosgen Analysis was conducted for each subwatershed of the Tenakill Brook Watershed. The analysis relied on data collected from the field and reliable third party sources. A GIS map was created for the entire watershed, where subwatersheds were delineated, based on the ten stations identified for monitoring, using ArcHydro (Version 1.1, August 2004) and the 10-meter digital elevation model (DEM) available from the NJDEP (Figure 9; Figure 15). The stream layer, current aerial photography, and site visits were used to visually determine if the stream has one or multiple threads. During the summer of 2007, flow data were collected every other week for each subwatershed. The entrenchment ratio was chosen based on multiple site visits to various locations in each subwatershed (Figure 15). To measure the flow, the depth and width of the stream at each sampling point was measured. These data were used to evaluate the width to depth ratio. Sinuosity is the ratio of the channel length versus the valley length of the stream. These two values are easily measured for each subwatershed using GIS. The DEM has elevation data for the entire state. The DEM with the stream layer was used to quantify the slope of each subwatershed. The NRCS has soil maps for the entire country which are available online (http://websoilsurvey.nrcs.usda.gov/app/WebSoilSurvey.aspx). From the website, a polygon can be created around any area to generate a soils map for the specified area. The area immediately surrounding the streams in each subwatershed was created. Stream reaches at each of the sampling stations were evaluated using the Rosgen Stream Classification System (Table 7). The data were compiled as 'Stream Classification,' as provided in the last row of Table 7.

Based on the analysis, several typical stream types were identified within the watershed. Type C is a low-gradient, meandering stream containing point-bars, riffle/pools, and alluvial channels within a broad, well-defined floodplain. This type of stream is fairly stable in plan and profile. Type E is a low-gradient, meandering riffle/pool steam with low width/depth ratio and little deposition, very efficient and stable. Type E streams have a high meander width ratio. Type G is an entrenched "gulley" step/pool stream with low width/depth ratio on moderate gradients. This type of stream is unstable with grade control problems and high bank erosion rates (Rosgen, 1994).

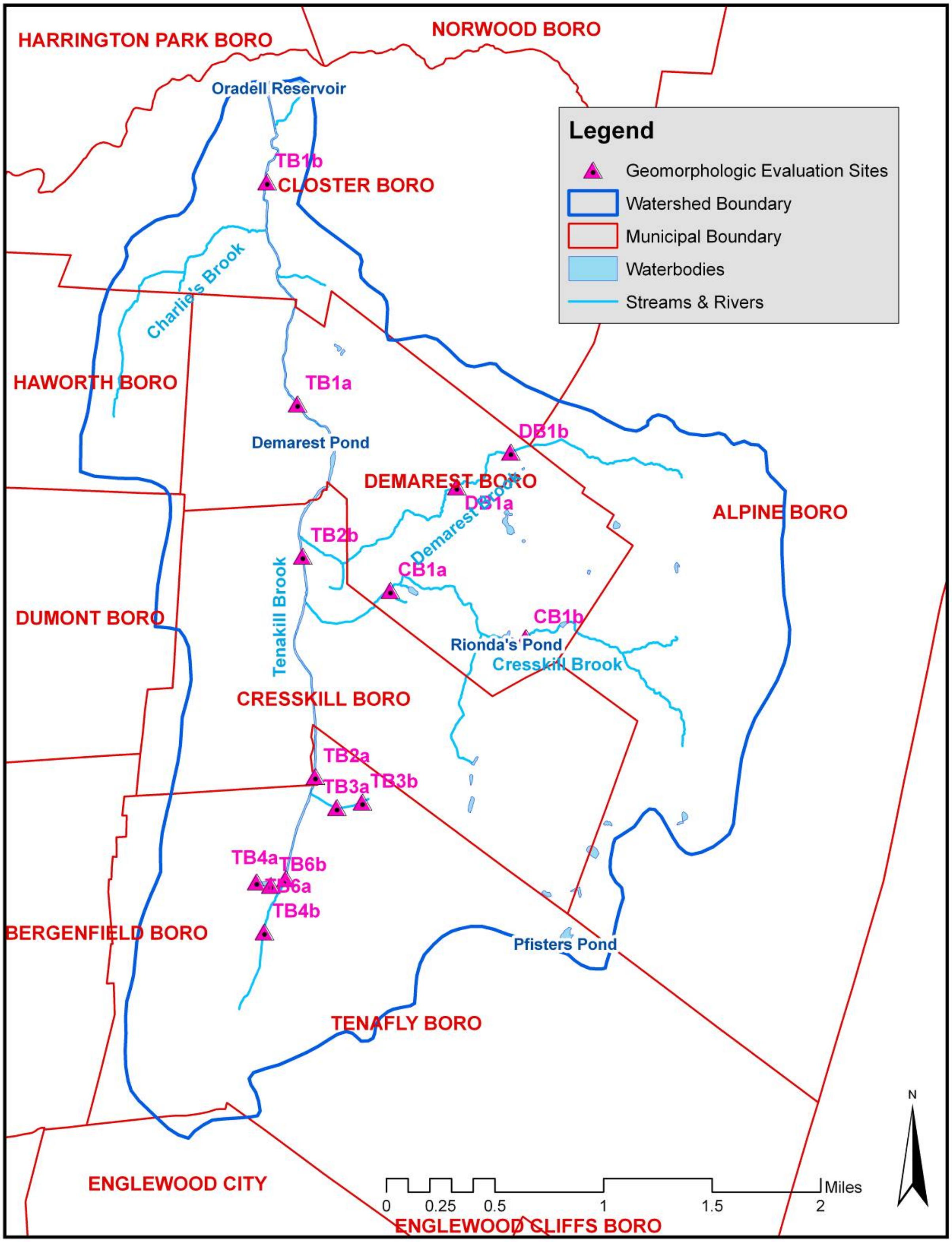


Figure 15: Sedimentation and erosion evaluation sites in the Tenakill Brook Watershed.

Table 7: Rosgen analysis results for the Tenakill Brook Watershed.

	CB1a	**CB1b**	**DB1a**	**DB1b**	**TB1a**	**TB1b**	**TB2a**
Single Threaded Channels	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Entrenchment Ratio	Slight	Slight	Slight	Entrenched	Moderate	Moderate	Slight
Width/Depth Ratio	<12	<12	<12	<12	<12	>12	<12
Sinuosity			1.329	1.329	1.165	1.165	1.055
Stream Type	C	C	C	A	F	C	B
Slope							.0008
Channel Material	Silt/Clay	Cobble	Gravel	Cobble	Silt/Clay	Sand/Silt	Clay/Silt
Stream Classification	C6	C3	C4	A3	F6	C6b	B6c

	TB2b	**TB3a**	**TB3b**	**TB4a**	**TB4b**	**TB6a**	**TB6b**
Single Threaded Channels	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Entrenchment Ratio	Entrenched	Slight	Moderate	Moderate	Slight	Entrenched	Slight
Width/Depth Ratio	=12	>12	<12	>12	<12	=12	<12
Sinuosity	1.055	1.074	1.074	1.029	1.029	1.141	1.141
Stream Type	G	F	C	C	C	G	E
Slope	.001			.0014		.0039	
Channel Material	Silt/Clay	Silt/Clay	Clay/Silt	Clay/Silt	Clay/Silt	Clay/Silt	Silt/Clay
Stream Classification	G6c		C6	C6	C6c	G6c	E6

Although Type C and E stream are identified above as stable, streams undergo morphological changes due to various alterations in the watershed such as increases in urbanization or changing of farming practices. Figure 16 illustrates the various stream type succession scenarios as these changes occur. Some streams start as Type C, very stable systems, but can change to Type G with downcutting and then change to Type F through widening, ultimately changing back to Type C, a stable condition with a connected floodplain and terracing (Figure 16). These evolutions are predominately caused by changes in land use in the watershed which alters watershed hydrology.

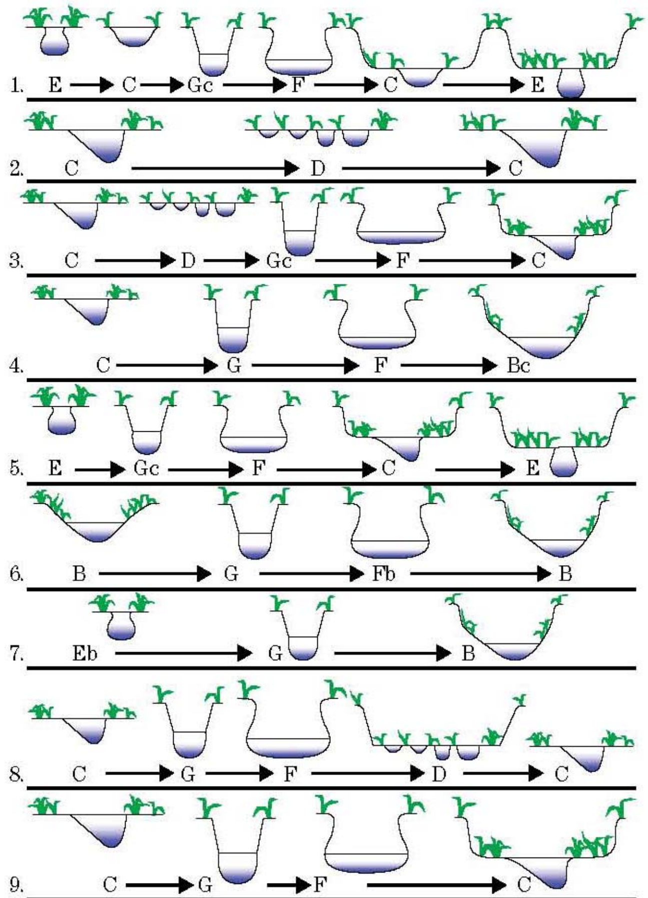


Figure 16: Rosgen stream type succession scenarios.

2. Channel Evolution Model Analysis

The fourteen sites evaluated in the Tenakill Brook Watershed using the Rosgen system were also evaluated with Channel Evolution Model (Figure 15) providing representative stream conditions found in the watershed.

The RCE Water Resources Program conducted site visits throughout the Tenakill Brook Watershed evaluating the geomorphic conditions of the system using Simon's (1989) Channel Evolution Model (Table 8). Reaches classified in Stage 2 or 3 are unstable and action would need to be taken to stabilize these reaches. These unstable reaches can be significant sources of sediment entering Tenakill Brook and its tributaries. Observations noted in the Channel Evolution Model evaluation reflect the impacts of the high percentage of urban land use in the Tenakill Brook Watershed. Streams in Stage 2 or 3 are most likely suffering from higher peak stormwater flows from urban land uses in the watershed. In most cases, the downcutting and widening seen in Stages 2 and 3 can be linked to impervious cover that is directly connected to the stream, resulting in flashy hydrology. Furthermore, these unstable reaches can contribute a significant amount of sediment to the stream.

Table 8: Channel Evolution Model evaluations for Tenakill Brook Watershed.

Site	Subwatershed	Stage
CB1a	CB1	2
CB1b	CB1	2-3
DB1a	DB1	1
DB1b	DB1	4
TB1a	TB1	2
TB1b	TB1	4
TB2a	TB2	1
TB2b	TB2	3
TB3a	TB3	2-3
TB3b	TB3	2
TB4a	TB4	2-3
TB4b	TB4	3
TB6a	TB6	2
TB6b	TB6	1-2

a) Subwatershed CB1

Site CB1a is unstable, in Stage 2 (Table 8). There are large amounts of sediments deposited in the stream in addition to major incisions, as well as headcutting on both banks of the Cresskill Brook. Bedrock and other cultural features are exposed. This site is located at the end of Sunset Road, off Piermont Road in Demarest Borough (Figure 15).

Site CB1b is also unstable. The left bank is likely in Stage 2, while the right bank is in Stage 3 (Table 8). The left bank has exposed cultural features, headcutting, and sediment deposits. The right bank is widening and its bank material is being eroded away; the bank slopes are nearly vertical. This site is located on Academy Lane, off Hillside Avenue, in Demarest Borough (Figure 15).

b) Subwatershed DB1

Site DB1a is classified as mostly stable, in Stage 1 (Table 8). There is a well developed base flow and bankfull channel, as well as a predicable pattern of stream morphology. One terrace is apparently above the floodplain which is covered by diverse vegetation. However there is evidence of headcutting occurring at this site. This site is located on Orchard Road between Lake Road and Anderson Avenue, in Demarest Borough (Figure 15).

Site DB1b is considered at Stage 4, stabilizing (Table 8). The streambank slopes are less than 1:1, with baseflow, bankfull, and floodplain channel developing. The sloughed stream bank material is not eroding, instead is colonized by vegetation. This site is located on Pine Terrace, between Lake Road and Anderson Avenue, in Demarest Borough (Figure 15).

c) Subwatershed TB1

Site TB1a is unstable, in Stage 2 (Table 8). There is noticeable headcutting, as well as large amounts of sediment deposits and exposed cultural features. The streambank slopes are vertical, near concave; incision is a serious issue at this site. The site is located in Wakelee Field Park area, off Wakelee Drive, in Demarest Borough (Figure 15).

Site TB1b is stabilizing, in Stage 4 (Table 8). There is a predictable sinuous pattern initiating, in addition to baseflow, bankfull, and floodplain features developing. The sloughed stream bank material is not eroding instead it is colonized by vegetation. This site is located on High Street, between West Street and Storig Avenue, in Closter Borough (Figure 15).

d) Subwatershed TB2

Site TB2a is stable, in Stage 1 (Table 8). There is a large amount of sediment deposited on the sides of the stream. This sediment is very muddy and easily sunken into. Floodplain features are easily identified, and a terrace is clearly apparent above the active floodplain. The banks have a strong odor and oil sheen is present. This is possibly due to runoff coming from an adjacent parking lot. The site is located in Brookline Park on the border of Cresskill Borough and Tenafly Borough (Figure 15).

Site TB2b is in Stage 3 (Table 8). The stream is clearly widening due to sloughing of the stream banks. Both banks are highly eroded, resulting in visible roots. Many geese were present along with their feathers and feces during the site visits. The site is located behind Cresskill High School off of Mezzine Drive, in Cresskill Borough (Figure 15).

e) Subwatershed TB3

Site TB3a is unstable, with features of both Stages 2 and 3 (Table 8). The right bank has headcutting present, in addition to exposed cultural features. The left bank has bank material eroding and widening the stream. This site is located on Piermont Road, between Prospect Terrace and Hudson Avenue, in Tenafly Borough (Figure 15).

Site TB3b is unstable, in Stage 2 (Table 8). Evidence of headcutting is present, as well as exposed cultural features and a large amount of sediment deposits. The right bank has a gabion fence of rock, while the left bank has dense vegetation and sediment accumulation. This site is located on Hudson Avenue, between Haring Lane and County Road, in Tenafly Borough (Figure 15).

f) Subwatershed TB4

Site TB4a is between Stages 2 and 3 (Table 8). There are signs of downcutting and exposure of roots along the left bank. The left bank is along a foot path that is frequented by people walking dogs. The right side is stable with diverse and dense floodplain vegetation. The bank slope is much lower than that of the left side's. The site is located in Roosevelt Commons on Riveredge Road, in Tenafly Borough (Figure 15).

Site TB4b is unstable, in Stage 3 (Table 8). The stream banks are sloughing, and the material is eroding away. The banks are vertical and concave in some spots along the stream. Also present are large sediment deposits downstream of West Clinton Avenue. This site is located on West Clinton Avenue (north side of road), between Tenafly Road and Foster Road, in Tenafly Borough (Figure 15).

g) Subwatershed TB6

Site TB6a is in Stage 2 (Table 8). There are signs of incision and sediment deposits are absent. Stream banks are heavily eroded, resulting in very steep banks. The buffer on the right bank is very bare, even absent at some sections. Ducks and duck feces were present, as well as dog feces. Geese were found nearby; roughly 10 minutes after 'geese police' came and left during the site visit. The site is in Roosevelt Commons on Riveredge Road, in Tenafly Borough (Figure 15).

Site TB6b is classified as unsteady, but contains features of steady streams in Stages 1 and 2 (Table 8). There is a well developed baseflow, diverse vegetation, and bank slopes of less than 1:1. However, headcutting is present, as well as sediment deposits and erosion on the inside of bends in the stream. The site is located in Roosevelt Commons Park just after the lake, in Tenafly Borough (Figure 15).

H. Stream Visual Assessment Protocol (SVAP) Data

The USDA SVAP methodology was followed to gain an understanding of potential physical changes in the Tenakill Brook Watershed's rivers and streams that may indicate water quality problems. The protocol provides an outline on how to quantitatively score in-stream and riparian qualities. Such assessed qualities include water appearance, channel condition, canopy cover, and riparian health.

Fifty stream reaches were evaluated in the Tenakill Brook Watershed (Table 9). While only six of the seven subwatersheds within the Tenakill Brook Watershed were evaluated (Table 9), SVAP assessment results provide an overall appraisal of watershed health. The overall mean SVAP assessment score for all reaches was 4.9, a resulting watershed quality of "poor." Manure Presence was noted at four different reaches, and the manure was determined to come from Canada geese (Table 9). Barriers to Fish Movement had the highest score assessment element with an average score of 7.0 (Table 9). Pools were the lowest scoring assessment element with a mean of 2.2 (Table 9). None of the assessed stream reaches received a score of "good" (Table 9).

Table 9: SVAP assessment elements and scores for the Tenakill Brook Watershed.

Subwatershed	Date	Reference Location	Hydrologic Alteration	Channel Condition	Riparian Zone Left Bank	Riparian Zone Right Bank	Bank Stability Left Bank	Bank Stability Right Bank	Water Appearance	Nutrient Enrichment	Riffle Embeddedness	Barriers to Fish Movement	Instream Fish Cover	Pools	Invertebrate Habitat	Canopy Cover	Manure Presence	Overall Site Average
CB1	6/25/2007	Stream between the dead ends of South St.	n/a	3.0	3.0	7.0	3.0	5.0	9.0	7.0	n/a	5.0	5.0	1.0	n/a	9.0	n/a	5.2
CB1	6/25/2007	Stream under Graham St. and near intersection with	n/a	7.0	8.0	10.0	3.0	3.0	8.0	8.0	n/a	8.0	3.0	1.0	n/a	10.0	n/a	6.3
CB1	6/25/2007	Stream under Anderson/County bridge.	n/a	1.0	6.0	8.0	2.0	2.0	7.0	7.0	n/a	1.0	3.0	3.0	n/a	9.0	n/a	4.5
CB1	6/25/2007	Stream under Church St. and close to intersection	n/a	7.0	9.0	9.0	7.0	8.0	8.0	7.0	n/a	7.0	3.0	2.0	n/a	10.0	n/a	7.0
CB1	6/25/2007	Near Duckpond and Hillside Ave.	n/a	3.0	5.0	5.0	6.0	6.0	8.0	7.0	n/a	6.0	3.0	1.0	n/a	8.0	n/a	5.3
CB1	6/25/2007	Located by Duckpond and Deerhill road.	n/a	7.0	5.0	3.0	6.0	5.0	7.0	7.0	n/a	1.0	3.0	5.0	n/a	6.0	n/a	5.0
CB1	6/25/2007	Stream running alongside Duckpond Rd (after 2nd po	5.0	10.0	10.0	10.0	3.0	3.0	8.0	7.0	n/a	3.0	3.0	2.0	n/a	8.0	n/a	6.0
DB1		Bridge over Warren Lane	1.0	1.0	2.0	0.0	1.0	0.0	7.0	7.0	1.0	1.0	2.0	1.0	n/a	5.0	n/a	2.2
DB1		End of Lake Road, left from walking path.	9.0	10.0	10.0	0.0	3.0	0.0	8.0	7.0	5.0	8.0	5.0	4.0	n/a	7.0	n/a	5.8
DB1	6/12/2007	School & Swim Club off Grove St	5.0	6.0	3.0	5.0	3.0	3.0	3.0	6.0	1.0	10.0	3.0	2.0	n/a	7.0	n/a	4.4
DB1	6/20/2007	Stream going over Pine Terrace (between Anderson A	4.0	6.0	3.0	3.0	4.0	4.0	7.0	7.0	n/a	5.0	5.0	7.0	n/a	6.0	n/a	5.1
DB1	4/3/2007	memorial park near cedar lane	n/a	6.0	1.0	1.0	3.0	1.0	4.0	5.0	n/a	9.0	4.0	5.0	n/a	1.0	1.0	3.4
DB1	6/20/2007	Bridge over Warren Lane	1.0	1.0	2.0	2.0	1.0	1.0	7.0	7.0	1.0	1.0	2.0	1.0	n/a	5.0	n/a	2.5
DB1	6/20/2007	Stream going under Berkery Road via pipe.	3.0	3.0	5.0	5.0	6.0	1.0	7.0	8.0	n/a	8.0	5.0	7.0	n/a	8.0	n/a	5.5
DB1	6/20/2007	Stream going under Litchfield Way.	3.0	3.0	5.0	5.0	1.0	2.0	7.0	8.0	n/a	4.0	1.0	1.0	n/a	10.0	n/a	4.2
TB1	6/12/2007	Intersection of Tenafly & Riveredge Rds	7.0	5.0	6.0	2.0	7.0	4.0	7.0	7.0	n/a	9.0	3.0	1.0	n/a	1.0	n/a	4.9
TB1	4/3/2007	Memorial Park on Harrington Avenue	na	7.0	1.0	1.0	5.0	3.0	3.0	2.0	n/a	9.0	5.0	1.0	n/a	3.0	5.0	3.8
TB1	4/3/2007	north of high street, closter	6.0	5.0	2.0	1.0	4.0	6.0	7.0	6.0	n/a	9.0	3.0	2.0	n/a	7.0	5.0	4.8
TB1	4/3/2007	south of high street crossing	6.0	5.0	3.0	2.0	3.0	4.0	7.0	7.0	n/a	9.0	4.0	3.0	n/a	3.0	n/a	4.7
TB1	6/20/2007	Stream over Central Ave.	5.0	5.0	3.0	1.0	7.0	7.0	8.0	1.0	n/a	8.0	3.0	1.0	n/a	4.0	n/a	4.4
TB1	6/28/2007	Between Chestnut and Beacon streets.	n/a	7.0	7.0	8.0	6.0	7.0	8.0	7.0	n/a	6.0	3.0	1.0	n/a	7.0	n/a	6.1
TB1	6/28/2007	Bemd of Pleasant Ln.	n/a	6.0	4.0	2.0	4.0	6.0	8.0	7.0	n/a	7.0	3.0	1.0	n/a	7.0	n/a	5.0
TB1	6/28/2007	End of Oak St.	n/a	1.0	1.0	1.0	4.0	4.0	8.0	5.0	n/a	1.0	3.0	3.0	n/a	1.0	n/a	2.9
TB1	6/28/2007	Stream near Brooks street.	n/a	5.0	3.0	1.0	5.0	1.0	8.0	7.0	n/a	6.0	5.0	3.0	n/a	7.0	n/a	4.6
TB1	7/9/2007	Behind A&P on Demarest Ave.	n/a	7.0	10.0	10.0	6.0	6.0	7.0	6.0	n/a	8.0	5.0	1.0	n/a	7.0	n/a	6.6
TB2	6/15/2007	Intersection of Merritt Ct and Columbus	5.0	9.0	1.0	1.0	5.0	5.0	8.0	9.0	n/a	8.0	3.0	1.0	n/a	3.0	n/a	4.8
TB2	6/15/2007	Just south Tenakill Swim Club	5.0	8.0	9.0	9.0	5.0	5.0	9.0	8.0	n/a	1.0	1.0	1.0	n/a	1.0	n/a	5.2
TB2	6/15/2007	Cresskill Firehouse Madison Ave	5.0	8.0	3.0	3.0	3.0	3.0	4.0	6.0	n/a	10.0	3.0	1.0	n/a	7.0	n/a	4.7
TB2	6/15/2007	Just South of the end of Tenakill Road	5.0	8.0	9.0	7.0	4.0	4.0	3.0	5.0	n/a	10.0	3.0	1.0	n/a	3.0	n/a	5.2
TB2	6/15/2007	Upstream of Grant Ave	5.0	3.0	4.0	2.0	2.0	8.0	7.0	7.0	n/a	10.0	2.0	0.0	n/a	4.0	n/a	4.5
TB2		School & Swim Club off Grove St	5.0	6.0	3.0	0.0	3.0	0.0	3.0	6.0	1.0	10.0	3.0	2.0	n/a	7.0	n/a	3.8
TB2	6/12/2007	Tenafly Rd along Park & Middle School	7.0	4.0	3.0	5.0	4.0	4.0	4.0	6.0	n/a	10.0	1.0	1.0	n/a	6.0	n/a	4.6
TB2	6/12/2007	Between ball park and swim club off Grove St	6.0	6.0	3.0	3.0	7.0	7.0	3.0	5.0	n/a	10.0	2.0	1.0	n/a	1.0	n/a	4.5
TB2	6/12/2007	Magnolia & 3rd St	5.0	7.0	9.0	5.0	5.0	7.0	2.0	4.0	n/a	10.0	3.0	1.0	n/a	4.0	n/a	5.2
TB2	6/20/2007	End of Old Stable Road	7.0	7.0	4.0	3.0	3.0	3.0	8.0	9.0	n/a	10.0	3.0	1.0	n/a	7.0	n/a	5.4
TB2	6/20/2007	Bridge on Meadow Street	5.0	7.0	1.0	1.0	1.0	1.0	10.0	10.0	n/a	8.0	1.0	1.0	n/a	4.0	n/a	4.2
TB2	6/25/2007	Bridge on Delmar Ave.	n/a	2.0	4.0	4.0	2.0	3.0	8.0	8.0	n/a	6.0	3.0	1.0	n/a	5.0	n/a	4.2
TB2	6/25/2007	Stream near Cresskill HS and Lincoln Dr.	n/a	7.0	3.0	8.0	3.0	4.0	7.0	8.0	n/a	10.0	5.0	7.0	n/a	7.0	n/a	6.3
TB2	6/28/2007	Stream (Tenakill Brook) near Wakelee Field	n/a	6.0	7.0	4.0	7.0	3.0	5.0	5.0	n/a	7.0	8.0	7.0	n/a	10.0	n/a	6.3
TB2	6/28/2007	Stream running under Hardenburgh Ave. bridge	n/a	1.0	1.0	1.0	8.0	8.0	6.0	3.0	n/a	8.0	4.0	1.0	n/a	1.0	n/a	3.8
TB2	6/28/2007	Stream by Deacon Pl.	n/a	8.0	9.0	5.0	7.0	4.0	4.0	3.0	n/a	8.0	3.0	7.0	n/a	3.0	5.0	5.5
TB2	6/28/2007	End of Messine Dr.	n/a	8.0	5.0	5.0	4.0	4.0	5.0	6.0	n/a	9.0	6.0	7.0	n/a	7.0	n/a	6.0
TB2	6/28/2007	Stream going under Grant Ave. bridge. Also close	n/a	6.0	3.0	7.0	4.0	4.0	7.0	4.0	n/a	5.0	4.0	3.0	n/a	7.0	n/a	4.9
TB3	7/9/2007	Piermont by Hudson near Commerce Bank	n/a	3.0	6.0	7.0	3.0	4.0	6.0	7.0	n/a	8.0	3.0	1.0	n/a	7.0	n/a	5.0
TB4	5/7/2007	Intersection of Hamilton Place and Palmer Ave	3.0	3.0	1.0	4.0	2.0	8.0	9.0	9.0	n/a	8.0	1.0	1.0	n/a	9.0	n/a	4.8
TB4	5/7/2007	Intersection of Benjamin Road and Louise Lane	1.0	3.0	1.0	1.0	9.0	9.0	9.0	9.0	n/a	8.0	1.0	1.0	n/a	9.0	n/a	5.1
TB4	5/7/2007	Bridge on Clinton ave	9.0	8.0	10.0	8.0	2.0	2.0	9.0	9.0	n/a	8.0	2.0	1.0	n/a	7.0	n/a	6.3
TB4	5/7/2007	Just upstream of Riveredge Road	9.0	8.0	9.0	8.0	3.0	3.0	8.0	9.0	n/a	8.0	1.0	1.0	n/a	2.0	n/a	5.8
TB4	5/7/2007	Parrellel to the tennis courts in Roosevelt Park	3.0	2.0	1.0	8.0	6.0	2.0	9.0	9.0	n/a	8.0	1.0	1.0	n/a	1.0	n/a	4.3
TB4	7/9/2007	Roosevelt Commons by Riveredge and Tenafly	n/a	3.0	7.0	7.0	7.0	7.0	1.0	1.0	n/a	1.0	3.0	1.0	n/a	7.0	n/a	4.1

Legend		
	(grey)	Good = assessment score > 7
	(yellow)	Fair = assessment score of 5-7
	(pink)	Poor = assessment score < 5

Descriptions of each indicator are available in the U. S. Department of Agriculture Stream Visual Assessment Protocols (USDA, 1998)

1. Cresskill Brook (Subwatershed CB1)

SVAP assessment scores ranged from “poor” to “fair” for reaches along the Cresskill Brook (Table 9). Stream bank stability was assessed as “poor” at many sites (Table 9; Figure 17a). This coincides with the lack of stream bank stability recorded during the Channel Evolution Model evaluations (Table 8).

Channelized sections of the stream were observed (Figure 17b), as well as significant barriers to fish passage (Figure 17c). This may be a significant issue to trout populations as the upper portion of the Cresskill Brook is classified for trout production (Figure 5).

Figure 17a: Poor bank stability in CB1. (Photo: RCE Water Resources Program)

Figure 17b: Example of channelized stream with no pools in CB1. (Photo: RCE Water Resources Program)

Figure 17c: Example of significant barrier to fish movement in CB1. (Photo: RCE Water Resources Program)

2. Demarest Brook (Subwatershed DB1)

As with other subwatersheds, reaches along Demarest Brook were scored "poor" for bank stability (Table 9). This may be due to the poor riparian buffers observed at many of the reaches (Figure 18).

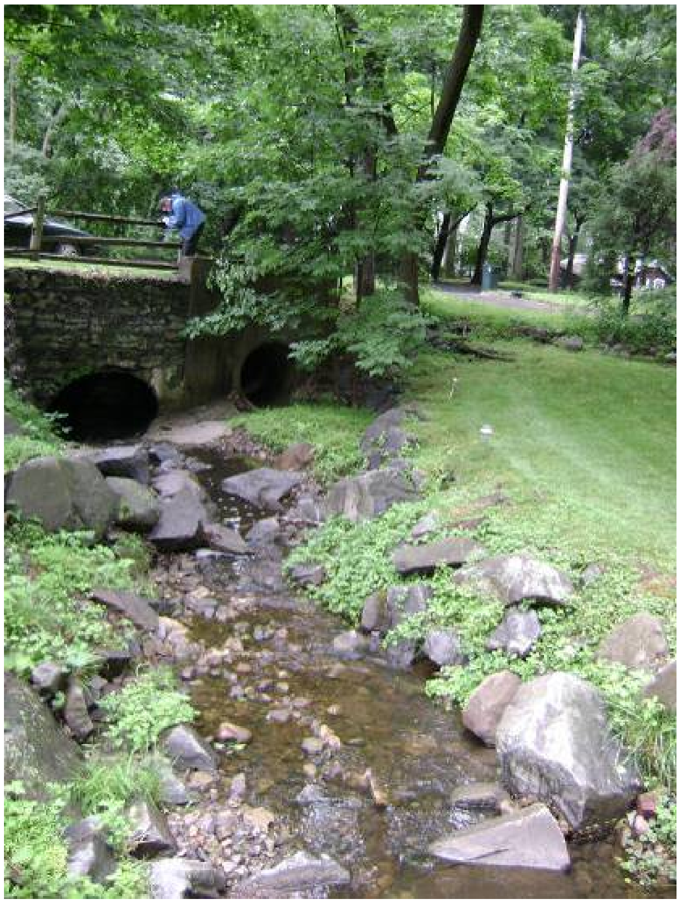


Figure 18: Poor riparian buffer in DB1.
(Photo: RCE Water Resources Program)

3. Tenakill Brook (Subwatersheds TB1 – TB4 & TB6)

Many of the reaches assessed along the Tenakill Brook were rated as "poor" (Table 9). Many of the low scores were given to elements assessing the stream bank stability and riparian zone (Table 9). These results correspond to the instability observed during the Channel Evolution Model evaluations (Table 8).

No SVAP assessments were conducted in subwatershed TB6 (Table 9).

VI. Estimated Loading Targets and Priorities

A. Pollutant Loading Targets

Load reduction targets for the *Tenakill Brook Watershed Restoration and Protection Plan* will adhere to the TMDL approved by the USEPA (NJDEP, 2003). In this plan, reduction targets are defined by the total pollutant load reductions that are required to satisfy the water quality criteria for FW2-NT streams. These targets will dictate the implementation projects and management measures developed by the RCE Water Resources Program to improve water quality within the Tenakill Brook Watershed.

As stated previously, a TMDL was established in 2003 for the Tenakill Brook requiring a 96% reduction in fecal coliform loadings (NJDEP, 2003). As there is no established TMDL for TP (and therefore no previously described reduction target), projects undertaken to reduce phosphorus loads will be chosen based upon maximum reductions possible, need on a subwatershed basis, impact on the watershed's discharge quality, overall cost-effectiveness, and best professional judgment.

B. Pollutant Loading Estimates

The two primary pollutants of concern in the Tenakill Brook Watershed are TP and bacteria (fecal coliform and *E. coli*, indicators of pathogen contamination). Flow and pollutant concentration from each sampling event were used to calculate the hourly load at each sampling location for each sampling event. For TP this provides an estimated load in grams of TP per hour (grams/hour). For fecal coliform, this calculation provides the number of millions of organisms per hour (millions org/hour). At the time of this project's initiation, fecal coliform was the accepted measure indicating pathogen pollution for New Jersey freshwaters. Since then, the fecal coliform standard has been replaced by an *E. coli* standard. Because the TMDL established for the Tenakill Brook refers to fecal coliform, both fecal coliform and *E. coli* loading rates were calculated and presented here.

Note that due to insufficient data, estimated loads for the selected parameters were not calculated for monitoring site TB6.

1. Total Phosphorus (TP)

All water quality monitoring stations exceeded the 0.1 mg/L standard two or more times during the sampling period (Table 4). Note that the state's TP monitoring standard for lakes

(0.05 mg/L) was used for site TB1, since it drains to the Oradell Reservoir (Table 1). This indicates elevated TP levels are causing impairments throughout the watershed. Stations TB1 and TB2, the most downstream sites, exceeded the TP standard most frequently (Table 4). This may be from cumulative impacts from throughout the Tenakill Brook Watershed.

For the analysis of TP data, wet and dry weather loads were compared. TP loads were calculated for both dry weather and wet weather events by multiplying concentrations by the flow measured at each station. Wet and dry dates were distinguished from each other by utilizing the USGS hydrograph separation model (HYSEP). HYSEP estimates the groundwater, or base flow, component of stream flow through one of three methods: fixed interval, sliding interval, or local minimum (Sloto and Crouse, 1996). The local minimum method was used in the Tenakill Brook Watershed. Baseflow is calculated in this method, and any flows measured during the course of this project that are above the calculated baseflow are considered "wet" events, while those below are considered "dry" events (Sloto and Crouse, 1996). In addition, downstream stations had upstream station loads subtracted from their total load to determine the contribution of individual subwatersheds. In some cases, this can lead to negative loads at a station due to there being a larger load upstream of that station. By using these methods, subwatersheds TB2 and TB4 were found to have the largest mean TP loads in the Tenakill Brook Watershed for wet weather events (Figure 19), and subwatersheds TB1 and TB2 had the largest dry weather TP loads (Figure 19). These subwatersheds have the greatest impact in regards to TP results as they are the stations furthest downstream and, therefore, closest to the Oradell Reservoir, a public drinking water supply.

All of the subwatersheds have increased loading rates during wet weather except for TB1 (Figure 19). TB1 acts as a sink according to the data during wet weather. This is possibly related to the elevation maintained by the reservoir downstream of TB1. The water elevation of the reservoir would be at its highest under wet conditions and has the potential to lead to water backing up or stagnating in the lower portion of the watershed, thus reducing flows upstream of the reservoir. This has a direct impact on the loading calculation. The reduction in flow could affect the loading calculation to a degree that TB1 could act as a sink, if this reduced flow was low enough. More research and monitoring would be needed on the flows at TB1 and the Oradell Reservoir to verify this assumption.

There are not many commonly known sources of TP during dry conditions but the Tenakill Brook Watershed is suspected to have faulty sanitary infrastructure that leaks human waste into the stream even during dry conditions. This untreated human waste is high in nutrients, such as TP, and pathogenic bacteria. Under wet conditions TP sources are better known. Excess fertilizer transported by stormwater runoff is a major source of TP during wet conditions. The Tenakill Brook Watershed is almost completely built (Figure 2) with lawns throughout the watershed. It is very probable that excess fertilizer is washed off lawns and other manicured landscapes (i.e., golf courses) during storm events and entering nearby streams.

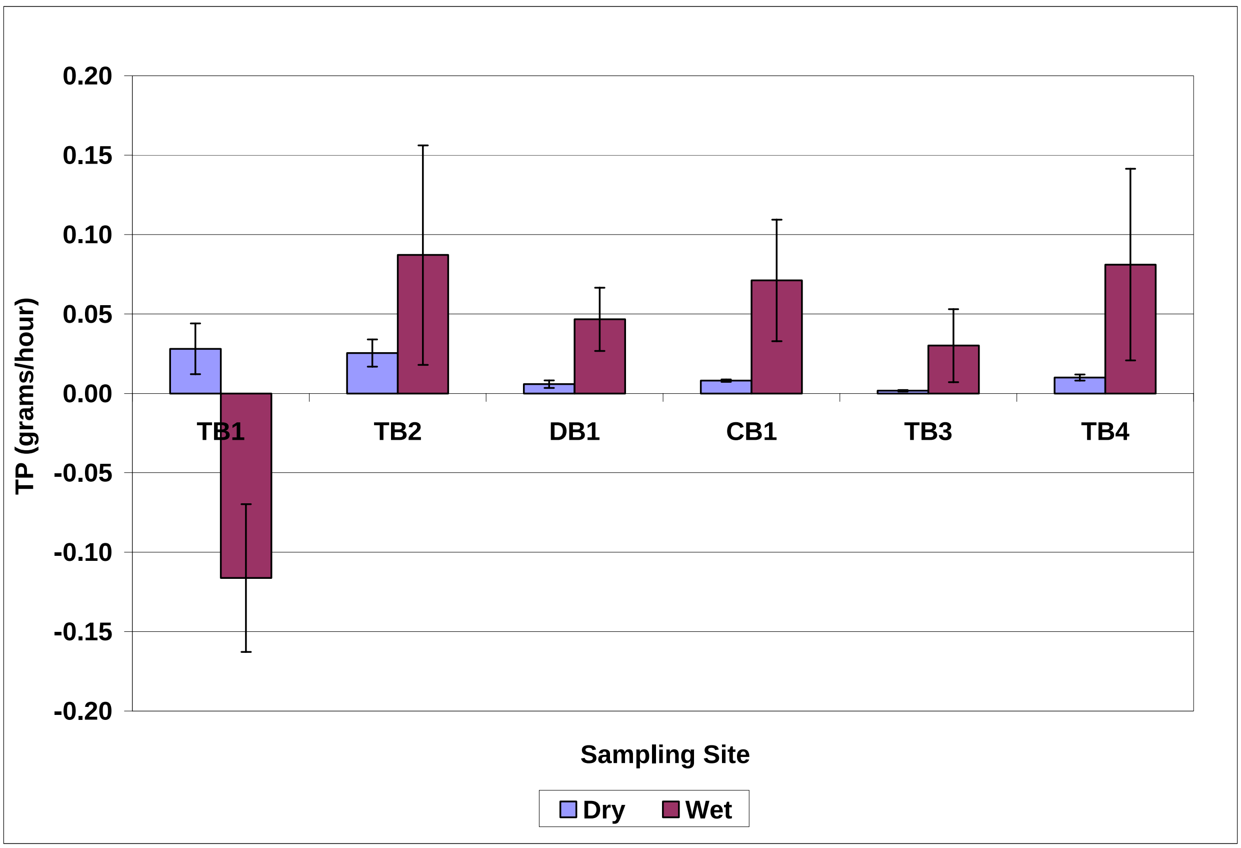
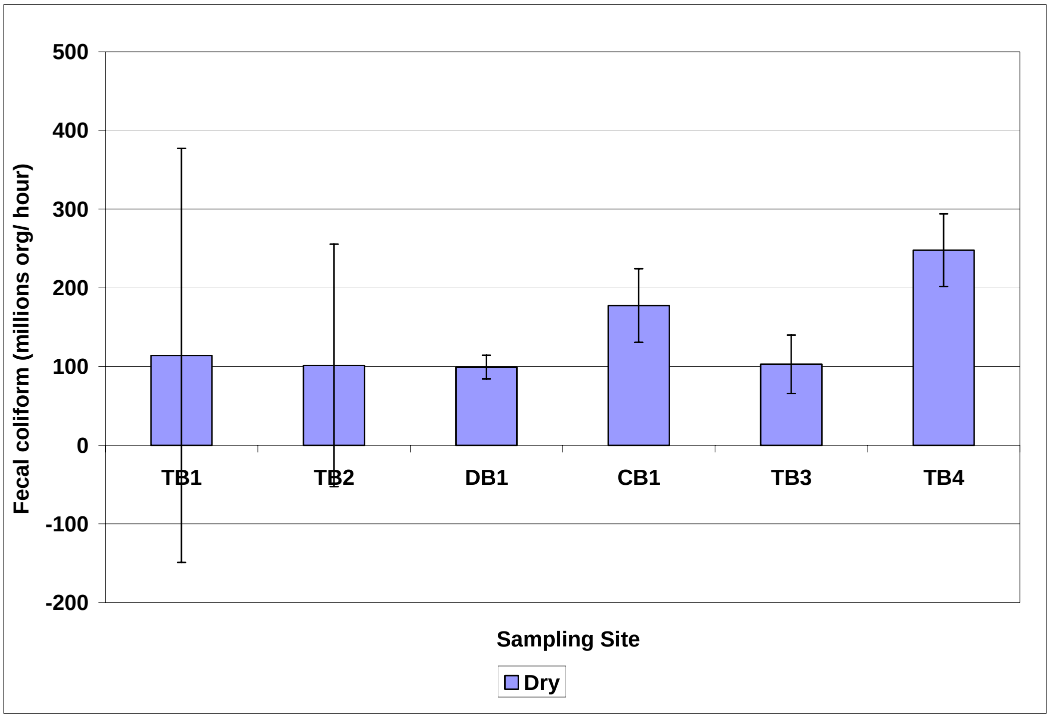


Figure 19: Comparison of hourly total phosphorus (TP) loads per subwatershed under dry and wet conditions.

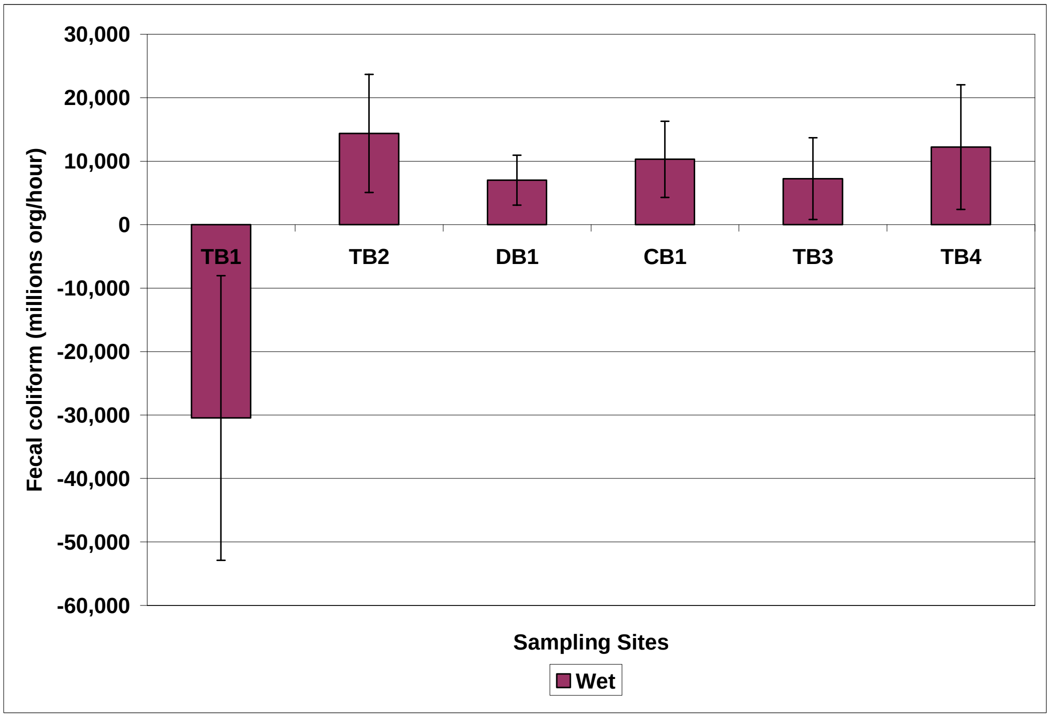
2. Fecal Coliform

The former surface water quality criterion for bacterial quality of FW2 surface waters was that the geometric mean of fecal coliform not exceed 200 counts of organisms (colonies) per 100mL (counts/100mL) and that 10% of the samples not exceed 400 counts/100mL (Table 1). Since initiation of this project, the indicator organism of bacterial quality has changed for freshwaters in New Jersey to the use of *Escherichia coli* (*E. coli*). For this report, however, both the former standard for fecal coliform and *E. coil* will be applied to data collected in the Tenakill Brook Watershed since it is a fecal coliform TMDL that is the driver of restoration efforts (Table 1). In the Tenakill Brook Watershed, all seven monitoring stations exceeded the geometric mean of 200 counts/100 mL over the course of the data collection period. In addition, all stations exceeded the 400 counts/100 mL standard on ten or more occasions during the sampling season (Table 4).

As stated in the TMDL, occurrences of high fecal bacteria in surface waters are largely due to storm events (NJDEP, 2003). Fecal coliform loads were calculated in the same manner as TP loads and were also compared between wet and dry events. Fecal coliform loads were greater in six of the seven subwatersheds during sampling events when stream volume was greater than baseflow (Figures 20A-20B). Only subwatershed TB1 had lower loadings during wet events (Figure 20B). Assimilation, predation, or some other loss of fecal coliform may be occurring upstream of this location.



(A)



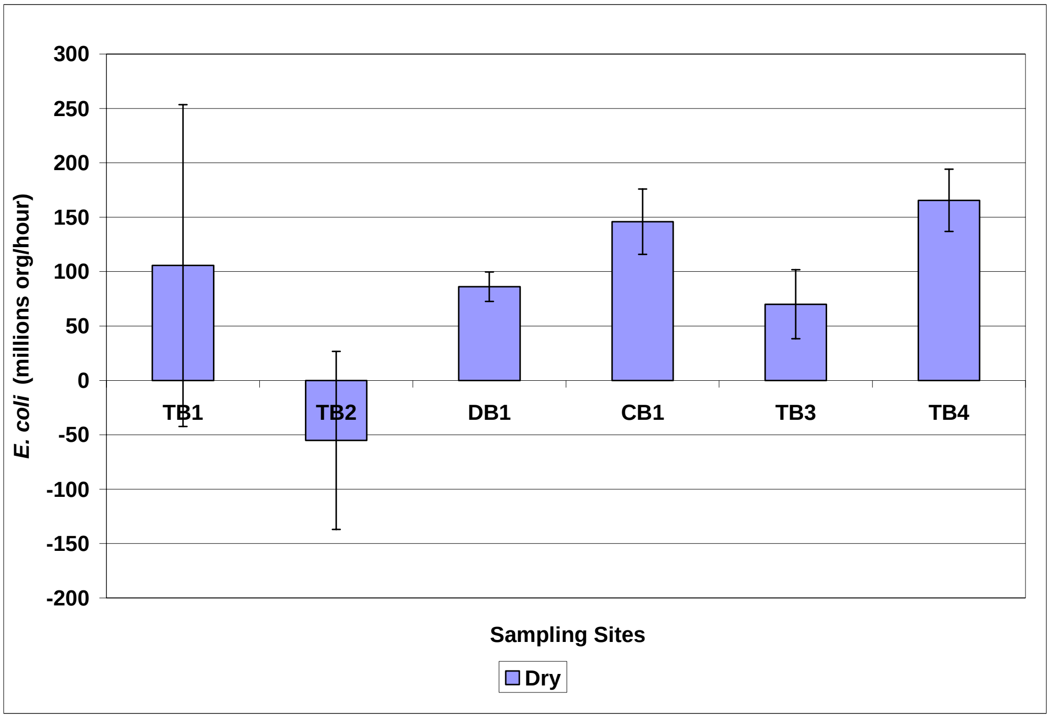
(B)

Figure 20: Comparison of hourly fecal coliform (FC) load by subwatershed under dry (A) and wet (B) conditions.

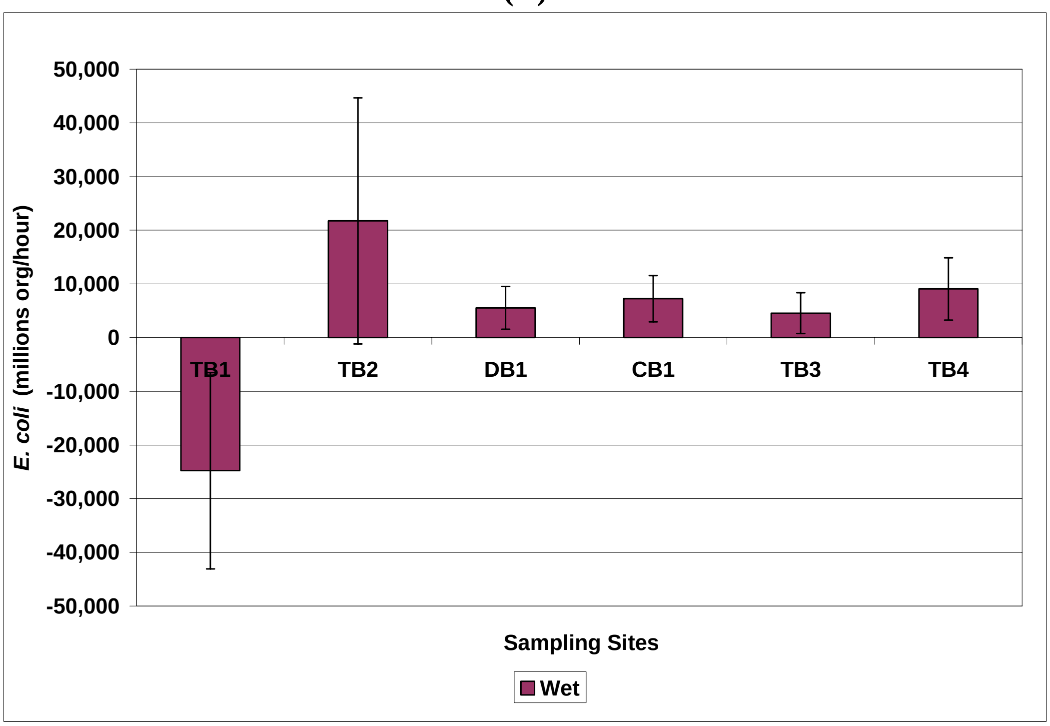
3. Escherichia coli (E. coli)

E. coli is one species of fecal coliform bacteria that is specific to fecal material from humans and other warm-blooded animals. The USEPA recommends *E. coli* as the best indicator of health risk from water contact in recreational waters and New Jersey changed its water quality criteria accordingly (NJDEP, 2011b). The newly adopted *E. coli* surface water quality criterion for FW2 waters is that the geometric mean not exceeds 126 counts/100mL (Table 1; NJDEP, 2011b). In the Tenakill Brook Watershed, *E. coli* results followed the same pattern as fecal coliform with all seven monitoring stations exceeding the water quality criteria over the course of the data collection period with maximum *E. coli* concentrations exceeding 235 counts/100 mL at least seven times at all stations during sampling (Table 4).

E. coli loads were calculated in the same manner as TP and fecal coliform loads and were also compared between wet and dry events (Figures 21A-21B). *E. coli* loads were greater in six of the seven subwatersheds during wet sampling events (Figure 21B). This is the same pattern seen in the fecal coliform data (Figures 20A-20B). Only subwatershed TB1 had lower loadings during wet events (Figure 21B). The TB2 subwatershed, which has the highest loads of *E. coli* during wet weather, is a sink for *E. coli* during dry weather in the Tenakill Brook Watershed (Figure 21A). The suspected loss mechanisms for fecal coliform (e.g., assimilation and predation) would also reduce *E. coli* levels upstream of these locations.



(A)



(B)

Figure 21: Comparison of daily *E. coli* load by subwatershed under dry (A) and wet (B) conditions.

VII. Source Identification of Pollutants of Concern

Due to the extent and frequency of violation of applicable water quality criteria, both TP and pathogenic bacteria (fecal coliform and *E. coli*) pollution are of primary concern in the Tenakill Brook Watershed (Table 4). Elevated levels of these parameters were seen at all stations during the course of this study. As stated earlier, a TMDL has been established to reduce fecal coliform levels in the watershed, indicating the importance of addressing this parameter and its impact on water quality. Control and reduction of pollutants, however, are only effective when their sources have been determined and targeted efforts are used.

A. Total Phosphorus (TP)

Lawn fertilizers, domestic animal wastes, and failing sewer systems are potential residential nonpoint sources of phosphorus carried by stormwater runoff and groundwater. Road runoff during storm events may also carry high concentrations of TP to streams and rivers (Flint and Davis, 2007).

In addition, there are many man-made impoundments and lakes along the Tenakill Brook (Figure 1). These areas may be accumulating sediments and sediment-bound phosphorus and harboring potential sinks for these pollutants. If the lakes are functioning as a sink for water quality contaminants, then it is likely that the water quality of the lake and its sediments are impacted. Nutrients that are accumulating in these waterways can create eutrophic conditions represented by algal growth, loss of dissolved oxygen, and lake filling. Study on the lakes and any accumulated sediment and sediment-bound phosphorus is beyond the current scope of this project, but further research would be necessary to determine the impact of these impoundments on water quality within the Tenakill Brook Watershed. Water quality of these lakes may ultimately indicate that the expensive option of dredging is necessary to maintain watershed health and improve water quality.

B. Fecal Coliform & E. coli

Using an indicator organism like fecal coliform or *E. coli* to solve pathogen problems in surface waters presents several challenges. First, these bacteria are solely indicators of fecal pollution and not a direct measure of fecal contamination. Second, the measurement of fecal coliform and *E. coli* concentration does not identify sources of fecal pollution as they are found in many different types of mammals. Therefore, it is imperative that prior to any remediation strategies the potential sources of pollution be identified. Failing septic systems are one potential source of fecal contamination. For those areas serviced by a centralized wastewater treatment plant, failing infrastructure could be a hazard that would result in waters impaired by bacteria.

Other sources throughout the Tenakill Brook Watershed include wildlife (deer, raccoons, and muskrats), pets (dogs and cats) and waterfowl (ducks and Canada geese). Canada geese were present at many locations during many SVAP assessments (Table 9). Canada goose access to waterways leads to direct discharge of fecal matter into the streams, and locations where waterfowl have access to surface waters have been identified through field visits. Improper disposal of domestic pet waste is also a potential source of pathogen pollution. Recently, dumpsters have been recognized as a source of pathogens in stormwater runoff due to birds using dumpsters as feeding locations; this is also true of rodents (Central Coast Water Board, 2006).

MST was employed to determine bacterial pollution sources within the Tenakill Brook Watershed. While it is difficult to pinpoint sources of pollution based upon two sampling events, sources could be estimated by the frequency of detection of specific markers at particular stations over these two summer events. Due to the presence of human-derived bacterial markers detected at many of the sites, potential sources could include failing septic and/or sewer systems or improperly treated human waste as potential sources of fecal contamination.

The potential for human fecal matter in streams is a serious public health threat and needs to be addressed. All subwatersheds in the Tenakill Brook Watershed should be considered for control of bacterial contamination due to the high number of samples that violated the water quality criteria for fecal coliform and *E. coli* (Table 4). Surface waters contaminated with human feces may also carry enteric pathogens including the hepatitis A virus, *Salmonella enterica* serovar Typhi, Norwalk group viruses, and others. Therefore, the control of human sources of pathogens is imperative for both ecological health and human health in the Tenakill Brook Watershed.

VIII. Priority Ranking

The calculated annual loads were used to rank the subwatersheds to prioritize restoration and protection efforts. Because stormwater best management practices and implementation projects typically target pollutant loading reductions during wet weather conditions, rankings are based on wet weather loadings.

The subwatershed with the highest loading rate was given one (1) point, the next highest was given two (2) and so on. The points were combined, and the subwatersheds were ranked highest to lowest according to their total points (minimum of 3 points to a maximum of 18 points, with lower values indicating highest loading impact). The loading rates show which subwatershed is contributing the most pollutants into the stream. The final step in this analysis was to combine the priority rankings for TP, fecal coliform and *E. coli* to create an overall ranking for each subwatershed. These rankings will help prioritize the implementation of stormwater best management practices. For all three pollutants of concern, loadings from subwatersheds TB2, TB4, and CB1 are the top three contributors to water quality impairments (Table 10).

Table 10: Priority subwatersheds of the Tenakill Brook Watershed based upon pollutant loadings.

Subwatershed	Priority
TB2	1
TB4	2
CB1	3
DB1	4
TB3	5
TB1	6
TB6	n/a

The prioritization and ranking reflect the conclusions drawn from the surface water quality sampling results. The Tenakill Brook Watershed is significantly impaired, with pollutant loadings due largely to human activities, potential infrastructure failures, and unstable stream conditions. Areas in the priority subwatersheds will be targeted for implementation of management measures to restore the watershed and improve water quality.

IX. Nonpoint Source Pollution Management Measures

The Tenakill Brook Watershed Restoration and Protection Plan was developed to identify projects and programs designed to reduce nonpoint source pollution. In the Tenakill Brook Watershed, bacterial contamination (by fecal coliform and *E. coli*) and excessive TP loads are of greatest concern. Implementation of the suggested projects will aid in achieving the goals set up in the appropriate TMDLs. These projects have been prioritized based on a subwatershed basis, percent removal of pollutants, impact on the watershed's discharge quality, overall cost-effectiveness, and best professional judgment. Projects aim to reduce connected impervious cover, improve riparian buffers, control geese access to streams, and improve stakeholder knowledge on the importance of stormwater management.

A. Recommended Management Measures

As the population within the Tenakill Brook Watershed has remained fairly stable and land use has not changed significantly in recent years, the observed impacts to the Tenakill Brook and within the watershed are not likely due to recent changes in the landscape. Similarly, the scope for future land use change is limited as much of the area within the Tenakill Brook Watershed has already reached capacity for development. Therefore, restoration and protection efforts need to focus on changes that can be accomplished within the current land use and environmental framework to be effective. This may include a combination of both institutional and structural controls. All proposed recommendations described below will function to decrease stormwater flows, increase infiltration, and ultimately reduce pollutant loading so that the Tenakill Brook and its tributaries meet the water quality criteria for its designated uses.

1. Rain Gardens

Designating areas within the watershed for increased stormwater infiltration is one method to reduce stormwater flow and does not require setting aside large tracts of land for construction. The general theory is to provide portions of the landscape where stormwater typically flows overland and changing the nature of the surface such that some of the stormwater volume is allowed to infiltrate into the ground. This requires permeable soils that allow stormwater to quickly seep into the soils before becoming saturated to the point of inefficiency. This recommendation is different from a detention/retention basin as it could spread the load of stormwater control over a large number of smaller infiltration areas, including individually-owned properties in the form of rain gardens or infiltration strips.

Rain gardens can be a simple and easily implemented best management practice (BMP) for private land owners and could also be employed on property right-of-ways where stormwater overland flow occurs. A rain garden is a landscaped, shallow depression designed to capture, treat, and infiltrate stormwater at the source before it reaches a stormwater infrastructure system or a stream. Plants used in the rain garden help retain pollutants that could otherwise degrade nearby waterways. Rain gardens are becoming popular in many suburban and urban areas. These systems not only improve water quality, but also help homeowners minimize the need for watering and applying fertilizer to large turf grass areas, as well as promote groundwater recharge. If designed properly, these systems improve the aesthetics of neighborhoods through the use of flowering native plants and attractive trees and shrubs.

A typical rain garden is designed to capture, treat, and infiltrate the water quality design storm of 1.25 inches of rain from a 1,000 square foot impervious area from an individual lot (i.e., a 25 foot by 40 foot roof for a house or a 20 foot wide by 50 foot long driveway). By collecting runoff generated by the first 1.25 inches of rainfall, the rain garden prevents the "first flush" of runoff from entering the stream, which characteristically has the highest concentration of contaminants. For the water quality design storm of 1.25 inches of rainfall, the rain garden needs to be 10 feet by 20 feet and six inches deep. Since 90% of all rainfall events are less than one inch, rain gardens are able to treat and recharge the majority of runoff from these storms. If designed correctly, rain gardens will reduce the pollutant loading from a drainage area by 90% wherever they are installed. Furthermore, they reduce stormwater runoff volumes and reduce the flashy hydrology of local streams. This reduction of flashy hydrology will minimize stream bank erosion and stream bed scour, thereby reducing TSS and TP loads to nearby waterways. Rain gardens have also been found to remove 90% of fecal coliform from stormwater runoff (Rusciano and Obropta, 2007).

Rain gardens can be installed almost anywhere. Ideally the best installation sites are those where the soils are well-drained so that an underdrain system is not required. However, any diversion runoff and filtration through native vegetation in the watershed would help reduce pollutant loading to the stream.

2. Pervious Pavement

Reduction of impervious surfaces with the installation of permeable or pervious surfaces is another BMP that can help reduce stormwater flow, increase groundwater recharge, and improve water quality. Pervious surfaces include asphalt, concrete, or even interlocking concrete blocks with soil and grass growing within the voids. These surfaces allow water to pass through the land surface into an underlying reservoir (stones or gravel) that provides temporary runoff storage until infiltration to the subsurface soils can occur. Primary applications for these surfaces are low traffic or parking areas that do not see a high volume of vehicular traffic but have significant areas of impervious surfaces.

3. Green Streets

Roadways cover a significant percentage of land in most urban communities, and thus offer a unique opportunity for stormwater management. Green streets can include combinations of features such as vegetated curb extensions, flow-through planter boxes, and pervious paving to reduce stormwater flow and improve water quality.

A curb extension is an angled narrowing of a roadway with a concurrent widening of the sidewalk space. Rain gardens can be incorporated into these extensions to capture stormwater flow from streets. Flow-through planter boxes are long, narrow landscaped areas with vertical walls and flat bottoms open to the underlying soil. They allow for increased stormwater storage volume in minimal space. The plants and topsoil within the boxes contribute to stormwater filtering and treatment for improved water quality. Planters can also be designed to incorporate street trees.

4. Rain Barrels

An additional recommendation to reduce a limited volume of stormwater flow from individually-owned properties is the installation of rain barrels at roof gutter downspouts. Considering that a vast majority of the Tenakill Brook Watershed is occupied by residential properties, there is a large surface area of roofs that contribute to impervious surface runoff. While many gutter systems drain to lawns where infiltration can occur, a significant portion of drainage systems were observed that drain gutter runoff directly to street curbs and even in some instances directly to the Tenakill Brook (see *Appendix B).* A rain barrel is placed under a gutter's downspout next to a house to collect rain water from the roof. The rain barrel holds about 50 gallons of water which can be used to water gardens and for other uses. Harvesting rain water has many benefits including saving water, saving money on utility bills, and preventing flooding of basements. By collecting rain water, homeowners are also helping to reduce flooding and pollution in local waterways. With education and implementation, it could become part of an overall approach for homeowner action.

5. Bank Stabilization, Riparian Buffer Restoration, and Floodplain Reconnection

Stream restoration is the re-establishment of the general structure, function and natural behavior of the stream system that existed prior to disturbance. It is a holistic process that requires an understanding of the physical and biological processes of the stream system and its watershed. Restoration includes a broad range of measures, including the removal of the watershed disturbances that are causing stream instability, installation of structures and planting of vegetation to protect streambanks and provide habitat, and the reshaping or replacement of unstable stream reaches into appropriately designed functional streams and associated floodplains.

There are a number of areas along the Tenakill Brook where steep and unstable or unvegetated banks are eroding. There are several bank stabilization methods that alleviate excessive sedimentation and allow for the interception of direct storm flow. The installation and planting of native riparian plant species in unvegetated areas is feasible for the Tenakill Brook Watershed to help stabilize the exposed and eroding bank areas and reduce the sediment loads in its waterways. This form of bank stabilization can be conducted in a relatively cost-effective manner.

Increased buffer areas in the riparian corridor can reduce both stormwater flow and pollutant loading. Riparian zones are recognized for their ability to perform a variety of functions, including erosion control by regulating sediment storage; stabilizing stream channels; serving as nutrient sinks; reducing flood peaks; and serving as key recharge points for renewing groundwater supplies. They create better macroinvertebrate habitat within the stream by increasing canopy cover and reducing water temperatures. Additionally, riparian buffers can also deter Canada geese and other waterfowl from entering the waterway.

Finally, there are sections of the Tenakill Brook where downcutting is occurring. This is the deepening of the river so that it loses its ability to rise beyond its banks into the floodplain. This disconnection from the floodplain makes the stream flow much faster during storm events and limits its ability to provide stormwater detention in its floodplains. Several of these areas should be examined for possible reconnection to the floodplain. Once reconnected to the floodplain, flood waters will move much slower downstream and receive treatment by floodplain vegetation. Caution needs to be taken in these reconnection projects so as to not put infrastructure and buildings in danger as a result of flood waters.

A riparian buffer restoration project was completed by the RCE Water Resources Program in 2007 in Roosevelt Commons Park to stabilize and vegetate 685 linear feet of streambank (see *Appendix A: Roosevelt Commons Shoreline Restoration Project*). This project was monitored in 2009 to determine the impact of the restoration on bacteria levels (fecal coliform and *E. coli*). The project was successfully able to reduce bacteria levels by 91% for fecal coliform and 84% for *E. coli*. For details on this project and its results see *Appendix A*.

B. Site Specific Restoration Projects

The major emphasis of the recommended remediation strategies is to retain stormwater runoff and reduce loadings by disconnection of impervious surfaces, riparian corridor restoration, implementing goose/waterfowl deterrents, and initiating or enhancing education for students, homeowners, businesses, and other audiences on the proper management techniques for runoff and pollutant control. Watershed-wide strategies should readily produce enhancements to the flow regime and water quality throughout Tenakill Brook Watershed. Site specific strategies should provide localized remediation for sources of stormwater runoff and the associated contaminants while also serving as a demonstration for universal application to foster a more effective restoration and protection program.

For each subwatershed, BMP opportunities were identified in each municipality. Each site was field inspected and a brief description of the site and possible BMPs are presented by municipality in *Appendix B: Site Specific Nonpoint Source Management Measures for Municipalities in the Tenakill Brook Watershed*. Each potential project was given a unique identification number to track the location and proposed remediation projects. In *Appendix B*, information for each project is presented including site description, land use, area of project, existing pollutant loading from each project site as calculated using areal loading coefficients, recommended management measure and type of proposed BMP, estimated implementation costs, and load reductions anticipated by the BMP. Areal loading coefficients were used to determine the load reductions for TP, total nitrogen (TN), and TSS (NJDEP, 2004b). These loading coefficients were multiplied by the area disconnected for each of the identified project sites. Annual pollutant loading reductions and water quantity reductions are based on 90% volume reductions as the proposed management measures are designed to capture all runoff from two-year rainfall events and are estimated to capture 90% of the annual rainfall (44.1 inches in Bergen County).

Loading coefficients have not been created for fecal coliform or *E. coli*, making estimation of load reductions by this method inappropriate (NJDEP, 2004b). Estimation of fecal coliform and *E. coli* is further made difficult due to multiple sources of fecal contamination (wildlife feces, improper pet waste disposal, leaking septic systems, faulty sewer infrastructure) having different bacteria concentrations and loading rates. For example, Canada geese (*Branta canadensis*) have been noted as a possible source of fecal contamination in the Tenakill Brook Watershed. The number of geese seen during field visits will vary for each site visit, due to the migratory nature of these animals. This makes proper enumeration of potential fecal loads extremely difficult to achieve. Beyond the ability to estimate bacterial loads from sampling data, estimation of bacterial loadings needs to be performed on a site by site basis to determine the impact of proposed water quality improvement projects. While rain gardens have been found to remove 90% of fecal coliform from stormwater runoff (Rusciano and Obropta, 2007), other measures described in this report (such as pervious pavement and rain barrels) do not have available information on bacteria removal rates.

C. Additional Recommended Actions

Additional projects and programs are recommended to improve water quality within the Tenakill Brook Watershed and are included in *Appendix C: Projects to Address Known Water Quality Impairments in the Tenakill Brook Watershed.* Each of these proposed actions provides the following project information:

- Summary of current conditions at the location or in the watershed
- Anticipated pollutant removal
- Potential funding sources and project partners
- An estimate of cost

These projects have been prioritized based on a subwatershed basis, percent removal of pollutants, impact on the watershed's discharge quality, overall cost-effectiveness, and best professional judgment. Projects aim to reduce connected impervious cover, improve riparian buffers, control geese access to streams, and improve stakeholder knowledge on the importance of stormwater management. Engineering drawings for selected projects can be found in *Appendix D: Engineering Plans for Implementation Projects to Address Known Water Quality Impairments in the Tenakill Brook Watershed*.

X. Point Source Pollution Management Measures

Although the primary focus of this plan is to address nonpoint source pollution, MST was conducted, and human bacterial contamination was detected, particularly in subwatersheds TB1, TB2, TB3, and TB4. Even though the significance of the human sources as compared to other sources is unknown, it is highly recommended that further study be completed to better track down these human sources and remediate them. A common practice among sewer authorities is to videotape the sanitary sewer lines to identify breaks that might allow wastewater to leak from the sewer lines and discharge into local waterways. Haworth Borough conducted such videotaping in 2008 and found deficiencies in the sanitary sewer infrastructure. Only a small portion of Haworth Borough, however, is located in the Tenakill Brook Watershed. The other municipalities in the watershed should consider videotaping their sewer lines and performing appropriate corrective measures, such as possibly installing liners in areas where leaks are detected.

XI. Information and Education Component

RCE helps the diverse population of New Jersey adapt to a rapidly changing society and improve their lives through an educational process that uses science-based knowledge. RCE focuses on issues and needs relating to agriculture and the environment; management of natural resources; food safety, quality, and health; family stability; economic security; and youth development. RCE is an integral part of the New Jersey Agriculture Experiment Station and Rutgers, The State University of New Jersey and is funded by the United States Department of Agriculture, the State of New Jersey, and County Boards of Chosen Freeholders.

The Water Resources Program is one of many specialty programs under RCE. The goal of the Water Resources Program is to provide solutions for many of the water quality and quantity issues facing New Jersey. This is accomplished through research, project development, assessment and extension. In addition to preparing and distributing fact sheets, RCE provides educational programming in the form of lectures, seminars, and workshops as part of our outreach to citizens. With New Jersey Agriculture Experiment Station funding and other State and Federal sources, RCE conducts research that will ultimately be used by stakeholders to improve water resources in New Jersey.

In addition to the RCE Water Resources Program, several not for profit organizations devoted to environmental protection and watershed management are active in the region. Bergen Save the Watershed Action Network (Bergen SWAN) and the Hackensack Riverkeeper, Inc. offer educational programs focused on their areas of interest. Examples of programs include paddle tours along the Hackensack River and other streams and rivers, environmentally friendly landscaping workshops, rain barrel and rain garden lectures, and river clean-ups. For more information on these organizations and their educational programs, please visit Bergen SWAN at http://www.bergenswan.org and the Hackensack Riverkeeper, Inc. at http://www.hackensackriverkeeper.org/.

Programs listed below are a small sample of educational opportunities offered by RCE and are available in New Jersey. The RCE Water Resources Program plays an important role, offering programs delivered to municipalities and working with local stakeholders to educate them on specific concerns in their area. Many of these programs have been developed and tested with great success throughout New Jersey. Some may have to be adapted to the specific conditions and issues affecting the Tenakill Brook Watershed prior to being delivered. Depending on the scope of the need for these programs, additional funding will have to be acquired by the RCE Water Resources Program to deliver the appropriate programs. Along with the RCE Water Resources Program, the USEPA and NJDEP offer newsletters, brochures and other outreach materials that can be used to supplement programs that educate stakeholders. These materials and the programs described below can be tailored to the specific needs and issues affecting the Tenakill Brook Watershed.

For more information on the RCE Water Resources Program and its educational opportunities, please visit http://www.water.rutgers.edu/.

A. Rain Garden Programs: Schools and Landscapers

The RCE Water Resources Program offers several outreach programs that work with various groups to install rain gardens. The goal of these programs is to help local groups build capacity to install rain gardens throughout their community and improve water quality. One such program is called *Stormwater Management in Your Backyard* that has the general public as the target audience (see description below). The program focuses on educating the public about stormwater management and provides alternatives for improving stormwater quality at home. As part of this program, participants are taught how to design and build a residential rain garden.

Stormwater Management in Your Backyard has been adapted by RCE Water Resources Program for use with school children under the program *Stormwater Management in Your School Yard.* This program focuses on educating K-12 students on stormwater management and also includes instruction on how to design and build a rain garden. Often this program is accompanied by the construction of a demonstration rain garden designed by the students on the school grounds.

Two rain garden certificate programs are also available from the RCE Water Resources Program. One is a certification program for individuals providing intensive instruction on how to design, build and maintain rain gardens. The second program is aimed at landscapers and is very similar to the certification program for individuals except it includes much more detail on how landscapers could offer rain garden construction as a service. To learn more about rain gardens, visit http://www.water.rutgers.edu/Rain_Gardens/RGWebsite/raingardens.html.

B. Stormwater Management in Your Backyard

This program provides in-depth instruction on stormwater management. It introduces the factors that affect stormwater runoff, point and nonpoint source pollution, impacts of development (particularly impervious cover) on stormwater runoff, and pollutants found in stormwater runoff. An overview of New Jersey's stormwater regulations is presented including who must comply and what is required. Additionally, TMDLs are introduced along with various other requirements of the Federal Clean Water Act that have serious implications in New Jersey. Different types of BMPs are presented and how these BMPs can be used to achieve the quality, quantity and groundwater recharge requirements of New Jersey regulations are illustrated. BMPs discussed include bioretention systems (rain gardens), sand filters, stormwater wetlands, extended detention basins, infiltration basins, manufactured treatment devices, vegetated filters, and wet ponds.

The program also discusses various management practices that homeowners can install including dry wells, rain gardens, rain barrels, and alternative landscaping. Protocols for designing these systems are reviewed in detail with real world examples provided. A step by step guide is provided for designing a rain garden so that homeowners can actually construct one on their property. Students have an opportunity to bring in sketches of their property for review and discussion of various BMP options for each site. The course also provides a discussion of BMP maintenance focusing on homeowner BMPs. The course concludes with a discussion of larger watershed restoration projects and how students can lead these restoration efforts in their communities. The course is very interactive, and ample time is set aside for question and answer sessions. For more information about *Stormwater Management in Your Backyard*, visit http://www.water.rutgers.edu/Stormwater_Management/SWMIYB.html.

C. Environmental Stewards Program

RCE partnered with Duke Farms in Hillsborough, NJ to create a statewide Environmental Stewardship certification program. Participants learn land and water stewardship, BMPs, environmental public advocacy, and leadership. Each group meets twenty times for classroom and field study. They are taught by experts from Rutgers University and its partners. Students are certified as Rutgers Environmental Stewards when they have completed sixty hours of classroom instruction and sixty hours of a volunteer internship. Classes were held at the Essex County Environmental Center in Roseland, Duke Farms, and the Rutgers EcoComplex in Bordentown. Partners ask students to provide volunteer assistance to satisfy their internship requirements.

Graduates of this program become knowledgeable about the basic processes of earth, air, water and biological systems. They gain an increased awareness of techniques and tools used to monitor and assess the health of the environment. They gain an understanding of research and regulatory infrastructure of state and federal agencies operating in New Jersey that relate to environmental issues. Unlike some programs, they are also given an introduction to group dynamics and community leadership. Participants are taught to recognize elements of sound science and public policy while acquiring a sense of the limits of our current understanding of the environment. The goal of the Rutgers Environmental Stewards program is to give graduates knowledge to expand public awareness of scientifically based information related to environmental issues and facilitate positive change in their community. For more information on the Rutgers Environmental Stewards Program, visit http://envirostewards.rutgers.edu/.

D. Streamside Living

Property owners living along streams, lakes, and ponds can assist with maintaining natural stream corridors, as well as protect and enhance their property by practicing watershed friendly property management. Watershed friendly property management entails planning, planting, and caring for lawns and gardens in ways that complement the soils, climate, and natural character and vegetation of the watershed. Properly landscaped streamside areas can be beautiful, environmentally friendly, and easy to maintain. They can also aid in preventing erosion, act as a filter for rainwater from downspouts, walkways and driveways, and promote water conservation.

States such as Pennsylvania and Virginia also have their own versions of Streamside Living educational programs that could be used as models for the development of programs specific to New Jersey, especially the Tenakill Brook Watershed's needs and conditions. The extension programs should include pertinent information on: limiting the use of pesticides, herbicides, and fertilizer; establishing a no-mow zone along banks; protecting storm drains from debris; planting native trees, shrubs, perennials and grasses; and identifying and removing invasive plants. The curriculum should include state and local regulations on the aforementioned issues to ensure that homeowners are in compliance with such rules.

More information on the Streamside Living program can be found in *Appendix C: Projects to Address Known Water Quality Impairments in the Tenakill Brook Watershed*.

E. New Jersey Watershed Stewards Program

The statewide program New Jersey Watershed Stewards (NJWS) was developed by the RCE Water Resources Program in 2009. The idea of the NJWS program was developed as a result of the Water Resources Program faculty and staff attending the National Water Conference in St. Louis in February 2009. The Water Resources Program faculty and staff learned about the successful Watershed Stewards programs of other states, such as in Maine and Texas. The success of these programs inspired the Water Resources Program faculty and staff to develop a Watershed Stewards program for New Jersey.

The NJWS program was designed to raise awareness and empower stakeholders to solve problems of nonpoint source pollution in watersheds throughout New Jersey. As part of the NJWS program, stakeholders complete in-class training, as well as participate in a watershed-scale apprenticeship to obtain the title of a "New Jersey Watershed Steward." Inducted stewards become instrumental in continuing participation in watershed projects in New Jersey and improve the water quality of New Jersey watersheds.

The first NJWS program was offered in spring 2010 at the Rutgers EcoComplex located in Bordentown, NJ. The program included four modules: one on the NJWS program, the second on watershed definition and classification, one on watershed impairments, and a final one on watershed approaches and solutions to watershed impairments. In addition to these modules, class activities were implemented to engage trainees in the program. Upon completion of a one day training program, trainees were required to participate in a NJWS apprenticeship project where they would participate in a watershed-scale project (e.g., installing rain gardens, visually assessing streams, assembling rain barrels, etc.).

The goals of the NJWS program are to:

- Increase stakeholder involvement in Watershed Protection Plan and/or TMDL development processes by educating and organizing local citizens
- Promote healthy watersheds by increasing citizen awareness, understanding, and knowledge about the nature and function of watersheds, potential impairments, and watershed protection strategies to minimize nonpoint source pollution
- Enhance interactive learning opportunities for watershed education across the state and establish a larger, more well-informed citizen base
- Empower individuals to take leadership roles involving community and watershed level water resource issues
- Integrate watershed assessment research, education, and extension
- Deliver local solutions to community and watershed level water resource issues

For more information regarding the NJWS program, please visit http://www.water.rutgers.edu/Watershed_Stewards/Watershed_Stewards.html.

F. Sustainable Jersey™

Sustainable Jersey™ is a certification program for municipalities in New Jersey that want to go green, save money, and take steps to sustain their quality of life over the long term. Sustainable Jersey™ identifies actions communities can take to become leaders on the path toward sustainability and in the process become "certified" communities. Sustainable Jersey™ provides the tools, guidance, and incentives to enable communities to make progress toward sustainability. The certification is a prestigious designation for municipal governments in New

Jersey. Municipalities that achieve the certification are considered by their peers, by state government, and by experts and civic organizations in New Jersey to be among municipalities leading the way toward environmental sustainability.

Of the eight municipalities within the Tenakill Brook Watershed, only Alpine and Demarest Boroughs are not registered with Sustainable Jersey™ (Sustainable Jersey™, 2011). Both of these Boroughs should be encouraged to enter the Sustainable Jersey™ certification process to help improve environmental conditions in the region. Englewood City has already become a certified community through this program (Sustainable Jersey™, 2011). Several of the actions that are required under the certification process also will help improve the water quality within the Tenakill Brook Watershed and achieve a portion of the goals of this plan. There are three Sustainable Jersey™ Actions that fall into this category: 1) Community Education and Outreach, 2) Water Conservation Education Program, and 3) Innovative Demonstration Projects - Rain Gardens. As the towns strive to achieve their Sustainable Jersey™ certification, they should focus on tailoring these three actions to help improve the water quality within the Tenakill Brook Watershed. For more information, visit http://www.sustainablejersey.com/ or email Sustainable Jersey™ at info@sustainablejersey.com.

G. Nonpoint Education for Municipal Officials (NEMO)

NEMO is a program created in the early 1990's to provide information, education and assistance to local land use boards and commissions on how they can accommodate growth while protecting their natural resources and community character. The program was built upon the basic belief that the future of our communities and environment depend on land use. Since land use is decided primarily at the local level, education of local officials is the most effective and most cost-effective way to bring about positive environmental changes and practices. This program is designed to provide educational programs for municipal officials, engineers, and department of public works employees. The goals of this program are to educate these groups on water quality issues associated with nonpoint source pollution, to provide possible solutions to mitigate nonpoint source pollution, and to inform on how land use decisions impact stream and river health. The NEMO program also includes low impact development training. Although there currently is not an official NEMO program in New Jersey, a program could be developed and implemented for municipalities in the Tenakill Brook Watershed if funding were available.

For more information, please contact Christopher C. Obropta, Associate Extension Specialist with the RCE Water Resources Program at obropta@envsci.rutgers.edu.

H. Green Infrastructure Seminars

The Water Resources Program partnered with the Sussex County Division of Planning in the fall of 2010 to pilot a Green Infrastructure Program throughout the county. The program focuses on reducing impacts to waterways and communities from aging sewer infrastructure and flooding and promoting groundwater infiltration and recharge in support of the water resources planning goals of the county. The initial program consisted of a series of educational and training seminars for communities throughout Sussex County and to implement four green infrastructure demonstration projects.

Topics covered during the seminars included educating community leaders, businesses, and residents on the benefits and opportunities for green infrastructure; training local contractors and professionals on green infrastructure installation techniques; and presenting opportunities to implement four green infrastructure demonstration projects in partnership with county and municipal entities in Sussex County. The initial series of educational seminars could be modified for Bergen County and specifically targeted to educating municipal staff and community leaders in the towns located within the Tenakill Brook Watershed. Specific demonstration projects presented during this seminar series would be taken from the list of implementation projects presented in this watershed restoration and protection plan. For more information on the Sussex County program and to view seminar slides, visit http://water.rutgers.edu/Projects/Sussex/Sussex.html.

XII. Interim Measurable Milestones

Development of this Watershed Restoration and Protection Plan is the result of analyzing previously collected data, collecting many water quality samples and several biological samples, and gathering input from local stakeholders. This multi-year and multi-step process is based on data collected in 2007 and follow-up field work completed in 2008. It is expected that since the time of data collection, some conditions in the watershed may have become altered, either benefiting water quality or worsening conditions.

With this in mind, implementation projects that have been identified are expected to have the most effective impact on water quality in the Tenakill Brook Watershed. The *Tenakill Brook*

Watershed Restoration and Protection Plan was developed using a holistic perspective, recommending projects and implementation efforts that will benefit local water quality beyond just what is mandated by TMDLs, including other parameters that may have yet been identified as impairing the watershed.

Projects that involve cessation of human-related pathogens are clearly the top priority, followed by erosion and sedimentation concerns and low cost-high benefit projects. It should be noted that many of these projects will entail several years of implementation before a project fully achieves its goals. Therefore, it is important that the *Tenakill Brook Watershed Restoration and Protection Plan* remain dynamic and its implementation an evolving process. This document should be consulted during the decision-making process for municipal and county governments as they proceed to plan for growth, keeping watershed protection and water resource protection an utmost priority.

XIII. Monitoring Component

Implementation of management measures will result in water quality improvements while minimizing flooding, promoting groundwater recharge or reuse, and other benefits. Both modeling and monitoring can be conducted to quantify these improvements.

Monitoring can be conducted to also quantify the improvements to the Tenakill Brook, its tributaries, and its watershed that result from implementation of this plan. NJDEP does maintain one benthic macroinvertebrate station on Tenakill Brook (Figure 10). This station can provide continued information on the improvement of water quality and its effects on aquatic biota. Moreover, water quality samples can be collected at the stations established by the RCE Water Resources Program (Figure 9) throughout the system and analyzed for various pollutants that are a concern within the watershed, such as nutrients and bacteria.

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