The Loantaka Brook Watershed Report
EPA Grant Number: X-97267701

Algal blooms on Kitchell Pond, Courtesy of Google Earth website, 2005 aerial

Submitted by:
Ten Towns Great Swamp Watershed Committee
2 Ridgedale Avenue
Suite 200
Cedar Knolls, NJ 07927
(973) 984-2000
1gerken@optonline.net

DUNS # 141565049
501(3)© - DLN:17053097012018
Fed Tax ID Number 22-3575281

Prepared by:
Princeton Hydro, LLC
Suite 1, 1108 Old York Rd.
P.O. Box 720, Ringoes, NJ 08551
(908) 237-5660
ssouza@princetonhydro.com

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Executive Summary –

This project was accomplished with funding (Grant Number: X-97267701) provided to the Ten Towns Great Swamp Management Committee (hereafter referenced as TTC) by the US Environmental Protection Agency (USEPA). The work detailed herein was implemented following an integrated work plan for Loantaka Brook and its watershed that was reviewed and approved by the USEPA, and includes water quality data collected following a USEPA approved Quality Assurance Protection Plan (QAPP).

The project's overall goal is to increase the brook's water quality and ecological services and functions using techniques that are cost-effective, sustainable, replicable and build on the success of past projects. This report is also the continuation of a nine-year dataset which details baseflow and stormflow pollutant concentrations and macroinvertebrate data. This data has been, and will continue to be, utilized as an empirical reference point for conducting watershed management in a logical progression to address those source areas which are the greatest threats to the Great Swamp's ecological integrity. While the focus of the sampling effort was Loantaka Brook, the project also investigated and documented the water quality conditions of the other tributaries of the Great Swamp.

Loantaka Brook is one of five main streams that drain to the Great Swamp National Wildlife Refuge. Together with Black Brook, Great Brook, Primrose Brook, and the Upper Passaic River, Loantaka Brook provides most of the inflow that sustains the Great Swamp National Wildlife Refuge. The Great Swamp National Refuge was established by Congress in 1960. The Great Swamp Refuge is located in Morris and Somerset Counties in New Jersey, and includes a 57 square mile watershed. It consists of 7,600 acres, and supports varied wildlife habitats for more than 244 species, including 26 state listed threatened and endangered species. Over any given year close to 300,000 people visit the Great Swamp Refuge which provides opportunities for hiking, wildlife observation and photography, and environmental education.

Loantaka Brook flows through the communities of Morristown, Morris Township, Chatham Township, and Harding Township. As with all of the streams draining to the Great Swamp, Loantaka Brook has been impacted by the development of the surrounding watershed. Of the five tributary streams, Loantaka Brook is documented as having the most impacted water quality. This is expressed as altered hydrology, and increased nutrient and sediment loading. The TTC has monitored the water quality, habitat, and biotic integrity of all the streams that drain to the Great Swamp. With these data the TTC developed comprehensive watershed management programs to correct the causes of nutrient and sediment loading. The objective of this project was to further refine the water quality database of Loantaka Brook, for the purpose of developing resource management and improvement solutions. The Scope of the Project, as presented in this report, essentially encompassed four main elements:

1. Expansion of the TTC's water quality database of Loantaka Brook and the other main tributaries of the Great Swamp through the analysis of water quality samples collected under baseflow and storm event conditions.
2. Detailed investigation of the stormwater collection system that currently channels stormwater runoff into Loantaka Brook. This involved a combination of field surveys of the systems and pollutant load modeling using a land-use based loading model
3. The identification of stormwater related impacts and development of conceptual specifications and plans for the correction of these problems. The focus of this element was on the stabilization of eroded stream segments in the upper, headwater reaches of Loantaka Brook. However, as the project evolved, it was discovered that the stream channel in this reach was not as unstable as theorized. As such the focus of this element of the project turned to the retrofit and upgrade existing stormwater detention basins and the conceptual design of a biodetention swale. It was determined that the brook's quality and ecological functions would be better served through such efforts as compared to realignment or restoration of the stream channel proper. Such measures can also be easily adapted and replicated in other areas of the Loantaka Brook watershed (as well as the other tributaries of the Great Swamp) thus expanding the utility of the recommendations presented in this report.
4. The conceptual design of a wetland system that will "polish" the effluent of a wastewater treatment plant that discharges to the brook immediately upgradient of the highly eutrophic

Loantaka Brook originates in a highly urbanized area of Morristown and receives much of its flow in the form of untreated stormwater runoff from roads and developed areas (Attachment A, Figures 2, 5 and 9). The main stem of Loantaka Brook flows south to Kitchell Pond and through the Loantaka Brook Reservation, one of the most heavily used recreational parks in Morris County, before entering the Great Swamp Refuge. Extensive water quality monitoring conducted for nine years by the NJDEP, the TTC and the Great Swamp Watershed Association (GSWA) identified the Loantaka Brook to be impaired, and Loantaka Brook is regarded as the highest contributor for nitrogen loading to the Great Swamp (Princeton Hydro, November 2008). Loantaka Brook also routinely suffers from elevated phosphorus, and sediment loads. A major source of nitrogen and phosphorus loading is the Woodland Wastewater Treatment Plant located immediately upstream of Kitchell Pond. Although the plant's operations are consistent with its NJPDES permit limitations, the effects are significant, especially in terms of the pond's eutrophication. However, additional sampling and modeling efforts have documented that the heavily developed headwater areas of Loantaka Brook are also contributing to the altered flow regimes and observed nutrient and sediment loading.

Modeling of the hydrologic and pollutant loading was conducted by Princeton Hydro utilizing the BasinSims 1.0 methodology, a Windows-ported version of GWLF (Generalized Watershed Loading Function). The modeling corroborated the water quality monitoring results, and identified the highly developed Subwatershed #1 within Loantaka Brook as the primary target for additional watershed management. The modeling identified Subwatershed #1 as contributing the highest loadings to Loantaka Brook of sediments, total phosphorous (TP), soluble reactive phosphorous (SRP), and was ranked as the second highest subwatershed for total nitrates (TN). Subwatershed #1 was also ranked as the second highest subwatershed for hydrology, contributing high runoff volumes.

The existing stormwater infrastructure and practices were evaluated for Loantaka Brook, with a focus on the densely developed Subwatershed #1 area north of Kitchell Pond. Various stormwater mitigation measures were evaluated and seventeen (17) potential mitigation measures are proposed in this report (Table 5.1, and Figure 20), with seven high priority mitigation projects outlined in more detail. Photographs, concept designs and mapping associated with the highest ranked mitigation projects are included in Attachment B and C.

As noted above, the Woodland Wastewater Treatment Plant is a major source of nutrient loading to the Loantaka Brook system. The water quality monitoring data compiled over the course of this study, along with the existing TTC database for Loantaka Brook, documents large spikes in phosphorus and nitrogen concentrations down gradient of the plant's discharge point. To abate this load, a created wetland complex was designed. This offline, multi-celled wetland complex is intended to "polish" the plant's effluent. The proposed treatment wetlands would be constructed within lands currently owned by the Morris County Parks Commission and utilized by the Seton Hackney Stables as pasture areas. As per the data developed in this study, the created wetlands are capable of treating approximately 60% of the effluent. At a design flow of 0.5 MGD, the system is capable of removing over 500 pounds of phosphorus per year mostly as a result of the attenuation of phosphorus by the wetland plants. Nitrogen removal will also occur through plant attenuation along with sedimentation and the volatilization of nitrogen gas and ammonia. Details of these plans are outlined in section 6.0 and concept plans are provided in Attachment D.

1.0 Introduction

The US Environmental Protection Agency (USEPA) awarded a grant (USEPA Grant Number: X-97267701) to the Ten Towns Great Swamp Watershed Management Committee (TTC) to conduct a series of watershed management related projects in the Loantaka Brook sub-watershed of the Great Swamp Wildlife Refuge and Wilderness Area. The overall purpose of this project was to address and correct documented non point source (NPS) related water quality impacts to Loantaka Brook. These impacts, which have been the subject of past studies and water quality sampling initiatives conducted by the TTC, are attributable to the development of the Loantaka Brook watershed and the mismanagement of the stormwater runoff. Some of these corrective measures include recommendations to:

- Implement stormwater best management practices and retrofits designed to decrease the rate and volume of runoff as well as intercept and decrease pollutant loading,
- Stabilize eroded stream banks through the implementation of bio-restoration and flow control measures,
- Restore the brook's ecological functions and services by improving its water quality

Through this project, the TTC sought to not only identify and quantify the means by which to correct established water quality impacts to Loantaka Brook, but to use this project as an opportunity to prevent such impacts to other streams, lakes and wetland environments occurring within the Great Swamp watershed.

The 7,450 acre Great Swamp National Wildlife Refuge and Wilderness Area (Great Swamp), located in Morris County, New Jersey, is a unique ecological system that is home to more than 200 bird and 1,000 plant species, including numerous threatened and endangered species. It is visited each year by over 300,000 people (http://www.fws.gov). As a major functioning wetlands ecosystem, the Great Swamp provides many benefits including flood control, groundwater recharge, storm water detention and filtration, wildlife habitat, ecological diversity, recreation, aesthetics and public education. The TTC was formed in 1995 through an inter-municipal agreement amongst the ten municipalities that are part of the Great Swamp watershed. This includes municipalities in both Somerset and Morris Counties. Over the past 14+ years the TTC has served as a critical guardian of the Great Swamp watershed by promoting and providing a pro-active approach to the study and management of the water quality, habitat, and biotic integrity of the streams draining to the Great Swamp. Over the years this information has been utilized to develop comprehensive watershed management programs which have served to identify and correct the causes of nutrient and sediment pollution impacting the tributary streams of the Great Swamp. This is reflected in the past work of the TTC highlighted by:

- Completion of the Great Swamp Watershed Management Plan in 1997 and municipal adoption in 1998;
- Establishment of a volunteer water quality monitoring program (conducted in concert with the GSWA);
- Implementation of Stormwater BMP demonstration projects;
- Development and adoption of model ordinances; and
- Completion of detailed stormwater inventories.

What the past studies conducted by the TTC and its partners have clearly shown is that while the Great Swamp is clearly an environmental treasure, the streams which drain to it are for the most part impacted by development, have altered hydrologic properties, and are characterized by high nutrient and sediment loading.

Loantaka Brook is one of the five major tributaries to the Great Swamp. It is designated by the NJDEP (as per N.J.A.C. 7:9B) as a freshwater, non-trout stream (FW2-NT). The lower segment of the brook which flows within the boundaries of the Great Swamp is classified by the NJDEP (N.J.A.C. 7:9B) as a Category 1 water, and is protected by the NJDEP's anti-degradation regulations. Essentially, this means that the quality of such waters cannot be "measurably nor calculably" impaired. Additionally, the regulations also include the provision establishing that C-1 streams documented as being impaired are to be targeted for improvement and enhancement. Over the past decade the TTC along with its partner municipalities and the Great Swamp Watershed Association (GSWA) have taken a number of steps to improve the condition of Loantaka Brook. Actions taken have spanned a wide array of initiatives including improved local land use development ordinances, more aggressive maintenance of the stormwater collection system, stream bank restoration projects and extensive public outreach and education efforts. These past projects have had their benefits, but they have also indentified specific problems that need additional attention. Two such problems specific to Loantaka Brook are the impacts of the Woodland Wastewater Treatment Plant and the need for better stormwater management in the upper, headwater reach of the brook.

The Loantaka Brook Watershed is located in the Watershed Management Area #6, within HUC 14: 02030103010040 of the drainage basin for the Upper Passaic River. The Upper Passaic River represents a significant source of drinking water for a large portion of northeastern New Jersey. The USEPA has approved a Total Maximum Daily Load (TMDL) to reduce phosphorous loading in the Passaic River. The results of stream sampling conducted by the TTC and Princeton Hydro from 1999 to 2008 indicate that Loantaka Brook routinely exceeds the New Jersey Water Quality Standard of 0.1 mg/L for total phosphorous, even during baseflow sampling events (Princeton Hydro, November 2008).

The *New Jersey Integrated Water Quality Monitoring and Assessment Report* provides a database for surface water quality, and identifies Loantaka Brook as Moderately Impaired for macroinvertebrate diversity at the monitoring stations at Bluestone Terrace in Morris Township (AN0220) and Green Village Road in Chatham Township (AN0221) (Figure 3). The results of macroinvertebrate sampling performed by Princeton Hydro in October

2007 and April 2008 at the same location also identified the brook to be Moderately Impaired (Princeton Hydro, November 2008). The impacts attributable to Loantaka Brook have not only impacted water quality, but have increased sediment loadings, increased channel scour, and degraded the overall ecological function of the brook.
http://www.state.nj.us/dep/wms/bwqsa/generalinfo.html

This report serves to continue the work initiated by the Ten Towns Great Swamp Watershed Committee. As such, the data contained within this document provides a continuation of a nine-year dataset which details baseflow and stormflow pollutant concentrations and macroinvertebrate data. This data has been, and will continue to be, utilized as an empirical reference point for conducting watershed management in a logical progression to address those source areas which are the greatest threats to the swamps ecological integrity.

Loantaka Brook is acknowledged to be the most significantly degraded tributary of the Great Swamp based on over nine years of water quality monitoring data (TTC 1999-2008 data). Sampling conducted through the combined efforts of the TTC and the Great Swamp Watershed Association (GSWA) document the brook as having grossly elevated total phosphorus, dissolved phosphorus, nitrate, total nitrogen, total kjeldahl nitrogen and total suspended solids concentrations under both baseflow and storm flow conditions. Based on the NJDEP 2008 Integrated Report of Water Quality (303d database), the Loantaka Brook, from Bluestone Terrace in Morris Township to Green Village Road is impaired for maintaining aquatic life. Loantaka Brook also fails to meet the New Jersey Surface Water Quality Standards for pathogens (Fecal coliform/E coli) and Total Dissolved Solids (TDS), and the brook is included on the 303(d) list for the development of a Total Maximum Daily Load (TMDL) for these parameters (August 2008). Nutrient concentrations in Loantaka Brook during both baseflow and stormflow conditions also routinely exceed New Jersey Surface Water Quality Standards and the USEPA Ecoregion reference criteria for ambient water quality conditions The impacts and impairments to the brook's water quality are the result of the discharge of non-point source pollution (NPS), in particular stormwater runoff high in levels of nutrients, sediments, total dissolved solids, BOD, fecal coliform, heavy metals and other pollutants.
http://www.state.nj.us/dep/wms/bwqsa/draft_2008_integrated_report.pdf

The impacts attributable to stormwater runoff have also created hydrologic and hydraulic impacts to this brook. Visual assessments were conducted to assess the brook's physical impacts, namely the extent and severity of stream bank erosion, loss of riparian vegetation, in-stream sedimentation, channel sour and overall degradation of the physical nature of the Loantaka Brook system. Large portions of the headwaters were found to be severely eroded. The high degrees of impervious cover and moderately dense development has contributed greatly to higher peak flows of shorter duration associated with stormwater runoff, decreased groundwater recharge and infiltration, degraded stream banks, and particulate and soluble nutrient loading to the brook.

1.1 Project Location

From the north, the main stem of Loantaka Brook originates Morris Town. The brook then flows across the Morris Township boarder south of Madison Avenue, and converges with a second smaller tributary that originates in Morris Township before flowing into Kitchell Pond. Immediately upgradient of the pond, the brook also receives inflow in the form of discharge form the Woodland Wastewater Treatment Plant. Although Kitchell Pond is a highly eutrophic waterbody, it remains an important focal point of one of Morris County's most heavily used public park and recreation areas, Loantaka Brook Reservation. This 574-acre linear park begins just upgradient of Kitchell Pond and extends southward to Green Village Road. As the brook continues through the Loantaka Brook Reservation, other streams originating in Harding and Madison Township converge with the main stem of the brook. The brook eventually discharges into the Great Swamp National Wildlife Refuge. (Attachment A, Figure 1)

Review of the 2002 aerial photograph of the watershed (Attachment A, Figure 2) clearly shows the level of development that has occurred in the headwater sections of the watershed. Land use in the more southerly sub-watersheds that originate in Madison and Harding Township's tend to be dominated by suburban types of development that are far less intense than the development characteristic of the Morristown and Morris Township headwater areas. The impervious cover present in the watershed is depicted on Figure 9, which illustrates that the majority of the residential development has an impervious cover of 20-40% and the commercial areas include 60-80% impervious cover, or more.

Review of NJDEP's land cover data (NJDEP 2002) shows that from its headwaters to Kitchell Pond, the Loantaka Brook watershed is highly developed, with land use dominated by commercial and high-density residential development (Attachment A, Figure 3). Through this area, Loantaka Brook is identified in the State's 303d database as impaired. According to the State's most recent 303d database, Loantaka Brook, from Bluestone Terrace in Morris Township to Green Village Road is unable to maintain aquatic life. The impaired water quality of Loantaka Brook is considered largely the result of non-point source (NPS) pollution, in particular contaminated runoff, in the form of both dissolved and particulate pollutants as well as sediments. Furthermore, Loantaka Brook does not meet State Water Quality Standards (SWQS) under either baseflow or storm flow conditions for Total Phosphorus (TP), Dissolved Reactive Phosphorus (DRP), Nitrate-N (NO_3), Total K Kjeldahl–N (TKN), Total Nitrogen (TN) and Total Suspended Solids (TSS) as based on median water quality data collected from 1999 to 2002. Total phosphorus concentrations also do not meet the New Jersey Standards and all measured TP concentrations exceed the EPA Ecoregion reference criteria. In addition, the data definitively show that nitrate concentrations measured in Loantaka Brook are greater than those measured in the TTC reference streams, background streams, and the other streams in the Great Swamp Watershed (June 2002 WQ report).

1.2 Project Strategies

Loantaka Brook is recognized as being the most highly impacted and impaired tributary of the Great Swamp. The brook's headwater reach, that is the section of the brook up-stream of Kitchell Pond, is characterized by degraded water quality, sediment accumulation, compromised stream banks and an eroding stream channel, and impaired ecological services and functions. The root cause of these problems is the unmitigated management of stormwater runoff. Though projects completed in 2007, successfully stabilized over 1,000 linear feet of stream channel (located south of Woodward Avenue) using bioengineering and naturalization techniques, the headwater reach of Loantaka Brook is recognized as the most impacted of the Great Swamp tributaries. Much of the stormwater related problems are a function of the age of the development occurring in this portion of the watershed. Constructed well before the advent of stormwater management requirements, runoff from the highly developed headwater watershed is conveyed to the brook with little if any controls. This has resulted in increases in peak flows, non-point source (NPS) pollution and alteration of baseflow and recharge. As a result, the brook suffers from the documented combination of poor water quality, eroded stream bed and banks and loss of ecological function. This project had four main tasks each intended to both more accurately characterize and identify problems, or to provide concept plans intended to correct documented problems. The four tasks, which are presented and discussed in detail in separate sub-sections within this report consisted of the following:

- **Hydrologic and Hydraulic Analysis (Sub-objective 1, Task 1.1 and 1.2)** – A detailed hydrologic and hydraulic analysis of the brook's headwaters, from its origin in Morris Town to Kitchell Pond in Morris Township was conducted. The objective of this task was to definitively establish the existing peak flows and associated erosive forces associated with the currently unmitigated runoff generated from the headwater area. These data, along with information based on field inspections of the stormwater collection and conveyance system, were used to identify where flow mitigation measures are required and the nature and extent of the required mitigation measures.

- **Complete an Inventory of Existing Stormwater Infrastructure (Sub-objective 1, Task 1.3)** – This task is built directly on the results of Task 1.1 and 1.2. Utilizing existing stormwater infrastructure mapping and data, along with site-specific reconnaissance of the stormwater collection systems throughout the sub-drainage areas encompassed by the study reach of Loantaka Brook, a relatively detailed inventory and mapping of the major outfalls and storm sewer collection systems was conducted. Recommendations were then developed for the retrofit, upgrade or construction of new BMPs and other stormwater NPS management solutions for the purpose of reducing existing peak flows, increasing if possible the amount of stormwater recharge and decreasing pollutant loading. Through this effort is was possible to develop conceptual plans for the reconstruction of an existing failing stormwater detention basin.

- **Stream Bank And Channel Stabilization (Sub-objective 2**) - The objective of this task originally focused on the design of stream bank and channel stabilization measures required to restore the eroded sections of the brook's headwater reach. The stabilization and restoration of this segment of the brook was intended to compliment the restoration of the +1,000 foot segment of the stream channel. Completed using NJDEP 319 funds and Morris Township in-kind services, the project resulted in the renovation of that portion of Loantaka Brook running south of Woodland Avenue to Dwyer Lane / Fanouk Road. However, upon closer investigation of the headwater reach north of Woodland Avenue it was determined that streambank stabilization measures were not needed. Although there was some evidence of erosion in this reach of Loantaka Brook, conditions were deemed stable. Attempts to restore the stream channel, especially in the reach adjacent to Woodland School, would result in significance disturbance of the forested riparian buffer that has matured along the stream. A geomorphological assessment deemed the channel stable and better protected going forward through the implementiatn of improved stormwater management. As a result, efforts were directed to the development of engineering concepts to upgrade the non-functional Parsons Village detention basin located off of Route 124.

- **Preliminary Design Of An Off-Line Created Wetland (Sub-objective 3**) - This task resulted in the preliminary design of an off-line created wetland treatment system. The purpose of the created wetland is to treat the effluent discharged from Morris Township's Woodland Wastewater Treatment Plant for the purpose of decreasing nutrient loading to both Loantaka Brook and the highly eutrophic Kitchell Pond. Although the wastewater treatment plant's effluent is in compliance with the facility's discharge permit limitations, it is still elevated, as verified by water quality analyses conducted up-stream and down-stream of the discharge. The offline created wetland would be constructed in a tract of land owned by the Morris County Park Commission that parallels the stream channel immediately adjacent to the wastewater treatment plant.

- **Analysis Of Water Quality And Biological Data (Sub-objective 4**)- The final task associated with this project involved the collection of water quality and biological data from Loantaka Brook and the other tributaries of the Great Swamp. These data were added to the existing long-term database for all the tributary streams of the Great Swamp. The data were statistically analyzed and used to evaluate and comment ion of the overall health and/or impairment of the tributaries.

The following sections of this report present the findings and recommendations of the primary tasks of this project.

2.0 Pollutant Loading and Hydrologic Analyses (Task 1.1)

This section of the report both explores and presents the results of the pollutant loading and hydrologic properties of the Loantaka Brook system. The analyses were conducted on a subwatershed basis, meaning the study reach of the Upper Loantaka Brook was divided into refined catchment areas. These catchments, or sub-watersheds, were delineated on the basis of topographic interpretation, review of site-specific stormwater sewer system plans, and field reconnaissance. The pollutant and hydrologic loading characteristics of the brook have been modeled simultaneously as they are inextricably linked and in reality function in concert. This component of the study therefore serves several purposes. First, it provides a simple description of the processes affecting stream hydrology and nutrient and solids loading in Loantaka Brook and can be used to identify areas of concern and serve as a baseline to evaluate future trends. Second, it can be used in conjunction with field collected water quality data to correlate and identify processes driving in-stream conditions. Finally, it is a management tool that can be utilized to identify and address specific impairments in the brook and provide the baseline data used to both formulate specific management solutions and later to evaluate and quantify their benefits.

Modeling was performed utilizing BasinSim 1.0, a Windows-ported version of GWLF (Generalized Watershed Loading Function). BasinSim utilizes GIS and otherwise compiled datasets which are transformed to text files to run the model. In essence, BasinSim consists of a variety of modules which contain algorithms to run well known models to calculate pollutant loads, hydrology, and the interactions between the two. The strength of this software package is the ability to easily calibrate the model with the use of specific watershed data including field measured values. While management efforts are focusing primarily on the headwater portions of Loantaka Brook the model was run for the entire watershed broken down into subwatershed categories. This analysis allows comparisons of headwater versus downstream areas and therefore provides additional information needed to make educated decisions as to targeted management efforts for the brook. In addition, point sources were included to provide a holistic view of mean annual hydrologic and nutrient loading to the Brook.

2.1 Modeling Methodology

The pollutant load study included a detailed sediment, phosphorus (total and dissolved), and nitrogen (total and dissolved) loading assessment of each of the subwatersheds using BasinSim 1.0. BasinSim was also utilized to calculate hydrology including runoff, groundwater, and potential evapotranspiration (PET). BasinSim uses an extensive array of databases such as land uses, population, soils, water discharge, water quality, climate, and point nutrient sources and a modified version of the Generalized Watershed Loading Function (GWLF) model in a single software package. It was designed to enable resource managers to visualize watershed characteristics, manipulate land use patterns, and simulate nutrient and sediment loadings under various land use scenarios.

There are four basic input elements used to run BasinSim: a weather file, a transport file, a nutrient file, and a discharge file. The weather file input data was created to simulate the hydrologic cycle of the watersheds by using the available 30-year NOAA weather data and CLIMOD climatic data records for each of these key subwatersheds. The transport file input data was derived using GIS soil and slope data along with NRCS soils data integrated using the erosion product parameters from the Universal Soil Loss Equation and NRCS based curve numbers. The nutrient and sediment file input data was developed using land use / land cover loading coefficients obtained through the literature but modified to reflect as best as possible subwatershed specific conditions. The discharge files utilized existing discharge datasets, primarily from the USGS, that were modified to characterize hydrology on gauged tributaries at a monthly level and on a unit area basis.

As noted above, given that BasinSim 1.0 interfaces with GIS, it is thus sensitive to land use, land cover and other related watershed attributes (slopes, soils, etc.) that affect the generation or mobilization of pollutants typically transported over the landscape by stormwater runoff. With this model it is possible to identify the magnitude of loading associated with specific types of lands use activities (residential, commercial, agricultural, etc.). Additionally, this model accounts for loading both from surface and groundwater sources, which is especially important in the headwaters and wetlands of the project area and due to the unique hydrology of the system affected by the high level or impervious coverage. The model was applied to finite subwatershed units as deemed appropriate, thus enabling accurate load computations for small to large watershed areas of varied land use types. The modeling approach was expanded to interface with loading generated from point sources, such as the wastewater treatment plant, and atmospheric deposition (wet and dry-fall). The pollutant loading coefficients used in this analysis were based on literature values. These coefficients were further modified to reflect the localized effects of soils and slopes; landscape attributes that can increase the overland runoff related flux of nutrients and sediments.

The results section which follows details the results of this modeling effort. Specifically, hydrologic, phosphorus, nitrogen, and sediment loads are evaluated on a subwatershed level of detail. Since Loantaka Brook is influenced by a single point source discharge, the Woodland Wastewater Treatment Plant, loading numbers are presented in this report both with and without the inclusion of the point source portion of the load. As will be discussed below, while the treatment facility contributes a significant portion of the nutrient load to this stream it is not in exceedance of any regulatory restrictions and as such it is useful to separate this pollutant source for those management efforts which target the greatest sources of non-point source pollution. These are mostly the more urbanized areas of the headwater subwatersheds (Subwatersheds #1 and #2). To further expand the utility of the modeling effort a ranking matrix was developed. The ranking matrix assigns simple coefficients to numerous modeled parameters and when summed, creates a management decision making tool that directs attention to those subwatersheds that disproportionably degrade Loantaka Brook either through altered hydrologic / hydraulic conditions or through excessive nutrient loading.

The following section provides detailed information as to hydrologic and nutrient / sediment loading to Loantaka Brook from each of the six delineated subwatersheds along with back calculated mean monthly nutrient concentrations which are compared to the historical empirical database therefore allowing for a high degree of model confidence and applicability.

2.2 Subwatershed Determination and Land Use / Land Cover Classification

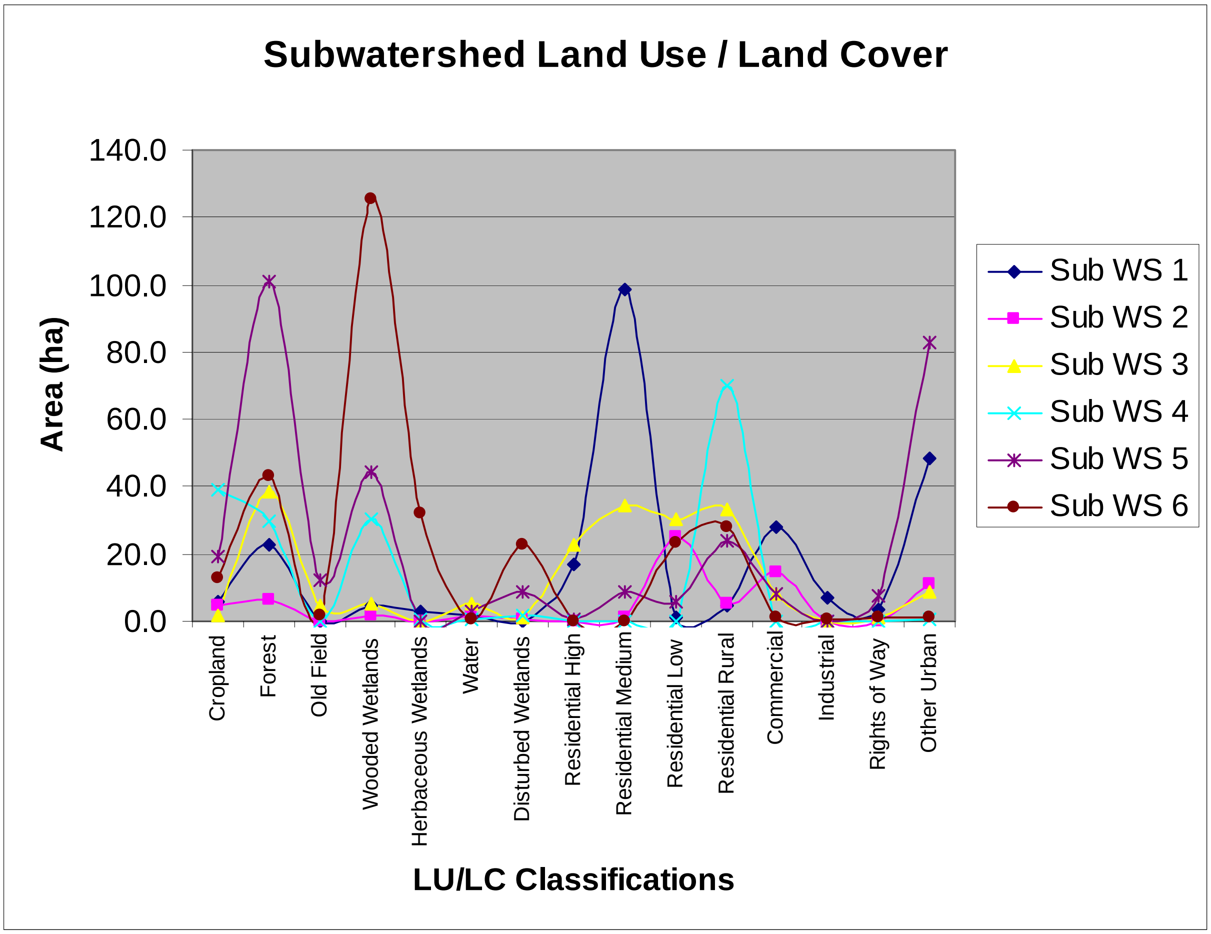
The Loantaka Brook watershed was modeled from the headwaters, located in Morristown, NJ, to the point at which the stream discharges into the Great Swamp National Wildlife Refuge. This portion of Loantaka Brook is designated as a FW2-NT waterbody and is listed on the NJDEP 303(d) list for impaired macroinvertebrate communities at two locations of the stream, at Bluestone Terrace in Morristown (WMA 06) and at Green Village Road (WMA 06), the latter correlating with the water quality sampling location. Overall, the watershed encompasses 1,306 hectares (3,227 acres). The following table lists land use type and area within the watershed and its percent contribution. It should be noted that New Jersey GIS data provides numerous LU/LC classification which were simplified for presentation purposes (i.e. medium density and low density residential were simply grouped into the "residential" category). The NJDEP LU/LC data is illustrated on Attachment A, Figure 5.

Table 2.1: Loantaka Brook Watershed Land Use and Area

LU/LC	Area	Percent of Watershed
	(ha)	(%)
Agriculture	101.40	7.8
Water	13.20	1.0
Wetlands	282.70	21.6
Residential	434.00	33.2
Urban	152.70	11.7
Commercial	60.00	4.6
Industrial	7.60	0.6
Right of Way	12.90	1.0
Forest	241.60	18.5

Land use / land cover classifications varied significantly throughout subwatersheds and were one of the primary determinants in delineating subwatershed boundaries. Overall, forest and wooded wetlands were some of the largest contributors to land use, but residential and urban LU/LC collectively was the largest component with the majority of these land uses associated with the headwater subwatersheds (Subwatersheds #1 and #2). In general, the upper watershed is dominated by higher-intensity residential and urban development than is the lower reaches of the stream. Once south of Woodland Avenue, the extent of development (whether commercial or residential) decreased. Of note is the fact that much of the watershed draining to the central reach of the brook lies within the boundaries of the Loantaka Brook Reservation, a sprawling linear park system managed by the Morris County Park Commission. Further downstream in the watershed lower-intensity residential development, forests, and wetlands dominate the landscape. Agriculture was an important component of land use only in Subwatershed #4.

Exhibit 2.1: Loantaka Brook Subwatershed LU/LC



2.3 Subwatershed Hydrologic and Pollutant Loading

The following section details the hydrologic and pollutant loading characteristics of Loantaka Brook on a subwatershed level of detail. This analysis pertains to both modeled non-point source pollution and the inclusion of point source hydrologic and nutrient loads derived from the Woodland Wastewater Treatment Plant. Throughout the following sections the load derived for each modeled nutrient parameter is presented as a total mean annual value (point source + non-point source) and also as non-point source only. Parsing of the dataset in this way was performed due to the overriding influence the Woodland wastewater treatment facility has in terms of contributing excessively elevated phosphorus and nitrogen loads to the Brook. Since this plant is within regulatory compliance in terms of effluent concentrations it is useful to remove this source to analyze NPS loads alone.

2.3.1 Hydrologic Loading

The Exhibits 2.2 – 2.4 provide mean monthly breakdowns of groundwater discharge, surface water discharge, and total discharge volumes for each of the six subwatersheds.

Exhibit 2.2: Groundwater Loading (m^3)

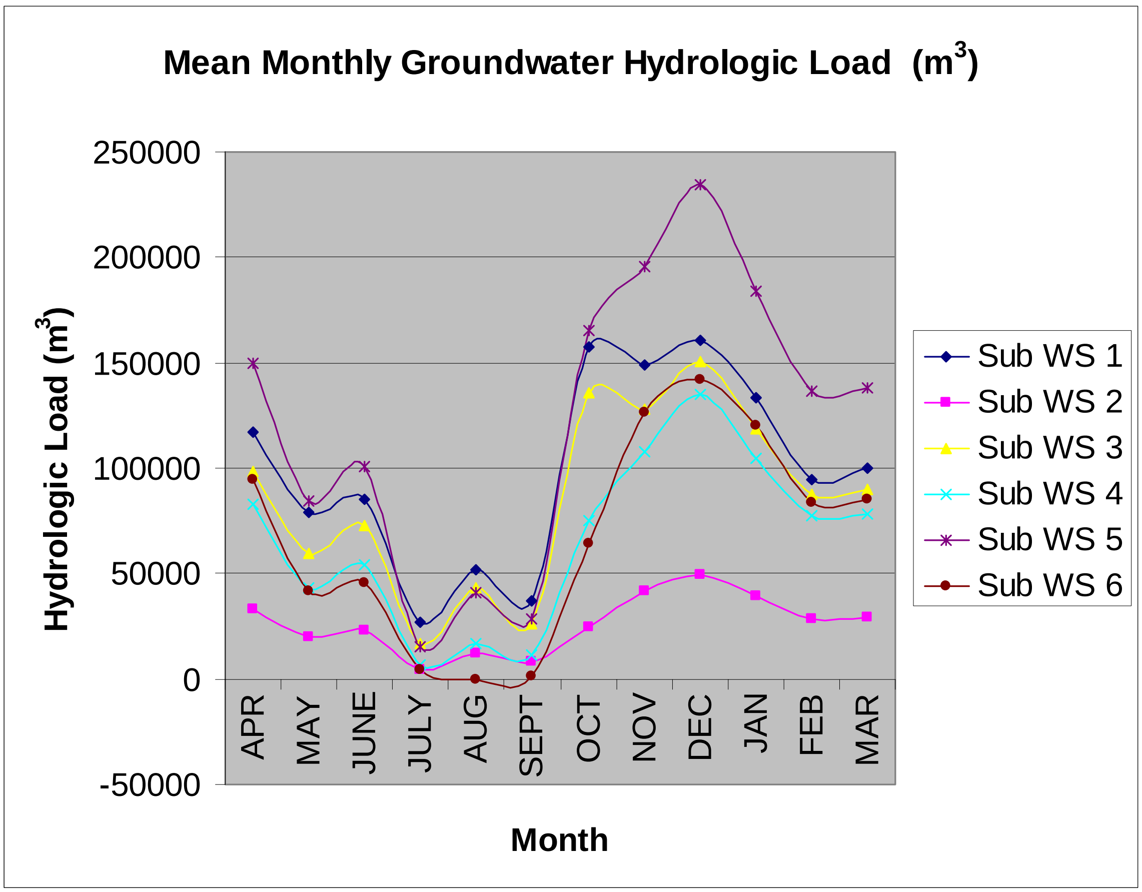


Exhibit 2.3: Surface Water Loading (m^3)

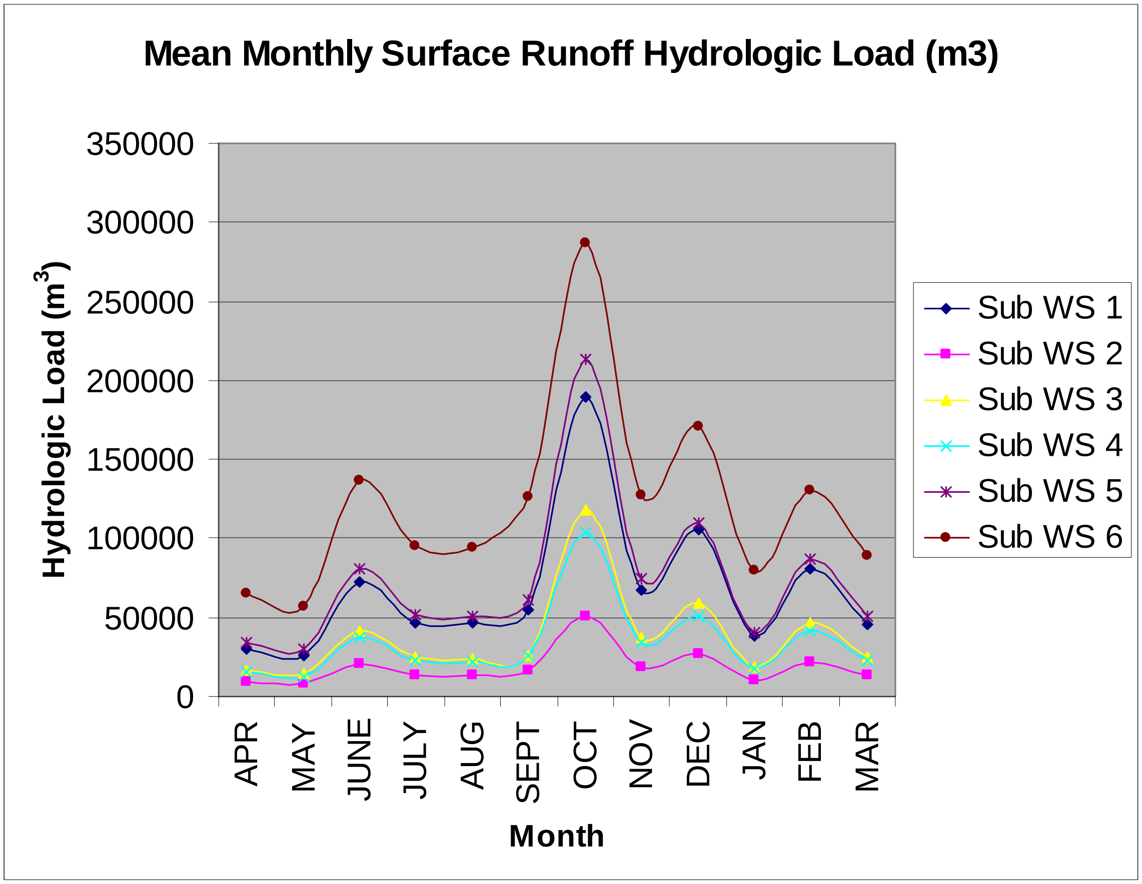
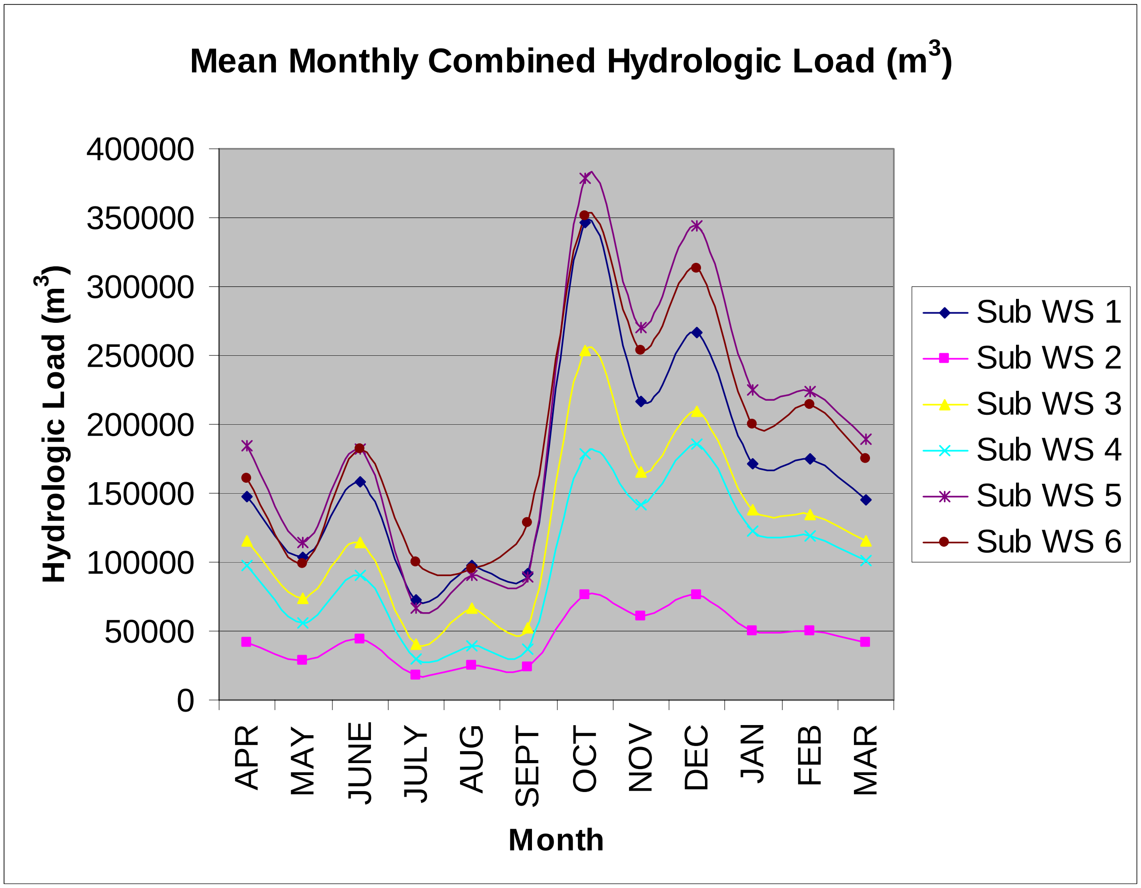
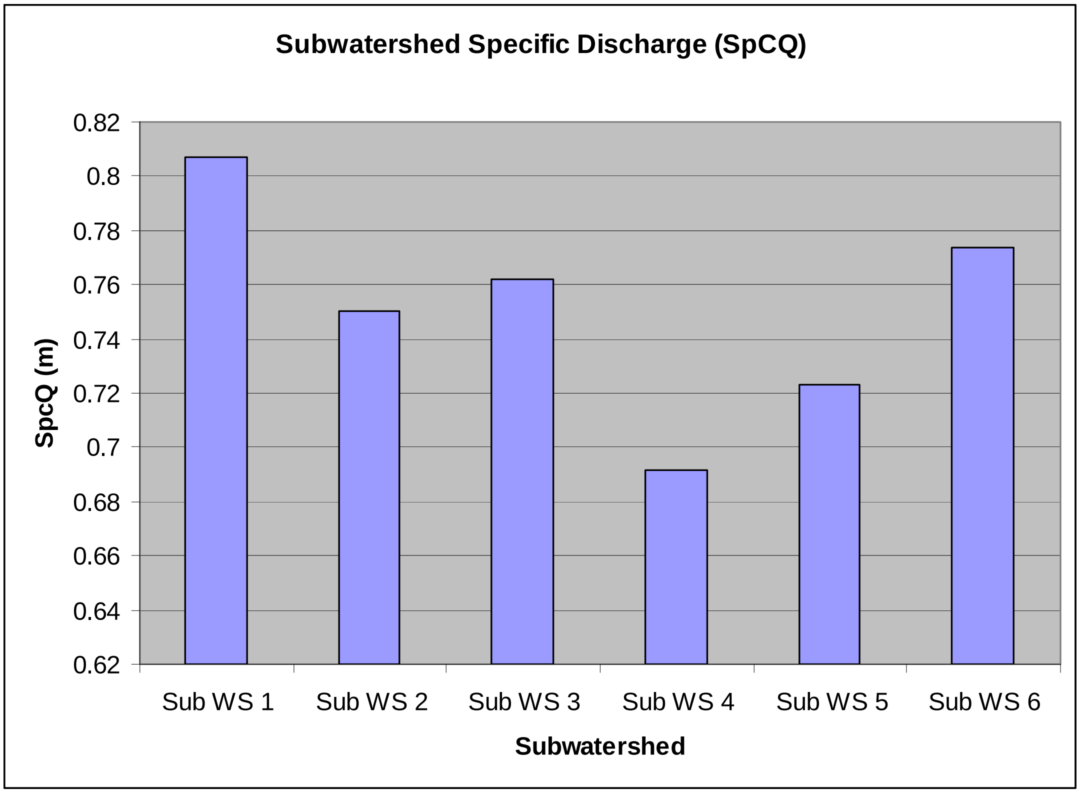


Exhibit 2.4: Mean Monthly Hydrologic Loading (m^3)



Hydrologic discharge, on an absolute basis, is greatest at Subwatershed #5 and generally followed site specific patterns due to subwatershed size. As such, hydrologic discharge was further evaluated by normalizing load for unit area to determine which areas contribute the highest portion of total discharge per unit of subwatershed area. This analysis is much more useful for management purposes as inherent deviations in hydrologic discharge and the sources of this water, may offer valuable insight as to those areas which are in need of management. The following Exhibit 2.5 provides total discharge for each subwatershed normalized for area.

Exhibit 2.5: Specific Hydrologic Discharge



Hydrologic loading, normalized for subwatershed area, shows the primary headwater subwatershed, Subwatershed #1, as the highest contributor per unit area of hydrologic loading to Loantaka Brook. This pattern is likely the direct result of elevated impervious areas within this area with a majority of percent impervious coverages ranging from 40 – 100% due to development within Morristown, NJ. When the total specific discharge is further broken down into specific surface and groundwater loading another pattern is highlighted which shows Subwatershed #1 to have the second highest surface and groundwater contributions per unit area (Exhibits 2.6 through 2.7).

Exhibit 2.6: Specific Groundwater Loading

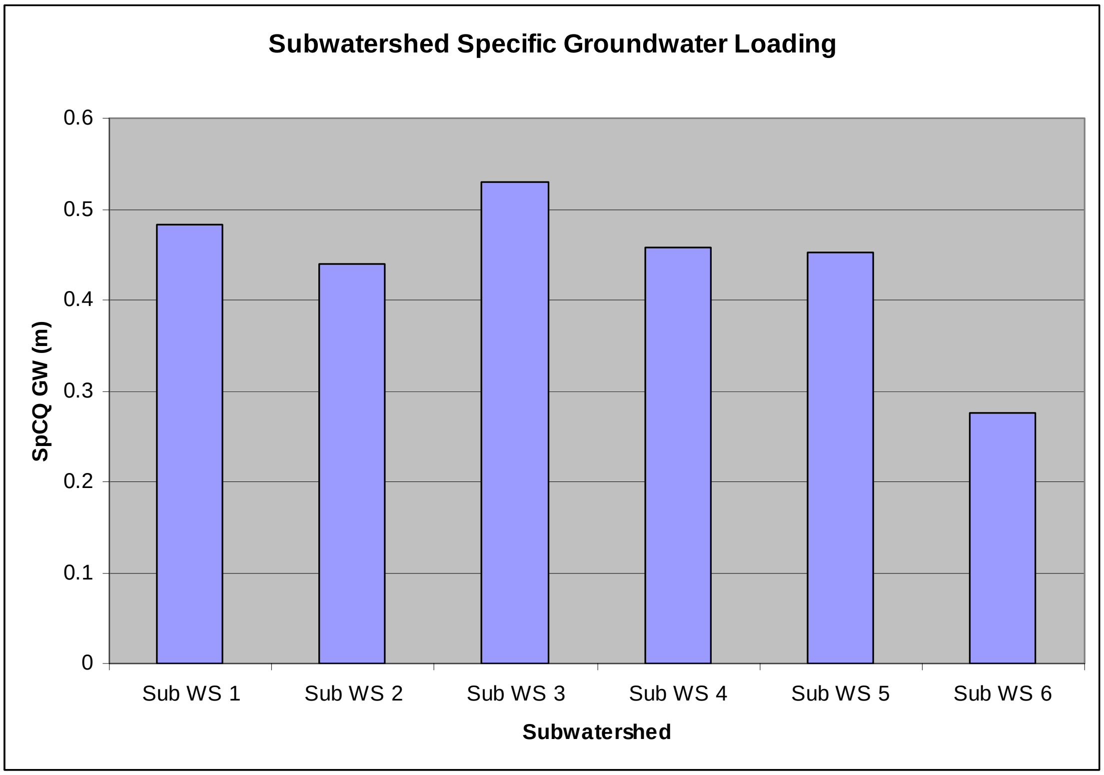
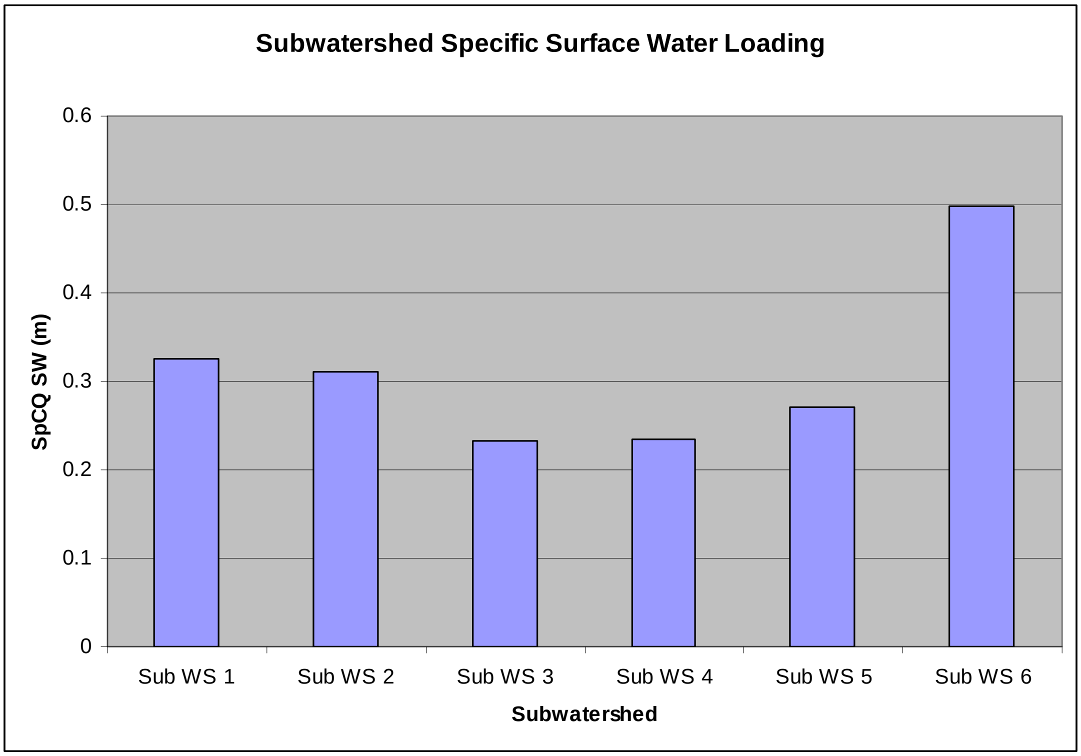


Exhibit 2.7: Specific Surface Water Loading



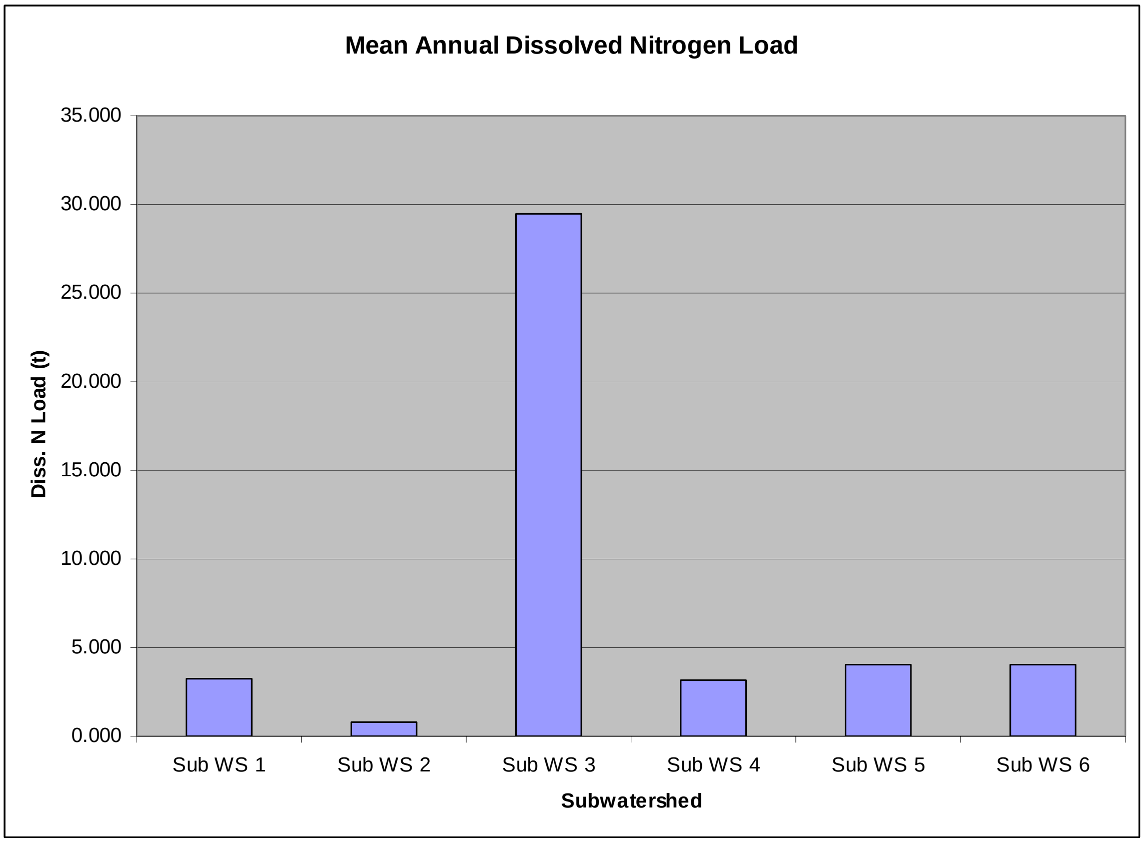
While the highest overall specific surface water loading occurs from Subwatershed #6 this subwatershed is not a primary contributor to altered hydrologic loads as these calculations are largely the result of large wetland complexes associated with this watershed which were not treated as hydrologic sinks for modeling purposes. With this subwatershed removed from the analysis it becomes clear that the two headwater subwatersheds (Subwatersheds #1 and #2) have the highest specific surface water loading and are therefore are altering hydrologic loading to the stream the most. As previously mentioned, the elevation of surface water loading in the two aforementioned subwatersheds is primarily the results of elevated impervious surfaces within these areas. As such, the headwaters of Loantaka Brook are routinely subject to elevated flows of short duration which serve to alter the natural morphology of these reaches through increased stream bank and bed erosion which subsequently serves to degrade this particularly sensitive reach.

2.3.2 Mean Annual Nitrogen Loading

Dissolved Nitrogen

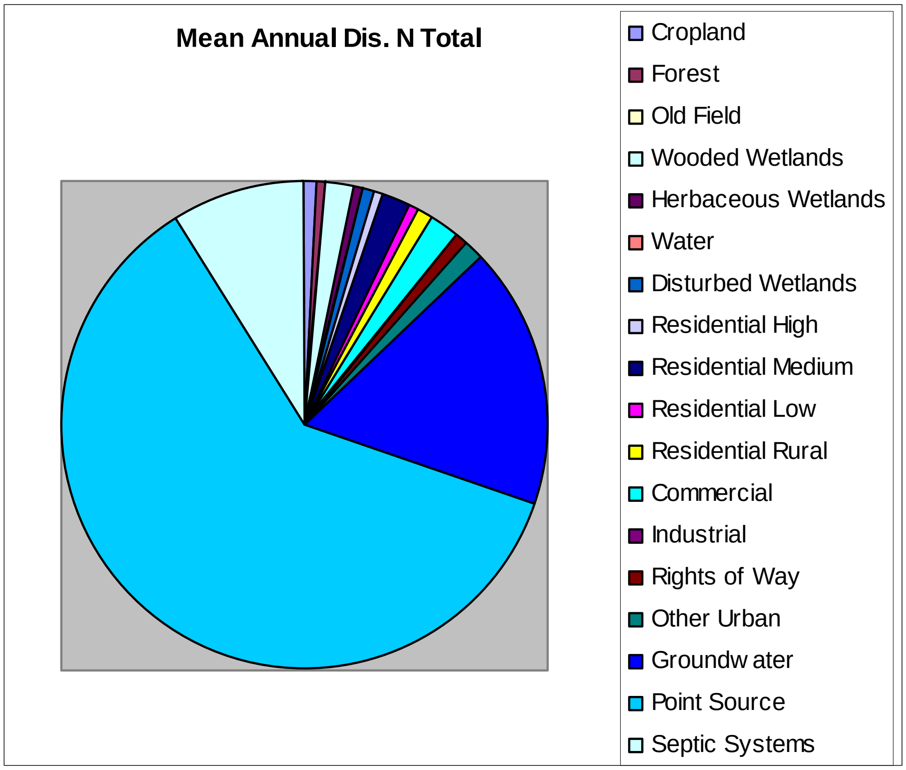
The total annual dissolved nitrogen load to Loantaka Brook was modeled at 44.84 tons (40,682 kg). Of this total load the greatest loading contribution is derived from Subwatershed #3 with a modeled load of approximately 29.4 tons (26,710 kg) per year.

Exhibit 2.8: Mean Annual Dissolved Nitrogen Loading



Further breakdown of the mean annual dissolved nitrogen load shows that point sources within Subwatershed #3 are the primary contributor of this nutrient with this source alone accounting for 61% of the entire annual dissolved nitrogen load to Loantaka Brook (Exhibit 2.9).

Exhibit 2.9: Absolute Dissolved Nitrogen Load – Segregated By Source



The only identified and modeled point source within the Loantaka Brook watershed is that of the Woodland Wastewater Treatment Plant. As this facility has not exceeded their NJPDES discharge permit requirements this source is further removed from the analysis to ascertain those subwatersheds and sources which are the greatest contributor of non-point source loads.

The following Exhibit 2.10 depicts the mean annual dissolved nitrogen load to Loantaka Brook with the exclusion of point sources while Exhibit 2.11 normalizes these loads for subwatershed area therefore allowing for direct comparison amongst subwatersheds.

Exhibit 2.10: Mean Annual Dissolved Nitrogen Load – Minus Point Source

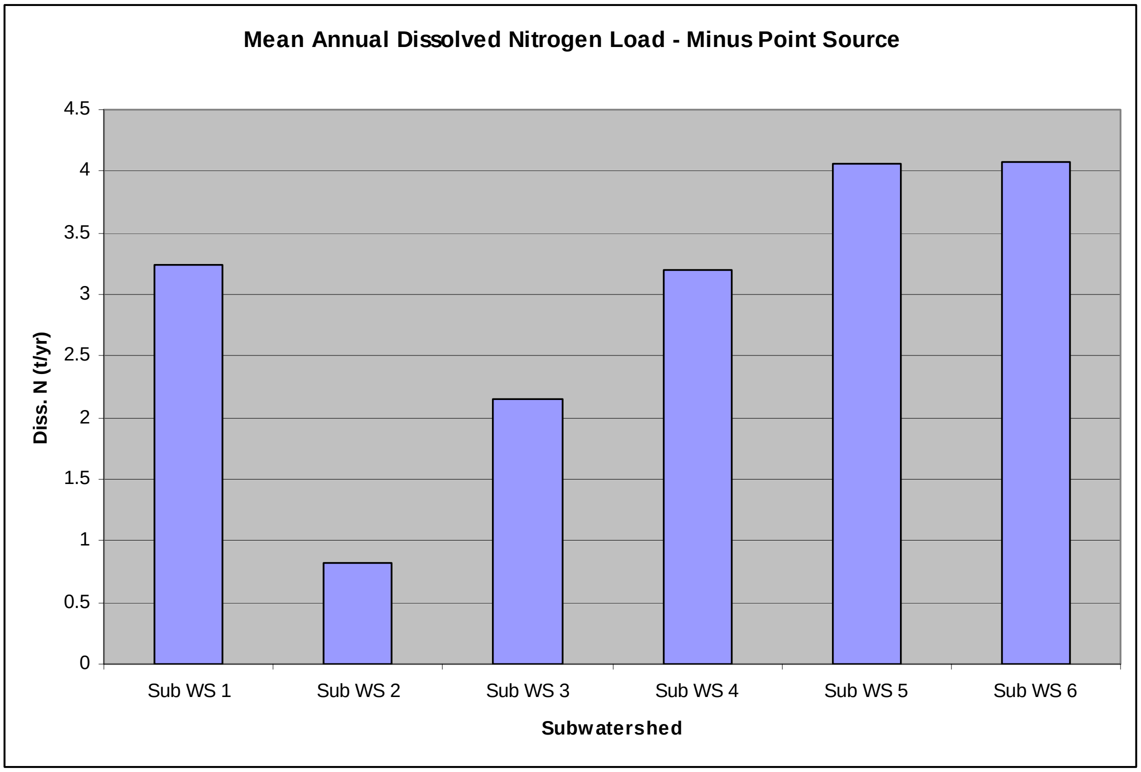
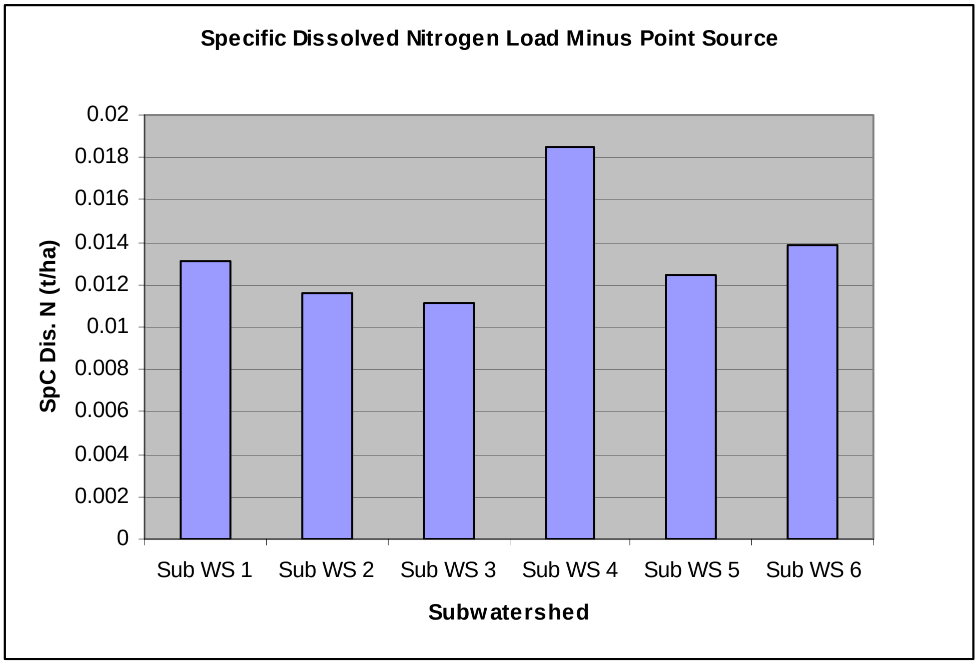
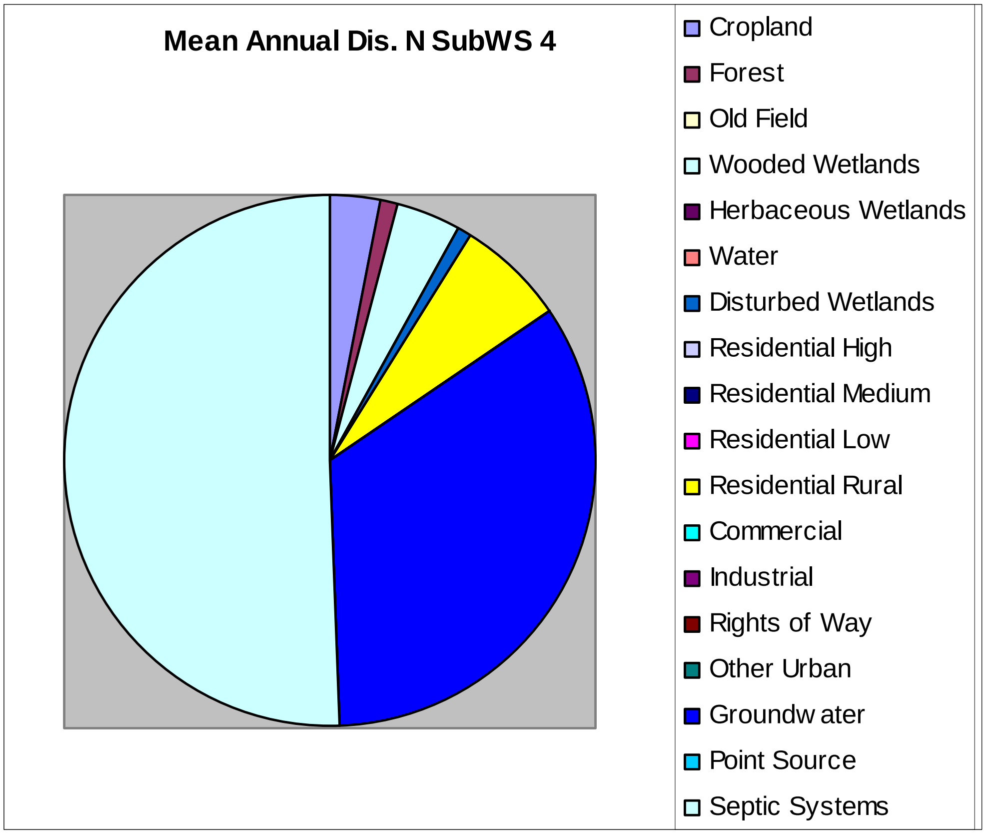


Exhibit 2.11: Specific Mean Annual Dissolved Nitrogen Loading – Minus Point Source



Overall, Subwatershed #4 has the highest NPS dissolved nitrogen load per unit area followed by Subwatershed #6 and #1. The primary contributors to dissolved nitrogen loading to Subwatershed #4 is that of septic systems which comprise 50.5% of the total dissolved nitrogen load for this subwatershed (Exhibit 2.12).

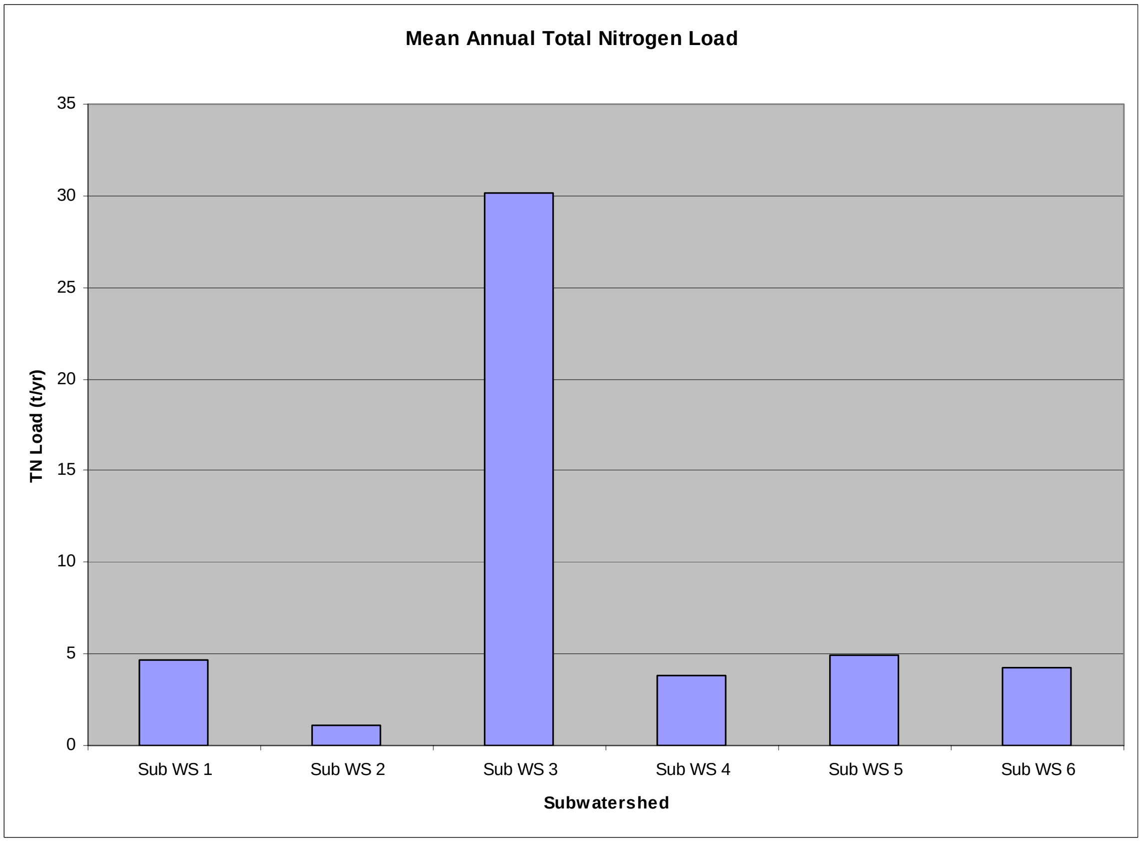
Exhibit 2.12: Subwatershed 4 – Dissolved Nitrogen Sources



Total Nitrogen (TN) Load

The TN load and patterns are nearly identical to those described above for dissolved nitrogen although non-point source loads for residential land uses contribute a larger portion of the total load with a proportional decrease in groundwater sources. TN is largely driven by dissolved nitrogen with particulate sources of nitrogen contributing approximately 10% of the TN load. Overall, point sources are still the primary driving force behind total nitrogen loading given the predominance of dissolved inorganic nitrogen in total nitrogen metrics. Of the total nitrogen load of 48.94 t (44,400 kg) point sources again comprise 27.286 t (24,753 kg) or approximately 55.8% of the mean annual total nitrogen load. The following exhibit 2.13 depicts each subwatersheds contribution to the total nitrogen load of Loantaka Brook.

Exhibit 2.13: Mean Annual Total Nitrogen Load



As previously mentioned the WWTP contributes the majority of nitrogen to Loantaka Brook and since this facility is within regulatory effluent requirements it is subsequently removed to conducted NPS loading analysis. The following Exhibit (2.14) depicts mean annual NPS total nitrogen loading while Exhibit 2.15 normalizes those loads for subwatershed land area.

Exhibit 2.14: Mean Annual Total Nitrogen Load – Minus Point Source

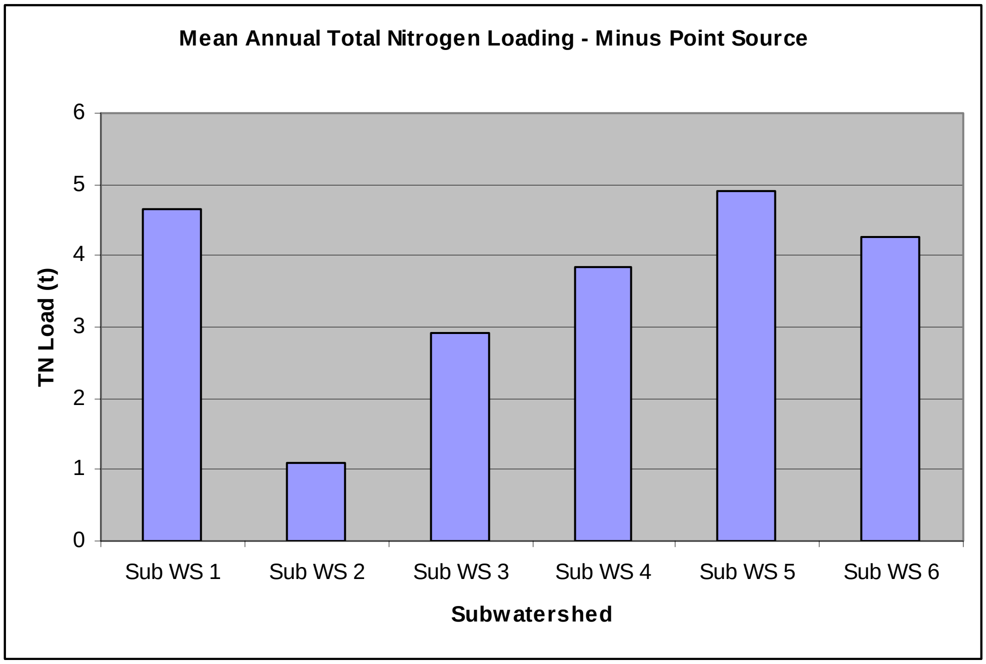
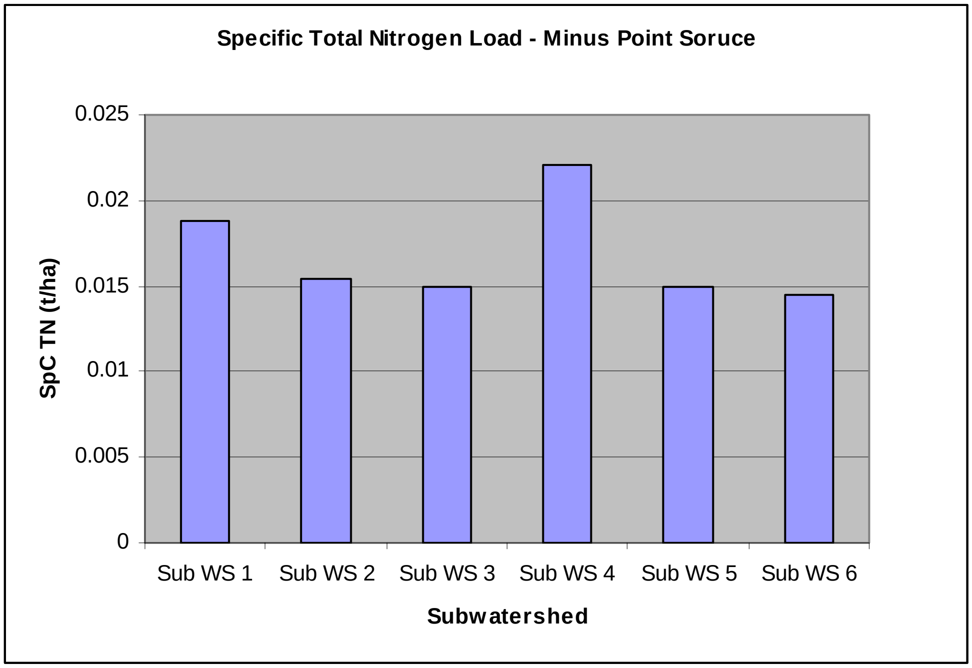


Exhibit 2.15: Specific Mean Annual Total Nitrogen Loading – Minus Point Source



Absolute mean annual NPS total nitrogen loading is greatest at Subwatershed #5 followed by Subwatershed #1. When these loads are normalized for subwatershed area it becomes clear that Subwatershed #4 is again the greatest contributor of NPS based total nitrogen loading followed closely by the Subwatershed #1 which is located in the headwaters region of Loantaka Brook. The source contributors to total nitrogen loading are divergent between Subwatersheds #4 and #1 with septic systems and groundwater contributing the majority of nitrogen in Subwatershed #4 while groundwater and residential land use contributes the majority of nitrogen in Subwatershed #1 (Exhibits 2.16 – 2.17).

Exhibit 2.16: Subwatershed 4 – Mean Annual Total Nitrogen Sources

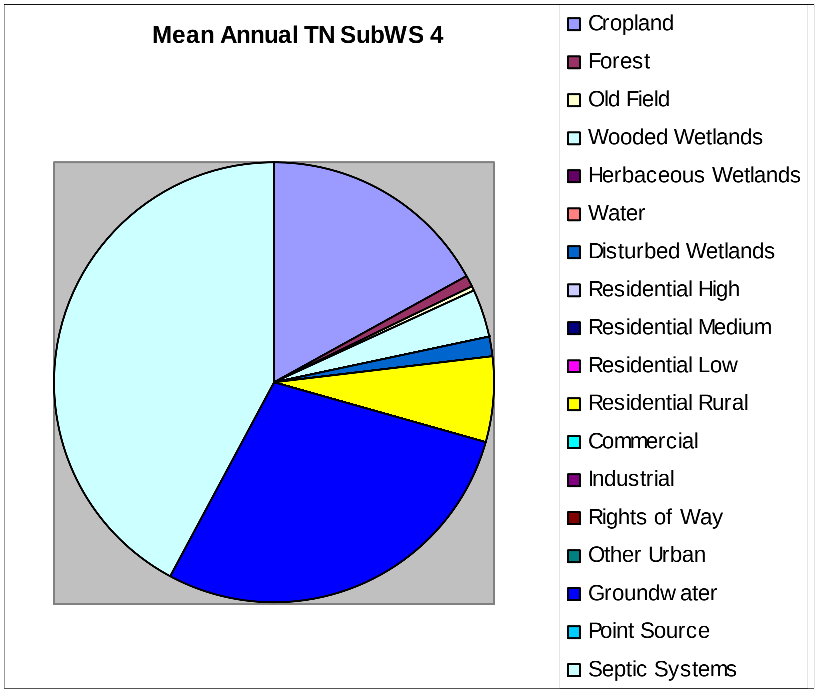
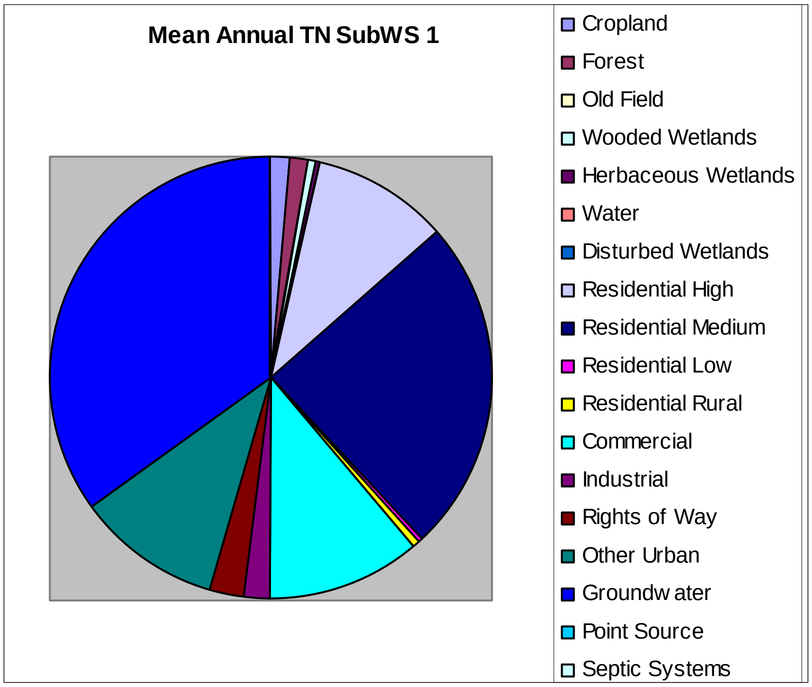


Exhibit 2.17: Subwatershed 1 – Mean Annual Total Nitrogen Sources



2.3.3 Mean Annual Phosphorus Loading

Dissolved Phosphorus Load

The patterns observed for dissolved phosphorus are similar to dissolved nitrogen in scale, but vary greatly in magnitude. Point source contribution in Subwatershed #3, derived from the Woodland Wastewater Treatment Plant, is the main driver of dissolved phosphorus loading in the watershed. In the headwaters groundwater is a major source as is surface runoff due to large areas of impervious coverage. In the lower watershed groundwater and wetlands tend to be the biggest contributors to the dissolved phosphorus load. Septic loading is not a contributor. The following Exhibit (2.18) depicts mean annual dissolved phosphorus loading with the inclusion of the WWTP while Exhibit 2.19 depicts the same load with the exclusion of the WWTP while Exhibit 2.20 normalizes these loads for subwatershed land area.

Exhibit 2.18: Mean Annual Dissolved Phosphorus Load

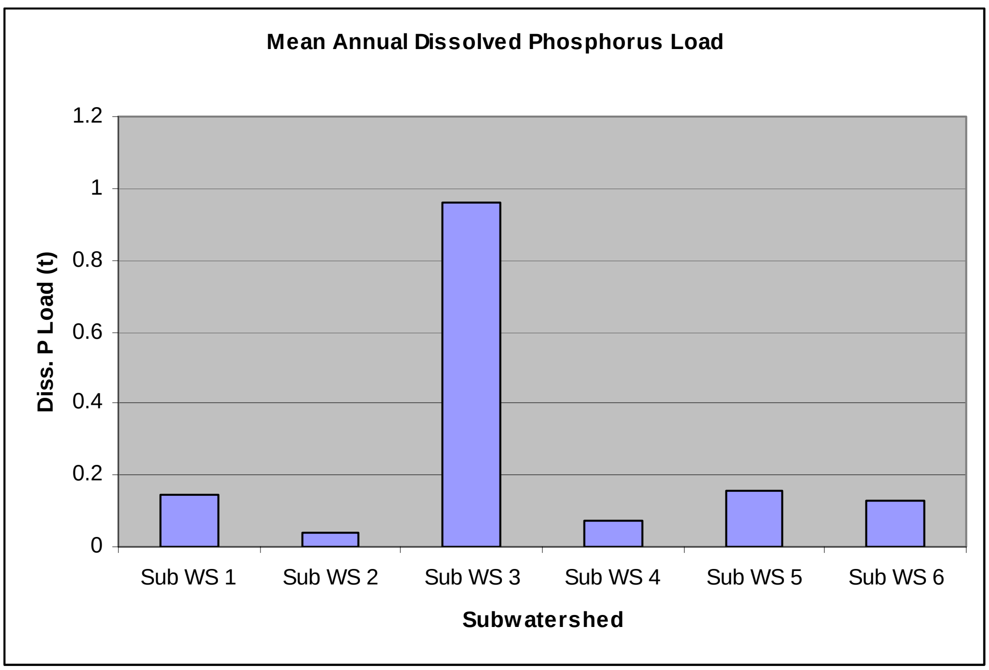


Exhibit 2.19: Mean Annual Dissolved Phosphorus Load – Minus Point Source

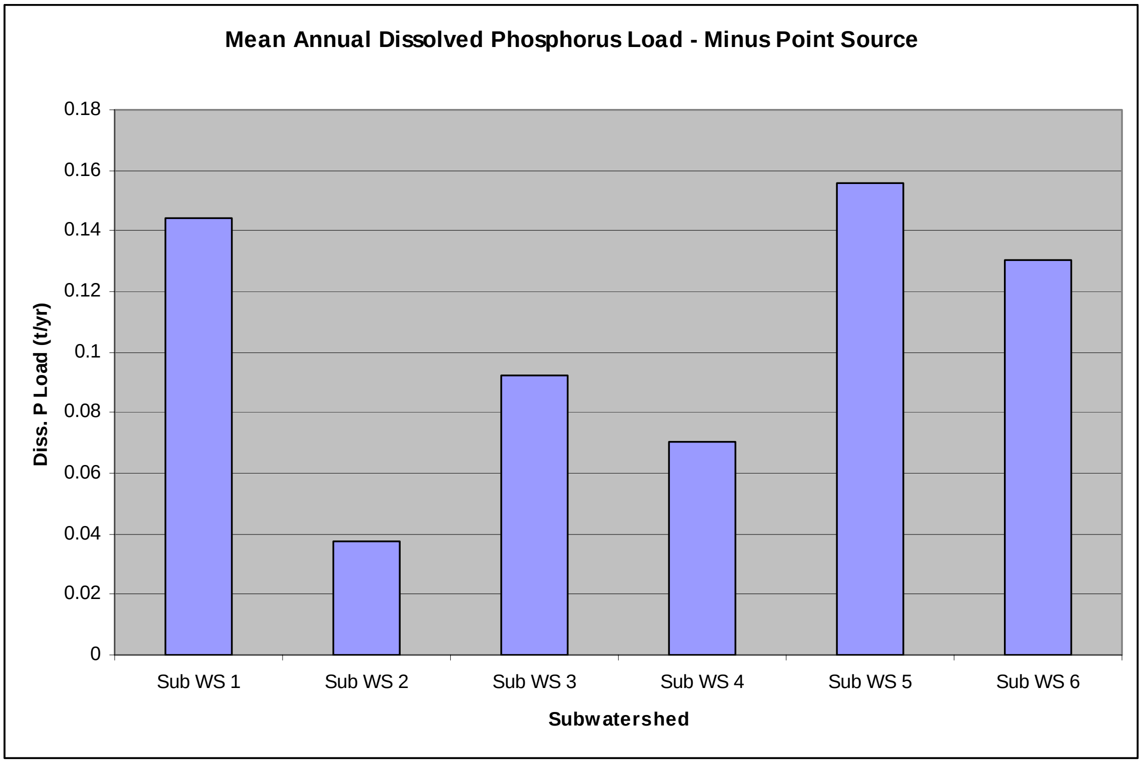
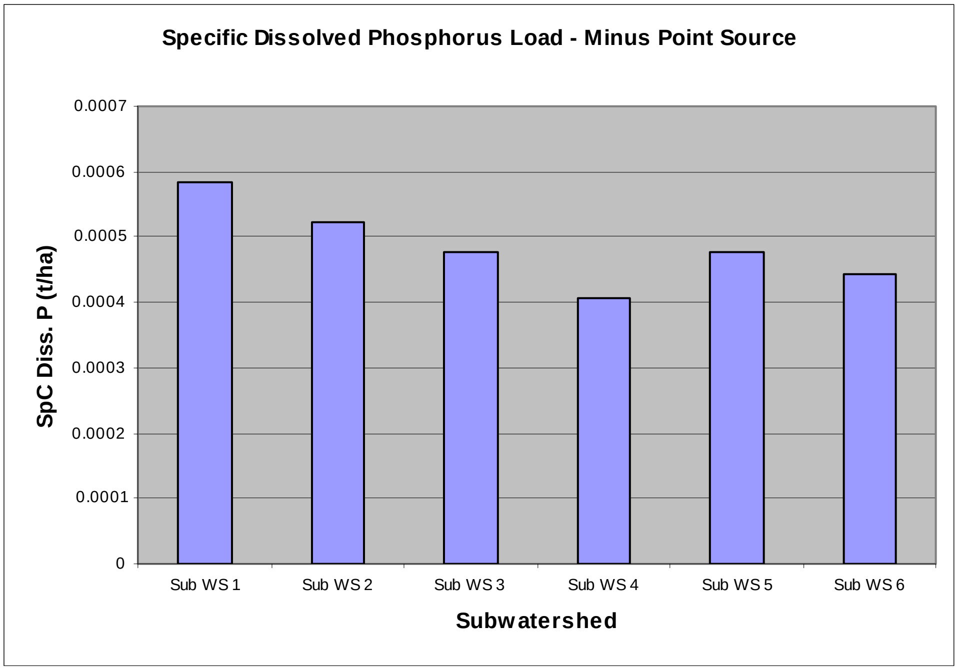


Exhibit 2.20: Mean Annual Specific Dissolved Phosphorus Loads – Minus Point Sources



When NPS loads are normalized for subwatershed area Subwatersheds #1 and #2 are shown to contribute the highest soluble phosphorus loads to Loantaka Brook. Groundwater is the primary contributor to dissolved phosphorus loads within these two watersheds while Medium Density Residential and Commercial land use make up the second and third contributors in Subwatershed #1 and Commercial and Low Density Residential make up the second and third contributors in Subwatershed #2 (Exhibits 2.21– 2.22).

Exhibit 2.21: Subwatershed 1 Dissolved Phosphorus Sources

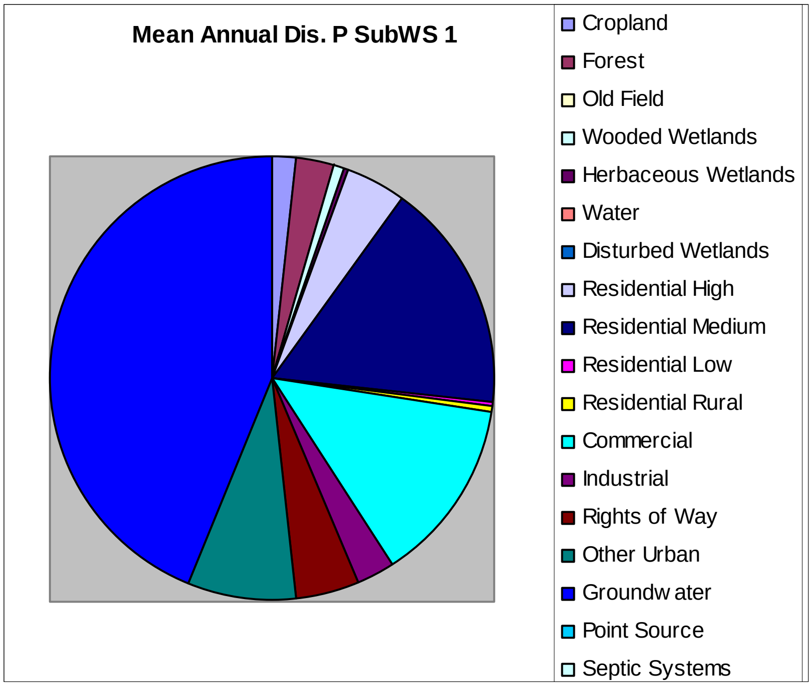
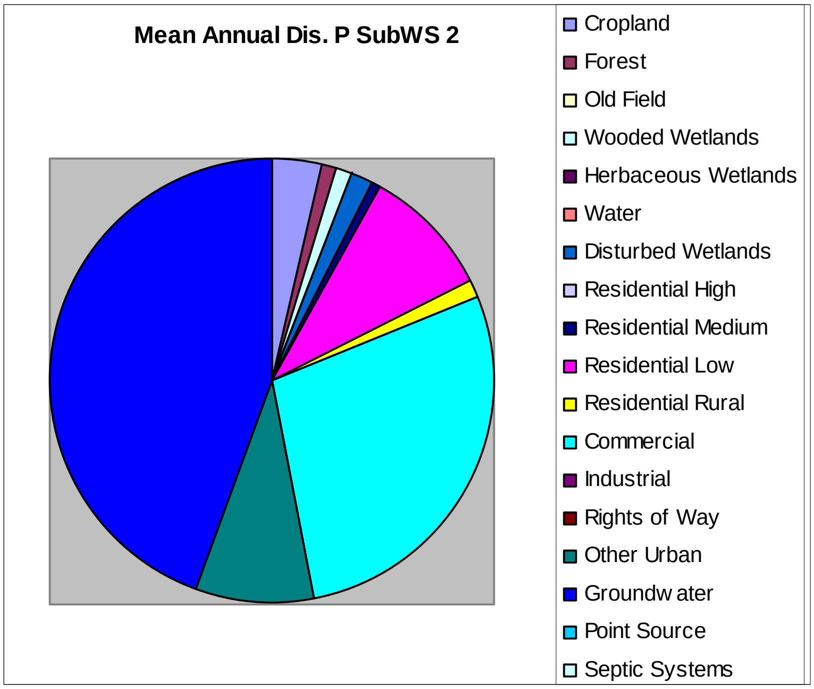


Exhibit 2.22: Subwatershed 2 Dissolved Phosphorus Sources



Total Phosphorus (TP) Load

TP load deviates significantly from the other nutrient parameters, although it is evident that point sources are the single largest contributors, although account for only approximately 25% of the total load. Land use is a much more important driver of TP loads as the solid portion of TP load is at least as great as the dissolved fraction and therefore is related to particulates generated through erosion. Agriculture and higher-density residential land uses are important contributors to increased TP loading. As such, land use and degree of disturbance are the primary driving forces in total phosphorus loading in each subwatershed, with the exception of Subwatershed #3.

Exhibit 2.23: Mean Annual Total Phosphorus Load

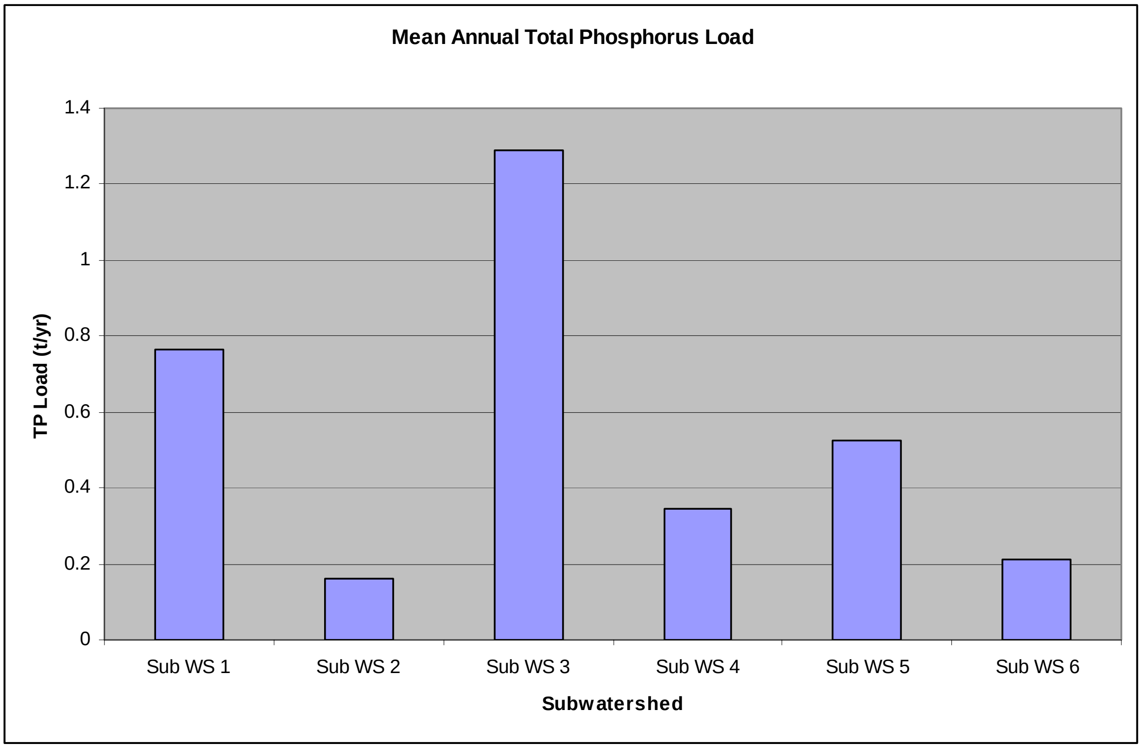
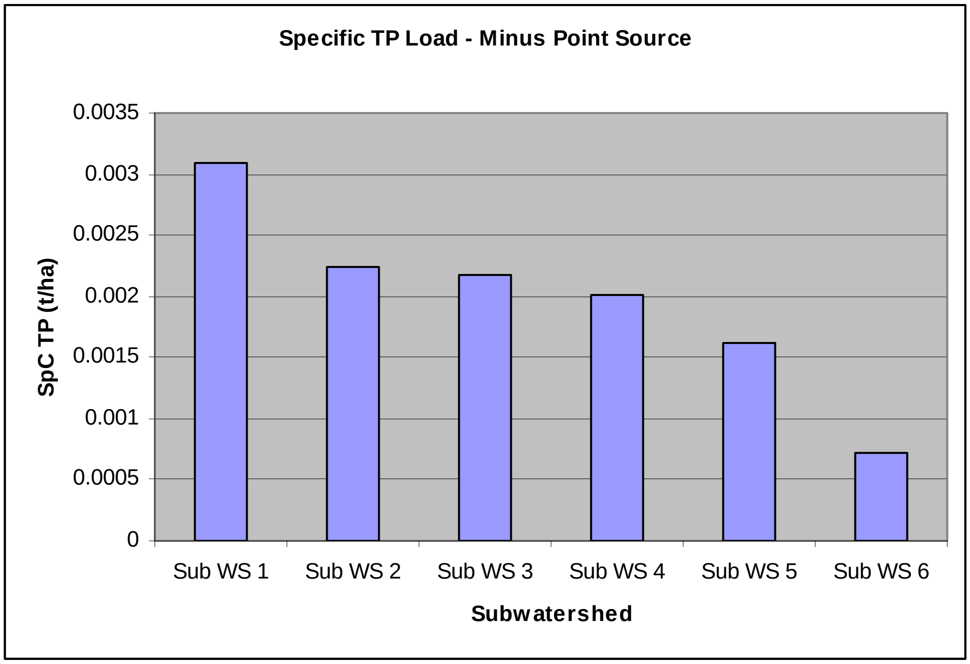


Exhibit 2.24: Mean Annual Specific Total Phosphorus Load – Minus Point Sources

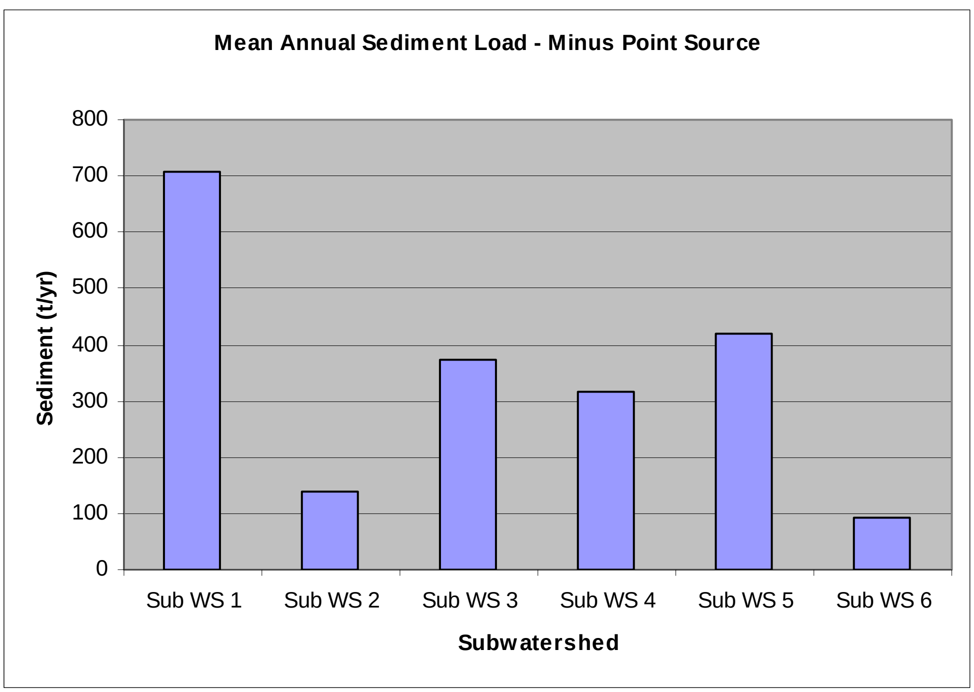


Overall, Subwatershed #1 contributes the greatest NPS TP load to Loantaka Brook followed by Subwatershed #2. The primary source of TP from Subwatershed #1 is derived from medium and high density residential while the primary sources from Subwatershed #2 are derived from cropland and secondarily from low density residential. These sources serve to elevate TP loading both through direct watershed transport and through the source creation of altered hydrologic regimes which serve to increase stream bed and bank scour and erosion.

2.3.4 Mean Annual Sediment Load

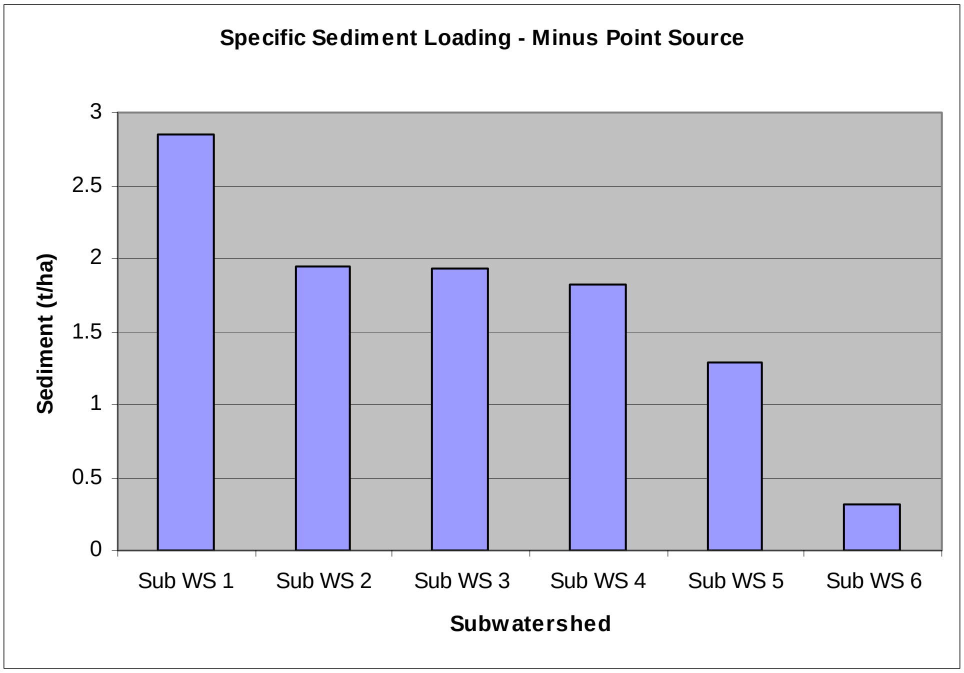
The mean annual sediment load revealed a pattern much different than the various nutrient parameters, although some of the same trends at a much reduced scale were observed in TP. As with the solid fraction of TP loading, sediment loading is a function of land use, slope, vegetative cover, and soil erodibility. On a source basis sediment generation was largely related to higher-density residential development classifications, infrastructure (i.e. rights-of-way), and agriculture. Loads were highest in the headwaters (Subwatersheds #1), which had the steepest slopes, most erodible soils, and highest development levels which correlated with high impervious area coverages. Agricultural loading was high in subwatersheds 4, while residential loads were developed in Subwatersheds #3. Cropland was the major source of sediment loads in Subwatersheds #2, #4, #5, and #6. The inclusion of sediment loading from point sources is not an available input option in BasinSim 1.0 but simple calculations utilizing mean monthly discharge and TSS concentrations arrived at a load of 4,661 kg which is a very small portion (0.25%) of the total sediment yield to Loantaka Brook which was modeled at 1,862,561 kg. The following exhibit depicts mean annual sediment loading for each subwatershed (Exhibit 2.25).

Exhibit 2.25: Mean Annual Sediment Loading



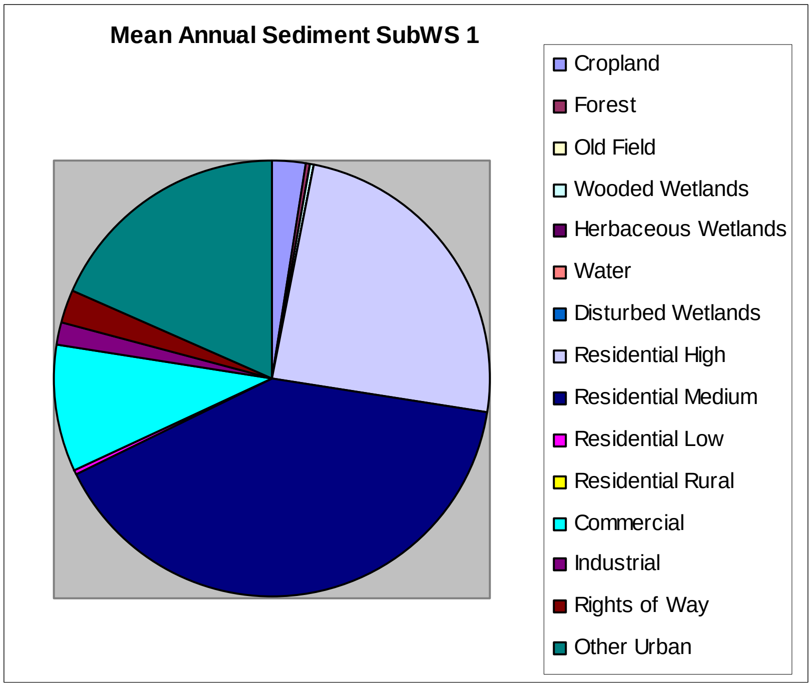
As with other parameters, it is crucial to normalize the aforementioned sediment load per unit area to address those areas which contribute a disproportionate amount of this load (Exhibit 2.26)

Exhibit 2.26: Mean Annual Specific Sediment Loads



As previously mentioned, Subwatershed #1 contributes the greatest portion of the sediment load to Loantaka Brook on a per unit area basis. Sediment loading derived from this subwatershed is largely the result of residential, urban, and commercial land use as indicated in Exhibit 2.27.

Exhibit 2.27: Subwatershed 1 – Sediment Sources



3.0 Pollutant Model Calibration - Mean Monthly Concentrations

This data was used to validate modeling efforts and compared to empirical data collected by F.X. Brown and Princeton Hydro beginning in 1999 and continuing through 2008. While BasinSim does not directly output concentrations mean monthly concentrations were back-calculated utilizing nutrient load and hydrologic data. Specifically, a cumulative effect of the components was utilized to calculate a mean concentration at the most downstream part of the watershed (Subwatershed #6) which correlates with the water quality sampling site located at the Green Village Road stream crossing. Since Subwatersheds #1 and #2 are headwaters no cumulative effect was modeled. Subwatershed #4 represents the only anomaly because it and subwatershed five are not true topographical watersheds in the sense that they each account for only one side of Loantaka Brook. Therefore, modeled concentrations for Subwatershed #5 in fact represent the true modeled mean concentration at the downstream bound for both 4 and 5; Subwatershed #5 observes cumulative effects of Subwatersheds #1- #4. The following Exhibits (3.1 – 3.3) provide back calculated concentrations for total nitrogen, phosphorus, and solids.

Exhibit 3.1: Modeled TN Concentrations

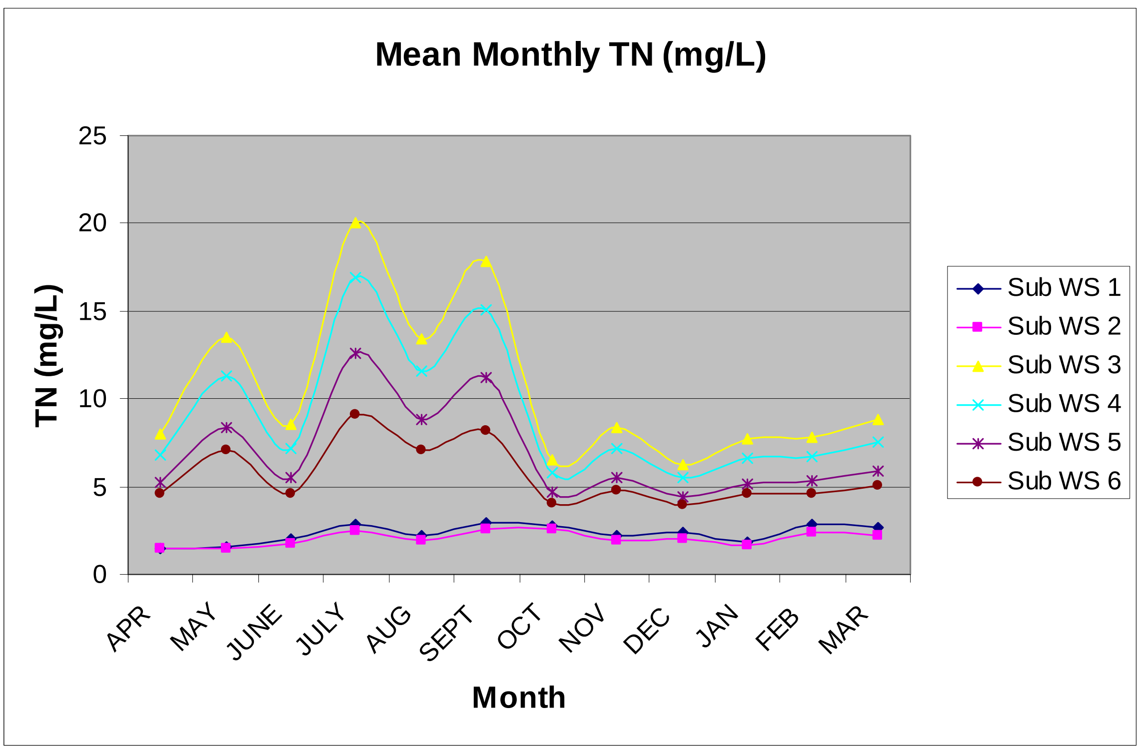


Exhibit 3.2: Modeled TP Concentrations

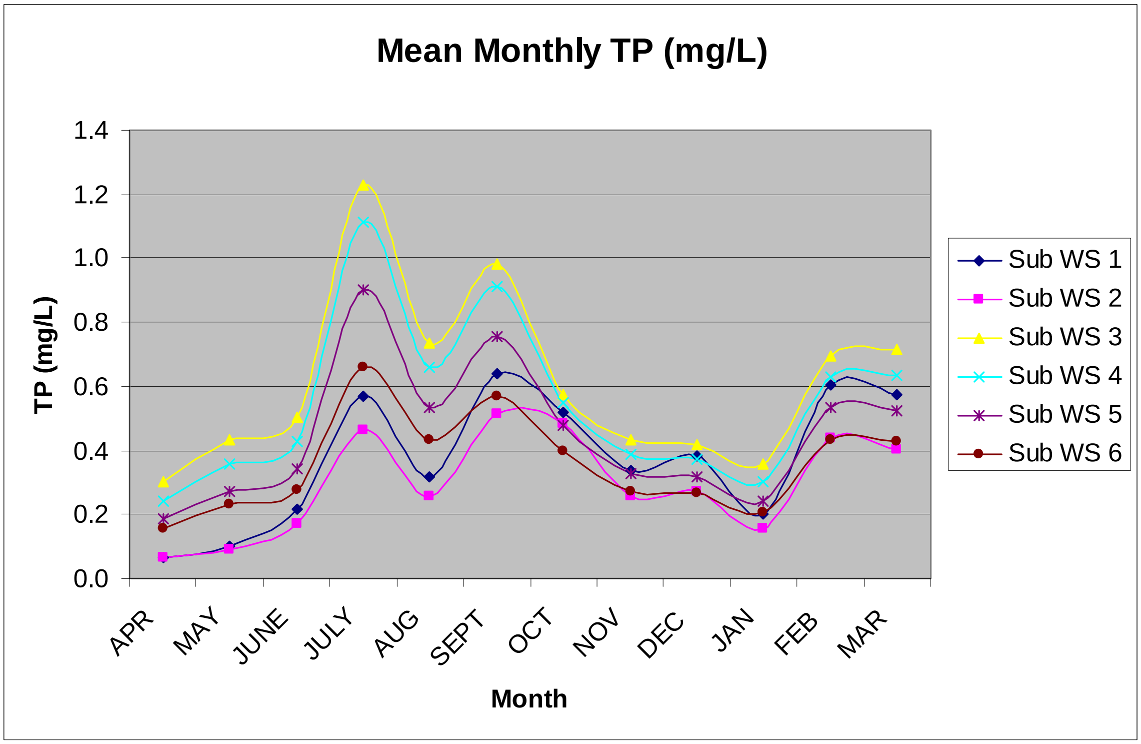
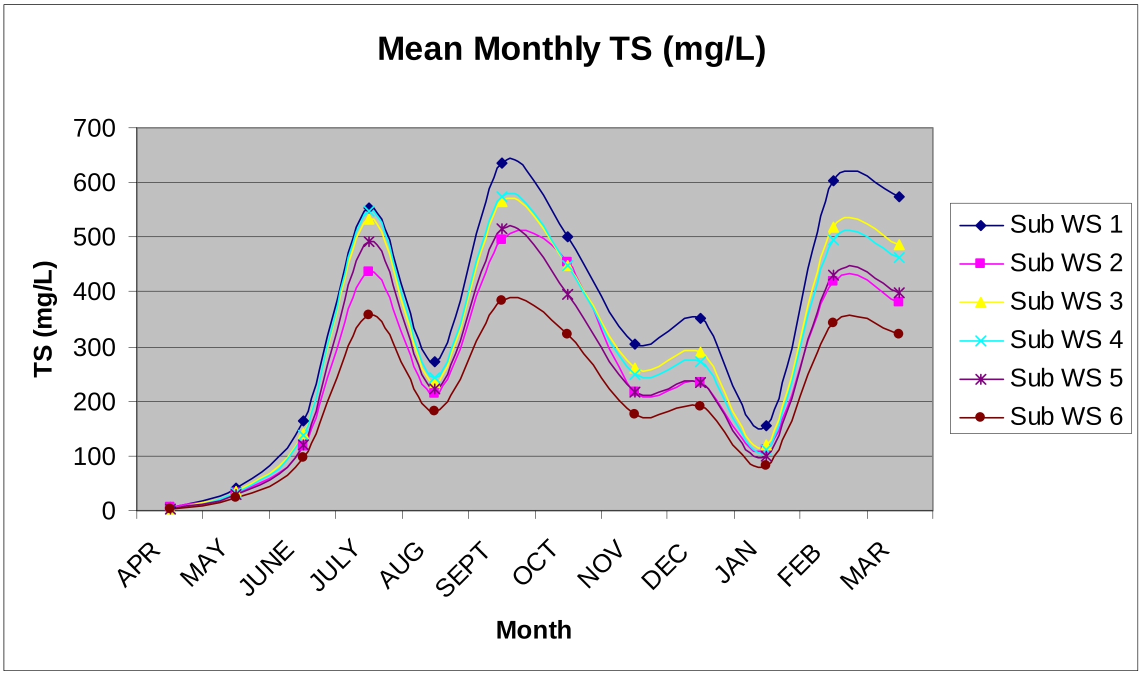


Exhibit 3.3: Modeled TSS Concentrations



The first pattern that is readily evident across all modeled parameters is that monthly concentrations vary widely over time. While not plotted this pattern is also evident in the annual statistics and is largely dependent on inter-annual climatic variability. The second pattern is that concentration varies widely between subwatersheds. For all nutrient parameters Subwatershed #3 had the highest concentrations which were at least an order of magnitude greater than the upstream subwatersheds and subsequently declined in the lower subwatersheds. Nutrient concentrations also tended to be higher during reduced flows in the summer months, a pattern that corroborates with empirical water quality data which routinely showed inverse relationships between flow and nutrient concentrations attributable to point source discharges. Monthly solids loading, which includes settleable, suspended, and dissolved solids, were closely related to development patterns and soil properties, were highest in Subwatershed #1 and lowest in Subwatershed #6. Solids concentrations were highest during both reduced flow and elevated flows but were reduced during moderate flows. Cumulative discharge increased throughout the watershed in a linear fashion from Subwatersheds #1 through #6, with the exception of Subwatershed #2 which is a smaller branch of Loantaka Brook. Discharge tended to be highest from the autumn through the spring months.

4.0 Subwatershed Management Ranking Matrix

In order to prioritize areas to concentrate mitigation, restoration, and general improvement efforts a ranking system was developed to identify those areas in greatest need of rehabilitation. The basic scheme was to assign a rank to each of the Subwatersheds of 1 through 6, with the assigned rank dependent on the results of the modeled parameters. In general, 1 represents the best possible rank and 6 represents the worst. Thus, a subwatershed with a numerically higher rank exhibits more pollutant loading or hydrology issues and thus is in greater need of management. Once each subwatershed has been ranked across all parameters are totaled. The subwatershed with the highest summed rank is thus identified as the subwatershed of greatest concern and mitigation effort.

Parameters were evaluated across three general groupings including area, hydrology, and load. For area, larger watersheds are ranked numerically higher. For the hydrology grouping, subwatersheds contributing the most groundwater are ranked lowest (1), while subwatersheds with the greater contributions of surface water runoff are ranked highest (6). For loading, parameters examined include Dissolved N, TN, Disssolved P, TP, and Sediment. For each of these parameters the highest load gets the highest score. Two separate sums were then developed: a load sum representing the nutrient and sediment loads, and a total sum including which includes load, area, and hydrology.

This ranking scheme was utilized four times on different datasets. The first iteration utilized gross budgets while the second used specific budgets. Iterations three and four utilized gross and specific loads respectively with point source contributions subtracted. As such, iterations three and four are the primary focus for management in terms of reducing non-point source pollution loading.

All four iterations varied but the most powerful scenario is the fourth which ranks specific loads without point sources. As such, this scenario identifies the relative health of each watershed on a per unit basis therefore allowing for an objective view of nutrient loading without accounting for greater loading simply based on subwatershed size.

In the ranking schemes utilizing gross and specific budgets with point source contributions Subwatershed #3 always scored worst with the highest combined score due to discharge from the wastewater treatment facility. In rankings without point source contributions Subwatershed #1 scored the worst in all four sums and sub-totals as this subwatershed has a high percent coverage of residential and commercial land use associated with increased impervious coverage. In the specific loading ranking without point source, which is the preferred ranking structure, Subwatershed #1 was identified as the primary target for management while Subwatershed #2 was the second; these are the headwater subwatersheds. The remaining subwatersheds faired much better in terms of rank due to reduced pollutant loading and lower hydrologic alteration.

It should be noted that the modeled pollutant loading data presented in the following tables identify that the large office complexes and parking areas located in Subwatershed #2 contribute significant stormwater flows and NPS loadings. The topography of the area indicates that drainage from this area is to Loantaka Brook. However, field inspections of several detention basins suggest that some of the delineated stormwater infrastructure in Subwatershed #2 discharges to the west, towards Route 287, and may be part of the Great Brook watershed. Only one stormwater pond located on South Street was confirmed to discharge to a tributary of Loantaka Brook. Based on these field observations the modeled data for Subwatershed #2 should be reviewed with caution. The preliminary data indicates that focus should be placed on Subwatershed #1 as the most significant contributor of the pollutant loading and hydraulic loading to Loantaka Brook.

Table 4.1: Subwatershed Ranking Matrices

Gross Budget Ranks

	Area	**Hydrology Rank**		**Load**					**Rank Sum**	
Subwatershed	Area	Groundwater	Runoff	Dis. N	TN	Dis. P	TP	Sediment	**Load Sum**	**Sum**
Sub WS 1	4	2	4	3	4	4	5	6	**22**	**32**
Sub WS 2	1	6	1	1	1	1	1	2	**6**	**14**
Sub WS 3	3	3	3	6	6	6	6	4	**28**	**37**
Sub WS 4	2	5	2	2	2	2	3	3	**12**	**21**
Sub WS 5	6	1	5	4	5	5	4	5	**23**	**35**
Sub WS 6	5	4	6	5	3	3	2	1	**14**	**29**

Specific Budget Ranks

	Area	**Hydrology Rank**		**Load**					**Rank Sum**	
Subwatershed	Area	Groundwater	Runoff	Dis. N	TN	Dis. P	TP	Sediment	**Load Sum**	**Sum**
Sub WS 1	4	2	5	3	4	5	5	6	**23**	**34**
Sub WS 2	1	5	4	1	3	4	4	5	**17**	**27**
Sub WS 3	3	1	1	6	6	6	6	4	**28**	**33**
Sub WS 4	2	3	2	5	5	1	3	3	**17**	**24**
Sub WS 5	6	4	3	2	2	3	2	2	**11**	**24**
Sub WS 6	5	6	6	4	1	2	1	1	**9**	**26**

Gross Budget Ranks Minus Point Source Contribution

	Area	**Hydrology Rank**		**Load**					**Rank Sum**	
Subwatershed	Area	Groundwater	Runoff	Dis. N	TN	Dis. P	TP	Sediment	**Load Sum**	**Sum**
Sub WS 1	4	2	4	4	5	5	6	6	**26**	**36**
Sub WS 2	1	6	1	1	1	1	1	2	**6**	**14**
Sub WS 3	3	3	3	2	2	3	4	4	**15**	**24**
Sub WS 4	2	5	2	3	3	2	3	3	**14**	**23**
Sub WS 5	6	1	5	5	6	6	5	5	**27**	**39**
Sub WS 6	5	4	6	6	4	4	2	1	**17**	**32**

Specific Budget Ranks Minus Point Source Contribution

	Area	**Hydrology Rank**		**Load**					**Rank Sum**	
Subwatershed	Area	Groundwater	Runoff	Dis. N	TN	Dis. P	TP	Sediment	**Load Sum**	**Sum**
Sub WS 1	4	2	5	4	5	6	6	6	**27**	**38**
Sub WS 2	1	5	4	2	4	5	5	5	**21**	**31**
Sub WS 3	3	1	1	1	2	3	4	4	**14**	**19**
Sub WS 4	2	3	2	6	6	1	3	3	**19**	**26**
Sub WS 5	6	4	3	3	3	4	2	2	**14**	**27**
Sub WS 6	5	6	6	5	1	2	1	1	**10**	**27**

Generally, a rank of 1 represents the best possible rank and 6 represents the worst. Thus a subwatershed with a numerically higher rank exhibits more pollutant loading or hydrology issues and thus is in greater need of management.

5.0 Stormwater Infrastructure Inventory (TASK 1.3)

The land use in the Loantaka Brook watershed includes approximately 51% urban land, 21% wetlands, 19% forests, 6% agricultural lands, 0.75% water and 0.14% barren land, as depicted in Figure 5, Attachment A. The USEPA and NJDEP support studies completed by the Center for Watershed Protection conclude that stream channels and water quality can become degraded from runoff and non-point source pollution (NPS) from drainage areas with an impervious cover greater than 10%. Impervious cover for the Loantaka Brook watershed is depicted on Figure 9, Attachment A, and indicates that the area upstream of Kitchell Pond has an impervious cover of 20-40% within the residential areas, and within the commercial centers the impervious cover soars to 60-80%. In addition, much of this development occurred prior to NJDEP's regulation for stormwater controls; therefore, much of the stormwater is conveyed via storm sewers to the brook without treatment, detention or retention. A limited number of stormwater facilities were identified and evaluated to provide recommendations for improved stormwater controls. GIS mapping of the known stormwater infrastructure was obtained from Morris Township and is depicted in Figures 11 and 20, Attachment A. Field investigations were conducted by Princeton Hydro to better refine available information pertaining to storm sewer outfalls, detention basins and other BMPs located within the watershed boundaries of the Loantaka Brook, upstream of Kitchell Pond.

In 1999, FX Browne completed a study prepared for the Ten Towns Committee entitled, "*Nonpoint Source Inventory of the Loantaka Brook Watershed*." This report identified and mapped over 88 stormwater outfalls and potential sources of NPS pollution that discharge to Loantaka Brook. The report identified that nearly the entire four mile stream suffered from eroded streambanks, and streambank stabilization measures were recommended for the entire stream length.

In 2002, FX Browne completed a second report for the TTC, to locate and evaluate stormwater detention basins and stormwater outfalls throughout the entire Great Swamp Watershed. This work is summarized in a report entitled, "*Detention Basin Retrofit and Stormwater Outfall Inventory*". That report identified 49 detention basins and 273 outfalls throughout the Great Swamp watershed. The primary identified problems included eroded streambanks observed at 37% of the stormwater outfalls. In general, the earlier reports recommended the following measures:

- **Perform routine maintenance** to remove the sediment and trash from the low flow channels, inlets and outlet structures and orifices. Trash and debris were noted on 14% of the basins assessed.
- **Stabilize the eroded areas** within the basins or near the outlets with geotextile, plantings and rip rap as necessary.
- **Create a multistage outlet structure for all basins**. Multi-stage outlets were observed at some of the assessed basins. A multi-stage outlet generally includes a low-flow orifice (3 inch) at the bottom of the outlet structure able to discharge minimal flows. During high intensity storms, the low flow orifice causes water to be

retained in the basin, allowing particle settling and some infiltration and groundwater recharge. The multi-stage outlet generally includes an overflow weir to manage higher flow capacities, and includes a grate or trash rack to control floatables and debris.

- **Remove concrete low flow channels and replace with gravel beds and vegetation**. Concrete low flow channels ease maintenance but convey short duration storms without significant detention, infiltration, or NPS removal. These concrete channels could be removed and replaced with gravel beds. In addition, the basins could be planted with erosion resistant vegetation or wetland plants and grasses to reduce erosion, increase filtration, deter geese, reduce maintenance, and increase potential habitat areas and aesthetics. These measures could be completed at basins #2, 9, and 27.
- **Plant trees within and around basins and ponds where feasible to provide shade and reduce water temperatures**.

Other suggested basin retrofit measures included:

- Install aerators in wet ponds.
- Convert detention basins to created wetlands or bioretention systems where soil conditions are feasible.
- Control invasive plant species. Many vegetated basins maintained privately in this watershed have become dominated by *Phragmites*, an invasive plant species.

5.1 Municipal Stormwater Plans, Ordinances and Mitigation Lists and Green Building Designs

In 2005, Morris Township adopted a Stormwater Plan and Ordinances in accordance with the New Jersey Stormwater Rules that address <u>*future*</u> major developments. Because much of the watershed is already significantly developed, Morris Township may consider amending their existing Stormwater Plan and Ordinance to address existing developments that are not currently addressed by these regulations. The following stormwater management recommendations are provided for consideration in order to protect the public health and safety, to address current surface water impairments from nutrients, pathogens and sediments, and to reduce these loadings to Loantaka Brook as recommended by the NJDEP.

- Require existing commercial properties and townhouse/apartment complexes to inspect and document the conditions of their current stormwater facilities and to document their current stormwater maintenance programs and schedules.
- The Township should jointly inspect some of these major facilities and provide recommendations to address stormwater maintenance concerns.
- Require major redevelopment projects to provide additional appropriate stormwater controls, as a condition of their approval. The general recommendations outlined by

TTC in earlier for modifying existing stormwater facilities can be recommended for implementation. Currently, under the NJ Stormwater rules (N.J.A.C. 7:8) if redevelopment projects stay within the existing footprint of disturbance, additional stormwater controls are not required.

- Encourage redevelopment to incorporate innovative stormwater controls such as disconnecting impervious cover, vegetated roofs, dry wells, bioretention swales or basins, rain gardens, rain water reuse, and other measures supported by the US Green Building Council's Leadership in Energy and Environmental Design (LEED) Green Building Rating System. The nationally-recognized LEED Certification program promotes sustainable site development and building practices that can reduce impacts from stormwater runoff. Adopt the LEED program as a goal for redevelopment within the Stormwater Plan.
- The stormwater recommendations included in this report can be incorporated into the Morris Township Stormwater Management Plan and on the List of Potential Mitigation Measures, as recommended in the Stormwater Rules (N.J.A.C. 7:8). When future development or re-development is proposed in the community, the Township can potentially negotiate to implement these measures.

Portions of Loantaka Brook are located within the boundaries of the New Jersey Highlands Region – Planning Area (Attachment A, Figure 6). The New Jersey Highlands Council adopted the Highlands Regional Master Plan (RMP) in July 2008, which provides various recommendations and policies for improved stormwater management, water conservation, aquifer recharge, riparian corridor preservation, and wildlife habitat protection. By implementing the proposed watershed mitigation measures outlined in the next section (5.2), and promoting redevelopment to incorporate innovative stormwater controls into their plans, the communities would be advancing the goals of the Highlands Regional Master Plan.

5.2 Stormwater Infrastructure Recommendations for Loantaka Brook

Princeton Hydro was tasked to supplement the TTC's earlier cumulative investigations specific to the Loantaka Brook Watershed, and to provide recommendations for potential upgrades, retrofits or stream bank mitigation measures to improve the water quality and ecological functions of Loantaka Brook. In general, improving stormwater management can be accomplished by:

- Maximizing the natural overland flow,
- Maximizing infiltration,
- Maximizing vegetation buffers and the utilization of floodplains,
- Disconnecting stormwater down spouts that are connected directly to storm sewers
- Constructing additional small bioretention basins on public lands, and
- Working with commercial property owners to improve stormwater maintenance and the management of the existing stormwater systems

In general, the recommendations provided herein support BMPs that provide additional rate control, volume reduction and nutrient load mitigation. Retrofit measures for Loantaka Brook should focus on providing volume control through infiltration, additional peak flow control through modifications to existing infrastructure, and nutrient removal through biotreatment measures. These methodologies also provide enhanced water quality benefits including suspended sediment removal.

Brief summaries of seven high priority NPS stormwater projects for the Loantaka Brook subwatershed are outlined below. Various other recommended stormwater mitigation measures are summarized in Table 5.1. These recommendations were evaluated and ranked in terms of (1) anticipated mitigation effectiveness, (2) environmental benefits given the magnitude of the stormwater concerns, (3) a benefit-cost valuation, and (4) site constraints. In addition, the mitigation measures proposed in the upper watershed were prioritized as potentially more effective in addressing stormwater runoff controls, than the mitigation measures proposed in the lower watershed.

5.2.1 Retrofit the Stormwater Controls for Kitchell Pond

The Morris County Park Commission owns Kitchell Pond, located within the Loantaka Brook Reservation. Under a separate 319(h) grant, TTC and Morris County are currently implementing plans to remove some of the asphalt parking area, retrofit the existing storm water catch basins, construct bioretention basins, and plant shoreline vegetation to stabilize the shoreline, improve stormwater runoff quality, reduce runoff volumes, and deter the congregation of geese in the area.

5.2.2 Construct a Bioretention Basin for the Seton Hackney Stables

The Morris County Park Commission owns the Seton Hackney Stables, located within the Loantaka Brook Reservation, and leases the operation to provide facilities for public horse riding. Under current conditions, stormwater runoff from the stable area, barn, riding areas and pastures flows essentially uncontrolled into an existing drainage swale and directly into Loantaka Brook. In an effort to provide water quality and peak flow/volume benefits, a bioretention basin is proposed for the Hackney Stables. This retrofit application will help address the existing nutrient loading that is associated with the stable area.

In 2008, proposals for this project were submitted to the USDA-NRCS and the Center for Watershed Protection (CWP) to fund the bioretention basin at the Hackney Stables on behalf of the TTC and Morris County. However, funding was not obtained. The detailed proposal for stormwater retrofit measures at the Seton Hackney Stables and photographs of the site are included as Attachment B and C.

5.2.3 Construct a Bioretention Basin for the Woodland Elementary School

Under current conditions stormwater flow from portions of the Woodland Elementary School and associated parking areas is directed to a series of catch basins at the southern end of the parking lot. The runoff collected by the school's existing stormwater system flows unattenuated and untreated directly into the main stem of the Loantaka Brook via a 150 foot long 18 inch diameter storm sewer. The headwall of this outfall was broken in half from recent storm flow events. The existing stormwater management at the school could be greatly enhanced with the construction of a bioretention basin.

- The bioretention basin would provide peak flow attenuation, water quality functionality, and is also expected to provide some level of volume control through infiltration. The basin (~2,000 ft2) would be located at the base of the sloped area between the parking area and ball field towards the tree line along the eastern side of Loantaka Brook. The site would require grading to create the shallow depression for the BMP.
- This retrofit would also entail the removal of portions of the existing stormwater conduit. The outflow from the basin could either be routed back into the existing conduit or the conduit could be replaced with a vegetated swale to provide additional treatment.
- The bioretention basin would be planted with native vegetation to increase infiltration, nutrient removal and provide some level of flow rate reduction.
- In addition to the BMP the section of the forested riparian area near the basin's outfall would be improved by the removal of existing asphalt piles and various, large debris to accommodate the drainage swale discharge from the proposed bioretention basin. This retrofit would also be a high visibility location and would provide excellent educational and outreach opportunities.
- Additional engineering evaluations are needed to prepare conceptual plans. Details for these recommendations and photographs of the basin's current condition are provided in Attachment B and C.

Two key components, adequate topography and available public land are both present to facilitate the construction of a bioretention measure at the Woodland Elementary School. It should be noted that because of the urban nature of the watershed there are few situations where both components exist.

5.2.4 Madison Avenue –Parson Village Detention Basin

The existing Parson Village detention basin is approximately 400 ft by 75 ft and is defined by a 20 ft tall retaining wall along the northern side and an exterior berm that slopes from 1-3 feet. The basin is located near the Parson Village apartment complex, but receives runoff via storm sewers from the large commercial complex and parking areas on Madison Avenue. Due to the highly urbanized characteristics of the drainage area the exact extent of the drainage area was unclear based on a cursory examination of the inlets in the area. The orientation of the basin's main inlet and outlet structure is such that during typical storm events, stormwater flows directly to the outlet structure with the shortest possible flow path, with minimal opportunities for treatment and flow attenuation. Furthermore the outlet structure of the basin has a 24" orifice set at the base of the basin. The relatively large flow capacity of the 24" orifice also provides minimal opportunity to detain stormwater in the basin. This condition is especially magnified during typical and frequently occurring storm events where inflow peak flow rates do not exceed the capacity of the outlet structure and the basin provides no peak flow attenuation.

The basin's existing outlet structure and drainage configuration provides an excellent opportunity for a straightforward retrofit which can greatly enhance the basin's peak flow attenuation and water quality performance.

- First, the basin should be regraded to lengthen the flow path between its inlet and outlet. This would be accomplished by creating a small earthen berm in the center of the basin. The berm will separate the direct connection that now exists between the inlet and outlet structures. It would force the runoff volumes generated by the more common storm events (1-2 year frequency of occurrence) to actually fill the western end of the basin. Focusing on the smaller events actually will result in the management of approximately 95% of the storms experienced during any single year. It will also negate any backwater issues that could arise if an attempt was made to further control larger events. The construction of the berm will maximize the flow length through the basin from the inlet to the outlet structure. With an increase in flow length will come an increase in contact time. This translates to better filtration of the incoming runoff and greater opportunity for the assimilation of nutrients by the basin's plantings.
- In the process of installing the berm the basin bottom would be renovated by basically scarifying and restoring the porosity of the soils. This will increase the opportunity for infiltration thus decreasing the volume of runoff released downstream to Loantaka Brook.
- The existing relatively unrestricted 24" orifice outlet structure will be retrofitted with the addition of a V-notch weir constructed within the existing concrete structure. This would require modification to the existing trash rack. The V-notch weir would be sized to restrict flow from smaller, more frequent storm events (again focusing on the 1 and 2 year events) that the basin currently fails to provide any rate reduction attenuation. The retrofit would also greatly enhance the water quality performance of the basin by drastically increasing the residence time and allowing additional treatment and suspended solids and nutrient removal. During larger storms the flow would overtop the retrofit weir and therefore no compromise the original large storm flood control design intention of the basin.
- The basin is currently densely vegetated with *Phragmites*, which increases the likely spread of *Phragmites* downstream. The renovation of the basin will therefore entail its re-vegetation with wet tolerant plants. Such plants, such as *Juncus* and *Scirpus* can withstand inundation, yet do well during the drier conditions that will exist between storm events. The actual plant mix will be developed with the evolution of the plans from the existing concept stage to implementation stage. It should be noted

that even with the proposed renovation maintenance of the basin will need to be improved to ensure the native species not only become will established, but over time are not out-competed by the highly aggressive, invasive *Phragmites*.

- A conceptual plan with details for these recommendations and photographs are provided in Attachment B and C, along with photographs of the basin's current condition.

5.2.5 Retrofit of the Village Drive Detention Basin

Stormwater enters the Village Drive detention basin via a five foot diameter outfall. The runoff conveyed by this pipe originates from an office complex located near 110 Madison Avenue. It is unclear whether some flow from the Village Drive apartment complex also utilizes this basin. This basin is privately owned and maintained, and the existing configuration of the basin is somewhat complicated. Due to its unusual configuration, the original design intention and supporting construction documentation for this basin needs to be reviewed. Correspondence with the Township Engineering Department failed to yield any design plan or as-built plans for this basin.

Based on storm event inspections of the basin, as inflow enters the basin it is directed into a ponded sediment forebay. Flow from the forebay can either flow directly into the detention basin or bypass the basin altogether and flow over a large concrete weir. Flow that bypasses the basin and flows over the weir has essentially no flow attenuation due to the large size of the weir and small size of the sediment forebay area. This bypass flow is directed into swale that then discharges under Johnston Avenue to a tributary of Loantaka Brook. Due to this significant bypass the potential flow attenuation provided by the detention basin is questionable. It is possible that the functionality of the basin has over time been compromised due to inadequate maintenance. It is possible that the weir was intended to function as a by pas only during larger events. However, in its present state, the basin appears to provide little opportunity for stormwater treatment.

The operation of the basin is further complicated and likely compromised by the excessive sedimentation in the forebay area; evidence of the aforementioned inadequate maintenance. Approximately two feet of sediment were observed in the five foot diameter inlet conduit. Furthermore a large sediment bar has formed near the inlet which appears to be diverting a disproportionate amount of inflow to the bypass weir and not into the basin where additional flow attenuation and water quality treatment could be accomplished. Based on the visual assessment it appears that the excess sedimentation and lack of maintenance may have drastically impacted the original design operation of the basin.

- The basin's original design intent and as-built geometry should be reviewed to determine the proposed basin operation and extent of sedimentation. Furthermore the large sediment deposits and *Phragmites* stand need to be removed. These efforts may help restore some of the suspended sediment treatment capabilities of the basin and help ensure that the basin is not acting as a source for *Phragmites* propagation downstream.

- In addition to the maintenance requirement, the basin should be retrofitted to provide additional peak flow control and water quality benefits. After reviewing the original design documentation, the bypass weir and detention basin outlet structures could be modified to provide additional storage and attenuation during storm events. This may entail further restricting the existing 18" orifice of the basin and modifying the bypass weir to ensure that incoming stormwater runoff from small, frequent storms utilize the entire detention basin, and the bypass weir only functions as a spillway for larger less frequent storms.
- Renovation of the basin will also entail its replanting. This basin appears to retain more of a saturated condition than does the Parson Village basin. As such, it appears capable of sustaining more of a wetland plant complex as opposed to simply a wet tolerant plant complex. Further analysis of this basin's hydrology is needed, especially with respect to the volume gained through the removal of the accumulated sediment and *Phragmites.* Photographs of the basin's current condition are provided in Attachment C.

5.2.6 Village Drive Ravine Recommendations

A dry stormwater drainage ravine runs behind the Madison Avenue office complex in the far northeast section of this subwatershed. The ravine has a 48" open culvert outlet, which likely flows into the Village Drive basin. This ravine is likely privately owned and may be owned by more than one entity. The banks of the ravine are eroded and are a likely source of sediment loading to the Village Drive basin and Loantaka Brook.

- A scoured bank 4 feet high is present just before the outlet. Although a detailed hydraulic and hydrologic study is needed to verify the existing performance characteristics of this feature it appears that planting the ravine's slopes with live stakes would stabilize the scoured bank.
- The 48" culvert should be retrofitted by constructing a small wall or gabion rock structures in front of the culvert, about 10-15 feet from the opening. This will accomplish two things. First, it will aid in the dissipation of some of the scour energy of storm flows discharged from the pipe. A low structure positioned near the mouth of the pipe could also provide some detention that could further reduce peak flows, facilitate the settling of sediment and other sediment-bound particulate pollutants. The 48"culvert could also be retrofitted with a trash gate, to reduce litter and floatables. It must be stressed that additional hydrologic and hydraulic analyses are needed before any of these modifications go forward. The placement of a low weir or gabion structure in front of the pipe needs to be in a manner that ensures the stability of the installation, does not exacerbate scour, and does not result in a back water effect. Details for these recommendations and photographs of the basin's current condition are provided in Attachment C.
- Placement of a Stormceptor unit or Suntree Baffle Box could also be considered for this site to reduce sediment loadings downstream. However, significant grading would be needed for such retrofit options. Also these devices would not provide any

greater detention. As such, the cost-effectiveness of the use of these or other manufactured treatment devices (MTDs) must be strongly assessed.

5.2.7 Crum-Foster Drainage Retrofit

The Crum Foster office complex and a two story parking garage facility on Madison Avenue are located in the far northeast corner at the upper portion of Subwatershed #1. Stormwater from a large portion of the site is directed through storm sewers to a severely undermined outfall towards the rear of the parking area. The flow is directed into a dry drainage swale in a wooded area. The stormwater swale is approximately 12 feet wide and runs though the woods and into an open meadow, and possibly to a stormwater catch basin. The storm sewer inlet appears to be buried under possibly a foot of sediment and woody debris. Ownership and responsibility for maintenance of the outfall, the wooded drainage area, meadow and storm sewer inlet should be determined by Morris Township. The drainage swale flows through a meadow area, where a natural gas line is also located. Stormwater drainage from the Crum-Foster facility could be better managed with improved maintenance and some retrofits to the existing stormwater systems.

- As previously mentioned, the concrete apron of the outfall is severely cracked, and has been eroded and undermined. Based on the observations made during various site inspections of the structure under different weather and seasonal conditions it appears that there is no stormwater detention provided for this drainage area.
- Detention and water quality treatment could be achieved by constructing an earthen berm and weir at the edge of the drainage swale within the wooded area; thus creating a small detention/infiltration area without the need for significant removal of vegetation. However, extensive hydrologic and hydraulic analyses are needed before any modifications proceed. The placement of a low weir or gabion structure within the ravine needs to be in a manner that ensures the stability of the installation, does not exacerbate scour, and does not compromise the existing wooded understory vegetation.
- Photographs of the basin's current condition are provided in Attachment C.

Table 5.1: Loantaka Brook Stormwater Mitigation Projects				
Project Description	**Location**	**Ownership / Responsibility**	**Priority**	**Costs**
1. Kitchell Pond, Loantaka Reservation, Morris County Design & construct bioretention swales and basins for runoff from parking	Loantaka Reservation,	Public/ Morris County Park Commission	High Project recently funded for 2009	$161,720
2. Seaton Hackney Stables – Loantaka Reservation - Design, construct new bioretention basin.	South Street	Public/ Morris County Park Commission	High Funding sought from NRCS and CWP	$23,500
3. Woodland Elementary School – Design & construct new bioretention basin. (Outfall #21*)	Johnston Rd & Township Ball field	Public / Morris Twp Board of Education	High	$30,000
4. Parson Village – Redesign and re-construct stormwater basin and outfalls. (Outfall #13*)	65 Madison Avenue & Parson Village Rd	Private	High	$105,000
5. Village Drive & Turtle Rd Basin #2 – Retrofit the stormwater basin and outfall. Eradicate *Phragmites* with plantings.	Village Drive & Turtle Rd	Private	High	$75,000
6. Village Drive Ravine - Redesign and retrofit ravine culvert to detain peak flows.	North end of Village Drive	Private	High	$82,000
7. Crum-Foster Redesign and retrofit ravine to detain peak flows	Crum-Foster Madison Ave	Private	High	$63,000
8. Morris Township Municipal Building– Disconnect downspouts. Basin not feasible.	Woodland Avenue	Public / Morris Twp	Medium	TBD**
9. Morris Township Police Building– Design & construct bioretention swales and basins for runoff from parking and buildings. (Outfalls #24*)	Dwyer Road	Public / Morris Twp	Medium	$23,500

Table 5.1: Loantaka Brook Stormwater Mitigation Projects (cont)

Project Description	Location	Ownership / Responsibility	Priority	Costs
10. Morris Township Fire Building– Design & construct bioretention swales and basins for runoff from parking and buildings (Outfalls 27*)	Dwyer Road	Public / Morris Twp	Medium	$23,500
11. Morris Twp Parks -Create bioretention swales and basin for runoff from the tennis courts, pool and parking area. (Outfalls 28, 29 & 32, 38, 39)	Woodland Avenue & Dwyer Lane	Public/ Morris County Park Commission	Medium	$23,500
12. Loantaka Reservation, Morris County, South Street Parkland - Design, construction new bioretention basin (downstream of outfall #47)	South Street Parkland	Public/ Morris County Park Commission	Low	$23,500
13. Fanock Rd Outfall - Modify outfall with rip rap to dissipate storm flow. (near outfall 40)	Fauck Rd Outfall by Woodland Wastewater Treatment Plant woods.	Public / Morris Township	Low	TBD**
14. Woodland Rd & Seymor Rd outfall - Morris Township & Morris County – Modify outfall with rip rap to dissipate storm flow.	Woodland Rd & Seymor Rd,	Public / Morris Township & Morris County	Low	TBD**
15. Modify outfall at Fox Hollow & Braidburn to detain flow. (upstream of outfall 49-52)			Low	TBD**
16. Loantaka Reserve Bluestone Terrace - Stabilize outfall with plantings. Outfall #54	Loantaka Reservation, Bluestone Terrace	Public/ Morris County Park Commission	Low	TBD**
17. Kitchell Rd -Stabilize the slope with plantings. Outfall #175	Kitchell Rd, Loantaka Reservation,	Public/ Morris Twp and Morris County Park Commission	Low	TBD**
18. Loantaka Rd crossing – Streambank restoration.	Streambank Stabilization	Public Morris/Chatham Twp	Medium	Needs further analysis

* The Outfall ID sequence are references from the FX Browne reports. Note some of these mitigation measures were also previously included in the recommendations from earlier TTC reports.

** To Be Determined – low priority projects, mostly simple repairs/renovations costing less than $5,000

5.3 Streambank Stabilization North of Woodland Avenue (Sub-objective 2)

Field investigations were conducted during dry and storm events of the upper segment of Loantaka Brook north of Woodland Avenue to evaluate the potential location for stream bank restorations measures. However, based upon the field conditions it appears that the stream corridor is actually quite stable. Thus, streambank stabilization measures are not necessary in this segment. Additionally, with the advent and recent passage of the NJDEP Flood Hazard Control Area (FHA) regulations (N.J.A.C. 7:13), it would be difficult given the existing status of the stream corridor to qualify for permits (see below). Rather more focus should be placed on the stormwater mitigation measures in the upper watershed as outlined in the previous section of this report. This segment of Loantaka Brook is located adjacent to the Woodland Elementary School, refer to Attachment C for locational maps of the subject area. Outlined below is a summary of the field conditions and factors that affected this recommendation.

1. **Flood Hazard Control Area (FHA) Regulations** - In November 2007, the NJDEP adopted the new Flood Hazard Control Area (FHA) regulations that outline specific requirements for activities within riparian zones and stream channels, including streambank restorations and stormwater outfall repair and maintenance (N.J.A.C. 7:13 subchapters 9, 10 and 11). Generally, the new rules increase strict environmental and engineering standards to protect the public safety, minimize the flood damage, and ensure that flooding does not increase. The new rules also require various new permits for many actions that may disturb riparian zones. Based on site conditions and these regulatory requirements it was determined that the potential streambank restoration north of Woodland Avenue was not a cost effective measure.

2. **Floodplain & Riparian Zone Condition**: The floodplain and riparian zone along this reach of Loantaka Brook included intact forested areas and forested wetlands greater than 50 feet in.

    - Based on field observations, the adjacent riparian zone for the upper reach of Loantaka Brook is best classified as a forested area dominated by red maple. The forest canopy also includes Norway maple, pin oaks, red oaks, locust, elm, willows, and mulberry. The forest understory is somewhat impaired by large patches of invasive plant species including Japanese Knotweed, multi-floral rose, and Japanese stilt grass, various vines. The density of these plants suggests extensive deer browse related damage to the understory vegetation. Ferns, skunk cabbage and jack-in the pulpit were present in the wetland areas on the west bank, and a large specimen black willow tree, with a 4 foot diameter, is present within the school property riparian zone.
    - As the stream meanders adjacent to the Morris Township ball fields, an older fence line is present to provide for children safety. With the construction of these fields, the forested riparian zone has becomes thinned to approximately 25 feet as the stream approaches the Woodland Avenue culvert crossing.

Invasive species such as multi flora rose, honey suckle, poison ivy, and bittersweet vines dominate the understory and canopy.

- Generalized GIS mapping of the outfalls, FEMA floodplains, wetlands, and critical habitat areas are provided for this segment in Attachment C. Formal wetland delineation was deemed unneeded and unwarranted as the direction of the project shifted away from any form of streambank modification, grading or restoration.
- The NJDEP provides information and mapping of potential wildlife habitat under the Landscape Project GIS database. Based on this information, the study area is labeled as a forested wetland, and the NJDEP did not identify the area as suitable habitat for critical wildlife or species of concern such as wood turtles or box turtles. The urban nature of the watershed and the frequent high storm flows in this active floodplain, likely reduce the viability of these wetlands as critical wildlife habitat areas.

3. **Floodplain Access**: Streambanks are greater than 3-4 feet in height in the northern section just downstream of the 36" outfall that services the Parson Village apartments and offices on Madison Avenue. Some evidence exists of past efforts to perhaps straighten or channelize the stream in these reach. However, there is a wide "breach" in the streambank. It could not be determined if the breach was man-made or natural. Inspection of this site, including analysis of the vegetation, shows that during larger events the stream height reaches the elevation of the "breach" thus enabling the stream to access the floodplain and associated wetlands. Providing additional access to the floodplain by regrading the streambanks in the northern segment was an identified project task and was carefully considered for this project, but was eventually rejected for the following reasons:
    - The presence of sediment, mud encrusted leaves, and relatively limited understory indicates that portions of the northern floodplain, adjacent to the Woodland Elementary School site, are routinely accessed and inundated by storm flows.
    - As noted above there is some evidence of channelization. Specifically, in the northern section, soil (1-2 feet) appears to have been placed on top of the stream banks several years ago, possibly to keep storm flows within the channel. The presence of mature trees and moss growing on the banks and this fill material indicates that the banks are stable. It was determined that actions taken to remove this material could actually create more problems for the stream.
    - Clearing portions of the forest areas in this riparian zone and forested wetlands would be necessary to regrade the streambanks. This could only be accomplished using heavy equipment. This work would also require NJDEP permits, and it did not appear that the required work would be consistent with the permit limitations and constraints. Thus, the cost-benefit to regrade the streambanks in order to provide additional limited access to the floodplain

was deemed disproportionate and the project was scuttled.

- Further downstream closer to Woodland Avenue, the streambanks are lower (1-2 feet high) and access to the floodplain (forests and ball fields) by the higher flows is available. It could be possible to reconnect the stream to the adjacent floodplains. However, given the proximity of the ball fields it was determined that doing so was not feasible.
- Although an element of the original proposed work scope, detailed wetland mapping, topographic surveys and draft permit applications were not developed for this project task because the streambank restoration or enhanced floodplain access for this stream section was deemed not only infeasible but also not warranted. As such, increased effort was placed in the development of conceptual corrections for upstream stormwater management problems. These were discussed in the previous sub-section.

4. **Streambank Stability**:

- Despite receiving significant volumes of stormwater runoff, the streambanks in this upper segment of Loantaka Brook are fairly stable, with limited signs of erosion. This is in contrast to the eroded streambank conditions that once existed downstream of Woodland Avenue. These streambanks have been subsequently stabilized. Overall, the intact forested buffer is successfully maintaining stable bank conditions.
- There is a sharp bend (nearly 90 degrees) just upstream of the 60” inch outfall and the west bank is eroded; however, this bank is private land. Limited streambank plantings utilizing live stakes (without regrading) was considered for this segment; however, the existing dense tree canopy would likely shade out attempts to vegetate and stabilize this bank.
- Downstream of the 60” outfall the streambanks are 2 feet or less, in stable condition, and the floodplain (ball field and private yards) is readily accessible. The floodplains within the residential yards are also likely inundated by higher storm flows. Plantings, such as river birch, sycamore or willows, may enhance the riparian zones in these private yards.
- **Stormwater Conveyances**: The stream segment receives significant volumes of stormwater runoff from six major outfalls. These outfalls are depicted on mapping in Attachment C.

Table 5.2: Outfall Size & Conditions North of Woodland Ave		
Outfall Size	**Outfall Condition**	**Drainage Area**
36 inch	Concrete outfall within concrete headwall, minor repairs needed, large scour hole, 4-5 foot banks, some access to floodplain,	Parson Village apartments & 65 Madison Avenue Office complex
48 inch	Concrete outfall and headwall, bank and bed stable, 3-4 foot banks, limited access to floodplain	Dorado Drive apartments and Madison Avenue offices
18 inch	Concrete outfall and broken headwall; 2 foot banks, access to floodplain, stream eroded behind headwall, bank and bed scoured, sediment deposition	Woodland Elementary School parking lot
12 inch	Concrete outfall without a headwall; 2 foot banks, access to floodplain, eroded stream bank and bed scoured, sediment deposition in bed	Johnston Dr and Woodland Elementary School parking lot
60 inch & a 12 inch	Concrete elliptical outfall and headwall, and a 1 ft outfall with no headwall. 2 ft stable banks, access to floodplain, flooding of residential yards	Johnston Dr, and apartments and offices along Village Drive and Madison Avenue
24 inch	Concrete culvert under Woodland Avenue bridge, 2 ft banks reinforced with stone, access to floodplain, some street flooding	Woodland Avenue

5. **Outfall Conditions**: Each of these outfalls and headwalls are in stable condition with the following exceptions:

- High stormwater flows from upstream sources has contributed to eroding the streambank behind the headwall and discharge pipe for the 18” outfall that services the Woodland Elementary School, exposing 1-2 ft of pipe behind the headwall. It was documented during one of the site inspections conducted during this study that the headwall has been broken in half. It was unclear whether the Township is removing this headwall while in the process of retrofitting the outfall.
- Sediment bar deposition is evident immediately downstream of each outfall indicating the storm runoff provides significant sediment loading to Loantaka Brook, from each of these outfalls. The 48” and 60” outfall servicing Dorado Avenue, Village Drive and Johnston Avenue had the largest sediment depositions.

Photograph 5.1: Woodland Elementary School Outfall with broken headwall and exposed discharge pipe, October 22, 2008.

6. Recommendations for Loantaka Brook north of Woodland Avenue:

- Debris, including 20 tires, lawn equipment, old drums, asphalt mounds, and several bags of aluminum cans are strewn throughout this floodplain. A volunteer cleanup of this area would improve the habitat and reduce the loading of trash and litter to the stream.
- Invasive plants dominant the floodplain and could be removed and plantings of river birch, sycamore or willows, may stabilize the floodplain and improve the habitat. State permits would not be needed for any clearing and plantings in the floodplain.
- Sediment bars appear to partially block the outfalls for the two 12" outfalls, and manually cleanouts could be performed.

6.0 Preliminary Design of an Off-Line Created Wetland (Sub-Objective 3)

Basic hydrologic analyses were conducted on modeled stream flow and point source discharge data. These analyses seem to indicate that the ability of using such a wetland to treat stormwater loads in the Loantaka Brook would be limited to managing only relatively small storm events. As such, focus of this project has been directed more to the management and reduction of the point source load associated with the effluent discharged from the Woodland Wastewater Treatment Plant. Again it must be emphasized that although the plant is in compliance with its wastewater discharge permit limitations it is still a significant source of nutrient loading to the brook as well as to Kitchell Pond.

6.1 Wetland Project Background

Water quality sampling of the Loantaka Brook has been performed by numerous agencies including the NJDEP, the TTC, and the GSWA. As previously noted, these investigations have consistently documented that the water quality of Loantaka Brook is significantly impaired. Loantaka Brook consistently exceeds the New Jersey standard for phosphorus (0.1 mg/L for streams). In some locations, the stream even regularly fails to meet the Human Health standard for nitrate (10 mg/L as N) (GSWA, 2008). The typical phosphorus concentrations measured in the brook easily exceed EPA ecoregional reference criteria. Furthermore, Loantaka Brook has failed to meet any of the water quality standards set by the TTC, including the standards for total nitrogen and total phosphorus (TTC, 2002). Due to the stream's impaired water quality, Loantaka Brook is widely recognized as being the most degraded tributary of the Great Swamp, and the largest tributary source of nutrient loading to the Great Swamp.

As documented in Section 2, 4 and 5, the headwaters of Loantaka Brook are heavily developed. Impervious cover can range from 15% – 60%. The amount of impervious cover, in concert with the lack of suitable stormwater management, is responsible for the excess stormwater runoff and flashy/high peak flow conditions that characterize the headwater areas of the brook. Along with the runoff comes the typical NPS pollution that is associated with stormwater. However, although elevated relative to the other tributaries of the Great Swamp, the NPS load is not the biggest problem. The water quality monitoring and modeling data show that the brook's elevated nutrient levels are greatly exacerbated, and even driven, by the point source discharge from the Woodland Wastewater Treatment Plant. This facility is operated by the Woodland Water Pollution Control Utility (WPCU). The nutrient concentrations in Loantaka Brook appear to be somewhat inversely proportional to flow; emphasizing the role of the point source loading. Further affirmation of the significance of the Woodland Wastewater Treatment Plant's nutrient loading is demonstrated by a simple comparison of stream flow and effluent discharge flow rates. The discharge data for the Woodland Wastewater Treatment Plant (NJPDES Permit No NJ0024929) shows the plant has an average flow of approximately 1.3 MGD over a thirteen-year period (1994-2006). As such, the plant consistently operates approximately 0.7 MGD below its permitted flow. Stream flow measurements conducted by the GSWA indicate that during baseflow conditions (the vast majority of the year) the Woodland Wastewater Treatment Plant discharge exceeds the stream flow in the Loantaka Brook near the treatment plant outfall. Therefore, the water quality of the stream is dictated by the quality and nutrient content of the plant's effluent. Based on water quality sampling and stream flow measurements the treatment plant has been identified as the "primary contributor" of phosphorus loads to Loantaka Brook (Benzing et al., 2006). The Woodland Wastewater Treatment Plant is located only 3,000 ft upstream of Kitchell Pond and is therefore a major source of nutrient loading to the pond. Elevated nutrient levels are responsible for the frequent algal blooms that plague pond.

6.2 Wetland Project Objective

The objective of this section is to outline the preliminary design and feasibility study of a constructed treatment wetland to reduce the nutrient and total suspended solids (TSS) loading of the Woodland Wastewater Treatment Plant effluent discharge. The goals of this investigation included the establishment of a potential location and configuration of the constructed treatment wetland along with basic engineering design parameters and calculations to further establish the feasibility and potential performance of the constructed treatment wetland. Other goals of this work include the development of a preliminary cost estimate and the identification of potential permit requirements that would be required to construct the treatment wetland. Due to the preliminary nature of the design, this report does not contain the complete plans or specifications that would be required to construct the treatment wetland; instead it sets a framework for the development of more detailed plans and specifications.

6.3 Wetland Project Location

The Woodland Wastewater Treatment Plant is located at the end of Florence Avenue approximately 500 ft from the intersection of Florence Avenue and Fanok Road. The treatment plant and effluent outfall are located on the eastern side of the Loantaka Brook. The land surrounding the treatment plant on the eastern side of the Loantaka Brook consists primarily of residential areas. Directly adjacent to the Woodland Wastewater Treatment Plant are two parcels of land located on either side of Florence Avenue. The parcel to the southeast of Florence Ave is approximately 8 acres and the parcel on the opposite side is only 2 acres. While this land is located directly adjacent to the Woodland Wastewater Treatment Plant, there are numerous reasons that preclude it from further consideration for the location of a constructed wetland. These heavily wooded areas provide an important buffer zone between the treatment plant and the adjacent residential areas. The larger parcel also contains wetlands classified as "Deciduous Wooded Wetlands" according to the NJDEP. Therefore no further consideration was given to locating the constructed wetland in area northeast of the treatment plant.

The land directly across from the Woodland Wastewater Treatment Plant, on the opposite side of Loantaka Brook, was also considered. This land is home to the Seaton Hackney

Stables Equestrian Center and is maintained by the Morris County Park Commission. The Seaton Hackney Stables are located between South St. (Morris County 601) to the west and the Loantaka Brook to the east. A small portion of the stable facility, located to the east outside of the main corral lies directly adjacent to Loantaka Brook. This area encompasses 4.6 acres of the >20 acre equestrian complex. Currently the land is used as a pasture area for horses and is divided into three smaller areas separated by fencing. The land is grazed by horses and is largely covered by grass with some higher trafficked areas with exposed soil. The fencing along the Loantaka Brook is approximately 20 feet from the stream. The stream corridor through this reach is sparsely wooded. The constructed wetland preliminary design was based on this location as the pasture area is the best candidate for the potential installation of the constructed treatment wetland. Detailed photographs of the site and concept plans are provided in Attachment D.

6.4 Constructed Treatment Wetland Design

The following sections outline the design process involved in the preliminary design and sizing of a constructed treatment wetlands for the Woodland Wastewater Treatment Plant effluent discharge. Various treatment wetland references were used as guidance in the design process and are referenced at the end of the report.

The land along the western side of Loantaka Brook is a relatively flat, low-lying area which is currently mapped as "Managed Wetlands (Modified)" according to the latest NJDEP wetlands data for Morris County, because they continue to be used as pasture land. No critical wildlife areas are located in the vicinity of the proposed treatment wetland. The NJDEP Landscape Area coverages are summarized in Map 3 of Attachment D. The flat topography of the site is ideal for the construction of a treatment wetland. As previously mentioned the area is currently used as a pasture and grazing area for horses as is shown in Photograph 6.1.

Photograph 6.1 Aerial View Looking East Of Paddock Area Along Loantaka Brook (Source: Microsoft Virtual Earth).

Two main soil types are mapped in the vicinity of the proposed constructed treatment wetland. These soils include Minoa silt loam (MknA/B) and Parsippany silt loam (PbpAt). These soils are well-suited for wetland vegetation and will likely not require amendments to support the wetland vegetation. USDA soil descriptions the soils are provided in Attachment D. The NRCS soils data (SSURGO) for the area and the NJDEP wetlands data for the project area are summarized in Map 2 of Attachment D. The elevation of the groundwater table in the project area has not been determined but it is likely consistent with the water surface elevation in the adjacent stream which is roughly 4 ft below the average ground surface elevation in the project area. A topographic survey of the area would be required to further quantify the elevations needed for a final engineering design and grading of the constructed treatment wetlands.

6.4.1 Wetland Sizing and Configuration

The three fenced enclosures shown in Photograph 6.1 encompass approximately 4.6 acres in total. This is a relatively small area with respect to the 1.3 MGD discharge of the Woodland Wastewater Treatment Plant. Therefore the design approach was to first make the maximum use of the available area and use the effluent flow rate as a design variable; with the understanding that the area is likely not large enough to treat the entire effluent flow rate of the Woodland Wastewater Treatment Plant.

Existing literature and treatment wetland performance data indicates that a series of interconnected pools, or treatment bays, connected in series, provides the best treatment and pollutant removal. This configuration inhibits internal flow short circuiting and also provides the maximum variety of conditions for both the physical and biological treatment/removal of nutrients and TSS. Design guidance indicates that there should be a minimum of at least 2-3 treatment bays (USEPA, 1999). The depth of water in a constructed treatment wetland should vary, containing both deep zones and shallow areas. This creates planting zones for both submerged and emergent vegetation. Deep zones also provide open water areas. These open water areas help maintain dissolved oxygen concentrations in the wetland which can help improve the nitrification process, prevent potential odor problems, and prevent mosquito breeding problems. Design guidance indicates that the treatment wetland should have approximately 20 percent open water (USEPA, 1999).

Another important feature of a constructed treatment wetland is the existence of an initial setting zone or sediment forebay. Often these areas are responsible for a large portion of the TSS removal. Ideally these areas should have the capacity to provide at least one day of retention time at the effluent discharge flow rate. The sediment forebay should be deep enough to provide temporary storage of solids and still prohibit the growth vegetation in the forebay.

The proposed wetland configuration is shown in Map 4 of Attachment D. The wetland is shown outside of the required 50 ft stream buffer (shown in red). This configuration provides for a series of four (4) treatment bays connected in series, in addition to a sediment forebay. The design provides a natural meandering flow path that maximizes the flow distance through the wetland and inhibits short circuiting. The flow path (shown as a dashed blue line in Map 4) is 1,422 ft not including the 150 ft length of the sediment forebay. The wetland can be roughly divided into three different zones based on the design depth. These zones include the shallow wetland areas with depth from 1-2 ft, the treatment bay perimeter areas (2-3 ft), and the deep treatment bay areas (3-4 ft). The following table summarizes the depth, total areas, and volumes of the sediment forebay and each of these three zones (see Table 6.1).

Table 6.1: Summary of Wetland Sizing and Volume Calculations

Description	Depth Ranges (ft)	Area (ft^2)	Volume (ft^3)
Forebay	0-5	10,525	49,900
Shallow Wetland Areas	0-2	82,708	82,708
Treatment Bay Perimeters	2-3	51,040	127,600
Deep Treatment Bays	3-4	22,327	78,145
	Total	166,600	338,353

The different depth zones in the wetland dictate the distribution of wetland vegetation in the treatment wetland. A final design of the treatment wetland would include a detailed planting plan complete with a species list, planting densities, and distributions. Commonly used emergent vegetation in treatment wetlands includes *Typha* spp. (Catail), *Scripus* spp. (Bulrush), *Juncus* spp. (Rushes), and *Carex* spp. (Sedges) (USEPA, 1988). In deeper water (>3 ft) submerged vegetation is often used (*Potamogeton*, *Elodea* and others) (USEPA, 1999).

6.4.2 Treatment Wetland Hydraulics

The single most important design characteristic of a constructed treatment wetland is the residence time of the wetland. Residence times of at least four (4) days are typical of treatment wetlands that exhibit sufficient pollutant removal efficiencies. Residence time is a function of the effective volume of the wetland and the design flow rate. As was previously mentioned, the design process was to make maximum use of the available area and then determine the maximum effluent flow rate to the wetland within certain criteria to prevent potential overloading the wetland.

The proposed treatment wetland, including the sediment forebay, would have a volume of approximately 340,000 ft^3 (2.5 MG). However, to be conservative, the *effective* volume of the wetland only accounts for the volume not occupied by plant material. For the free water surface treatment wetland proposed here a porosity of 80% is applicable. That is to assume that the plant material occupies approximately 20% of the wetland by volume. The equation for residence time is as follows:

$$t = \frac{Vn}{Q}$$

Where: V = total volume of wetland [L^3]
n = porosity of wetland volume [-]
Q = effluent flow rate [L^3/T]
t = residence time [T]

Another measure of the size of the treatment wetland to the effluent flow rate is the hydraulic (or areal) loading rate. The hydraulic loading ratio is defined as follows:

$$q = \frac{Q}{A}$$

Where: q = hydraulic loading ratio [L/T]
A = wetland surface area [L^2]
Q = effluent flow rate [L^3/T]

Based on the above equations and the proposed wetland geometry, both of these design parameters can be plotted as a function of the effluent flow rate as illustrated in Exhibit 6.1.

Exhibit 6.1 Residence Time And Hydraulic Loading Rate As A Function Of Design Effluent Flow Rate For Proposed Constructed Treatment Wetland.

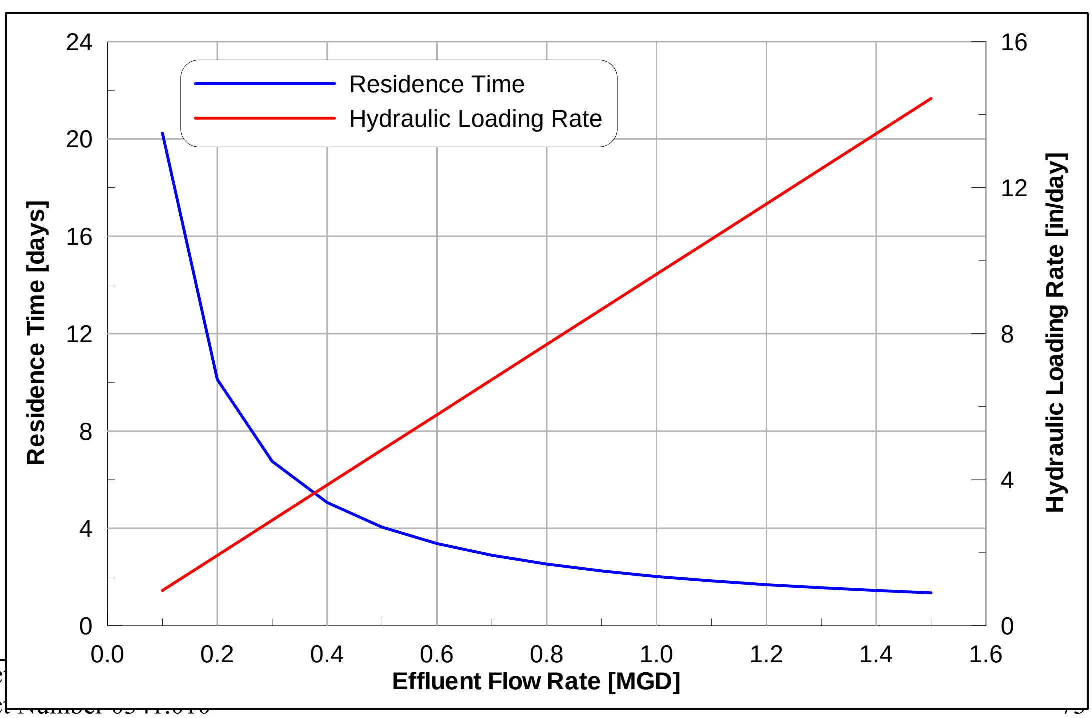


Exhibit 6.1 shows a flow rate of 0.5 MGD (0.8 cfs) corresponds to the minimum recommended residence time of four days, and results in a hydraulic loading rate of approximately 5 in/day. This flow is 60% of the average plant discharge. Once the treatment wetland is established, the flow could be varied and increased to treat a larger portion of the plant outflow. The treatment wetland would have to be monitored to make sure it does not show evidence of overloading or reduced treatment performance. At this flow rate the sediment forebay has been sized to provide a residence time of approximately one day for optimal particulate settling.

Inlet and outlet details and sizing were not explicitly considered in this analysis. In its current configuration the Woodland Wastewater Treatment Plant discharge would have to be redirected approximately 500 ft upstream and across the Loantaka Brook to reach the sediment forebay. The effluent discharge will most likely need to be pumped to the inlet of the sediment forebay. There is a possibility that the conduit may be able to flow via gravity to the inlet; this would be determined as part of a detailed survey which would include the current elevation and configuration of the Woodland Wastewater Treatment Plant effluent discharge.

Inflow distribution structures for flow rates of this magnitude are typically precast concrete structures with a series of weirs used to evenly distribute the flow across the entire width of the sediment forebay. Outlet structures are generally similar in design and should be designed to collect flow evenly over the width of the wetland. Both inlet and outlet structures should be locked and secured to prohibit vandalism; but also be accessible for maintenance.

Another important characteristics of outlet structures for constructed wetland in the ability to control the water surface elevation in the wetland. This can be accomplished by using flash board configurations or swivel or otherwise adjustable pipe elevations (ITRC, 2003). This is critical to ensure that the wetland maintains the proper water surface elevation needed for vegetation development and proper treatment. Flow in constructed treatment wetlands is assumed to be adequately approximated as uniform flow, and therefore sufficiently described by Manning's equation. Manning's equation was applied to the proposed treatment wetland design. Using the design flow rate of 0.5 MGD, the proposed channel geometry, and conservative estimates for the Manning's roughness coefficient (*n*); the slope of the water surface elevation over the design flow length of the wetland could be calculated. This calculation results in an expected change in water surface elevation of approximately two (2) inches over the length of the treatment wetland.

6.4.3 Treatment Mechanisms

The treatment mechanisms in constructed treatment wetlands vary for different constituents of interest. The treatment processes can be roughly divided into two categories; biological processes and physical/chemical processes. Typical physical and chemical treatment mechanisms include sedimentation (suspended solids and associated particulate nutrients or sediment adsorbed metals), sorption (nutrients), precipitation (heavy metals), oxidation (nutrients and organics), and direct volatilization (organics and nutrients). Common biological treatment mechanisms target mostly nutrients and heavy metals and include aerobic/anaerobic microbial biodegradation and the assimilation of pollutants by wetland vegetation (ITRC, 2003).

As discussed in the Section 6.1, the main pollutants of concern are nutrients; specifically phosphorus and nitrogen. Phosphorus is readily removed from the water column by wetland vegetation and through microbial uptake. However, in temperate climates such as that of New Jersey this represents a short term removal of phosphorus, as the phosphorus can be released back into the water column with seasonal cessation of the vegetation. This short term limitation can be avoided though by seasonally harvesting the plant material, thus increasing the system's nutrient sink functions. The primary long term removal of phosphorus is accomplished through the incorporation of the phosphorus into the sediment in the wetland. This is a result of vegetation and microbial detritus being incorporated into the wetland sediment and also direct phosphorus precipitation with iron, aluminum, or calcium (USEPA, 1999). The accumulated sediment can be periodically removed from the treatment wetland if required. Nitrogen cycling and consequent removal occurs through a complex biogeochemical cycle that is dependant on a numerous environmental conditions. Treatment areas with these necessary conditions should all exist in a properly designed treatment wetland. These conditions include open water with sufficient dissolved oxygen and sediment and others areas with low to no dissolved oxygen. Ultimate removal of nitrogen occurs through sedimentation and the volatilization of nitrogen gas and ammonia. The proposed wetland design has considered these treatment processes and maximized their net benefit in context of the previously discussed land constraints.

TSS removal occurs primarily through gravimetric settlement. This is facilitated through the design of treatment wetlands with low velocity and dense vegetation. There will also be some filtration and adsorption of sediments by the vegetation mass itself. Dense growth and long residence times increase the opportunity for such removal. Based on the design flow rate and wetland geometry, the proposed wetland design has an average flow velocity of only 0.008 feet per second (7 in/min), and would therefore provide excellent TSS removal. The majority of the TSS removal would likely occur in the sediment forebay. The forebay must be designed so that is easy to maintain and facilitate periodic removal of accumulated solids. This will include the allowance for proper machine access to the forebay and the construction of a concrete slab at the base of the forebay. The frequency of this maintenance would be determined once the wetland is in operation, but it would likely be an annual procedure.

6.4.4 Phosphorus Removal

Due to the numerous ongoing treatment processes and environmental variables, empirical methods are typically used to estimate the removal efficiencies of constructed treatment wetlands. These methods are based on the measured removal efficiencies of other treatment wetlands. The USEPA has assembled a database of treatment wetland performance called the North American Treatment Wetland Database (NADB). This database summarizes numerous wetlands and contains (in total) hundreds of operation data. Total phosphorus removal averaged 61% for wetlands that had similar inflow concentrations to those measured for the Woodland Wastewater Treatment Plant effluent. However, these wetlands typically had lower hydraulic loadings rates than the current one. Based on WCPU Discharge Monitoring Report the total phosphorus of the Woodland Wastewater Treatment Plant effluent ranged from 0.25 to 0.9 mg/L as P. Based on an average concentration of 0.6 mg/L and an estimated removal percentage of 50%, at the design flow of 0.5 MGD the treatment wetland could remove over 500 pounds of phosphorus per year.

6.4.5 Operation and Maintenance

The operation and maintenance requirements of a properly designed constructed treatment wetland are minimal. The two most important aspects of maintaining a constructed treatment wetland is the inspection and maintenance of the water surface elevation and the flow distribution within the treatment wetland. The water surface elevation is simply controlled by the outlet structure which should be easily accessible by maintenance personnel. The flow distribution is controlled by the inlet and outlet structures as well as the internal topography of the treatment wetland. The inlet and outlet structures should be routinely checked for clogging to ensure an even distribution of flow. Vegetation should be periodically checked and areas replanted if needed. A complete operation and maintenance manual should be prepared during the final design phase of the treatment wetland. As previously mentioned, the sediment forebay will need periodic inspection and removal of accumulated solids.

6.4.6 Design Summary

In summary a preliminary constructed treatment wetland has been designed to fit within the 4.6 acre area across from the Woodland Wastewater Treatment Plant. The land is ideal for the construction of a treatment wetland due to its proximity to the Woodland Wastewater Treatment Plant, its existing flat topography, and the existing soil types which are conducive to the propagation of wetland vegetation. Another ancillary benefit of the treatment wetland location is that currently the area has an existing nutrient load to Loantaka Brook as a result of the equestrian activities on the land. Similarly, the treatment wetland could be configured to accept stormwater runoff from the adjacent horse paddocks thereby further reducing the current nutrient load to Loantaka Brook. This would require some additional site grading of the Morris County Park Commission's Seaton Hackney Stables riding area. As this was not the focus of the project, no attempt was made to evaluate the engineering feasibility of routing runoff from the paddock area to the wetland However, as discussed in Section 5 an summarized in Table 5.1 there is an alternative independent means of managing the runoff from the Seaton Hackney Stables

Finally, Although an original design consideration, due to size constraints, the wetland would not be able to treat both the Woodland Wastewater Treatment Plant effluent and adequately manage storm flows from the main stem of the Loantaka Brook. Additionally, it was determined as based on available stream flow data that such a configuration would likely result in the re-suspension and consequent export of solids from the treatment wetland.

The treatment wetland would require the conveyance (possibly by gravity flow) of effluent from the treatment plant under Loantaka Brook to the western side of the stream approximately 500 ft upstream. The wetland would be capable of treating the majority of the flow from the Woodland Wastewater Treatment Plant but the area is expected to be too small for adequate treatment of the entire potential 1.3 MGD discharge of the Woodland Wastewater Treatment Plant. Nevertheless, a constructed treatment wetland at the site could be expected to drastically reduce the TSS loading to the Loantaka Brook. The treatment wetland would also reduce the nutrient loading of the Woodland Wastewater Treatment Plant discharge which has been shown to be the major source of nutrient loading to Kitchell Pond, and a major contributor to the nutrient loading of the Great Swamp. Specifically the treatment wetland could be expected to remove over 500 lbs of phosphorus (as P) on an annual basis.

The wetland would consist of a sediment forebay and four treatment bays all connected in series. The proposed wetland has a meandering flow path, which in conjunction with the treatment bays, makes maximum use of the total land area and configuration. The proposed geometry and topography of the treatment wetland would create various depth zones ideal for the propagation of wetland vegetation.

6.4.7 Cost Estimate

The cost estimate does not include land costs as the land in question is currently owned by the Morris County Park Commission. The estimated cost per acre for a surface flow constructed treatment wetlands can be estimated from the known cost of previous projects. The NADB summarized the capital cost of 29 constructed treatment wetlands. The average cost per acre was $150,000 (1993 US Dollars) (Kadlec and Knight, 1996). This estimate multiplied by the area of the proposed wetland and corrected for inflation to the current year (2009), equals approximately $1,000,000. This estimate does not include permitting costs which are summarized in the following section. Operation and maintenance of constructed treatment wetlands is fairly minimal and expected to be less than $10,000 per year (Kadlec and Knight, 1996).

6.4.8 Permit Requirements

There are a number of relevant permitting requirements that would be necessary for the construction of the proposed treatment wetland. Due to the size of the disturbed area (4.6 acres), the construction phase of the project would require the submittal and certification of Soil Erosion and Sediment Control (SE&SC) plans prepared by a professional engineer. Additionally, the project would require a NJPDES stormwater discharge permit (>1 acre disturbed area). Both of these permits would be issued through the Morris County Soil Conservation District.

There are also numerous applicable permits that are issued from the state level. The first and most comprehensive permit would be an Individual Wetlands Permit. This permit is required due to the current wetlands designation of the land in question, and the fact that the scope of work is beyond any of the more typically issued General Permits. Although the land is currently a horse pasture, the NJDEP recognizes the area as modified wetlands. This permit includes an alternatives analysis to justify the project being located in the wetlands designated area. This permit would likely be granted by the NJDEP due to the increased ecological value of the land under the proposed condition.

The State recently adopted the Flood Hazard Area Control Act (FHA) regulations (N.J.A.C. 7:13). These regulations specifically focus on riparian areas. Due to the proximity of the site location to the Loantaka Brook, the project would be subject to the requirements of the FHA. Currently there are no State adopted delineations for the Loantaka Brook. Therefore the flood depth and consequent extent of the flood hazard area needs to be determined by one of the methods outlined in the FHA. Based on the Approximate Method ("Method 5" as outlined in N.J.A.C. 7:13) the Loantaka Brook in the vicinity of the project location would have a flood depth of 10 feet. This depth would likely encompass a large portion of the site. The FHA regulations outline a number of general permits but here again the proposed treatment wetlands would require an Individual Permit.

Due to the diversion of a large portion of the effluent discharge, the WCPU would have to submit a modification to their existing NJPDES Discharge to Surface Water Permit to the New Jersey Bureau of Point Source Permitting Region 1 (WMA 6). Contingent on the modification of the discharge permit (Permit #NJ0024929), would be the completion of a Treatment Works Approval (TWA) permit.

The individual freshwater wetlands permit would be the most time and cost intensive permit, followed likely by the FHA individual permit. In total the permitting costs for the entire project should be expected to be between $30,000 and $40,000.

7.0 Monitoring Water Quality and Biological Community Data

As discussed in the earlier sections of this report, the impaired water quality of Loantaka Brook is considered to largely be the result of NPS pollution, in particular, stormwater runoff high in levels of dissolved and particulate nutrients and sediments. These effects are most pronounced in the headwaters of Loantaka Brook which originates in the heavily developed Morristown area. Land use comprising the watershed of the Loantaka Brook headwaters consists primarily of medium to high density suburban and residential coverage associated with approximately 15% impervious area (Section 2). The combination of large areas of impervious coverage and outdated storm water infrastructure has served to severely degrade the headwaters of Loantaka Brook through altering the natural hydrograph of this reach. This is largely reflected in the reduced watershed attenuation of peak flows characteristic of most urbanized areas. As such, the headwaters are routinely inundated with elevated peak flow volumes occurring over short durations. The altered hydrology has in turn impacted the ecology of this reach through the contribution of elevated nutrient loads, accelerated streambank erosion, and modification of the natural morphology of the first order tributaries of this stream. The aforementioned environmental changes have served to severely degrade this stream to such a state that the sections from Bluestone Terrace in Morris Township to Green Village Road are unable to maintain aquatic life (NJDEP 303d), while the entire stream reach routinely fails to meet New Jersey Surface Water Quality Standards (N.J.A.C 7:9B) per its FW2-NT (fresh waters, non-trout) designation outside of the Great Swamp National Wildlife Refuge and its Category 1 (C1) designation within the Refuge.

Since 1999 the TTC has conducted watershed wide water quality monitoring of each stream which drains to the Great Swamp. Through this effort a substantial water quality database of physical, chemical, and biological data has been compiled which has served as an empirical reference for evaluating compliance with New Jersey Surface Water Quality Standards (N.J.A.C. 7:9B). This long term dataset has proved invaluable not only in assessing water quality impairments but also in statistically analyzing water quality trends both on a intra- and inter-stream basis therefore serving as the scientific basis for directing management efforts to those reaches which have shown the greatest degree of degradation.

To continue documenting water quality conditions throughout the Great Swamp Watershed the TTC earmarked part of the funding received through USEPA Grant X-97267701 to build upon the historical water quality database of all streams which drain to the Great Swamp. As such, the following report details water quality monitoring which was initiated in September of 2006 and continued through August of 2008. This data serves as a continuation of water quality monitoring efforts initially implemented in 1999 by the GSWA, therefore representing a nine year water quality database of these streams. During this monitoring effort Princeton Hydro conducted monthly baseflow and quarterly stormflow water quality monitoring of *in-situ* and key discrete water quality parameters. In addition, Princeton Hydro installed staff gages at each stream station and measured stream discharge in order to compute ratings curves for those stations. This data was then used in concert with discrete chemical data to assess nutrient and sediment loading within each stream and also used as an empirical reference in calibrating the modeled pollutant and hydrologic loading for the headwaters of Loantaka Brook. Finally, the macroinvertebrate community of each stream was sampled during two events and compared to historical data collected by Dr. Lee Pollock of Drew University to assess any changes to each streams biotic community over time.

All of the collected data was referenced to state standards (N.J.A.C. 7:9B) and utilized to conduct intra- and inter-stream comparisons to asses what changes in water quality have occurred throughout the nine year dataset. Through this analysis water quality management measures implemented by the TTC are evaluated as to their impacts on decreasing NPS pollution loading to each tributary. In addition, this data serves as an empirical benchmark upon which the BMP's implemented in the headwaters of Loantaka Brook will be gauged.

7.1 Water Quality Monitoring Methodology

For this project, the sampling stations were the same as those utilized in past water quality monitoring projects conducted by the TTC and GSWA volunteers. Doing so negated the potential effects of spatial variation in data analysis and allowed for trhe seamless comparison of the 2006/2008 data with the historical dataset. Specifically, sampling was conducted at a single station located along each of the five tributaries which drain to the Great Swamp as well as at the discharge point of the Great Swamp into the Passaic River. The six (6) streams which were sampled as part of this project are depicted on Figure 4 and 4B, and are referenced as:

- Black Brook
- Loantaka Brook
- Great Brook
- Primrose Brook
- Upper Passaic River (Passaic In)
- Lower Passaic River (Passaic Out - Great Swamp outlet).

It is important to note that the sampling station established on the Passaic River outlet is at the same location as a United States Geologic Survey (USGS) stream flow monitoring station (USGS 01379000 Passaic River near Millington, NJ).

Monthly baseflow sampling of discrete chemical parameters was conducted at each of the above locations by means of a grab sample. That is, samples were collected from each stream location directly into properly preserved, laboratory supplied containers. For the purposes of this project baseflow sampling is defined as a period of at least 48 hours with no significant rainfall (< 0.5"). In addition, at each sampling station, a calibrated multi-probe meter was used to monitor the *in-situ* parameters dissolved oxygen (DO), temperature, pH and specific conductance. Instrumentation used for the collection of *in-situ* data (dissolved oxygen, temperature, pH and conductivity) was calibrated in advance of its use in conformance with the manufacturer's instructions. Princeton Hydro is a New Jersey state-certified (ID # 10006) laboratory for the use of *in-situ* monitoring equipment for the measurement of dissolved oxygen, temperature, pH and conductivity.

Quarterly storm water sampling was also conducted at each of the above locations by means of an ISCO composite sampler. Princeton Hydro personnel visited each of the five Great Swamp inlet stream sites in advance of a predicted precipitation event to program the ISCO units. Utilizing the same protocol that GSWA volunteers utilized in previous studies, and based on the flow/water level meter present on the ISCO units at that time, Princeton Hydro personnel would program the ISCO to start a composite cycle when water levels rose approximately 0.1' over the current water level reading. This 0.1' rise in stream level has been shown is previous Great Swamp studies to reflect the first flush of watershed runoff for each stream. The ISCO units continued to sample for every 0.1' rise in the stream levels. This composite sampling continued until the stream level receded back to the original stream level before the precipitation event. This composite methodology allowed the ISCO units to operate based on the specific length and intensity of each precipitation event therefore allowing for an accurate representation of the entire storm hydrograph.

Chemical analysis for both baseflow and stormflow conditions were performed for the following parameters:

- Total Phosphorus (TP)
- Soluble Reactive Phosphorus (SRP)
- Nitrate (NO_3-N)
- Total Kjeldahl Nitrogen (TKN)
- Ammonia (NH_3-N)
- Total Suspended Solids (TSS)
- Total Dissolved Solids (TDS)

All of the water samples, both grab and composite, were collected following the protocols and procedures outlined in the approved quality assurance protection plan (QAPP) utilizing standard methods outlined in the NJDEP Field Sampling Procedures Manual (NJDEP, 2005). Grab water samples were collected directly into NJDEP recommended sampling containers, placed in coolers and stored on ice at 4° C for transport to Environmental Compliance Monitoring (ECM), a NJDEP Certified Laboratory (#18630), for analysis. The composite water samples were collected from the ISCO units and placed directly into the NJDEP recommended sampling containers, placed in coolers and stored at 4° C for transport to Environmental Compliance Monitoring (ECM). A chain of custody manifest was maintained for each sample from the point of collection to the point of transfer to the laboratory for all samples. Subsequent analysis of the specified parameters was conducted by ECM following both USEPA and NJDEP approved methodology as outlined in the associated QAPP.

7.2 In-situ Analysis Results

In-situ data was collected during each baseflow monitoring event over the course of the 2006 – 2008 sampling program. Specifically, real time measurements of temperature, dissolved oxygen, pH, and specific conductivity were made utilizing a calibrated multi-probe sampling meter. This data was subsequently compared on a inter- and intra-stream basis to assess variances in critical water quality parameters. In addition, temperature, dissolved oxygen, and pH are compared to state standards as listed in N.J.A.C. 7:9B to assess the attainment status of these water quality criteria.

7.2.1 Temperature

Temperature is a crucial parameter in lotic ecosystems as it directly influences the rate of many biochemical processes within streams. Primary productivity, community metabolism, and aquatic community composition are all factors which are strongly influenced by water temperature. Temperature not only serves to regulate the rates of productivity and respiration but also affects the solubility of gases, such as carbon dioxide and oxygen, which are critical components of the aforementioned processes. Simply put, warmer water has less capacity to hold dissolved oxygen than cooler water. Therefore, increases in water temperature serve to increase community metabolism while concomitantly serving to decrease the solubility of oxygen which is crucial in aerobic metabolic processes. These conditions may serve as extreme stressors to aquatic organisms in the late summer months when water temperatures are warmest and net primary production is highest.

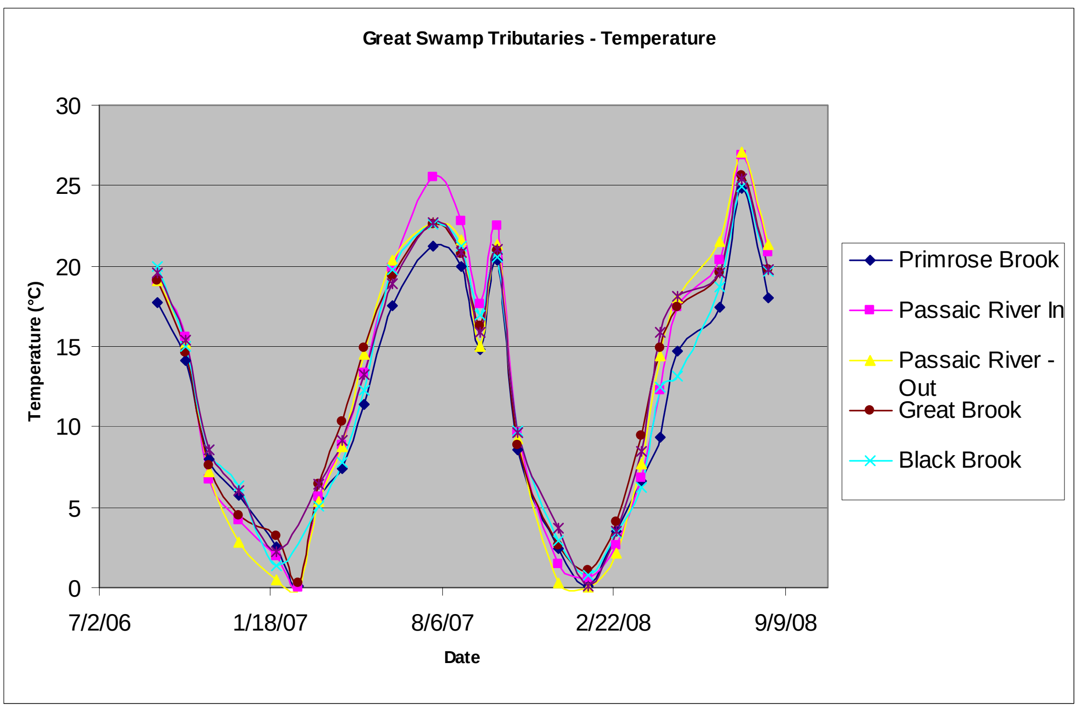
As such, the NJDEP has strict temperature requirements under N.J.A.C. 7:9B in order to uphold biotic integrity within stream systems. Specifically, temperatures within Primrose Brook, which is categorized as a FW2-TPC1 stream, are not to exceed a summer seasonal average of 20°C (68°F) while all other streams in this study, categorized as FW2-NT, are to not exceed a summer seasonal average of 30°C (86°F). These standards are generally based on fishery community structure with the more stringent requirements in Primrose Brook attributable to maintaining the proper thermal regimes for production of trout (subfamily: Salmonidae).

Deviations in thermal regimes within stream ecosystem are strongly influenced by several factors. The vegetative composition and spatial expansiveness of riparian corridors are one of the primary influencing factors in temperatures within lotic systems as tree cover serves to absorb and dissipate solar irradiance which would otherwise reach the waters surface. Destruction of these riparian corridors has been shown to increase baseline summer stream temperature and to increase diurnal temperature fluctuations therefore serving to alter biotic community compositions and increase net primary productivity within those streams with a degraded riparian corridor.

An especially pertinent factor in terms of altering stream water temperature lies in increased coverage of impervious areas throughout each streams watershed. Parking lots, roofs, and heavily compacted soils serve to alter hydrologic loading to stream systems by imparting a greater degree of surface water runoff while impeding percolation and groundwater recharge. The increase in surface water discharges along with concomitant reduction in groundwater discharge serves to elevate stream water temperatures due to a proportional increase in warmer surface water inflow and decrease in cool groundwater discharge. Riparian vegetation destruction and increases in impervious areas are generally correlated to increased watershed development. Therefore, increased development may be directly related to altering thermal regimes within lotic ecosystems. Management measures aimed towards maintaining appropriate riparian corridor width while also serving to treat stormwater will serve to maintain appropriate thermal regimes within the Great Swamp tributaries therefore serving to protect the physical, chemical, and biotic integrity of each stream.

The following Exhibit (7.1) depicts temperatures measures throughout all sampling stations over the course of the 2006 – 2008 sampling period.

Exhibit 7.1: Temperature Distributions



As shown above, temperature distributions were generally similar amongst stations throughout the majority of the sampling period. Notable variation from this pattern occurred during the summer of 2007 whereby temperatures measured at the Passaic-In station were routinely higher than those measured at all other sampling stations. This pattern is likely the result of the Osborne Pond impoundment which is located immediately above this station. Numerous studies have documented the effects of man-made impoundments on altering water temperature between the inflow and outflow as a result of increased water residence time within these impoundments. While the Passaic-In station showed a noticeable temperature increase as a result of Osborne Pond the mean summer seasonal temperature never exceeded the NJDEP threshold of 30°C for FW2-NT waters. It should be noted that there is no specific definition within N.J.A.C. 7:9B as to what calendar period represents "summer," therefore; we have assumed summer to represent those months of June, July, and August for this analysis. The lowest summer seasonal mean temperatures were recorded at the Primrose Brook station with a summer seasonal mean temperature of 19.60°C. This mean temperature is slightly below the threshold temperature for this stream (20°C, FW2-TPC1). It should be stressed that this mean was based on only three measurements made throughout the summer period with all measurements made during the daylight hours. Therefore, the aforementioned temperature distributions, while offering valuable insight as to spatial variations in temperature amongst streams, may not truly reflect mean seasonal temperatures of each waterbody due to limited sample size and the absence of night temperature measurements which would likely serve to lower the mean temperatures for all tributaries.

Temperatures measured throughout the 2008 summer period (June through August) again showed the highest mean summer temperatures to occur at the Passaic-Out station followed by the Passaic-In station whereby mean summer seasonal temperatures were 23.29°C and 22.71°C respectively. Temperatures were again the lowest at Primrose Brook whereby a summer seasonal mean temperature of 20.11°C was measured. While the summer seasonal mean temperature measured at Primrose Brook is slightly above that stated in N.J.A.C. 7:9B it is likely a misrepresentation of the true seasonal mean temperature due to the limited sample size and an absence of night time sampling and is therefore no cause for concern in terms of negatively affecting this streams ability to sustain a cool-water fishery.

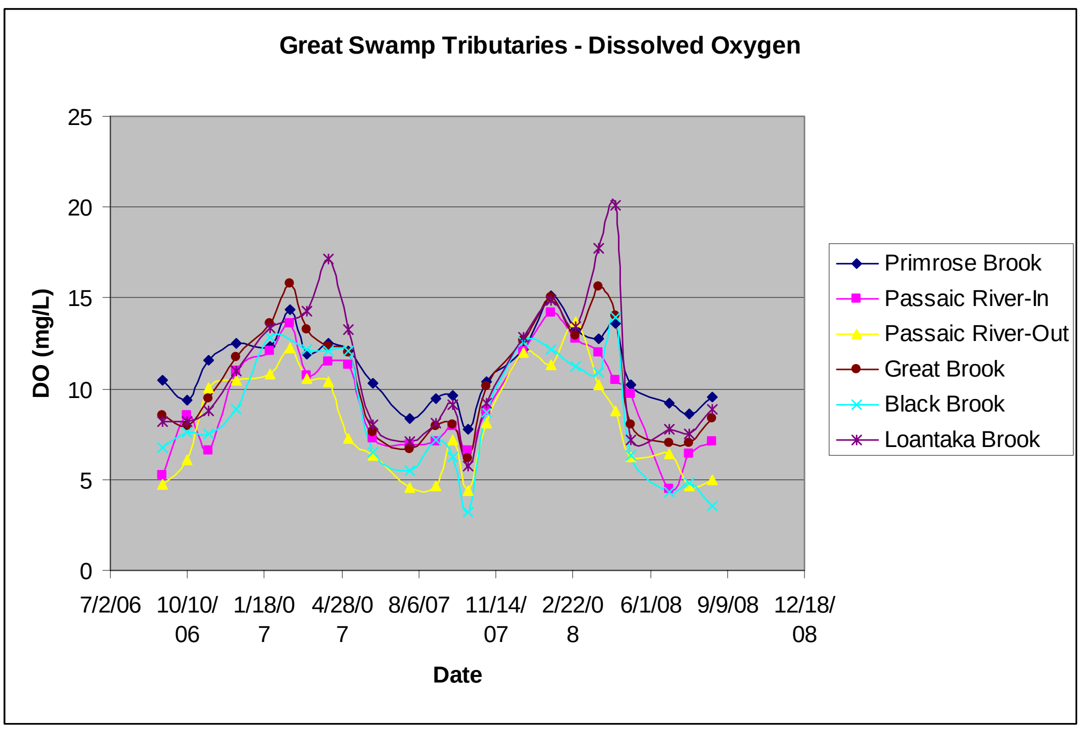
7.2.2 Dissolved Oxygen

Dissolved oxygen is crucial to almost all biochemical reactions occurring in freshwater ecosystems. Primary sources of dissolved oxygen are diffusion from the atmosphere and photosynthesis, while sinks are biological respiration and bacterial decomposition of organic matter. The abundance and distribution of dissolved oxygen in a lotic system is based on relative rates of producers (photosynthetic organisms) versus consumers (metabolic respiration). Again, as noted above, it is also greatly influenced by the thermal characteristics of the stream. Additional variation in dissolved oxygen may be attributable to stream morphology. Specifically, those streams with an abundance of riffles and other high velocity sections serve to have higher concentrations of dissolved oxygen due to increased atmospheric diffusion as a result of increased turbulence at those areas. In contrast, those streams which are dominated by pools and slow moving runs may have lower dissolved oxygen as a result of decreased turbulence and build up of organic matter which serves to reduce atmospheric oxygen replenishment while increasing sediment oxygen demand.

Dissolved oxygen concentrations strongly affect the streams ability to support a diverse and rich assemblage of aquatic life. Therefore, the NJDEP has strict limitations in terms of dissolved oxygen concentrations based on stream designation. New Jersey Surface Water Quality Standards (N.J.A.C. 7:9B) state that those waters designated FW2-NT are to have dissolved oxygen concentrations not less than 5.0 mg/L during a 24 hour period with no instance of dissolved oxygen falling below 4.0 mg/L at any point in time. Standards are more stringent for those tributaries designated FW2-TPC1 with dissolved oxygen concentrations to not fall below 7.0 mg/L at any time.

The following Exhibit 7.2 depicts dissolved oxygen concentrations measured at all tributaries over the course of the 2006 – 2008 monitoring period.

Exhibit 7.2: Dissolved Oxygen Distributions



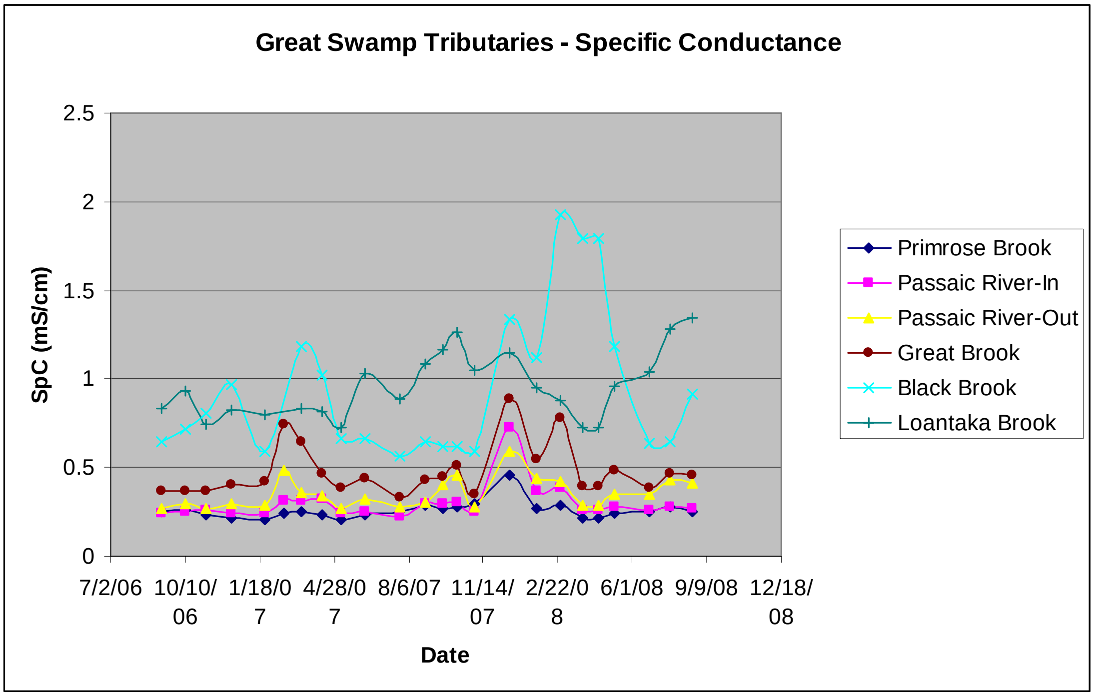
Dissolved oxygen concentrations were generally above the thresholds set forth in N.J.A.C. 7:9B at all tributaries throughout the year with the exception of Black Brook, which had a single instance of DO < 4.0 mg/L on the 10/9/07 and 8/21/08 sampling events. Primrose Brook, which has the most stringent dissolved oxygen standards as a result of its FW2-TPC1 status, were above the 7.0 mg/L threshold during all sampling events with DO concentrations ranging between 7.74 mg/L and 15.10 mg/L.

Overall, dissolved oxygen concentrations within all tributaries were sufficient to sustain aquatic life and did not show extreme variation as a result of excessive primary productivity or community respiration. The only notable exception to this occurred in Black Brook which routinely had depressed DO concentrations. This is likely a direct result of this streams morphology which is dominated by shallow, stagnant pools which serve to inhibit atmospheric diffusion of oxygen lost to degradation of excessive accumulations of organic matter.

7.2.3 Specific Conductance

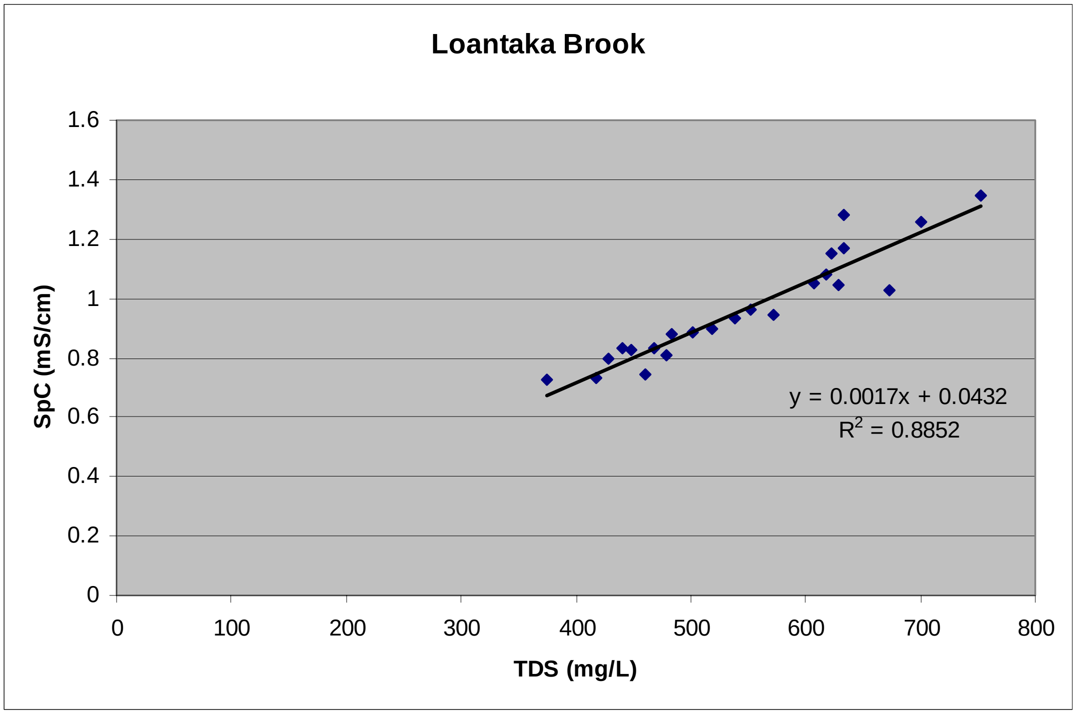
Specific conductance is defined as the ability of water to conduct an electrical current, normalized for temperature. Determined primarily by the amount and type of dissolved ions in water, specific conductance values are often a direct result of the composition and erosion potential of the geologic formations underlying the stream bed and watershed which drains to each tributary. As such, specific conductance values are often positively correlated to the dissolved solids load entering a waterbody. Variation from baseline values are often a strong indicator of watershed based nutrient loading in streams due to anthropogenic source inputs of lawn fertilizer, salts utilized for road de-icing, and point sources such as wastewater discharges. Specific conductance values measured under baseflow conditions throughout the 2006 – 2008 monitoring period at all stations are presented in Exhibit 7.3.

Exhibit 7.3: Specific Conductance



Specific conductance values were routinely low for Primrose Brook while consistently elevated for both Black and Loantaka Brook. While there are no set standards for specific conductance under N.J.A.C. 7:9B it is clear that values measured at Black and Loantaka Brook are above baseline conditions and as such are likely elevated as a result of anthropogenic sources. Namely, conductance values within Loantaka Brook are routinely elevated under baseflow conditions with conductance values showing strong correlation to total dissolved solids concentrations (R^2 = 0.89, Exhibit 7.4).

Exhibit 7.4: Loantaka Brook – Specific Conductance / TDS Relationship



Routinely elevated specific conductance measures at the Loantaka Brook station under baseflow conditions is a strong indicator of point source pollution within this waterbody, likely as the result of discharges from the Woodland wastewater treatment facility which discharges upstream of the sampling location.

Specific conductance values measured at the Black Brook station were also elevated throughout the 2006 – 2008 sampling season although showing higher variation than those measured at Loantaka Brook with elevated conductance values measured from the December 2007 through May 2008 sampling events. Elevated conductance values at the Black Brook station are likely a direct result of runoff from salts utilized for road de-icing given that the highest conductivity values were measured during the winter and spring months. The effects of watershed based salt loading is most pronounced at Black Brook given that several stormwater pipes discharge immediately above the sampling location and the general lack of flow at this station which prevents adequate flushing of dissolved solids.

While specific conductance values were generally acceptable at all other stations monitored there is a notable pattern whereby specific conductance values were elevated during the winter months at all stations. The strong periodicity of elevated specific conductance measures is a strong indicator of the effects of seasonal applications of salts utilized for road de-icing. Furthermore, these patterns serve to substantiate work conducted by Great Swamp Watershed volunteers who documented elevated concentrations of chloride and sodium within the upper reaches of Loantaka Brook under baseflow conditions (Edwards, 2008). This work has shown that the headwater areas of Loantaka Brook, which are associated with relatively high densities of urban and suburban watershed development, and are unaffected by point source discharges from the wastewater treatment facility, are experiencing elevated loading of watershed based salts. While salt concentrations were not directly measured at all stations the utilization of specific conductivity as a proxy measure for dissolved ionic constituents substantiates the role of salt loading to these streams following winter applications of road de-icing agents.

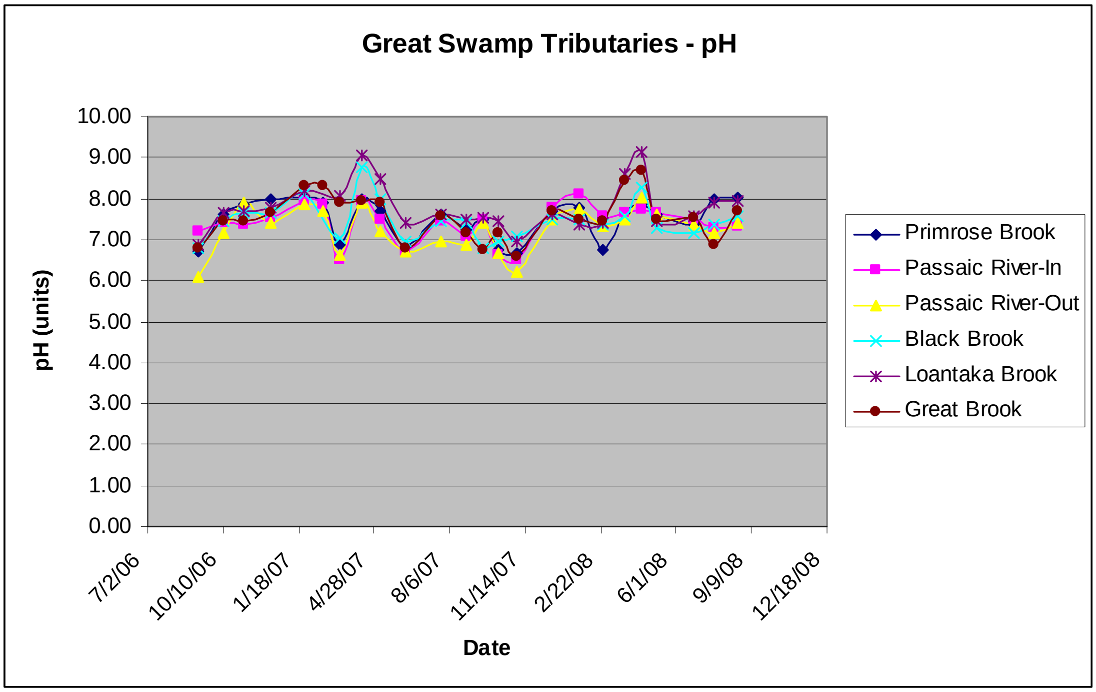
7.2.4 pH

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

The pH of water is a crucial component of stream ecosystems as it directly affects both the solubility and biological availability of chemical constituents and nutrients within the ecosystem. For example, waters of high pH decrease phosphorus binding capacity to iron and aluminum compounds but increase sorption capacity to carbonate molecules. Not only is pH a factor in terms of primary productivity and metabolic activity but is also affected by these processes. When plants and algae photosynthesis they collectively take up carbon dioxide associated with hydrogen species while releasing anions, which serves to raise pH values. At night, when these plants and algae respire, carbon dioxide is actively released, thereby decreasing pH values. These processes are generally kept in balance in healthy ecosystems but may cause elevated diel (daily) variations in impaired waterbodies.

Baseline pH values in streams are determined primarily by watershed geology as the ions derived from these sources serve to form the natural buffering capacity of the stream system. N.J.A.C. 7:9B standards indicate pH values are to not deviate from a range of 6.5 – 8.5 in all FW2 waterbodies. Deviations from this range are commonly attributable to excessive primary productivity, which elevates pH values, or community respiration, which serves to decrease pH values. As such, monitoring pH is often times an excellent proxy measure of stream eutrophication. pH values measured throughout the 2006 – 2008 sampling program at all tributaries are presented in Exhibit 7.5.

Exhibit 7.5: Great Swamp Tributaries - pH



pH values measured at all sampling locations throughout the 2006 – 2008 monitoring period ranged from 6.08 to 9.12. NJDEP surface water quality standards were contravened once at the Passaic River-Out, Black Brook, and Great Brook station and three times at the Loantaka Brook station. Overall, the majority of sampling sites, during the majority of the monitoring period, had pH values which were within the proper range in terms of ecological health and regulatory restrictions. Elevated pH values measured at Loantaka Brook were associated with increase primary productivity which served to increase pH values over the 8.50 threshold reaching a maximum of 9.12 on the April 17, 2008 sampling event.

7.3 Nutrient Data Results and Discussion

The following section details discrete chemical data collected over the course of the 2006 – 2008 monitoring period. Specifically, grab samples were collected under baseflow conditions monthly while composite stormwater samples were collected quarterly. The results of this data are herein compared under varying spatial and temporal scales in order to assess the relative degree of impairment of each stream in terms of nutrient loading and to assess what changes have occurred over time as a result of targeted management efforts or increased pollutant loading. In addition, parameters are assessed over varying flow regimes (e.g. baseflow versus stormflow) to assess the role NPS pollution plays in contributing nutrient and sediment loads to each waterbody. As such, water quality monitoring conducted during the 2006 – 2008 sampling period represents a vital continuation of water quality monitoring which began in 1999.

The resulting data (Appendices I and II) were compared to New Jersey Water Quality Standards (N.J.A.C. 7:9B). An additional metric, based on site-specific water quality statistics developed for both dry weather and wet weather conditions (Water Quality Standards for the Great Swamp Watershed, 2002) was also used to evaluate the comparative quality of each stream.

The data compiled between 1999 and 2008 were segregated into three timeframes. The data collected under the direction of F.X. Browne are grouped in the 1999 through 2001 data set. Those collected under the direction of Princeton Hydro are grouped in the 2002-2005 and 2006 - 2008 data set. It should be noted that the data collected between 2002 and 2005 consisted of four baseflow and four storm flow events sampled by GSWA volunteers with the subsequent analysis of the collected samples conducted by ECM, a NJDEP State certified analytical laboratory. All samples collected under the 2006 – 2008 monitoring period were collected by Princeton Hydro and forwarded under chain of custody procedures to ECM for laboratory analysis.

A major conclusion of the earlier data set presented in the 2002 monitoring report was that the water quality of the streams located in the more developed watersheds had higher base flow and storm flow nutrient and sediment concentrations relative to the streams located in the less extensively developed watersheds. The 2002-2005 and 2006 - 2008 data sets show the same trend. This finding is not unusual. In most cases, developed watersheds will generate more non-point source pollutants than undeveloped watersheds. This results from stormwater runoff's rapid transport of accumulated particulate pollutants from impervious surfaces as well as the dissolution and mobilization of dissolved pollutants from both pervious and impervious surfaces. Similarly, it is not unusual under storm events to observe higher TSS concentrations in streams flowing through developed areas as opposed to streams that drain largely undeveloped lands. Although this may be in part due to the aforementioned mobilization and transport of particulate pollutants and sediments, it is often more a case of the erosion of stream channels and stream beds caused by flooding, stormwater surges and increased flows.

These general trends tend to apply to the streams of the Great Swamp watershed. Overall, some of the streams have strikingly good water quality while others have consistently poor or degraded water quality. The data collected from 1999 through 2008, were compared, where possible, to NJDEP water quality standards (N.J.A.C. 7:9B). In some cases, the data were also compared to water quality threshold values developed for the Great Swamp's tributaries based on statistical analysis of historical water quality data.

7.3.1 Phosphorus (Total and Soluble Reactive Phosphorus)

Phosphorus has gained significant attention in the eutrophication of many freshwater bodies given that it is generally the limiting nutrient in these systems. That is, phosphorus is generally present in least supply relative to biological demand. As such, small increases in phosphorus are often linked to exponential increases in primary productivity. Phosphorus is crucial in aquatic ecosystems as it is a critical element in the structural framework of DNA and RNA, the energy transport molecule ATP, and as a component in phospholipid cellular membranes. While phosphorus is absolutely necessary in the proper biological functioning of any freshwater system problems arise whereby excessive phosphorus loading resulting from anthropogenic watershed disturbances lead to excessive primary productivity (algal growth).

Excessive phosphorus loading is commonly correlated with increasing watershed disturbance. Stormwater based loading from disturbed watersheds serves to transport phosphorus from sources such as lawn fertilizers, malfunctioning or undersized septic systems, and through accelerated sediment erosion as phosphorus molecules are generally strongly bound to soils. The magnitudes of these processes are generally correlated to the degree of watershed disturbance and land use patterns within a particular watershed. Those watershed which are comprised largely by agricultural or dense urban land use generally contribute excessive phosphorus loads while those watersheds predominated by forested lands or sparse residential land uses generally correlate with lower watershed disturbance and therefore lower phosphorus loading.

Additionally, point sources often play a strong role in phosphorus loading with primary sources attributable to waste water treatment facilities. While secondary wastewater treatment facilities are equipped to treat nitrogenous wastes through denitrification processes they generally are ill equipped to remove phosphorus from wastewater. As such, phosphates excreted through human wastes, or as byproducts from household goods or food decomposition, are generally passed directly through the treatment facility and into the effluent whereby they enter the receiving waters.

Stringent surface water thresholds have been established in New Jersey (N.J.A.C. 7:9B) given that phosphorus is the primary nutrient associated with eutrophication of freshwater bodies. For all FW2 tributaries draining to the Great Swamp TP concentrations are to not exceed 0.10 mg/L. Additional water quality thresholds were also developed utilizing statistical analysis of the historical Great Swamp tributary dataset thereby establishing TP concentrations for both baseflow and stormflow conditions. Under these tailored thresholds TP concentrations under baseflow conditions are to meet the 75^{th} percentile of baseflow concentrations, or 0.05 mg/L, whichever is less. TP concentrations under stormflow conditions are less stringent with concentrations to not exceed the 75^{th} percentile of Passaic River stormflow, or 0.10 mg/L, whichever is less.

Mean phosphorus concentrations (± 1 standard error) measured under baseflow conditions for the entire nine year dataset are presented in Exhibits 7.6 – 7.7.

Exhibit 7.6: Total Phosphorus - Baseflow

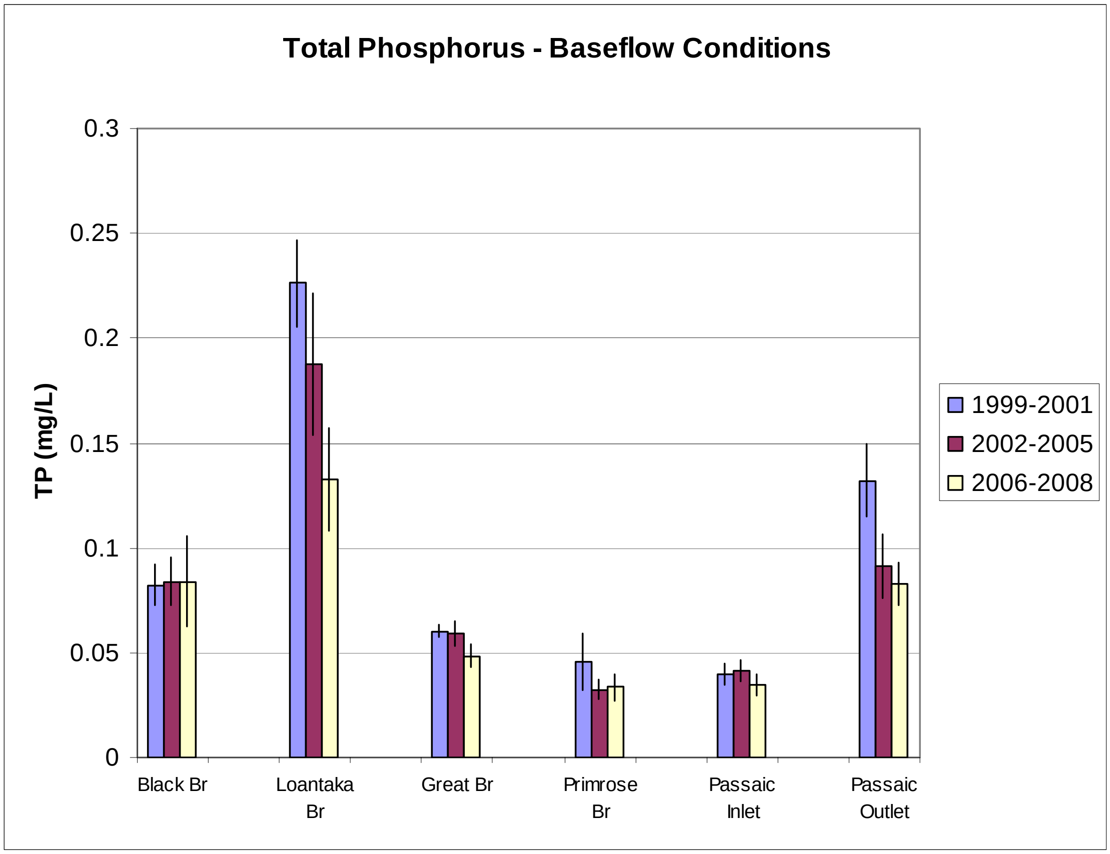
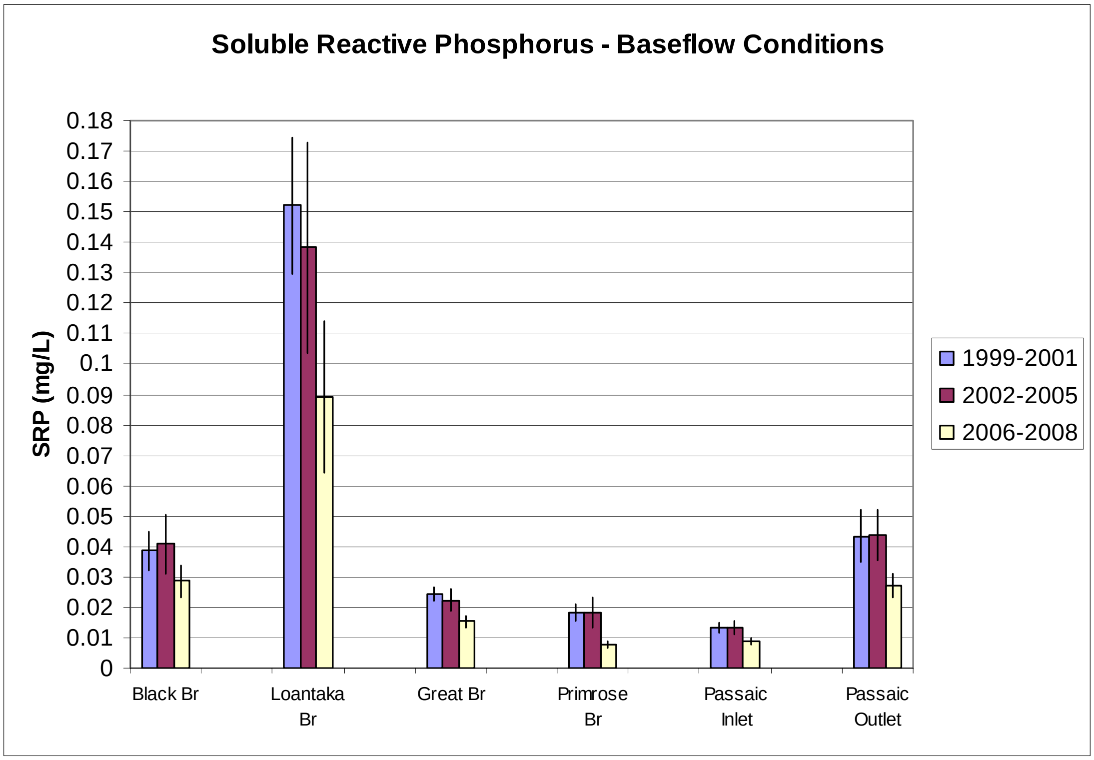


Exhibit 7.7: Soluble Reactive Phosphorus - Baseflow



Mean total phosphorus concentrations have continued to decline during the 2006 -2008 monitoring period at Loantaka Brook, Great Brook, Passaic In, and Passaic Out. Mean TP concentrations were generally consistent with historical data collected at Black Brook while increasing very slightly at Primrose Brook. New Jersey state standards of 0.10 mg/L were routinely contravened at Loantaka Brook while several tributaries (Black Brook, Loantaka Brook, and Passaic Out) contravened the 0.05 mg/L threshold developed for Great Swamp tributaries as based on the 75th percentile of baseflow TP concentrations measured at all tributaries. Soluble reactive phosphorus has declined at all sampling sites for the 2006 – 2008 sampling season but is still well above the tailored standard of 0.02 mg/L at Black Brook, Loantaka Brook, and the Passaic Out station. In addition, SRP continues to represent a large portion (67.2%) of total phosphorus metrics at Loantaka Brook under baseflow conditions.

Mean (± 1 standard error) stormwater TP and SRP concentrations are graphically summarized in Exhibit 7.8 – 7.9.

Exhibit 7.8: Total Phosphorus - Stormflow

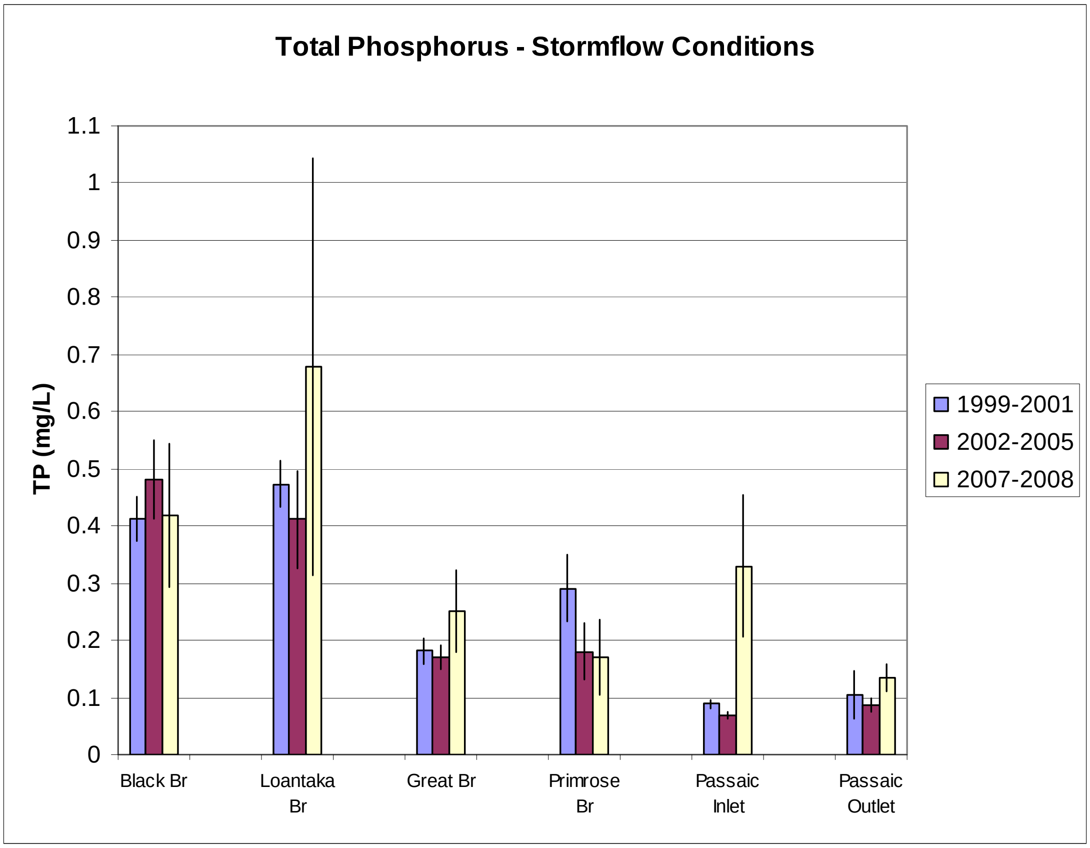
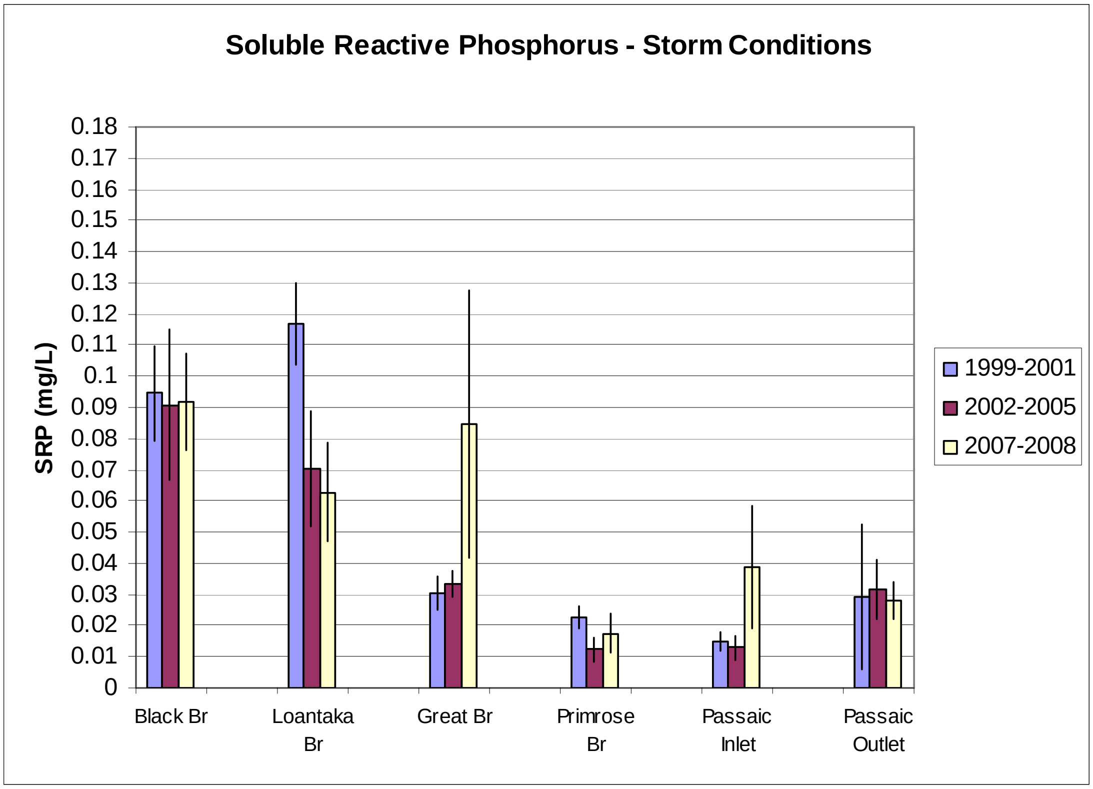


Exhibit 7.9: Soluble Reactive Phosphorus - Stormflow



As expected, mean stormwater TP concentrations were routinely higher at all sampling locations when compared to baseflow measurements with concentrations ranging from 0.13 mg/L at the Passaic-Out station to 0.68 mg/L at Loantaka Brook. Data collected over the course of the 2006 – 2008 time period is rather variable amongst tributaries when compared to historical data with a marked increase at Loantaka Brook, Great Brook, Passaic In, and Passaic Out stations. In contrast, mean stormwater TP concentrations declined at Black Brook and Passaic Brook in comparison to data collected during the 2002 – 2005 season. It should be noted that while mean stormwater TP concentrations declined at the two aforementioned stations there was still a large amount of standard error associated with these measurements. As such, sampling frequency may need to be increased to reduce this error in order to gain a better understanding of the true parametric mean of stormwater based TP concentrations.

Mean SRP concentrations taken under stormflow conditions for the 2006 – 2008 season ranged from 0.017 mg/L at Primrose Brook to 0.092 mg/L at Black Brook. While there is no set standard for SRP concentrations per New Jersey surface water quality standards the tailored threshold of 0.02 mg/L based on the historical Great Swamp tributary dataset was contravened by all stations except for Primrose Brook during the 2006 – 2008 season.

A notable pattern which continues to play out during the 2006 – 2008 season is the repeated elevation of soluble reactive phosphorus during baseflow conditions at the Loantaka Brook sampling site. This pattern is the direct inverse of that which was observed at all other tributaries whereby stormflow SRP concentrations were routinely higher than those collected under baseflow conditions. Such patterns strongly indicate the role point source loading resultant from the Woodland Wastewater Treatment Plant plays in contributing excessive soluble phosphorus to this tributary.

7.3.2 Nitrogen (Total Kjeldahl Nitrogen, Ammonia, Nitrate)

While phosphorus is generally recognized as the limiting nutrient in freshwater ecosystems nitrogen can also limit primary productivity at times. Nitrogen represents a significant element to biological productivity as it plays a critical role in the formation of nucleic acids and amino acids within organisms.

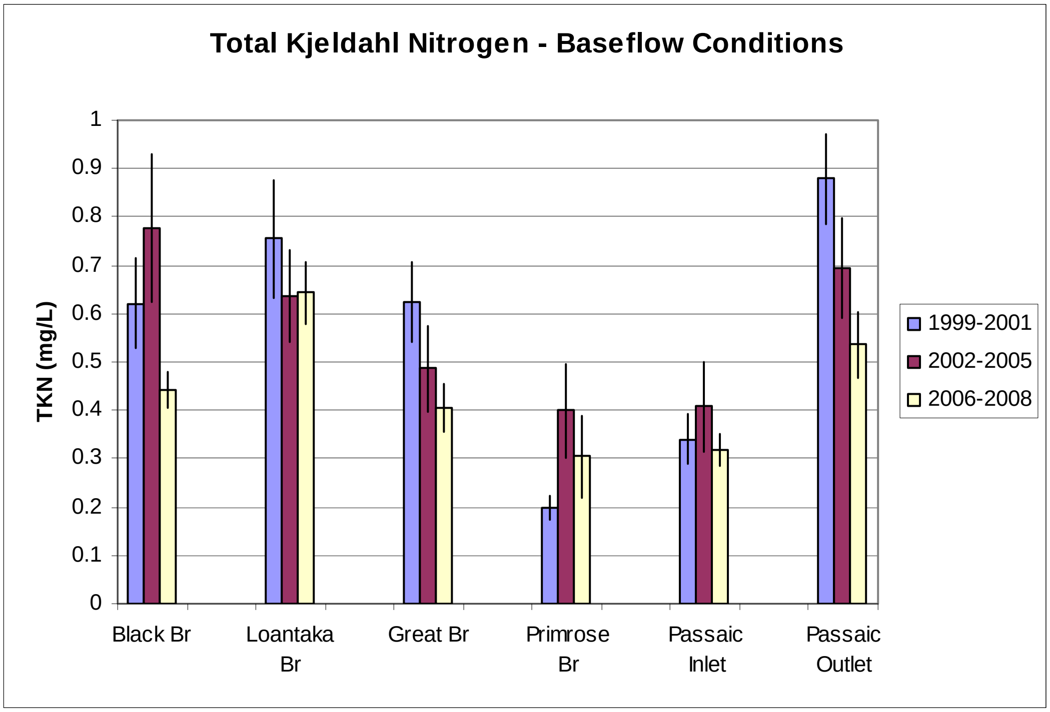
Nitrogen is prevalent throughout the atmosphere as a gas but in aquatic ecosystems is commonly represented as organic, reduced ($NH_3 \leftrightarrow NH_4^+$), or oxidized ($NO_3^-$) forms. Nitrogen is most commonly present as nitrate within oxygenated aquatic systems. Ammonia, produced upon the death or decomposition of organisms or excretion by animals, is typically present in low concentrations as the ammonium ion is readily assimilated by algae for growth or readily oxidized to nitrite (NO_2^-) then to nitrate (NO_3^-) through the dentrification process. Total Kjeldahl nitrogen represents the sum of ammonia and organic forms of nitrogen and when added to nitrate-nitrite concentrations, represents total nitrogen in aquatic systems. Total nitrogen is a critical parameter in aquatic systems as the ratio between total nitrogen and total phosphorus provides valuable information as to nutrient limitation.

The following sections detail nitrogen concentrations measured throughout the 2006 – 2008 season and compare these results on spatial and temporal scales. In addition, nitrogen concentrations are compared to criteria developed per New Jersey surface water quality standards, and where applicable, to the tailored thresholds derived from the historical Great Swamp tributary dataset.

7.3.3 Total Kjeldahl Nitrogen (TKN)

Total Kjeldahl nitrogen concentrations measured throughout the 2006 – 2008 monitoring season, under baseflow and stormflow conditions, are graphically summarized in Exhibits 7.10 and 7.11.

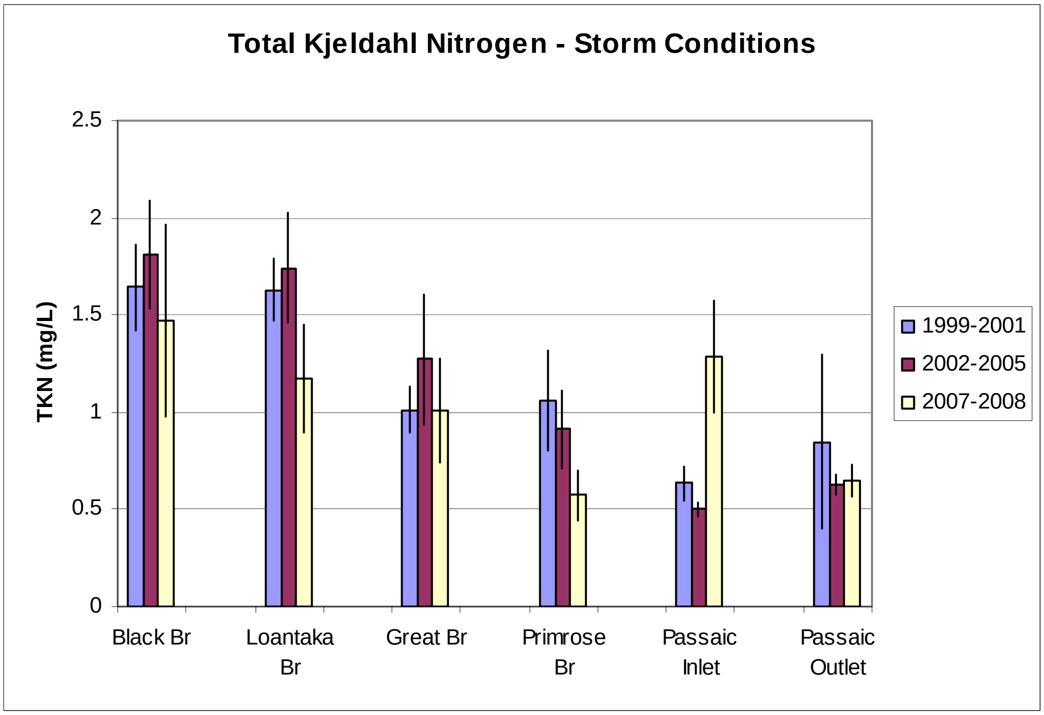
Exhibit 7.10: TKN - Baseflow



Mean TKN concentrations, under baseflow conditions, ranged from 0.30 mg/L at Primrose Brook to 0.64 mg/L at Loantaka Brook throughout the 2006 – 2008 sampling period. The mean concentrations measured during this period represent a general declining trend for every monitored tributary with the exception of Loantaka Brook, which showed a minor increase in mean TKN concentrations during this time period.

Stormwater based mean TKN concentrations ranged from 0.57 mg/L at Primrose Brook to 1.47 mg/L at Black Brook during the 2006 – 2008 sampling period. Mean stormwater TKN concentrations were lower at Black, Loantaka, Great, and Primrose Brooks when compared to those concentrations from the 2002 – 2005 time period. Concentrations measured at the Passaic Outlet showed a minor increase compared to the 2002 – 2005 dataset while those measured at the Passaic Inlet were markedly higher than mean concentrations measured since 1999.

Exhibit 7.11: TKN – Stormflow



TKN has no set threshold under N.J.A.C. 7:9B 7:9B but was addressed by previous studies which utilized the 75th percentile of Primrose Brook baseflow concentrations (0.3 mg/L) as the standard for that stream and the 75th percentile of baseflow concentrations for the Passaic River (0.4 mg/L) as the standard of all other tributaries. Stormflow threshold concentrations were based on a concentration slightly higher than the 75th percentile of the Passaic River stormflow concentration (1.0 mg/L).

Under these guidelines, mean baseflow and stormflow TKN concentrations contravened standards at Passaic-Out, Loantaka Brook, and Black Brook. Of all tributaries which contravened standards Loantaka Brook had the highest mean baseflow TKN concentration while Black Brook showed the highest stormwater based mean TKN concentrations. While several sites showed elevated TKN concentrations throughout the 2006 – 2008 sampling period the general trend of declining concentrations over time is a positive sign in terms of increasing water quality throughout the majority of sampled tributaries.

Stormwater based mean TKN concentrations ranged from 0.57 mg/L at Primrose Brook to 1.47 mg/L at Black Brook during the 2006 – 2008 sampling period. Mean stormwater TKN concentrations were lower at Black, Loantaka, Great, and Primrose Brooks when compared to those concentrations from the 2002 – 2005 time period. Concentrations measured at the Passaic Outlet showed a minor increase compared to the 2002 – 2005 dataset while those measured at the Passaic Inlet were markedly higher than mean concentrations measured since 1999.

7.3.4 Ammonia (NH_3-N)

Ammonia represents a new parameter to the water quality database of those tributaries which drain to the Great Swamp. While this parameter was monitored throughout the 2006 – 2008 season it was excluded in sampling from 1999 – 2005. As such, long term temporal trends in ammonia concentrations may not be made as was performed for all other sampled parameters. Nevertheless, a two year dataset of ammonia concentrations was collected and therefore represents a significant dataset for making inter-stream comparisons. In addition, statistical analysis of this dataset shows relatively low standard error associated with the mean therefore indicating that the collected data is a reliable estimator of the true mean ammonia concentrations within the tributaries under baseflow and stormflow conditions. Ammonia concentrations measured under baseflow and storm flow conditions are are graphically summarized in Exhibits 7.12 and 7.13.

Exhibit 7.12: Ammonia – Baseflow

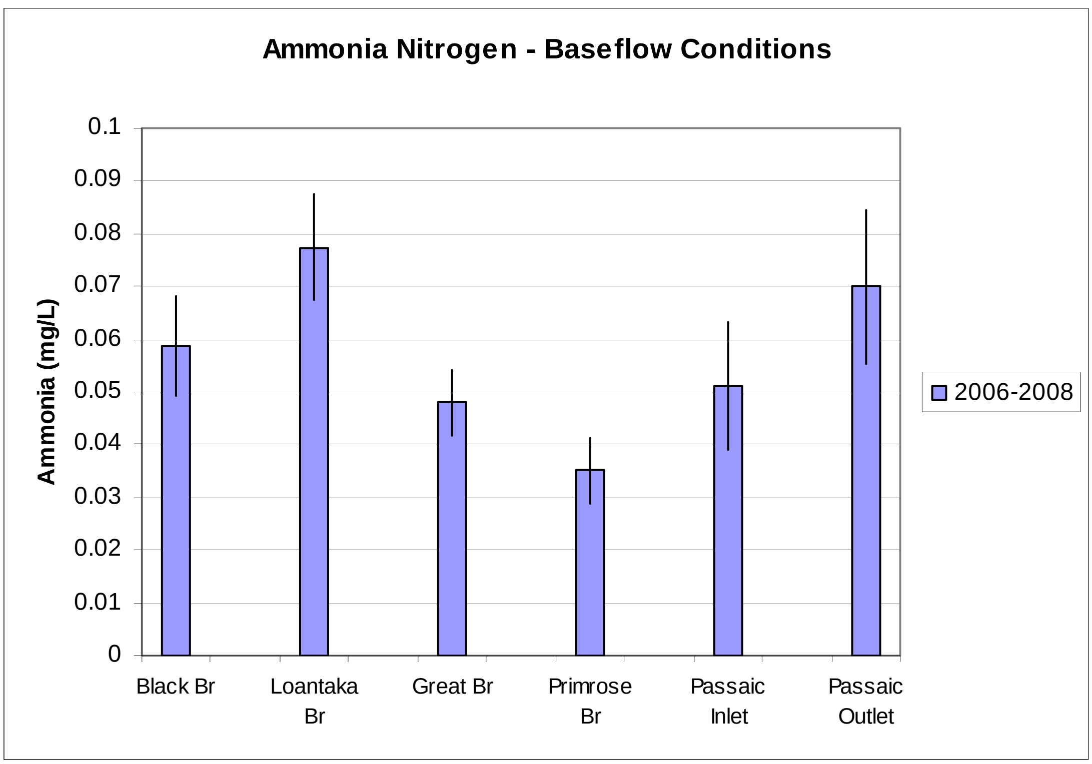
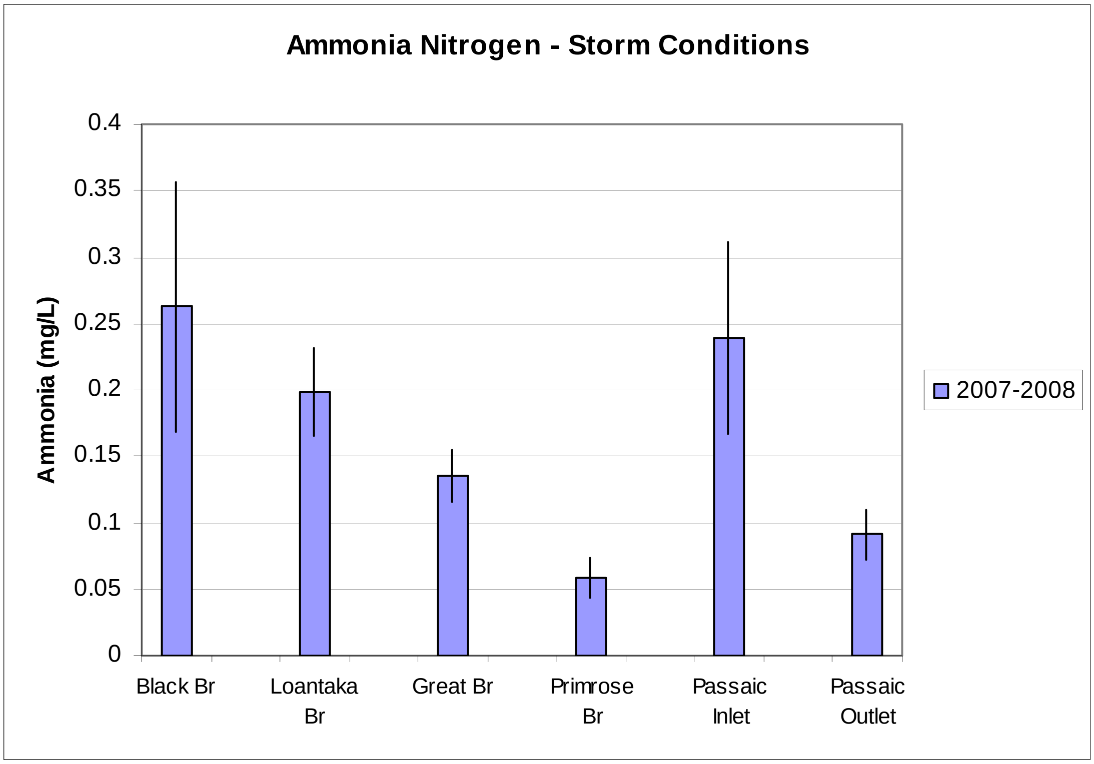


Exhibit 7.13: Ammonia – Stormflow



Mean ammonia concentrations under baseflow conditions ranged from 0.04 mg/L at Primrose Brook to 0.08 mg/L at Loantaka Brook. Mean ammonia concentrations under stormflow conditions were higher than those measured under baseflow conditions at all sampled tributaries with concentrations ranging from 0.06 mg/L at Primrose Brook to 0.26 mg/L at Black Brook. The pattern of elevated baseflow ammonia concentrations at Loantaka Brook and elevated stormflow concentrations at Black Brook are consistent with those trends observed for other monitored nutrients and highlights the excessive nutrient loading of each of these stations.

Ammonia concentrations were compared to acute and chronic toxicity standards per N.J.A.C. 7:9B surface water quality standards. These standards are further stratified based on tributary designation (FW2-TP and FW2-NT), season (for FW2-NT waterbodies only) and pH value at the time of sampling. As such, samples were compared to state standards during each event in contrast to simply assessing the mean ammonia concentration as pH and temperature values directly dictate the acute and chronic toxicity standards as these factors directly influence the percentage of the un-ionized form of ammonia in aqueous solution. It should be noted that calculated threshold concentrations for acute criteria are to be expressed as three-hour averages using MA1CD10 flow (meaning the minimum average one day flow with a statistical recurrence interval of 10 years) while chronic criteria are to be expressed as the 30-day average using MA30CD10 flow (meaning the minimum average 30 consecutive day flow with a statistical recurrence interval of ten years). Since detailed flow data for each stream is not available all concentrations are simply compared to the calculated threshold values under baseflow conditions.

The following table depicts each tributary sampled throughout the 2006 – 2008 season and number of sampling events which contravened acute and chronic toxicity standards (table 7.1).

Table 7.1: Ammonia Standards

Tributary	Sample frequency	Exceedance Frequency		Percent Exceedance	
		Acute	Chronic	Acute	Chronic
Black Brook	23	4	18	17.4%	78.3%
Great Brook	24	3	15	12.5%	62.5%
Loantaka Brook	23	4	16	17.4%	69.6%
Passaic-In	24	4	16	16.7%	66.7%
Passaic-Out	24	7	19	29.2%	79.2%
Primrose Brook	24	1	15	4.2%	62.5%

Acute ammonia toxicity standards were infrequently contravened throughout the 2006 - 2008 sampling period with exceedance frequency ranging from a single event at Primrose Brook to 7 events at the Passaic-Out station. Chronic toxicity exceedances were much more frequent with exceedance frequency ranging from 15 events at Primrose and Great Brook to 19 events at the Passaic-Out station correlating with percent exceedances ranging from 62.5% to 79.2%.

The high percentage of exceedances under the chronic toxicity category is some cause for concern in terms of elevated watershed based nitrogen loading. While the Passaic-Out station showed the highest occurrence of exceeding chronic toxicity standards all streams contravened standards more than 50% of the time.

7.3.5 Nitrate (NO_3-N)

Mean nitrate concentrations, under baseflow and stormflow conditions, are graphically summarized presented in Exhibit 7.14 through 7.15.

Exhibit 7.14: Nitrate - Baseflow

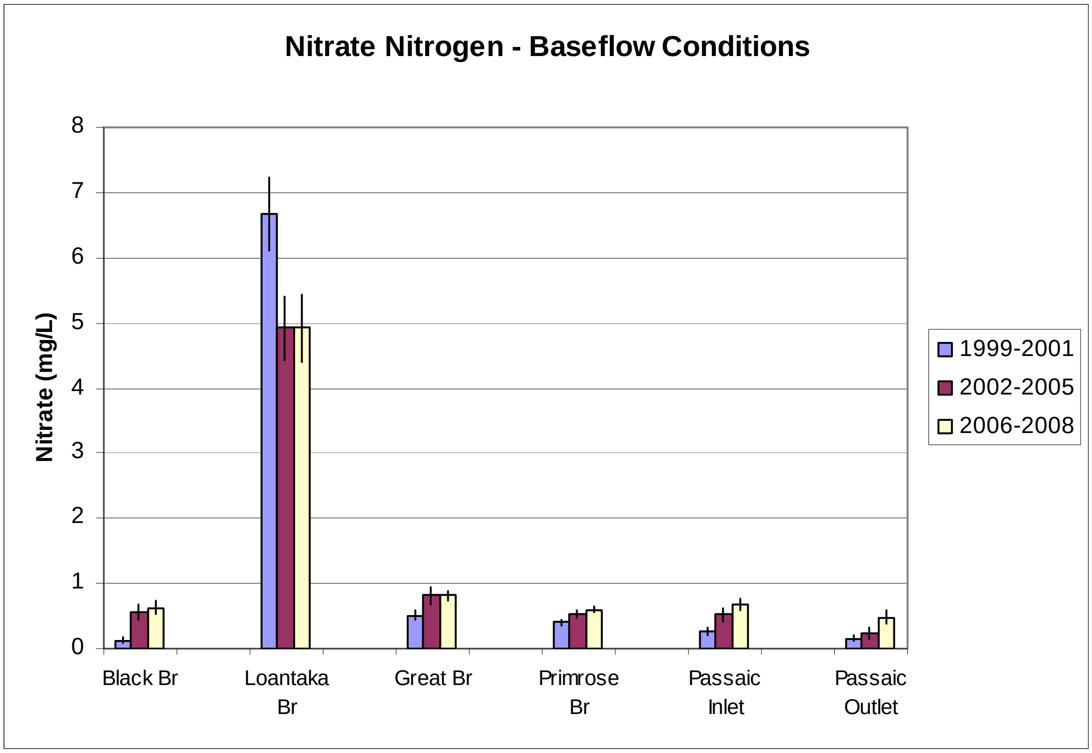
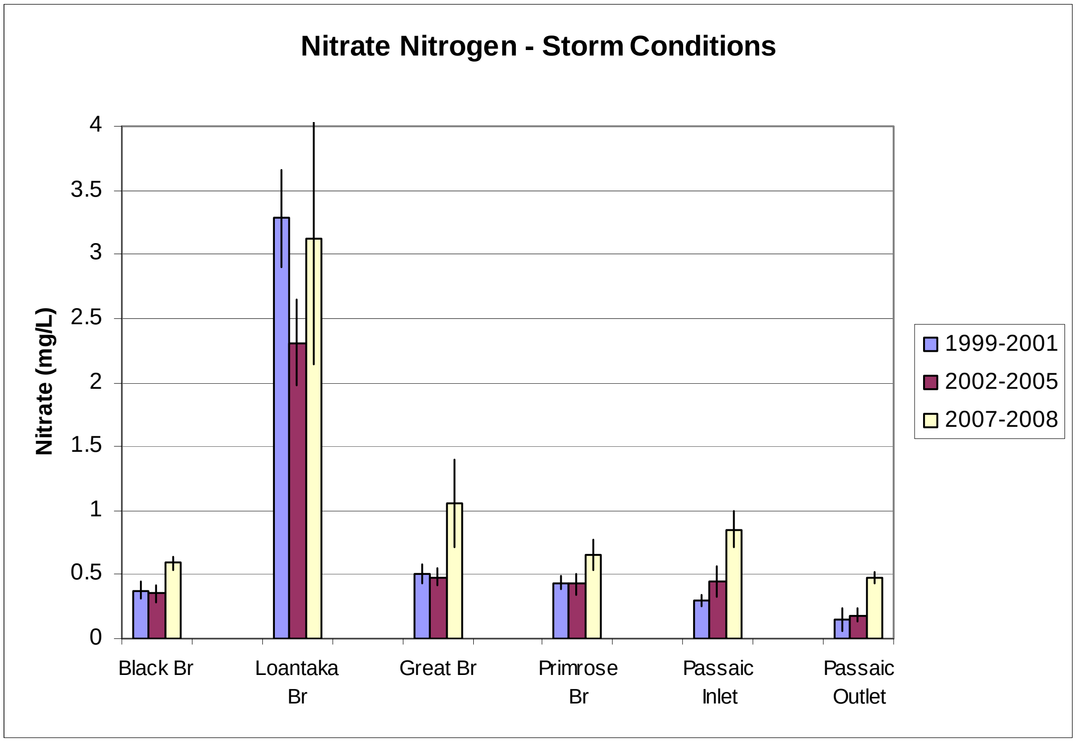


Exhibit 7.15: Nitrate - Stormflow



Mean nitrate concentrations under baseflow conditions ranged from 0.49 mg/L at the Passaic-Out station to 4.93 mg/L at Loantaka Brook over the course of the 2006 – 2008 sampling season. Mean baseflow concentrations showed little variation when compared to samples taken in the previous two time periods with extremely elevated concentrations measured at Loantaka Brook due to discharges from the wastewater treatment facility.

Mean stormflow concentrations ranged from 0.48 mg/L at the Passaic-Out station to 3.12 mg/L at the Loantaka Brook station during the 2006 – 2008 sampling period. Mean nitrate concentrations were higher during the 2006 – 2008 period when compared to all other time frames with the exception of the 1999 – 2001 time period for Loantaka Brook which had higher mean nitrate concentrations than those measured during the 2006 – 2008 sampling period.

When mean nitrate concentrations are compared to N.J.A.C. 7:9B standards all measures fell below the recommended threshold concentration of 10,000 mg/L. It should be noted that this threshold is based primarily on human health standards aimed towards preventing methemologlobinemi in infants and is not aimed towards preventing adverse environmental impacts. As such, additional water quality thresholds have been developed for all tributaries, with the exception of Loantaka Brook, as based on the 75th percentile of historical data collected under baseflow and stormflow conditions for each stream. Given that Loantaka Brook has nitrate concentrations which are routinely an order of magnitude greater than those measured at all other stations additional metrics were utilized to develop a threshold concentrations for this tributary. Specifically, threshold nitrate concentrations for Loantaka Brook are based on a measure of 2.0 mg/L which ranges between the 5th and 25th percentiles of all concentrations (including baseflow and stormflow) measured in Loantaka Brook.

Mean nitrate concentrations under both baseflow and stormflow conditions exceeded each streams respective tailored threshold value for the 2006 – 2008 monitoring period. The greatest exceedances on a percentage basis relative to each threshold occurred at the Passaic-In station under baseflow conditions and at Black Brook under stormflow conditions. Overall, nitrate concentrations were routinely the highest at Loantaka Brook with baseflow concentrations higher than those measured under storm conditions. This is a recurring trend with all pollutants measured and is a strong indicator of point source pollution in this reach derived from the wastewater treatment facility. The second highest mean nitrate concentrations under both baseflow and stormflow conditions were measured at Great Brook with mean concentrations of 0.82 mg/L and 1.10 mg/L respectively. The remaining tributaries, while having mean nitrate concentrations above their respective standards, generally had nitrate concentrations within the proper range for ecological functioning and did not show much variation when comparing baseflow and stormflow concentrations.

7.4 Solids (Total Suspended Solids and Total Dissolved Solids)

7.4.1 Total Suspended Solids (TSS)

Total suspended solids represent the sum of all suspended organic and inorganic material within the streams water column. Increases in TSS concentrations within a stream ecosystem are generally positively correlated to increased land disturbance due to either urban or agricultural usages. Urban land use serves to elevate TSS concentrations within stream systems during storm events primarily as the result of increased stream bank and bed erosion due to elevated flow volumes which are resultant of increased surface and sheet flow due to high areas of impervious coverage. In contrast, elevated TSS concentrations in those streams with watersheds dominated by agricultural land use are primarily the result of direct disturbance and erosion of watershed soils. The interrelationships of land use, hydrology, and stream morphology on the mobilization and transport of suspended solids within a stream ecosystem are critical factors which need to be analyzed in a holistic manner to truly identify and rectify increased solids loading to a waterbody. Effects of elevated TSS concentrations within a stream ecosystem are vast and include alteration of stream morphology, increased embeddedness of stream substrate leading to decreased macroinvertebrate richness and diversity, increased nutrient transport, infilling of fish spawning areas, and irritation of fish gills.

N.J.A.C. 7:9B standards for total suspended solids concentrations are 25 mg/L for FW2-TP waters (Primrose Brook) and 40 mg/L for all FW2-NT waters. It is important to note that N.J.A.C. 7:9B standards do not associate flow regimes or sampling frequency into evaluating TSS standards. Since TSS concentrations generally show a strong positive correlation to flow the analysis of concentrations strictly under baseflow conditions may strongly misrepresent solids loading to each stream. As such, additional water quality thresholds were developed based on statistical analysis of the historical dataset with standards established for both baseflow and stormflow conditions. Those standards are 4 mg/L for baseflow conditions and 25 mg/L and 40 mg/L for stormflow for FW2-TP and FW2-NT streams respectively.

TSS concentrations measured under baseflow and stormflow conditions are presented in Exhibits 7.16 and 7.17.

Exhibit 7.16: TSS - Baseflow

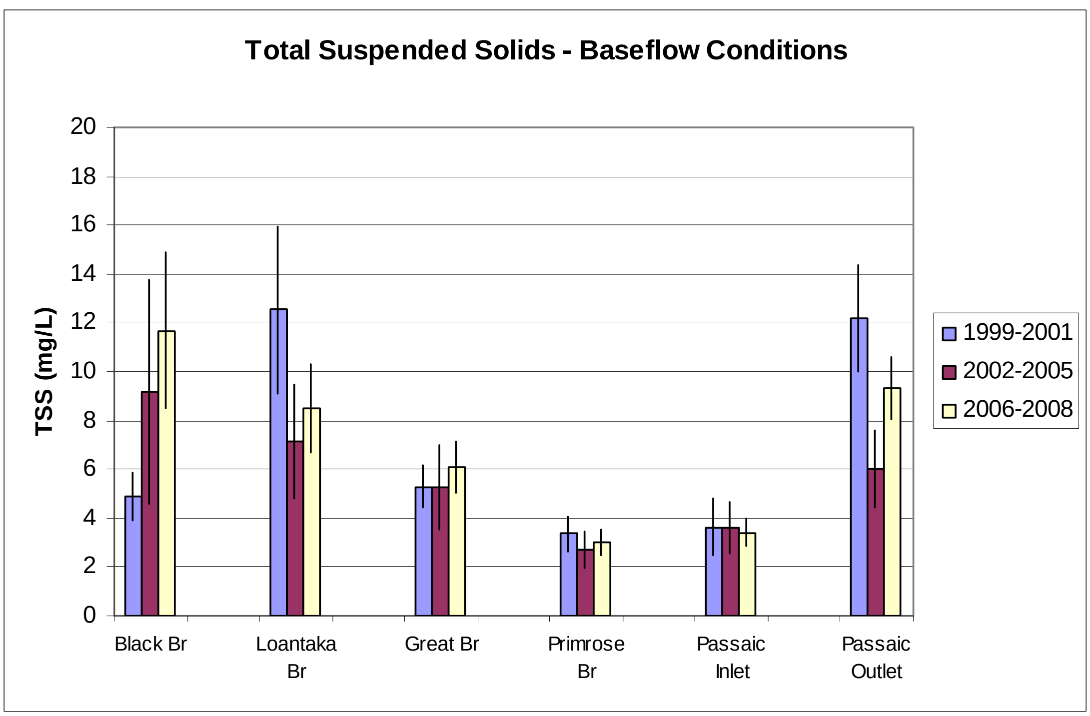
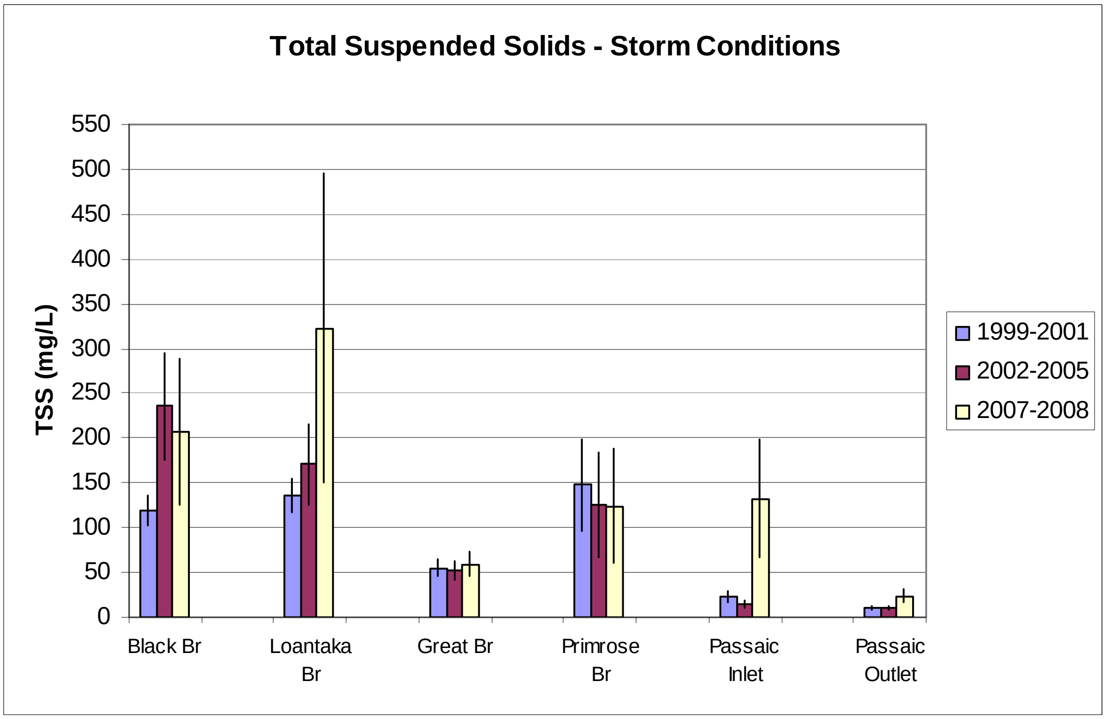


Exhibit 7.17: TSS - Stormflow



Mean TSS concentrations under baseflow conditions ranged from 3 mg/L at Primrose Brook and the Passaic Inlet to 12 mg/L at Black Brook. Mean concentrations from the 2006 – 2008 time period were higher than those measured during the 2002 – 2005 time period at all stations with the exception of the Passaic Inlet station.

Mean TSS concentrations measured under stormflow conditions were considerably higher than those measured under baseflow conditions ranging from 24 mg/L at the Passaic-Out station to 323 mg/L at Loantaka Brook. Concentrations measured during the 2007 – 2008 time period were variable when compared to historical data with mean concentrations at Loantaka Brook, Passaic-In, Passaic-Out, and Great Brook higher than those taken during the 2002 – 2005 time period.

When compared to state standards all baseflow concentrations are well below regulatory thresholds. In contrast, stormflow based TSS concentrations were well above state regulatory standards at each station except the Passaic River Outlet. Tailored standards based on historical baseflow data showed exceedances at all stations with the exception of the Passaic River Inlet and Primrose Brook. Tailored stormwater based thresholds were the same as those set forth in N.J.A.C. 7:9B and as such all stations exceeded their respective thresholds with the exception of the Passaic River Outlet.

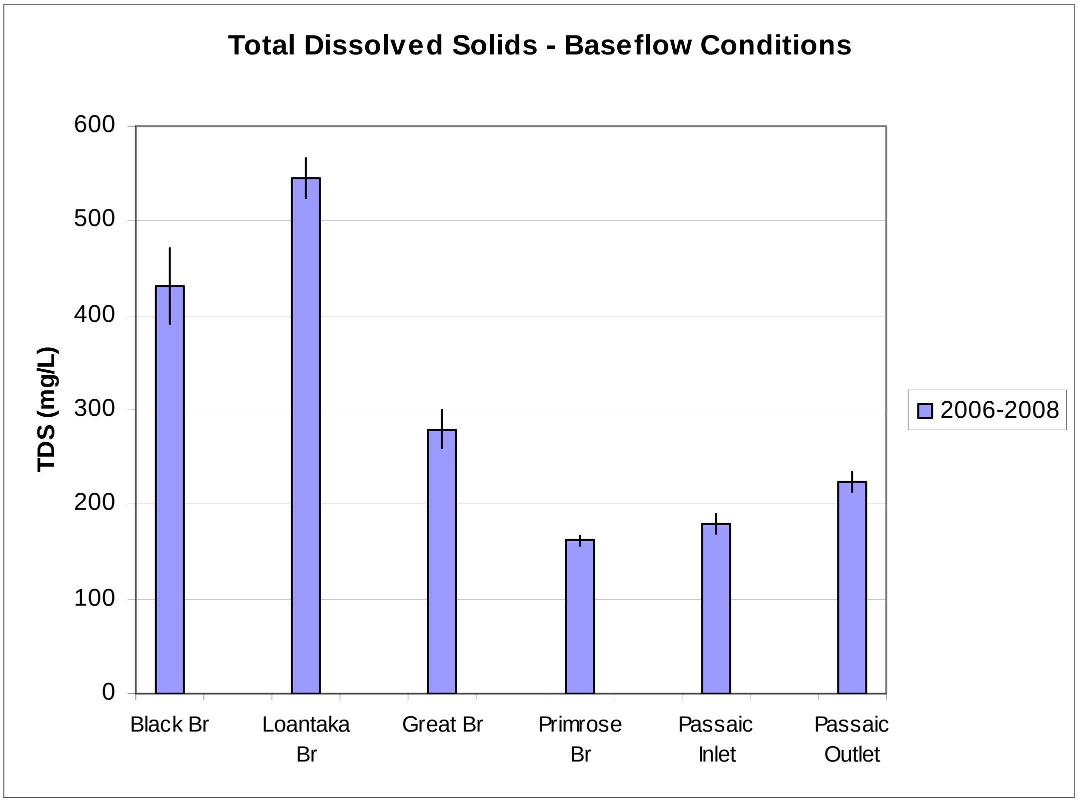
7.4.2 Total Dissolved Solids (TDS)

While total suspended solids represents the sum of all particulates within the water column total dissolved solids represents only those particles which are able to pass through a filter of 2 µm in size. As such, this metric is commonly associated with substances which are present in a molecular, ionized, or micro-granular form. Baseline sources of TDS in freshwater ecosystems are derived from the weathering of watershed soils and bedrock which leads to the natural dissolution of those ionic constituents which make up that geology. Increases above baseline conditions are commonly attributable to anthropogenic sources including wastewater discharges, agricultural runoff, and contamination from road salts in northern climates. Increased TDS measures resultant from salt loading may be attributable to direct runoff or from persistent leaching from soil contamination as these salts may build up in watershed soils over time. Increased TDS concentrations may adversely affect aquatic life through disruption of osmoregulation. Sensitivity to elevated TDS measures are generally dependent on species and life stage with juvenile and spawning fishes showing the greatest sensitivity to elevated concentrations.

New Jersey Surface Water Quality Standards for total dissolved solids state that concentrations are to not increase above background concentrations which would interfere with each streams designated or existing uses, or 500 mg/L, whichever is more stringent. An additional standard is indicated by N.J.A.C. 7:9B which states TDS should show "No increase in background which may adversely affect the survival, growth, or propagation of the aquatic biota. Compliance with water quality-based WET limitations or $LC_{50} \geq 50$ percent, whichever is more stringent, shall be deemed to meet this requirement. For the purpose of this study all mean concentrations will be compared to the 500 mg/L standard as this is the only numerical reference point in the New Jersey regulatory literature. Since TDS is a new parameter to the water quality dataset, only being monitored during the 2006 – 2008 time period, there is no tailored statistical thresholds as was conducted for several other parameters.

TDS concentrations under baseflow and stormflow conditions are presented in Exhibits 7.18 and 7.19.

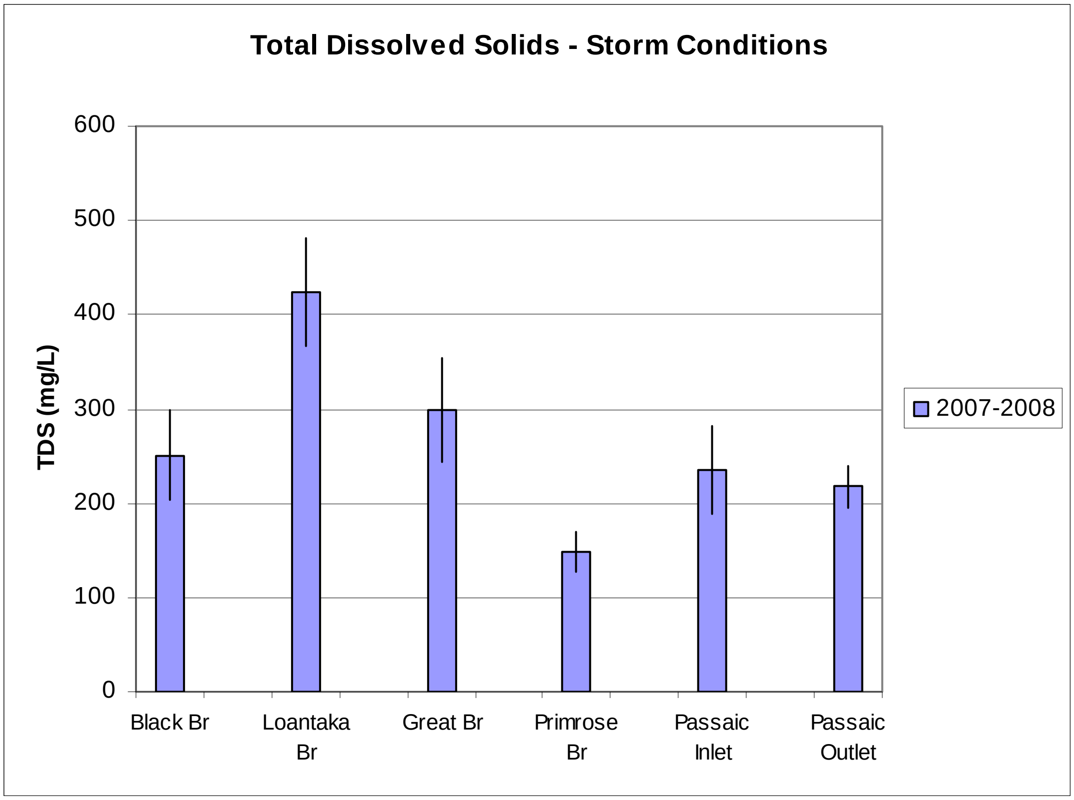
Exhibit 7.18: TDS - Baseflow



Mean TDS concentrations under baseflow conditions ranged from 162 mg/L at Primrose Brook to 546 mg/L at Loantaka Brook while mean stormflow concentrations ranged from 148 mg/L at Primrose Brook to 424 mg/L at Loantaka Brook. Overall, Loantaka Brook continued to show the highest degree of impairment in terms of having the highest mean TDS concentrations under baseflow and stormflow regimes with the highest concentrations being recorded under baseflow conditions. Again, this pattern strongly suggests effluent from the wastewater treatment facility is serving to elevate this parameter above baseline conditions.

When mean concentrations are compared to N.J.A.C. 7:9B standards the only station which contravenes those standards is Loantaka Brook under baseflow conditions. The second highest station, Black Brook, while having elevated TDS concentrations does not contravene the state standard although this stream is clearly impacted.

Exhibit 7.19: TDS - Stormflow



8.0 Biological Monitoring - Macroinvertebrate Community Assessment

An important component in assessing the ecological health of the tributaries throughout the Great Swamp watershed is accurately describing the benthic macroinvertebrate community of each tributary. Biomonitoring has garnered significant attention as a relatively cost-efficient yet effective method of comprehensively evaluating stream water quality through the analysis of biological indicators. Species comprising the macroinvertebrate community occupy distinct niches governed by environmental conditions including aqueous chemistry, suitable habitat, food resources, hydrologic conditions, and thermal regimes. Any perturbations of the aforementioned variables will more than likely cause shifts in the resident macroinvertebrate community through changes in species richness and diversity and as such offer insight as to declines or improvements to biological integrity and overall stream water quality.

The following sections focus on describing the macroinvertebrate communities identified during two sampling events at six stream stations throughout the Great Swamp watershed. This data will serve to build upon the biological database of these streams since the initiation of biomonitoring in 2000 and serve as an accurate characterization of water quality during the time of sampling. In addition, this data is compared to that collected by Dr. Pollock of Drew University in order to assess temporal variation in macroinvertebrate assemblages at each tributary.

8.1 Macroinvertebrate Methodology

Princeton Hydro collected six infaunal samples during two events conducted on October 15, 2007 and April 18, 2008 at the following stream stations:

- Primrose Brook
- Passaic River – In
- Passaic River – Out
- Black Brook
- Great Brook
- Loantaka Brook

Samples were collected according to specifications set forth in the QAPP following standardized procedures derived from the USEPA's and the NJDEP's AMNET sampling procedures (Barbour et al. 1999, NJDEP 2001). Specifically, this entailed the collection of a single composited macroinvertebrate sample at each stream station. Each sample was prepared from ten (10) unit area samplings of the stream benthos selected from the highest quality riffle and run habitats. Each unit area sample entailed placing a D-framed net (500 µm mesh) against the stream bottom and manually disturbing the benthos in a 1-foot square area upstream of the net by hand and foot for 30 seconds. All subsequent unit samplings were collected moving upstream. The composited samples were rinsed into a bucket after five (5) unit area samplings. After a total of ten (10) unit area samplings were conducted the collected matter was washed into a bucket with the retained material transferred to properly labeled sampling bottles containing a preservative of 70% isopropyl alcohol.

Upon field collection samples were transferred under chain of custody procedures to the independent laboratory *EcoAnalysts* for analysis. Upon receipt samples were randomly sub-sampled until 100 organisms were identified to lowest practical taxon, generally, genus or species level. In the case that 100 organisms were not present in the sample then every organism was included in the final count. For the purpose of this study samples ranged from a minimum of 86 individuals to a maximum of 131 individuals with a mean sample containing 113 individuals and a standard deviation of 14.3 individuals. Upon identification Princeton Hydro calculated five common index metrics which, in concert, are utilized to calculate the New Jersey Impairment Score (NJIS). Those metrics calculated are briefly discussed below:

- **Taxa Richness (Total Families)** – Represents the total number of taxa within the sample. The healthier the community is, the greater the number of taxa.

- **EPT Index** – The Ephemeroptera, Plecoptera, and Trichoptera (EPT) index displays taxa richness within the insect groups which are considered most sensitive to pollution. A low index is indicative of impaired water quality.

- **Percent EPT** – Relates the abundance of EPT organisms to the total number of organisms in the sample. A low percentage is indicative of impaired water quality.

- **Percent Dominance (%CDF)** – Relates the abundance of the dominant family to the total number of organisms in the sample. A high percent dominance is associated with impaired water quality.

- **Modified Family Biotic Index (Hilsenhoff Index)** – A biotic index developed by Hilsenhoff (1982) to provide a single 'tolerance value' which is the average of the tolerance values of all species within the benthic community. The index was subsequently modified to the family-level with tolerance values ranging from 0 (very intolerant) to 10 (highly tolerant) based on the organism tolerance to organic pollution. A high FBI is associated with impaired water quality.

The results of the five aforementioned parameters were subsequently utilized to calculate the New Jersey Impairment Score (NJIS) for each stream site as based on the following table (Table 8.1).

Table 8.1: New Jersey Impairment Score (NJIS)[1]

Index Metrics	6	3	0
Taxa Richness	>10	10-5	4-0
EPT Index	>5	5-3	2-0
Percent Dominance	<40	40-60	>60
Percent EPT	>35	35-10	<10
Modified Family Biotic Index	<5	5-7	>7

1 – Source: NJDEP (2007)

Each index metric is scored according to the above table and then summed, with the result correlating to a biological assessment status as listed below (Table 8.2).

Table 8.2: Biological Assessments of NJIS[1]

Biological Assessment	Total Score
Non-impaired	24-30
Moderately Impaired	9-21
Severely Impaired	0-6

1- Source: NJDEP (2007)

8.2 Macroinvertebrate Results

In total, six sites were investigated with field sampling conducted on two sampling dates, October 15, 2007 and April 17, 2008. The following section outlines the results of the sampling including statistical and biometric analysis.

Table 8.3: Macroinvertebrate Results for the Great Swamp Tributaries

Tributary	Impairment Findings	
	10/15/07	**4/17/08**
Primrose Brook	Non-impaired	Non-impaired
Passaic River – Out	Moderately Impaired	Moderately Impaired
Passaic River – In	Non-impaired	Moderately Impaired
Black Brook	Moderately Impaired	Moderately Impaired
Great Brook	Moderately Impaired	Moderately Impaired
Loantaka Brook	Moderately Impaired	Moderately Impaired

8.2.1 Primrose Brook

The sampling station on Primrose Brook, located at the Baileys Mill Road stream crossing, extended for approximately 100 m downstream of the bridge. The substrate in the sampled reach consisted primarily of mixed cobbles, coarse rocks, and gravel with minimum embeddedness although fine grains and small gravel with high embeddedness were located immediately upstream and downstream of the sampling location. This station is located in close proximity to "PB2" under Dr. Pollock's study and as such data gathered from this station will be compared to PB2 to minimize effects of spatial variation which would occur by comparing this data to any other station along this brook.

Table 8.4: Primrose Brook Macroinvertebrate Results

Metric	10/15/07	4/17/08
Taxa Richness	19	20
Abundance	118	117
EPT Index	9	10
Percent EPT	70.34%	41.88%
Dominant Family	Hydropsychidae	Chironomidae
Percent Dominance (family)	51.69%	33.33%
MFBI	4.80	4.59
NJIS	**27**	**30**
Impairment Status	**Non-impaired**	**Non-impaired**

Primrose Brook exhibited the highest taxa richness, EPT index, and lowest MFBI of all stream sites sampled during both sampling dates. During the October sampling event Primrose brook's macroinvertebrate community was comprised of 19 different families of which Hydropsychidae represented the dominant family with a percent dominance of 51.69%. The elevated abundance of Hydropsychidae was the primary factor in the high percent EPT metric although 8 additional families were identified in this category.

The macroinvertebrate community shifted during the April sampling event to one dominated by Chironomidae (33.33%). Although chironomids are a pollution tolerant family they made up much less of the overall community abundance than the Hydropsychidae did during the October event and as such did not negatively influence this streams NJIS score. Taxa richness and EPT index was slightly higher during the April event although percent EPT was lower with a value of 41.88%.

In summary, Primrose Brook may be categorized as "Non-impaired" with a mean NJIS score of 28.5 out of a maximum score of 30. The predominance of numerous EPT families in this stream along with a relatively diverse community of pollution intolerant organisms are the primary driving factors behind the high NJIS scores for this tributary. The non-impaired designation is in keeping with data collected by Dr. Pollock over the course of 2000-2005 which consistently highlighted Primrose Brook as the highest quality stream from a macroinvertebrate standpoint.

8.2.2 Passaic River – Out

The Passaic River - Out station was sampled downstream of the South Maple Avenue bridge at USGS gaging station # 01379000. Samples were taken approximately 50 yards below and above the USGS gaging station. This sampling station was located farther downstream than any station sampled by Dr. Pollock as such direct comparisons between sampling sites may not be warranted as this run is of significantly higher order than those sampled by Dr. Pollock.

Substrate at this station was comprised primarily of large, angular rocks of medium embeddedness. Flow and depth regimes at this station were generally homogenous consisting of deep runs with some shallower riffles along the upstream portion of the transect.

Table 8.5: Passaic River – Out Macroinvertebrate Results

Metric	**10/15/07**	**4/17/08**
Taxa Richness	12	11
Abundance	131	117
EPT Index	3	3
Percent EPT	58.78%	17.09%
Dominant Family	Hydropsychidae	Simuliidae
Percent Dominance (family)	56.49%	49.57%
MFBI	5.24	5.24
NJIS	**21**	**18**
Impairment Status	**Moderately Impaired**	**Moderately Impaired**

During the October sampling event the Passaic River – Out station was characterized by the lowest taxa richness of all sampling sites with only 12 families identified. The dominant family, Hydropsychidae, made up 56.49% of the total community and represented the majority of this stations percent EPT. As such, EPT index was very low with only 3 families identified.

Community metrics were somewhat similar during the April sampling event with markedly low taxa richness as was observed during the October event. The dominant family during this event was Simuliidae, which accounted for 49.57% of the entire community. EPT index numbers were again low with a value of 3. Percent EPT

(17.09%) was markedly lower than during the October event due to a decrease in Hydropsychidae abundance.

New Jersey Impairment Scores ranged from 21 during the October event to 18 during the April event. Both scores place the Passaic River – Out station in the "Moderately Impaired" category.

8.2.3 Passaic River – In

The Passaic River – In station, located immediately downstream of Lees Hill Road bridge, extended for approximately 100m downstream of the Osborn Pond impoundment. This station most closely resembles that denoted "PR 1" in Dr. Pollock's study. Substrate within this reach was comprised primarily of medium, angular rocks and gravel with minimal embeddedness. Sample composites were taken in a mixture of shallow riffle, and deep and shallow run flow regimes.

Table 8.6: Passaic River – In Macroinvertebrate Results

Metric	10/15/07	4/17/08
Taxa Richness	19	17
Abundance	127	115
EPT Index	8	4
Percent EPT	37.80%	6.96%
Dominant Family	Chironomidae	Chironomidae
Percent Dominance (family)	24.41%	37.39%
MFBI	5.05	5.59
NJIS	**27**	**18**
Impairment Status	**Non-impaired**	**Moderately Impaired**

The macroinvertebrate community identified during the October sampling event showed high taxa richness with 19 families identified. The EPT index was the second highest of all sampling stations with 8 families identified whose abundance made up 37.80% of the entire community. The dominant family was the pollution tolerant Chironomidae which accounted for 24.41% of community abundance. Overall, elevated taxa richness and a predominance of EPT families helped to give this site a high impairment score of 27 which correlated with "Non-impaired" status.

Although the macroinvertebrate community was evenly balanced and diverse during the October event a marked shift occurred during the April event. While taxa richness was only slightly lower than that identified during the October event there were half the number of EPT families identified which made up only 6.96% of community abundance. Chironomidae was again the dominant family whereby it made up 37.39% of community abundance. The decreases in EPT index and percent EPT led to a much lower New Jersey Impairment Score of 18 which would categorize this station as "Moderately Impaired" at the time of sampling.

The divergent community characteristics between the October and April sampling events may be attributable to increased pollution but are more likely simple factors of temporal variation as has been documented from previous studies.

When the above data is compared to that collected by Dr. Pollock over the course of 2000-2005 it becomes clear that the Passaic-In station does suffer some impairment especially when this data is compared to macroinvertebrate assemblages located upstream of the Osborn Pond impoundment. Dr. Pollock has cited the effects of increased water temperatures and decreased dissolved oxygen concentrations as possible perturbations resulting from the impoundment of this reach. While the data from this site seem to indicate periods of acceptable macroinvertebrate assemblages there are clearly site specific perturbations which serve to favor pollution tolerant organisms within this stretch.

8.2.4 Black Brook

The Black Brook sampling station extended approximately 100m downstream of the Southern Boulevard stream crossing. This station most closely represents that listed as "BB 1" by Dr. Pollock as this station was located just downstream of sampling conducted by Princeton Hydro. Sediment composition at the sample site was composed almost entirely of fine grains and sands. Flow and depth regimes were homogenous throughout the sample site and were dominated by slow flowing runs.

Table 8.7: Black Brook Macroinvertebrate Results

Metric	**10/15/07**	**4/17/08**
Taxa Richness	17	11
Abundance	86	89
EPT Index	2	1
Percent EPT	3.49%	4.49%
Dominant Family	Tubificidae	Chironomidae
Percent Dominance (family)	26.74%	83.15%
MFBI	7.88	6.02
NJIS	**12**	**9**
Impairment Status	**Moderately Impaired**	**Moderately Impaired**

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While taxa richness was rather high for the October sampling event there were very few EPT families with an index of 2 and percent EPT of only 3.49%. The dominant family at the time of sampling was represented by the pollution tolerant Tubificidae which accounted for 26.74% of the total population. The high abundance of this family translated to a rather high MFBI score of 7.88. All of these factors in concert translated to a rather low NJIS of 12 which characterized this reach as "Moderately Impaired."

Taxa richness showed a marked decline during the April event with only 11 families identified. The EPT index was again extremely low with only 1 family identified which made up 4.49% of community abundance. The dominant family, chironomidae, made up an extremely large percentage of the community abundance accounting for 83.15%. The marked absence of EPT families in conjunction with very poor species diversity, and the predominance of pollution tolerant chironomids combined to provide a low NJIS of 9, which again characterized this reach as "Moderately Impaired."

The lack of suitable structure and mixture of flow / depth regimes within the Black Brook sampling station translated to extremely low species diversity and a predominance of pollution tolerant organisms. These issues have been historically documented by Dr. Pollock who cited impairment due to poor habitat, elevated TDS values, and low DO concentrations. Degraded DO concentrations and elevated TDS values are likely attributable to the high degree of development in this streams immediate watershed which is associated with golf courses, and medium density residential / commercial land.

8.2.5 Great Brook

The Great Brook sampling station consisted of an approximately 100m reach downstream of the Woodland Road stream crossing. This sampling station is located in close proximity to that designed as "GB 2" by Dr. Pollock in his previous studies. Sediment within this transect was comprised primarily of fine grained sands and small gravel. Embeddedness within this reach was rather elevated. Flow regimes within this section were dominated primarily by runs with a limited occurrence of riffles.

Table 8.8: Great Brook Macroinvertebrate Results

Metric	10/15/07	4/17/08
Taxa Richness	19	13
Abundance	118	121
EPT Index	3	1
Percent EPT	52.54%	1.65%
Dominant Family	Hydropsychidae	Naididae
Percent Dominance (family)	43.22%	33.88%
MFBI	5.35	6.48
NJIS	**21**	**15**
Impairment Status	**Moderately Impaired**	**Moderately Impaired**

Taxa richness during the October sampling event was rather high with 19 families identified. The EPT index for this date was rather low with only 3 families identified. While the index was low percent EPT was high at 52.54%. Nevertheless, Hydropsychidae accounted for the majority of this percentage and total community abundance at a percent dominance of 43.22%. The low EPT index in conjunction poor species diversity led to a NJIS of 21 which categorized this reach as "Moderately Impaired."

Taxa richness was markedly lower during the April event with 13 families identified. The EPT index declined as well with only a single family identified. While EPT accounted for only 1.65% of community abundance the dominant family, Naididae, accounted for 33.88%. The general absence of EPT during the April event was the primary factor in this station's low NJIS of 15 which again categorized this reach as "Moderately Impaired."

Factors leading to this stations designation as Moderately Impaired continue to focus on the absence of suitable habitat and elevated sedimentation, both of which were documented by Dr. Pollock in historical studies.

8.2.6 Loantaka Brook

The Loantaka Brook sampling station consisted of an approximately 100m reach downstream of the Green Village Road stream crossing. This station is located in close proximity to that designated as "LB 1" by Dr. Pollock in historical studies. Sediment within this transect was comprised primarily of fine grained sands and small gravel. Embeddedness within this reach was rather elevated. Flow regimes within this section were dominated primarily by runs and secondarily by limited occurrences of riffles.

Table 8.9: Loantaka Brook Macroinvertebrate Results

Metric	10/15/07	4/17/08
Taxa Richness	14	12
Abundance	119	98
EPT Index	1	1
Percent EPT	17.65%	2.04%
Dominant Family	Elmidae	Chironomidae
Percent Dominance (family)	37.82%	29.59%
MFBI	5.60	5.75
NJIS	**18**	**15**
Impairment Status	**Moderately Impaired**	**Moderately Impaired**

Taxa richness was relatively low in comparison to all other sampling stations with 14 families identified during the October sampling event. Of all families identified only one fell into the EPT category with EPT accounting for only 17.65% of community abundance. The dominant family was Elmidae which accounted for 37.82%. The NJIS for the April event was 18 which correlated with a "Moderately Impaired" designation for this reach.

Taxa richness declined again during the April event with 12 families identified. The EPT index again consisted of only 1 family while EPT percent abundance was markedly lower at 2.04%. The dominant family consisted of the pollution tolerant Chironomidae which accounted for 29.59% of community abundance measures. The NJIS for this reach declined during the April event to 15 which again characterized this reach as "Moderately Impaired."

Impairment within this reach continues to be a factor of sedimentation, poor habitat structure, and altered water quality which is likely the result of discharge from the Woodland Wastewater Treatment Plant. Water quality data which was collected at this site was routinely poor with elevated total dissolved solids, nitrate, and soluble phosphorus. Dr. Pollock has historically documented the effects of the aforementioned perturbations in shaping the macroinvertebrate community structure with B-IBI ratings for this station ranging from "very poor" to "poor."

9.0 Visual Habitat Assessment

An integral component in fully evaluating lotic ecosystems lies in habitat analysis. In its broadest sense, "habitat" is the place where an organism or group of organisms lives. Defined by the geographic, physical, chemical, and biological characteristics of a particular system, habitat largely governs the biotic community which may thrive in those specific conditions. Habitat analyses are generally conducted utilizing four basic dimensions: temporal, spatial, physical-chemical, and biological. While each of these dimensions may be further broken down into their component parts it is necessary to fully define and evaluate project objectives in order to conduct the specific habitat analysis which will yield data that is directly germane to the study objectives.

For the purpose of this study habitat assessments were focused on analyzing the physical, chemical, and biological components of each stream system and their ability to sustain a rich and diverse infaunal (benthic dwelling) community. Community richness and diversity within high gradient lotic systems are particularly sensitive to several factors including substrate composition and quality, embededness, flow and depth regimes, stream bank condition, and riparian cover. In assessing these conditions it is often useful to denote a reference stream, that is, a waterbody located within the same geographic region as all other sampling stations that is least perturbed by anthropogenic sources. In this sense the reference stream may serve as a benchmark against which all other tributaries may be gauged and scored in terms of habitat quality. Utilizing habitat data in this sense is particularly useful as systematic deviations from reference conditions may be linked to environmental disturbances due to both point and non-point source pollution. Congruence between visual habitat assessment scores, nutrient criteria, macroinvertebrate studies, and observational data may therefore provide a holistic view of stream integrity and serve as the impetus for management efforts aimed at the improvement of those stream reaches which show the highest degree of impairment.

9.1 Visual Assessment Methodology

During the 2008 season a Princeton Hydro ecologist with significant experience conducting stream surveys within the New Jersey Piedmont Region performed a comprehensive visual habitat assessment of each of the six established stream sampling sites throughout the Great Swamp Watershed utilizing the standardized NJDEP High Gradient Stream Habitat Assessment protocol (NJDEP, 2001). This assessment protocol evaluated in-stream, stream bank, and riparian corridor conditions for their ability to provide a stable and functioning habitat template for the biota of the stream.

This assessment essentially consisted of scoring ten variables, on a scale from 0 – 20, to provide an overall habitat assessment score. Following the field assessment the overall score of each site was summed and then ranked against all other sample sites. In addition to providing critical information as to the overall habitat of each stream this data is utilized in concert with flow monitoring, nutrient, and macroinvertebrate data to provide a holistic view of the overall ecological integrity of each tributary throughout the Great Swamp Watershed.

9.2 Visual Assessment Summary Results

The following table (9.1) presents the scoring of each parameter at all six stations throughout the Great Swamp Watershed while exhibit (9.1) presents the same results graphically.

Station Descriptions

The following sections detail specific habitat attributes for each sampled station and their relative rank. For the purpose of this study the Passaic Out station will be excluded in ranking as it does not drain to the Great Swamp National Wildlife Refuge.

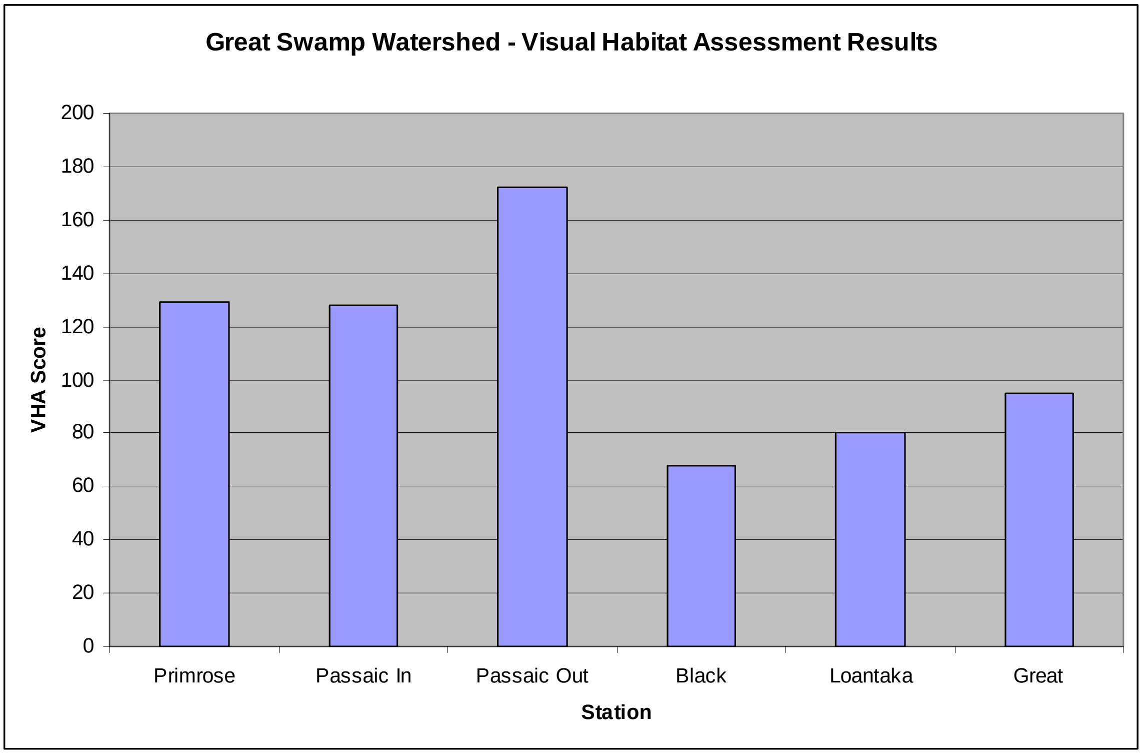
9.2.1 Primrose Brook

The visual habitat assessment performed for Primrose Brook was conducted approximately 50 m upstream and 50 m downstream of the Baileys Mill Road stream crossing. This section of Primrose Brook is designated as a FW2-TPC1 (Category 1) stream per NJDEP and as such is protected from environmental degradation through stringent water quality standards. This applies not only to that portion of the stream within the boundaries of the Great Swamp National Wildlife Refuge, but the entire stream starting from its headwaters. Previous studies conducted by Princeton Hydro have shown the immediate watershed of this area of Primrose Brook to be composed primarily of low-density development, specifically, large houses on large lots with spacious turf grass areas. The development within the immediate watershed surrounding this station is non-continguous, broken by forested areas throughout. The immediate watershed surrounding this branch of Primrose Brook seems to acutely affect stream quality through stormwater discharges from swales and residential discharges, which were collectively noted at 80% of the surveyed points from Princeton Hydro's previous study (Princeton Hydro, 2004). While the immediate sources of hydrologic perturbation around the sampling site are not much cause for concern this sampling station is certainly experiencing cumulative impacts from development further upstream, namely, storm water drainage from Routes 202 and 287. Elevated hydrologic loading from these major highway sources have certainly served to degrade this portion of Primrose Brook as comparisons of the current sample station to conditions upstream of these major road crossing have shown marked differences in habitat quality, most notably, sediment composition and bank stability.

Table 9.1: Visual Habitat Assessment Results

	Station Name and ID								
Parameter	**Primrose**	**Passaic In**	**Passaic Out**	**Black**	**Loantaka**	**Great**	**Min**	**Max**	**Mean**
Epifaunal Substrate	13	11	17	5	6	10	5	17	10
Embeddedness	11	11	18	7	1	5	1	18	9
Velocity/Depth Regime	14	16	17	3	8	11	3	17	12
Sediment Deposition	12	13	19	7	5	5	5	19	10
Channel Flow Status	15	14	20	17	12	11	11	20	15
Channel Alteration	15	11	19	5	13	13	5	19	14
Frequency of Riffles (or bends)	11	16	18	2	8	6	2	18	10
Bank Stability	16	18	18	18	10	14	10	18	16
Vegetative Protection	10	10	14	2	9	12	2	14	10
Riparian Vegetative Zone Width	12	8	12	2	8	8	2	12	8
Total Score	129	135	172	68	80	95	68	172	113

Exhibit 9.1: Visual Habitat Assessment Results[1]



1 – Results based on a scoring range of 0 – 200, higher scores correlate with optimal habitat

While there are several noted impacts of Primrose Brook this tributary still routinely experiences the best habitat, macroinvertebrate communities, and water quality conditions of all tributaries sampled throughout the Great Swamp Watershed. The visual habitat survey conducted in 2008 has shown that substrate composition immediately surrounding the Baileys Mill Road bridge is comprised primarily of cobble and large angular rocks with minimum embeddedness. Moving approximately 10 yards in either direction from the bridge shows a marked decline in sediment quality with composition dominated by highly embedded gravel and fine sands. The finer sediment deposits have shown significant accumulation within certain areas upstream of the bridge with notable bar formation. Bank stability was moderately stable scoring an 8 out of 10 for both left and right banks, although there were some noted instances of erosion these instances comprised a small area and as such were not much cause for concern. Vegetative protection of each bank was listed as marginal (5 out of 10) for both banks due to periodic disturbances of riparian vegetation due to the variable nature of development within this section whereby some riparian portions showed excellent corridor coverage (> 18 m) while others were subject to mowed turf grass extending up to the stream bank as a result of residential development.

Overall, Primrose Brook scored 129 out of a possible 200 points ranking this reach as the best of all five tributaries entering the Great Swamp. While this reach was ranked high comparably speaking it still suffers from some notable impacts, as such, habitat within the sampled reach may be characterized as "suboptimal". The primary habitat perturbations within the sampled reach consisted of an absence of suitable substrate conducive to epifuanal colonization. Numerous areas of deep, fine sands were prevalent throughout the 100m reach. These sediment inputs are likely a direct result of stormwater runoff from Routes 202 and 287 which are located approximately 0.6 miles upstream from the sample site. Elevated hydrologic loading resulting from unmitigated stormwater runoff from these roads is likely serving to accelerate bank erosion further upstream thereby leading to sediment deposition throughout the sample site.

9.2.2 Passaic - In

The Passaic - In station was sampled starting at the spillway of Osborne Pond which is located immediately to the south of Lees Hill Road and continued approximately 100 m downstream. As is the case with Primose Brook, this stream is designated by the NJDEP as Category 1, even outside the boundaries of the Great Swamp National Wildlife Refuge. As such, the stream is such the stream is protected by antidegradation provisions under N.J.A.C. 7:9B. The influence of the impoundment of Osborne Pond on the overall habitat of the studied reach is strikingly apparent in terms of altered flow regimes and overall sedimentation within the studied reach. Sediment composition within the reach was comprised primarily of large angular rocks near the spillway shifting to smaller gravel further away from the dam. Embeddedness was rather minimal (approximately 5%) immediately surrounding the spillway area due to scouring effects but did increase to approximately 50% further downstream. Sediment deposition was evident throughout this reach with approximately 25% of the stream bottom affected. As a result, portions of this reach were characterized by suboptimal channel flow conditions with some portions of the channel substrate exposed. While sedimentation was evident within this reach it would likely be much more of an issue if it were not for the impoundment of Osborne Pond as this waterbody likely serves to settle out much of the inflowing sediment load. While the impoundment served to increase scoring in the sediment deposition portion of this assessment it negatively affected the overall score in terms of the channel alteration category as this structure serves to alter the natural morphology of this system.

Flow regimes within the Passaic - In station were generally well represented with all four major velocity / depth profiles present within the reach. Shallow and deep riffles were prevalent throughout the sample area with relatively high riffle frequency.

Riparian conditions surrounding this reach were variable with extensive vegetative coverage on the left bank although the vegetative community consisted primarily of invasive species, most notably, Multiflora rose (*Rosa multiflora*). Riparian conditions along the right bank showed greater impairment as a result of development consisting of a pumping station and single residential unit. As such, the riparian corridor width along the right bank was markedly reduced ranging from approximately zero to 5 m in width.

Overall, the Passaic - In station scored 128 out of 200 possible points ranking this station as having the second highest habitat quality of all five tributaries which drain to the Great Swamp.

9.2.3 Black Brook

The Black Brook sampling station extended approximately 50 meters upstream and downstream of the Southern Boulevard stream crossing. The immediate watershed surrounding this sampling location consists of a golf course to the north and medium density commercial development to the south. These watershed features have served to severely degrade this reach due to removal of riparian vegetation and elevated stormwater hydrologic loads which have served to inundate this reach with nutrient rich sediments serving to alter substrate composition and flow regimes ultimately leading to very poor habitat for epifaunal colonization.

Epifaunal substrate and available cover within the studied reach was listed as “poor” with less than 20% stable habitat due to a lack of large woody debris, undercut banks, or other suitable hard structure. Substrate conditions within this reach were unsuitable for sustaining a healthy macroinvertebrate assemblage as they consisted primarily of deep, fine sands along with intermittent areas of heavily embedded (> 75%) cobbles. Stream morphology within this reach was characterized as poor due to low sinuousity as the result of channelization resulting from numerous sources including removal of riparian vegetation along the golf course, elevated hydrologic loading via stormwater from the roadside drainage system, and hard structuring of the left bank. The altered stream morphology translated to low diversity of flow / depth regimes with the dominant regime consisting of slow moving, deep runs. As such, riffles were generally non-existent within this reach.

Riparian vegetation was absent along both banks in the northern portion of this reach while present in limited area (< 3m) along the southern portion of the study area. As such, vegetative protection scores were low for both banks due to elevated riparian disturbance.

Black Brook cumulatively scored 68 points out of 200 thereby ranking the habitat of this tributary as the most degraded of all streams draining to the Great Swamp. The lack of riparian vegetation, poor substrate condition, absence of variable flow regimes, and channelization characterize this reach as unfit for supporting a healthy macroinvertebrate assemblage.

9.2.4 Loantaka Brook

The habitat assessment conducted for Loantaka Brook was located approximately 50 meters upstream and downstream of the Green Village Road stream crossing. Land use immediately surrounding this reach consisted almost entirely of low density residential housing associated with discontinuous areas of deciduous forest.

Epifaunal substrate within the studied reach of Loantaka Brook was ranked on the low end of "marginal" due to a lack of large woody debris, undercut banks, large cobbles, or any other structure which would provide colonization potential. The substrate within this reach was comprised almost entirely of fine grained sands interspersed with < 5% coverage of cobble. Where cobbles were present they were heavily embedded (70% - 90%) and as such provided little surface area for macroinvertebrate colonization. Sediment deposition throughout the reach was high with greater than 50% of the bottom area consisting of heavy deposits of fine grained sediments. In addition, approximately 35% of the reach area was affected by sediment bar formation including an expansive sediment bar located immediately under the Green Village Road bridge which served to prevent water from extending to both banks therefore decreasing the channel flow status score of this assessment.

Riparian conditions throughout this reach were variable ranging from suboptimal conditions at the left bank downstream of the bridge and right bank upstream of the bridge to poor conditions at the left bank upstream from the bridge and the right bank downstream of the bridge. Disturbances of riparian vegetation were resultant from vegetative removal associated with low density residential housing surrounding this reach.

Loantaka Brook cumulatively scored 80 points out of 200 ranking this reach as the second most degraded in terms of habitat of all tributaries within this study. The greatest impairments of Loantaka Brook are those of elevated sediment loading which has led to infilling of any suitable hard structure and alteration of flow / depth regimes. As such, this reach is unsuitable for sustaining a diverse macroinvertebrate community with varying macroinvertebrate community metrics ranking this site as "poor" to "moderately impaired" (Pollock, 2005 and Princeton Hydro, 2008).

9.2.5 Great Brook

Habitat assessments along Great Brook were conducted approximately 50 m upstream and downstream of the Woodland Road stream crossing which is located at a low-gradient portion of the stream reach near the inflow to the Great Swamp. Epifaunal substrate within the studied reach consisted primarily of heavily embedded gravel with larger, angular rocks located immediately at the base of the bridge abutments. Sediment deposition affected much of the studied reach with notable sand bar formation at the upstream portion of the studied reach. As such, velocity and depth regimes within this reach were dominated primarily by shallow and deep runs with few noted instances of shallow riffles. Channel flow status was rated "suboptimal" due to the presence of sandbars which prevented water from reaching both shores at portions of the studied area. Bank stability within this reach was listed as suboptimal for both the right and left banks with approximately 10% of the bank area showing some form of erosion.

Riparian corridor condition within the studied reach showed suboptimal conditions with approximately 75% of the streambank surface covered by vegetation. Riparian vegetative width was highly variable throughout the reach with poor (< 6 m in width) conditions upstream of the bridge. Riparian corridor width increased going further downstream with a vegetated corridor of approximately 15 m.

Overall, Great Brook scored 95 out of 200 possible points ranking this section as the median tributary of all stream entering the Great Swamp. Macroinvertebrate habitat within this section is generally poor as a result of heavy sedimentation and lack of diversity in flow / velocity regimes.

9.2.6 Passaic Out

Visual habitat assessment at the Passaic Out station was conducted at an approximately 100 m stretch located downstream downstream of the South Maple Avenue bridge at USGS gaging station # 01379000. Habitat conditions within the Passaic Out station were relatively conducive to the promotion of diverse infaunal communities with optimal conditions recorded for all component parameters with the exception of vegetative protection and riparian vegetative zone width.

Epifaunal substrate within this reach consisted primarily of medium to large angular rocks with minimal (< 15%) embeddedness. As such, sediment deposition within this reach was relatively low with no observation of sediment point bars or significant pool sediment deposition. Channel flow status within this reach was optimal with depth and flow regimes representative of all four major groups (slow-deep, slow-shallow, fast-deep, fast-shallow). Riffles, both shallow and deep, were prevalent throughout this reach. Channel alteration within this reach was minimal with only minor subtractions due to the establishment of bridge abutments located upstream from the sampling site.

Riparian conditions within the studied section were generally in good condition although did not obtain optimal ranking as vegetative growth was dominated by second growth deciduous trees. Riparian corridor width was suboptimal along the left bank, extending approximately 15 m in width while scoring slightly lower due to bisection of the riparian corridor by Pond Hill Road.

Overall, the Passaic Out station scored the highest of all sample sites with a cumulative assessment score of 172 out of 200. While this reach has optimal habitat for benthic macroinvertebrates it was not counted in ranking procedures as this station represents the outlet of the Great Swamp and is therefore not targeted for management in terms of reducing NPS pollution to the Great Swamp Refuge.

10.0 Stream Discharge and Development of Ratings Curves

Stage-discharge ratings curves describe the mathematical relationship between stream stage or staff gage height and stream discharge. These ratings curves are therefore used to estimate stream discharge at a given staff gage reading. For the purposes of this project, ratings curves were developed for all six tributaries. Ratings curves primarily present an easy way to estimate discharge; this information can then be used in a variety of ways. The primary use of the ratings curve in this study is to estimate both baseflow and stormflow discharge and to calculate pollutant loads, particularly during stormflow events, by multiplying the calculated discharge by the concentration of various analytes sampled in the water quality monitoring portion of the study. This data is then used to verify and calibrate modeled pollutant loads in the Great Swamp watershed and to provide a better understanding of the contributions of pollutant loads in the watershed.

The following sections relate in greater detail the methodology, results and discussion, and detailed uses of the stage-discharge ratings curves.

10.1 Stream Discharge Methodology

The development of stage-discharge ratings curves consists of several distinct components. These components include the installation and reading of staff gages, collection of detailed discharge data through direct field measurement, and various regression analyses to actually calculate the ratings curve.

Staff gage installation was the first task undertaken in this study. A staff gage is long piece of heavy-gauge sheet metal, painted and graduated into decimal feet, essentially resembling a large ruler. Staff gages are inserted somewhere in the stream channel and permanently fixed. At each tributary staff gages were installed either directly to bridge abutments or to cast iron pipes which were hammered into the substrate. The stability of installed staff gages is of utmost importance as any vertical movement of the gage will skew the relationship between stream stage or staff gage height and discharge.

The next component of developing ratings curves is the physical measurement of stream discharge. To develop an accurate curve a number of discharge measurements must be made over a variety of discharges and stream stages. For this study, discharge measurements were recorded both by Princeton Hydro during three events.

Discharge measurements performed by Princeton Hydro were made according to USGS methodology published in “Techniques of Water-Resources Investigations of the United State Geological Survey, Book 3, Applications of Hydraulics, Chapter A8, Discharge Measurements at Gaging Stations, by T.J. Buchanan and W.P. Somers, 1969”. Discharge measurements consist of three distinct parts measuring flow velocity, depth, and horizontal distance. Flow velocity measurements were made utilizing a vertical-axis Price meter, type AA, as recommended by USGS. These meters are preferred in low-velocity streams and have a high accuracy. Price meters are used in conjunction with a top-setting wading rod, which is used to measure stream depth and to set the Price meter at the 0.6-depth (six-tenths depth from the surface). Empirical evidence indicates that the average flow velocity of a narrow vertical column of water is approximated at the 0.6 depth, such that the average flow at a point in a stream with a depth of 1.0 feet is 0.4 feet, the 0.6-depth from the surface. A transect line is set across the stream, roughly parallel to the flow and perpendicular to either bank. Numerous flow velocity measurements are taken across the transect and flow velocity, depth, and distance from one selected bank is recorded. The number of points taken is not a fixed number nor is the interval between points, however at a minimum twenty (20) such measurements must be taken. The goal is to limit each integrated point to less than 5% of total discharge along the cross section of stream investigated. The integration of a single point is a subset of the larger discharge measurement along the transect line and is the multiplicative product of flow velocity, depth, and the width between adjacent points. As such, points are taken closer together in the middle of the stream as both depth and flow velocity increase, and further apart in shallower depths and decreased flow velocity nearer the banks. Total discharge is then calculated by summing the individual points. Staff gage readings are recorded immediately before and after discharge measurements to ensure static stream depths during sampling.

Stage-discharge ratings curves are then calculated by examining the relationship between stage and instantaneous discharge measurements. The procedure for calculating ratings curves is published by USGS in "Techniques of Water-Resources Investigations of the United State Geological Survey, Book 3, Applications of Hydraulics, Chapter A10, Discharge Ratings at Gaging Stations, by E.J. Kennedy, 1984". The method utilized in this study involved the natural logarithmic transformation of both staff gage height and discharge to yield an appropriate regression equation. The regression equation was further evaluated for stage-discharge relationship through the R^2 value. The R^2 value is a statistical tool used to describe the relation between the two investigated variables such that an R^2 value of 0.900 roughly indicates that 90% of the variation in the dependent variable, in this case discharge, is explained by variation in the independent variable, stream stage; higher R^2 values indicate a tighter relationship. Discharge is then calculated by inserting the selected staff gage height as variable x into the equation. Staff gage heights are entered in feet and the resulting discharge is calculated as cubic feet per second (cfs).

Some additional analyses were made concerning discharge and stage. Essentially, these consist of descriptive statistics of observed and calculated flow and stream stage.

10.2 Discharge Results

The following table (table 10.1) represents the derived stage-discharge rating curves at each tributary and the R^2 values as calculated by the methods described above.

Table 10.1: Stage Discharge Ratings Curves Summary

Tributary	Stage-Discharge Ratings Curves (cfs)	R^2
Primrose Brook	Discharge = 1.3347*staff gage height^5.4979	0.85
Passaic – In	Discharge = 3.5304*staff gage height^4.4419	0.99
Black Brook	-	-
Great Brook	Discharge = 4.9620*staff gage height^3.3381	0.95
Loantaka Brook	Discharge = 0.6326*staff gage height^3.1498	0.99

Overall, the ratings curves developed for each tributary showed excellent agreement between stage and discharge as indicated by high R^2 values. It should be noted that a ratings curve was not able to be developed for Black Brook as this tributary only had flow during one sampling event and as such did not have the dataset necessary to compute a curve. The ratings curves calculated for each tributary were developed from flow data gathered during seasonal baseflow conditions with discharge measurements for all tributaries (excluding Black Brook) ranging from 1.3 cfs to 16.7 cfs. Therefore, while the above equations are useful in calculating baseflow discharge values they may not be particularly accurate for calculating discharge during periods of elevated flow. Further calibration of each sites ratings curve may be necessary through the field collection of additional discharge values during periods of elevated flow to increase the range of discharge values that are able to be accurately calculated utilizing these curves.

11.0 References

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Appendix I
Water Quality Data - Baseflow

Great Swamp Watershed Baseflow Sampling - 9/8/06							
STATION	NH_3-N (mg/L)	NO_3-N (mg/L)	TKN (mg/L)	SRP (mg/L)	TP (mg/L)	TSS (mg/L)	TDS (mg/L)
Primrose Brook	0.05	0.61	0.84	0.013	0.12	2	165
Loantaka Brook	0.12	7.40	1.40	0.062	0.09	ND <2	468
Passaic River - In	0.08	0.84	0.84	0.016	0.03	2	167
Passaic River - Out	0.17	0.09	1.50	0.049	0.12	ND <2	192
Black Brook	0.15	0.41	0.97	0.042	0.10	21	143
Great Brook	0.15	0.91	0.84	0.028	0.06	4	227

Great Swamp Watershed Baseflow Sampling - 10/10/06							
STATION	NH_3-N (mg/L)	NO_3-N (mg/L)	TKN (mg/L)	SRP (mg/L)	TP (mg/L)	TSS (mg/L)	TDS (mg/L)
Primrose Brook	0.03	0.42	0.12	0.008	0.03	ND <2	169
Loantaka Brook	0.05	8.90	0.46	0.040	0.06	2	538
Passaic River - In	0.03	0.37	0.16	0.008	0.03	2	170
Passaic River - Out	0.05	0.04	0.53	0.033	0.08	6	209
Black Brook	0.05	0.28	0.21	0.032	0.05	ND <2	318
Great Brook	0.05	0.46	0.39	0.023	0.05	ND <2	235

Great Swamp Watershed Baseflow Sampling - 11/7/06							
STATION	NH_3-N (mg/L)	NO_3-N (mg/L)	TKN (mg/L)	SRP (mg/L)	TP (mg/L)	TSS (mg/L)	TDS (mg/L)
Primrose Brook	0.04	0.62	0.27	ND <0.002	0.01	145	ND <2
Loantaka Brook	0.07	5.50	0.75	0.016	0.05	461	ND <2
Passaic River - In	0.05	1.00	0.33	ND <0.002	0.01	153	6
Passaic River - Out	0.09	0.36	0.64	0.018	0.07	183	6
Black Brook	0.04	0.49	0.22	0.019	0.04	468	ND <2
Great Brook	0.07	1.00	0.27	0.018	0.07	234	ND <2

Great Swamp Watershed Baseflow Sampling - 12/12/06							
STATION	NH_3-N (mg/L)	NO_3-N (mg/L)	TKN (mg/L)	SRP (mg/L)	TP (mg/L)	TSS (mg/L)	TDS (mg/L)
Primrose Brook	0.02	0.33	0.17	0.004	0.01	ND <2	124
Loantaka Brook	0.10	3.60	0.49	0.018	0.04	2	448
Passaic River - In	0.03	0.73	0.31	0.016	0.02	ND <2	144
Passaic River - Out	0.08	0.50	0.49	0.014	0.05	6	167
Black Brook	0.03	0.27	0.35	0.012	0.03	10	345
Great Brook	0.04	0.92	0.40	0.015	0.05	18	215

Great Swamp Watershed Baseflow Sampling - 1/25/07							
STATION	NH_3-N (mg/L)	NO_3-N (mg/L)	TKN (mg/L)	SRP (mg/L)	TP (mg/L)	TSS (mg/L)	TDS (mg/L)
Primrose Brook	0.02	0.77	0.17	0.008	0.01	3	134
Loantaka Brook	0.08	5.00	0.56	0.014	0.07	7	429
Passaic River - In	0.03	1.50	0.29	0.006	0.02	4	151
Passaic River - Out	0.06	1.20	0.45	0.008	0.05	16	179
Black Brook	0.04	0.80	0.36	0.007	0.03	8	377
Great Brook	0.02	1.60	0.22	0.007	0.03	6	237

Great Swamp Watershed Baseflow Sampling - 2/20/07							
STATION	NH_3-N (mg/L)	NO_3-N (mg/L)	TKN (mg/L)	SRP (mg/L)	TP (mg/L)	TSS (mg/L)	TDS (mg/L)
Primrose Brook	ND <0.01	1.00	0.17	0.011	0.03	ND <3	137
Loantaka Brook	STREAM FROZEN - NO SAMPLE COLLECTED						
Passaic River - In	0.02	1.40	0.53	0.007	0.01	ND <3	186
Passaic River - Out	0.05	1.70	0.31	0.007	0.03	ND <3	272
Black Brook	STREAM FROZEN - NO SAMPLE COLLECTED						
Great Brook	0.02	1.70	0.28	0.005	0.01	ND <3	394

Great Swamp Watershed Baseflow Sampling - 3/14/07							
STATION	NH_3-N (mg/L)	NO_3-N (mg/L)	TKN (mg/L)	SRP (mg/L)	TP (mg/L)	TSS (mg/L)	TDS (mg/L)
Primrose Brook	0.02	0.80	0.14	0.003	0.02	ND <3	147
Loantaka Brook	0.02	3.20	0.21	0.003	0.06	ND <3	440
Passaic River - In	0.04	0.99	0.29	0.005	0.02	ND <3	203
Passaic River - Out	0.06	0.63	0.29	0.007	0.03	ND <3	190
Black Brook	0.04	0.63	0.38	0.005	0.03	3	614
Great Brook	0.02	1.20	0.19	0.005	0.02	ND <3	342

Great Swamp Watershed Baseflow Sampling - 4/11/07							
STATION	NH_3-N (mg/L)	NO_3-N (mg/L)	TKN (mg/L)	SRP (mg/L)	TP (mg/L)	TSS (mg/L)	TDS (mg/L)
Primrose Brook	0.10	0.73	0.10	0.004	0.01	ND <3	150
Loantaka Brook	0.03	2.90	0.31	0.005	0.05	ND <3	479
Passaic River - In	0.03	0.90	0.19	0.004	0.02	3	203
Passaic River - Out	0.03	0.31	0.24	0.008	0.05	3	199
Black Brook	0.02	0.46	0.24	0.002	0.04	ND <3	605
Great Brook	0.04	0.84	0.27	0.004	0.04	ND <3	268

Great Swamp Watershed Baseflow Sampling - 5/7/07							
STATION	NH_3-N (mg/L)	NO_3-N (mg/L)	TKN (mg/L)	SRP (mg/L)	TP (mg/L)	TSS (mg/L)	TDS (mg/L)
Primrose Brook	0.02	0.56	0.39	ND <0.002	0.03	3	113
Loantaka Brook	0.03	2.90	0.76	0.026	0.07	7	374
Passaic River - In	0.30	0.55	0.30	0.005	0.02	ND <3	134
Passaic River - Out	0.04	0.16	1.10	0.029	0.08	10	139
Black Brook	0.06	0.30	0.45	0.010	0.04	6	377
Great Brook	0.03	0.54	0.33	ND <0.002	0.04	4	188

Great Swamp Watershed Baseflow Sampling - 6/8/07							
STATION	NH_3-N (mg/L)	NO_3-N (mg/L)	TKN (mg/L)	SRP (mg/L)	TP (mg/L)	TSS (mg/L)	TDS (mg/L)
Primrose Brook	0.03	0.61	0.19	0.012	0.03	5	166
Loantaka Brook	0.05	4.50	0.46	0.086	0.14	8	673
Passaic River - In	0.05	0.44	0.21	0.018	0.06	12	186
Passaic River - Out	0.05	0.29	0.50	0.058	0.12	19	219
Black Brook	0.08	0.44	0.84	0.061	0.51	60	386
Great Brook	0.05	0.72	0.35	0.026	0.06	9	266

Great Swamp Watershed Baseflow Sampling - 7/26/07							
STATION	NH_3-N (mg/L)	NO_3-N (mg/L)	TKN (mg/L)	SRP (mg/L)	TP (mg/L)	TSS (mg/L)	TDS (mg/L)
Primrose Brook	0.06	0.69	2.10	0.009	0.03	5	172
Loantaka Brook	0.11	6.30	0.51	0.220	0.27	9	502
Passaic River - In	0.09	0.27	0.47	0.023	0.06	ND <3	164
Passaic River - Out	0.09	0.08	0.92	0.076	0.12	10	342
Black Brook	0.13	0.38	0.51	0.064	0.11	10	336
Great Brook	0.09	0.59	0.74	0.029	0.07	9	200

Great Swamp Watershed Baseflow Sampling - 8/29/07							
STATION	NH_3-N (mg/L)	NO_3-N (mg/L)	TKN (mg/L)	SRP (mg/L)	TP (mg/L)	TSS (mg/L)	TDS (mg/L)
Primrose Brook	0.03	0.50	0.35	0.011	0.02	3	174
Loantaka Brook	0.14	5.30	0.58	0.062	0.11	19	618
Passaic River - In	0.02	0.41	0.50	0.013	0.04	7	170
Passaic River - Out	0.13	0.22	0.80	0.061	0.15	18	199
Black Brook	0.02	0.24	0.50	0.031	0.05	5	372
Great Brook	0.04	0.51	0.66	0.006	0.05	6	237

Great Swamp Watershed Baseflow Sampling - 9/20/07							
STATION	NH_3-N (mg/L)	NO_3-N (mg/L)	TKN (mg/L)	SRP (mg/L)	TP (mg/L)	TSS (mg/L)	TDS (mg/L)
Primrose Brook	0.03	0.57	0.13	0.010	0.03	13	163
Loantaka Brook	0.08	9.50	0.57	0.063	0.10	19	634
Passaic River - In	0.03	0.42	0.23	0.007	0.02	5	130
Passaic River - Out	0.03	0.42	0.63	0.028	0.09	20	208
Black Brook	0.08	0.64	0.57	0.025	0.05	ND <3	372
Great Brook	0.03	0.81	0.13	0.018	0.04	6	229

Great Swamp Watershed Baseflow Sampling - 10/9/07							
STATION	NH_3-N (mg/L)	NO_3-N (mg/L)	TKN (mg/L)	SRP (mg/L)	TP (mg/L)	TSS (mg/L)	TDS (mg/L)
Primrose Brook	0.03	0.16	0.17	0.010	0.08	4	162
Loantaka Brook	0.07	5.50	0.79	0.290	0.33	3	700
Passaic River - In	0.03	0.09	0.17	0.007	0.04	3	174
Passaic River - Out	0.05	0.19	0.26	0.022	0.09	11	264
Black Brook	0.03	0.32	0.36	0.050	0.09	42	350
Great Brook	0.05	0.20	0.30	0.016	0.04	4	272

Great Swamp Watershed Baseflow Sampling - 11/2/07							
STATION	NH_3-N (mg/L)	NO_3-N (mg/L)	TKN (mg/L)	SRP (mg/L)	TP (mg/L)	TSS (mg/L)	TDS (mg/L)
Primrose Brook	0.02	0.41	0.21	0.015	0.08	ND <3	188
Loantaka Brook	0.05	1.40	0.89	0.076	0.11	26	608
Passaic River - In	0.04	0.71	0.23	0.014	0.03	ND <3	151
Passaic River - Out	0.04	0.19	1.10	0.033	0.08	ND <3	183
Black Brook	0.02	0.41	0.36	0.037	0.06	ND <3	349
Great Brook	0.08	0.65	0.36	0.033	0.06	4	206

Great Swamp Watershed Baseflow Sampling - 12/20/07							
STATION	NH_3-N (mg/L)	NO_3-N (mg/L)	TKN (mg/L)	SRP (mg/L)	TP (mg/L)	TSS (mg/L)	TDS (mg/L)
Primrose Brook	0.05	0.71	0.16	0.002	0.01	ND <3	258
Loantaka Brook	0.19	1.10	0.59	0.019	0.07	12	622
Passaic River - In	0.05	0.82	0.18	0.003	ND <0.01	8	384
Passaic River - Out	0.06	0.51	0.29	0.009	0.04	4	327
Black Brook	0.02	0.97	0.39	0.018	0.04	ND <3	755
Great Brook	0.05	0.80	0.35	0.015	0.03	6	459

Great Swamp Watershed Baseflow Sampling - 1/24/08							
STATION	NH_3-N (mg/L)	NO_3-N (mg/L)	TKN (mg/L)	SRP (mg/L)	TP (mg/L)	TSS (mg/L)	TDS (mg/L)
Primrose Brook	0.14	0.92	0.28	0.003	ND <0.01	3	178
Loantaka Brook	0.19	5.90	0.43	0.021	0.06	3	572
Passaic River - In	0.12	1.40	0.22	0.003	0.01	ND <3	235
Passaic River - Out	0.36	0.80	0.43	0.007	0.04	6	288
Black Brook	0.16	1.00	0.49	0.005	0.03	ND <3	632
Great Brook	0.07	1.50	0.22	0.010	0.02	20	342

Great Swamp Watershed Baseflow Sampling - 2/26/08							
STATION	NH_3-N (mg/L)	NO_3-N (mg/L)	TKN (mg/L)	SRP (mg/L)	TP (mg/L)	TSS (mg/L)	TDS (mg/L)
Primrose Brook	0.01	0.73	0.09	0.004	0.02	3	181
Loantaka Brook	0.02	2.20	0.18	0.013	0.06	8	483
Passaic River - In	0.01	1.10	0.16	0.003	0.04	6	231
Passaic River - Out	0.01	0.63	0.10	0.006	0.04	15	240
Black Brook	0.14	0.97	0.46	0.004	0.08	25	1037
Great Brook	0.01	1.10	0.16	0.006	0.03	8	433

Great Swamp Watershed Baseflow Sampling - 3/26/08							
STATION	NH_3-N (mg/L)	NO_3-N (mg/L)	TKN (mg/L)	SRP (mg/L)	TP (mg/L)	TSS (mg/L)	TDS (mg/L)
Primrose Brook	0.04	0.72	0.10	ND <0.003	0.01	3	150
Loantaka Brook	0.07	2.70	0.63	0.005	0.05	3	417
Passaic River - In	0.04	0.90	0.22	ND <0.003	0.03	ND <3	158
Passaic River - Out	0.03	0.49	0.39	0.008	0.03	4	174
Black Brook	0.06	0.59	0.35	ND <0.003	0.03	3	424
Great Brook	0.06	0.74	0.37	0.004	0.02	5	229

Great Swamp Watershed Baseflow Sampling - 4/17/08							
STATION	NH_3-N (mg/L)	NO_3-N (mg/L)	TKN (mg/L)	SRP (mg/L)	TP (mg/L)	TSS (mg/L)	TDS (mg/L)
Primrose Brook	0.04	0.23	0.25	0.009	0.02	ND <3	146
Loantaka Brook	0.04	1.80	0.85	0.020	0.09	9	518
Passaic River - In	0.02	0.36	0.42	0.006	0.05	ND <3	164
Passaic River - Out	0.03	1.90	0.27	0.020	0.05	9	214
Black Brook	0.02	2.50	0.42	0.019	0.03	ND <3	500
Great Brook	0.04	0.26	0.27	0.012	0.07	3	264

Great Swamp Watershed Baseflow Sampling - 5/7/08							
STATION	NH_3-N (mg/L)	NO_3-N (mg/L)	TKN (mg/L)	SRP (mg/L)	TP (mg/L)	TSS (mg/L)	TDS (mg/L)
Primrose Brook	ND <0.01	0.80	0.24	0.005	0.02	6	164
Loantaka Brook	0.09	5.70	0.73	0.052	0.11	9	552
Passaic River - In	ND <0.01	0.68	0.44	0.004	0.03	3	114
Passaic River - Out	0.02	0.35	0.57	0.029	0.08	11	244
Black Brook	0.02	0.44	0.33	0.019	0.05	5	192
Great Brook	0.02	1.00	0.49	0.011	0.04	13	163

Great Swamp Watershed Baseflow Sampling - 6/25/08							
STATION	NH_3-N (mg/L)	NO_3-N (mg/L)	TKN (mg/L)	SRP (mg/L)	TP (mg/L)	TSS (mg/L)	TDS (mg/L)
Primrose Brook	ND <0.01	0.55	0.27	0.016	0.04	4	169
Loantaka Brook	0.03	5.3	0.52	0.22	0.25	7	629
Passaic River - In	ND <0.01	0.42	0.27	0.012	0.05	4	180
Passaic River - Out	0.02	0.25	0.31	0.041	0.14	18	214
Black Brook	0.03	0.37	0.47	0.074	0.14	18	351
Great Brook	0.02	0.74	0.52	0.031	0.07	8	225

Great Swamp Watershed Baseflow Sampling - 7/21/08							
STATION	NH_3-N (mg/L)	NO_3-N (mg/L)	TKN (mg/L)	SRP (mg/L)	TP (mg/L)	TSS (mg/L)	TDS (mg/L)
Primrose Brook	0.04	0.47	0.16	0.020	0.11	3	168
Loantaka Brook	0.08	7.00	0.71	0.236	0.32	35	634
Passaic River - In	0.04	0.09	0.16	0.017	0.13	3	184
Passaic River - Out	0.08	0.17	0.42	0.053	0.24	14	272
Black Brook	0.07	0.53	0.47	0.090	0.23	32	364
Great Brook	0.06	0.27	0.37	0.028	0.14	3	271

Great Swamp Watershed Baseflow Sampling - 8/21/08							
STATION	NH_3-N (mg/L)	NO_3-N (mg/L)	TKN (mg/L)	SRP (mg/L)	TP (mg/L)	TSS (mg/L)	TDS (mg/L)
Primrose Brook	0.01	0.51	0.24	0.011	0.03	ND <3	163
Loantaka Brook	0.07	9.70	1.40	0.482	0.49	4	752
Passaic River - In	0.07	0.07	0.53	0.016	0.06	3	164
Passaic River - Out	0.05	0.17	0.34	0.027	0.12	13	242
Black Brook	0.04	0.95	0.47	0.029	0.07	11	250
Great Brook	0.04	0.57	1.20	0.016	0.05	3	571

Appendix II
Water Quality Data – Stormflow

Great Swamp Watershed Stormflow Sampling - 4/07							
STATION	NH_3-N (mg/L)	NO_3-N (mg/L)	TKN (mg/L)	SRP (mg/L)	TP (mg/L)	TSS (mg/L)	TDS (mg/L)
Primrose Brook	0.10	0.93	1.30	0.012	0.47	432	94
Loantaka Brook	0.30	4.60	0.47	0.010	3.20	1480	324
Passaic River - In	0.22	1.10	1.90	0.014	1.10	520	163
Passaic River - Out	0.07	0.35	0.38	0.011	0.21	75	197
Black Brook	0.10	0.56	0.80	0.032	0.39	369	187
Great Brook	0.09	0.89	0.23	0.014	0.23	106	232

Great Swamp Watershed Stormflow Sampling - 6/4/07							
STATION	NH_3-N (mg/L)	NO_3-N (mg/L)	TKN (mg/L)	SRP (mg/L)	TP (mg/L)	TSS (mg/L)	TDS (mg/L)
Primrose Brook	0.02	0.58	0.57	0.059	0.06	6	141
Loantaka Brook	0.06	2.80	2.50	0.051	0.47	292	453
Passaic River - In	0.62	0.82	2.50	0.170	0.45	100	190
Passaic River - Out	0.02	0.55	0.78	0.016	0.13	14	195
Black Brook	0.43	0.53	2.30	0.100	0.65	290	202
Great Brook	0.12	3.40	2.30	0.370	0.67	93	313

Great Swamp Watershed Stormflow Sampling - 8/10/07							
STATION	NH_3-N (mg/L)	NO_3-N (mg/L)	TKN (mg/L)	SRP (mg/L)	TP (mg/L)	TSS (mg/L)	TDS (mg/L)
Primrose Brook	0.05	0.30	0.74	0.017	0.12	35	91
Loantaka Brook	0.31	0.51	0.74	0.076	0.20	69	97
Passaic River - In	0.09	0.30	0.92	0.026	0.12	24	101
Passaic River - Out	0.09	0.38	0.92	0.050	0.15	22	118
Black Brook	0.31	0.36	1.40	0.130	0.25	46	110
Great Brook	0.17	0.43	0.74	0.053	0.21	46	125

Great Swamp Watershed Stormflow Sampling - 10/9/07							
STATION	NH_3-N (mg/L)	NO_3-N (mg/L)	TKN (mg/L)	SRP (mg/L)	TP (mg/L)	TSS (mg/L)	TDS (mg/L)
Primrose Brook	0.09	0.26	0.4	0.014	0.03	ND <3	153
Loantaka Brook	0.27	0.58	2	0.15	0.37	9	609
Passaic River - In	0.29	0.45	1.8	0.008	0.24	9	193
Passaic River - Out	0.06	0.24	0.44	0.033	0.12	11	265
Black Brook	0.83	0.44	4.55	0.12	1.2	683	281
Great Brook	0.21	0.41	2	0.01	0.1	45	308

Great Swamp Watershed Stormflow Sampling - 12/10/07							
STATION	NH_3-N (mg/L)	NO_3-N (mg/L)	TKN (mg/L)	SRP (mg/L)	TP (mg/L)	TSS (mg/L)	TDS (mg/L)
Primrose Brook	0.02	0.55	0.44	ND <0.002	0.02	3	273
Loantaka Brook	0.19	1.90	1.10	0.033	0.08	6	530
Passaic River - In	0.05	1.10	0.52	0.002	0.02	ND <3	357
Passaic River - Out	0.17	0.62	0.99	0.011	0.05	6	248
Black Brook	0.06	0.80	0.67	0.077	0.13	7	552
Great Brook	0.12	0.95	0.72	0.018	0.06	3	598

Great Swamp Watershed Stormflow Sampling - 2/13/08

STATION	NH_3-N (mg/L)	NO_3-N (mg/L)	TKN (mg/L)	SRP (mg/L)	TP (mg/L)	TSS (mg/L)	TDS (mg/L)
Primrose Brook	0.02	0.49	0.32	0.006	0.14	104	173
Loantaka Brook	0.08	1.10	0.42	0.036	0.16	51	412
Passaic River - In	0.03	0.89	0.27	0.007	0.04	12	509
Passaic River - Out	0.04	0.63	0.46	0.015	0.06	24	322
Black Brook	0.05	0.55	0.27	0.031	0.21	75	307
Great Brook	0.04	1.10	0.42	0.017	0.11	41	434

Great Swamp Watershed Stormflow Sampling - 5/9/08

STATION	NH_3-N (mg/L)	NO_3-N (mg/L)	TKN (mg/L)	SRP (mg/L)	TP (mg/L)	TSS (mg/L)	TDS (mg/L)
Primrose Brook	0.04	0.96	0.08	0.013	0.06	18	154
Loantaka Brook	0.21	8.60	1.60	0.049	0.39	311	546
Passaic River - In	0.44	1.50	1.80	0.053	0.42	302	198
Passaic River - Out	0.14	0.54	0.71	0.050	0.10	14	215
Black Brook	0.21	0.68	1.10	0.090	0.34	103	167
Great Brook	0.14	0.59	1.10	0.120	0.23	43	155

Great Swamp Watershed Stormflow Sampling - 7/24/08

STATION	NH_3-N (mg/L)	NO_3-N (mg/L)	TKN (mg/L)	SRP (mg/L)	TP (mg/L)	TSS (mg/L)	TDS (mg/L)
Primrose Brook	0.13	1.20	0.73	0.017	0.46	393	108
Loantaka Brook	0.17	4.90	0.55	0.098	0.55	365	422
Passaic River - In	0.17	0.68	0.55	0.030	0.25	91	174
Passaic River - Out	0.14	0.49	0.51	0.039	0.25	25	179
Black Brook	0.11	0.79	0.68	0.152	0.17	77	202
Great Brook	0.19	0.66	0.55	0.076	0.40	99	221

Appendix III
***In-situ* Data**

Great Swamp Watershed *In-situ* Sampling - 9/8/06					
Station	Temperature (°C)	Specific Conductance (mS/cm)	Dissolved Oxygen (mg/L)	pH (units)	Staff Height (ft)
Primrose Brook	17.68	0.251	10.44	6.70	NA
Passaic - In	18.97	0.242	5.22	7.20	NA
Passaic - Out	19.10	0.266	4.70	6.08	NA
Black Brook	19.93	0.643	6.76	6.80	NA
Loantaka Brook	19.54	0.832	8.16	6.87	NA
Great Brook	19.05	0.367	8.55	6.78	NA

Great Swamp Watershed *In-situ* Sampling - 10/10/06					
Station	Temperature (°C)	Specific Conductance (mS/cm)	Dissolved Oxygen (mg/L)	pH (units)	Staff Height (ft)
Primrose Brook	14.10	0.258	9.40	7.60	NA
Passaic - In	15.60	0.251	8.54	7.39	NA
Passaic - Out	15.20	0.299	6.05	7.14	NA
Black Brook	15.00	0.718	7.59	7.46	NA
Loantaka Brook	15.40	0.930	8.22	7.66	NA
Great Brook	14.60	0.366	7.98	7.46	NA

Great Swamp Watershed *In-situ* Sampling - 11/7/06					
Station	Temperature (°C)	Specific Conductance (mS/cm)	Dissolved Oxygen (mg/L)	pH (units)	Staff Height (ft)
Primrose Brook	7.95	0.230	11.60	7.85	NA
Passaic - In	6.68	0.263	6.55	7.38	NA
Passaic - Out	7.20	0.271	10.02	7.91	NA
Black Brook	8.55	0.804	7.55	7.64	NA
Loantaka Brook	8.54	0.746	8.80	7.70	NA
Great Brook	7.57	0.368	9.50	7.46	NA

Great Swamp Watershed *In-situ* Sampling - 12/12/06					
Station	Temperature (°C)	Specific Conductance (mS/cm)	Dissolved Oxygen (mg/L)	pH (units)	Staff Height (ft)
Primrose Brook	5.74	0.214	12.51	7.99	NA
Passaic - In	4.20	0.241	10.96	7.52	NA
Passaic - Out	2.79	0.297	10.47	7.40	NA
Black Brook	6.30	0.971	8.89	7.65	NA
Loantaka Brook	6.02	0.827	10.96	7.77	NA
Great Brook	4.47	0.407	11.70	7.65	NA

Great Swamp Watershed *In-situ* Sampling - 1/25/07					
Station	Temperature (°C)	Specific Conductance (mS/cm)	Dissolved Oxygen (mg/L)	pH (units)	Staff Height (ft)
Primrose Brook	2.53	0.210	12.29	8.03	NA
Passaic - In	1.93	0.245	12.11	7.94	NA
Passaic - Out	0.52	0.289	10.80	7.84	NA
Black Brook	1.35	0.587	12.82	8.12	NA
Loantaka Brook	2.24	0.795	13.36	8.17	NA
Great Brook	3.20	0.424	13.63	8.31	NA

Great Swamp Watershed *In-situ* Sampling - 2/20/07					
Station	Temperature (°C)	Specific Conductance (mS/cm)	Dissolved Oxygen (mg/L)	pH (units)	Staff Height (ft)
Primrose Brook	0.05	0.242	14.37	7.90	NA
Passaic - In	0.04	0.313	13.59	7.85	NA
Passaic - Out	0.06	0.488	12.25	7.70	NA
Black Brook		Stream Frozen - No Readings			NA
Loantaka Brook		Stream Frozen - No Readings			NA
Great Brook	0.26	0.745	15.82	8.33	NA

Great Swamp Watershed *In-situ* Sampling - 3/14/07					
Station	Temperature (°C)	Specific Conductance (mS/cm)	Dissolved Oxygen (mg/L)	pH (units)	Staff Height (ft)
Primrose Brook	5.55	0.252	11.93	6.86	NA
Passaic - In	5.66	0.316	10.69	6.50	NA
Passaic - Out	5.34	0.359	10.56	6.61	NA
Black Brook	5.03	1.182	12.13	7.04	NA
Loantaka Brook	6.44	0.832	14.28	8.05	NA
Great Brook	6.47	0.649	13.27	7.89	NA

Great Swamp Watershed *In-situ* Sampling - 4/11/07					
Station	Temperature (°C)	Specific Conductance (mS/cm)	Dissolved Oxygen (mg/L)	pH (units)	Staff Height (ft)
Primrose Brook	7.45	0.233	12.46	8.00	NA
Passaic - In	8.89	0.325	11.45	7.95	NA
Passaic - Out	8.80	0.337	10.38	7.89	3.12
Black Brook	7.84	1.025	12.06	8.77	1.35
Loantaka Brook	9.17	0.811	17.17	9.04	1.60
Great Brook	10.31	0.468	12.35	7.94	1.00

Great Swamp Watershed *In-situ* Sampling - 5/7/07					
Station	Temperature (°C)	Specific Conductance (mS/cm)	Dissolved Oxygen (mg/L)	pH (units)	Staff Height (ft)
Primrose Brook	11.38	0.208	12.05	7.69	NA
Passaic - In	13.30	0.239	11.30	7.49	NA
Passaic - Out	14.55	0.273	7.26	7.21	5.26
Black Brook	12.28	0.661	12.11	8.00	1.30
Loantaka Brook	13.23	0.724	13.23	8.47	1.74
Great Brook	14.91	0.389	12.03	7.92	1.50

Great Swamp Watershed *In-situ* Sampling - 6/8/07					
Station	Temperature (°C)	Specific Conductance (mS/cm)	Dissolved Oxygen (mg/L)	pH (units)	Staff Height (ft)
Primrose Brook	17.52	0.236	10.29	6.85	0.40
Passaic - In	19.88	0.248	7.25	6.69	NA
Passaic - Out	20.39	0.320	6.34	6.70	5.40
Black Brook	19.73	0.663	6.51	6.94	1.20
Loantaka Brook	18.89	1.027	8.01	7.42	0.60
Great Brook	19.37	0.436	7.57	6.79	0.50

Great Swamp Watershed *In-situ* Sampling - 7/26/07					
Station	Temperature (°C)	Specific Conductance (mS/cm)	Dissolved Oxygen (mg/L)	pH (units)	Staff Height (ft)
Primrose Brook	21.23	0.254	8.39	7.60	1.15
Passaic - In	25.49	0.227	6.91	7.45	1.25
Passaic - Out	22.72	0.279	4.53	6.97	5.19
Black Brook	22.61	0.562	5.45	7.45	1.00
Loantaka Brook	22.66	0.883	7.10	7.62	1.50
Great Brook	22.55	0.334	6.70	7.57	0.80

Great Swamp Watershed *In-situ* Sampling - 8/29/07					
Station	Temperature (°C)	Specific Conductance (mS/cm)	Dissolved Oxygen (mg/L)	pH (units)	Staff Height (ft)
Primrose Brook	19.94	0.289	9.45	7.23	1.16
Passaic - In	22.79	0.299	7.13	7.09	1.24
Passaic - Out	21.65	0.306	4.65	6.87	4.87
Black Brook	21.20	0.646	7.16	7.41	0.44
Loantaka Brook	20.87	1.083	8.15	7.50	1.49
Great Brook	20.74	0.434	7.92	7.15	0.65

Great Swamp Watershed *In-situ* Sampling - 9/20/07					
Station	Temperature (°C)	Specific Conductance (mS/cm)	Dissolved Oxygen (mg/L)	pH (units)	Staff Height (ft)
Primrose Brook	14.76	0.272	9.59	7.51	1.08
Passaic - In	17.66	0.294	7.98	7.47	1.10
Passaic - Out	15.02	0.404	7.17	7.39	NA
Black Brook	16.94	0.617	6.25	6.81	0.95
Loantaka Brook	15.84	1.169	9.12	7.53	1.40
Great Brook	16.25	0.450	8.05	6.74	1.75

Great Swamp Watershed *In-situ* Sampling - 10/9/07					
Station	Temperature (°C)	Specific Conductance (mS/cm)	Dissolved Oxygen (mg/L)	pH (units)	Staff Height (ft)
Primrose Brook	20.39	0.277	7.74	6.75	1.07
Passaic - In	22.46	0.305	6.63	6.64	1.07
Passaic - Out	21.31	0.461	4.35	6.66	NA
Black Brook	20.57	0.614	3.25	6.97	1.05
Loantaka Brook	21.06	1.260	5.72	7.46	1.49
Great Brook	20.93	0.515	6.20	7.14	0.70

Great Swamp Watershed *In-situ* Sampling - 11/2/07					
Station	Temperature (°C)	Specific Conductance (mS/cm)	Dissolved Oxygen (mg/L)	pH (units)	Staff Height (ft)
Primrose Brook	8.57	0.297	10.42	6.66	1.17
Passaic - In	9.69	0.254	8.78	6.50	1.20
Passaic - Out	9.30	0.280	8.10	6.20	4.25
Black Brook	9.74	0.594	8.68	7.08	1.07
Loantaka Brook	9.60	1.050	9.23	6.95	1.59
Great Brook	8.90	0.353	10.13	6.59	0.85

Great Swamp Watershed *In-situ* Sampling - 12/20/07					
Station	Temperature (°C)	Specific Conductance (mS/cm)	Dissolved Oxygen (mg/L)	pH (units)	Staff Height (ft)
Primrose Brook	2.39	0.457	12.20	7.69	1.25
Passaic - In	1.48	0.727	12.10	7.77	1.30
Passaic - Out	0.26	0.590	12.00	7.47	5.30
Black Brook	2.95	1.331	12.60	7.51	1.35
Loantaka Brook	3.73	1.151	12.80	7.63	1.90
Great Brook	2.63	0.886	12.70	7.70	1.05

Great Swamp Watershed *In-situ* Sampling - 1/24/08					
Station	Temperature (°C)	Specific Conductance (mS/cm)	Dissolved Oxygen (mg/L)	pH (units)	Staff Height (ft)
Primrose Brook	0.12	0.270	15.10	7.76	1.35
Passaic - In	0.54	0.370	14.20	8.10	1.40
Passaic - Out	0.01	0.438	11.30	7.73	5.20
Black Brook	0.75	1.117	12.20	7.50	1.25
Loantaka Brook	0.14	0.946	14.90	7.35	1.90
Great Brook	1.07	0.551	15.00	7.47	0.90

Great Swamp Watershed *In-situ* Sampling - 2/26/08					
Station	Temperature (°C)	Specific Conductance (mS/cm)	Dissolved Oxygen (mg/L)	pH (units)	Staff Height (ft)
Primrose Brook	3.50	0.285	13.25	6.75	1.49
Passaic - In	2.59	0.389	12.73	7.59	1.70
Passaic - Out	2.11	0.418	13.70	7.33	NA
Black Brook	3.37	1.930	11.21	7.37	1.32
Loantaka Brook	3.51	0.878	13.47	7.42	2.05
Great Brook	4.13	0.778	12.93	7.43	1.23

Great Swamp Watershed *In-situ* Sampling - 3/26/08					
Station	Temperature (°C)	Specific Conductance (mS/cm)	Dissolved Oxygen (mg/L)	pH (units)	Staff Height (ft)
Primrose Brook	6.65	0.219	12.78	7.66	1.54
Passaic - In	6.83	0.262	12.02	7.66	1.75
Passaic - Out	7.73	0.290	10.20	7.50	NA
Black Brook	6.19	1.790	10.91	7.59	1.28
Loantaka Brook	8.48	0.730	17.75	8.60	2.09
Great Brook	9.46	0.395	15.60	8.44	1.28

Great Swamp Watershed *In-situ* Sampling - 4/17/08					
Station	Temperature (°C)	Specific Conductance (mS/cm)	Dissolved Oxygen (mg/L)	pH (units)	Staff Height (ft)
Primrose Brook	9.33	0.232	13.62	7.84	1.36
Passaic - In	12.30	0.272	10.46	7.74	1.40
Passaic - Out	14.46	0.342	8.78	8.01	5.10
Black Brook	12.44	0.878	13.94	8.26	1.20
Loantaka Brook	15.89	0.895	20.13	9.12	1.82
Great Brook	14.92	0.460	13.98	8.69	1.10

Great Swamp Watershed *In-situ* Sampling - 5/7/08					
Station	Temperature (°C)	Specific Conductance (mS/cm)	Dissolved Oxygen (mg/L)	pH (units)	Staff Height (ft)
Primrose Brook	14.67	0.245	10.23	7.60	1.25
Passaic - In	17.39	0.278	9.73	7.65	1.30
Passaic - Out	18.06	0.349	6.22	7.60	4.95
Black Brook	13.19	1.182	6.30	7.30	1.15
Loantaka Brook	18.11	0.960	7.14	7.46	1.80
Great Brook	17.42	0.487	8.00	7.50	1.15

Great Swamp Watershed *In-situ* Sampling - 6/25/08					
Station	Temperature (°C)	Specific Conductance (mS/cm)	Dissolved Oxygen (mg/L)	pH (units)	Staff Height (ft)
Primrose Brook	17.47	0.253	9.20	7.37	0.90
Passaic - In	20.37	0.259	4.45	7.49	1.20
Passaic - Out	21.51	0.353	6.40	7.37	4.60
Black Brook	18.70	0.638	4.33	7.16	0.90
Loantaka Brook	19.60	1.043	7.80	7.57	1.40
Great Brook	19.54	0.382	7.02	7.55	0.85

Great Swamp Watershed *In-situ* Sampling - 7/21/08					
Station	Temperature (°C)	Specific Conductance (mS/cm)	Dissolved Oxygen (mg/L)	pH (units)	Staff Height (ft)
Primrose Brook	24.85	0.278	8.65	7.98	1.00
Passaic - In	26.93	0.282	6.44	7.27	1.00
Passaic - Out	27.04	0.427	4.66	7.18	NA
Black Brook	24.89	0.646	4.82	7.36	0.80
Loantaka Brook	25.42	1.281	7.51	7.90	1.30
Great Brook	25.61	0.466	7.01	6.88	0.75

Great Swamp Watershed *In-situ* Sampling - 8/21/08					
Station	Temperature (°C)	Specific Conductance (mS/cm)	Dissolved Oxygen (mg/L)	pH (units)	Staff Height (ft)
Primrose Brook	18.02	0.254	9.58	8.04	NA
Passaic - In	20.82	0.270	7.10	7.34	NA
Passaic - Out	21.33	0.414	5.00	7.40	NA
Black Brook	19.70	0.916	3.57	7.56	NA
Loantaka Brook	19.73	1.344	8.86	7.93	NA
Great Brook	19.76	0.461	8.40	7.68	NA

Attachment A

Great Swamp Tributaries Mapping Figures

Attachment B

Details for Stormwater Mitigation Projects

Attachment C

Concept Plan Parson's Village Biodetention Basin

Attachment D

Concept Plans for the Created Wetlands