Great Swamp Watershed

Water Quality Monitoring Report

June 2002

Ten Towns Great Swamp Watershed Management Committee

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Prepared For:

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Executive Summary

In 1998 the Great Swamp Ten Towns Watershed Management Committee initiated a comprehensive monitoring program designed to identify baseline environmental conditions of the Great Swamp and its watershed, document long-term trends in the conditions of the Great Swamp and its watershed, and ensure that the environmental goals and objectives of the watershed management plan are being met. The monitoring program included both hydrological and chemical monitoring of the following five major tributary streams flowing into the Great Swamp: Black Brook, Loantaka Brook, Great Brook, Primrose Brook, and the Passaic River. United States Geologic Survey (USGS) stream flow data were obtained and analyzed for an outlet stream station on the Passaic River below the Great Swamp. Chemical monitoring was also conducted at this outlet station.

Hydrologic data gathered during the study were used to calculate hydrologic loadings to the Great Swamp. Baseflow (dry weather) and stormflow (wet weather) samples were collected and analyzed for nutrients and suspended solids. The sampled concentrations were used to assess water quality of the tributary streams relative to New Jersey Water Quality Standards and EPA Reference Criteria. The sampled concentrations were also used in conjunction with the calculated hydrologic totals to quantify loads of nutrients and suspended solids entering and leaving the Great Swamp.

Water quality varied widely from stream to stream throughout the watershed and also within a single stream depending on the flow conditions. Both Primrose Brook and the Passaic River have good baseflow water quality and represent baseflow reference conditions for the watershed. The Passaic River also has relatively good water quality during stormflow conditions and is considered to be the watershed reference stream for stormflow conditions. Primrose Brook has elevated stormflow concentrations of particulate nutrients and suspended solids, which are somewhat unexpected for a relatively undeveloped and otherwise good quality stream. Great Brook is slightly impaired during baseflow and stormflow compared to Passaic River, Primrose Brook, New Jersey Water Quality Standards, and EPA reference criteria. Loantaka Brook is impaired during both baseflow and stormflow conditions and has the highest nutrient and suspended solids concentrations measured in the watershed. Loantaka Brook contributes the greatest loads of soluble inorganic nutrients, total nutrients, and total suspended solids to the Great Swamp. Black Brook is somewhat impaired during both baseflow and stormflow, although the nutrient and suspended concentrations are not as high as those in Loantaka Brook.

Water quality standards for both dry weather and wet weather conditions were developed for the streams in the Great Swamp watershed (Water Quality Standards for the Great Swamp Watershed, F.X. Browne, Inc., June 2002). The median dry weather and wet weather water quality data for each stream were compared to the water quality criteria, and a summary is shown in Table A. As shown in this table, Black Brook, Loantaka Brook, and Great Brook do not meet all of the water quality standards for baseflow and stormflow conditions. Primrose Brook and the Passaic River meet all of the baseflow water quality standards and most of the stormflow standards. These results indicate that the Great Swamp Watershed Management Plan must continue to be implemented in order to improve and/or maintain existing water quality in the Great Swamp watershed.

Table A: Comparison of Measured Stream Water Quality and Recommended Standards

Stream	Meets Baseflow Standard*						Meets Stormflow Standard*					
	TP	**DRP**	**NO_3**	**TKN**	**TN**	**TSS**	**TP**	**DRP**	**NO_3**	**TKN**	**TN**	**TSS**
Black Brook	No	No	Yes	No	Yes	Yes	No	No	Yes	No	No	No
Loantaka Brook	No	No	No	No	No	No	No	No	No	No	No	No
Great Brook	No	No	Yes	No	Yes	No	No	No	Yes	Yes	Yes	No**
Primrose Brook	Yes	Yes	Yes	Yes	Yes	Yes	No	No**	Yes	Yes	Yes	No
Passaic River	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes

* Based on median water quality data collected from 1999 to present
**Median value exceeds standard by less than 10%

TP = Total Phosphorus
DRP = Dissolved Reactive Phosphorus
NO_3 = Nitrate
TKN = Total Kjeldahl Nitrogen
TN = Total Nitrogen
TSS = Total Suspended Solids

1.0 Background

The goals and objectives of the Great Swamp Watershed Management Plan were developed based on existing, water quality and biological data for the Great Swamp and its watershed. Most of the chemical data consisted of dry weather data that did not accurately reflect the effects of stormwater runoff and nonpoint source pollution. As the plan was formulated and developed, it was decided that the existing conditions within the watershed must be accurately assessed in order to further develop and implement effective management strategies. To meet the need for additional water quality data, the Great Swamp Water Quality Monitoring Program was initiated in 1998 and water quality sampling began in 1999. The Great Swamp Water Quality Monitoring Program is a comprehensive monitoring program designed to identify baseline environmental conditions for the Great Swamp and its watershed, document long-term trends in the conditions of the Great Swamp and its watershed, and ensure that the environmental goals and objectives of the management plan are being met. A glossary of many of the technical terms used in this report can be found in Appendix A.

2.0 Water Quantity Monitoring

2.1 Flow Monitoring

The hydrologic monitoring phase of the program quantifies peak flow rates, stormwater runoff volume, and the annual flow of water into the swamp. Stream monitoring stations were installed along each of the following five tributaries to the Great Swamp: Black Brook, Loantaka Brook, Great Brook, Primrose Brook, and the Passaic River. Each station is equipped with an automated sampling unit, a submerged probe to record depth, and an in-stream staff gage. Additionally, tipping bucket rain gages that record rainfall totals at fifteen-minute intervals have been installed at the Black Brook and Passaic River stations. All monitoring stations were sited as close to the Great Swamp as possible to account for the total volume of water and total nutrient loads entering the swamp. There is a sixth monitoring station located on the Passaic River at Millington Gorge as it flows out of the Great Swamp where the United States Geological Survey (USGS) operates a gauging station. The USGS data have been incorporated into this study to provide information regarding the flow leaving the Great Swamp. The map in Figure 1 shows the locations of all six flow-monitoring stations.

Although the tributary monitoring stations were located as far downstream as possible to account for all of the water entering the Great Swamp, all of the watersheds, most noticeably that of Black Brook, also include land that drains into the stream below the monitoring station. Table 1 shows the area of each tributary’s sub watershed, the drainage area of each of the monitoring stations, and the impervious surface coverage within each watershed. The impervious surface statistics reflect the composition of the subwatersheds of the stations, not the entire subwatersheds. Delineations of the entire subwatersheds are from NJDEP GIS data and impervious surface cover statistics were developed from NJDEP Land Use/Land Cover data for Morris and Somerset Counties.

Figure 1: Great Swamp Water Quality Monitoring Station Locations

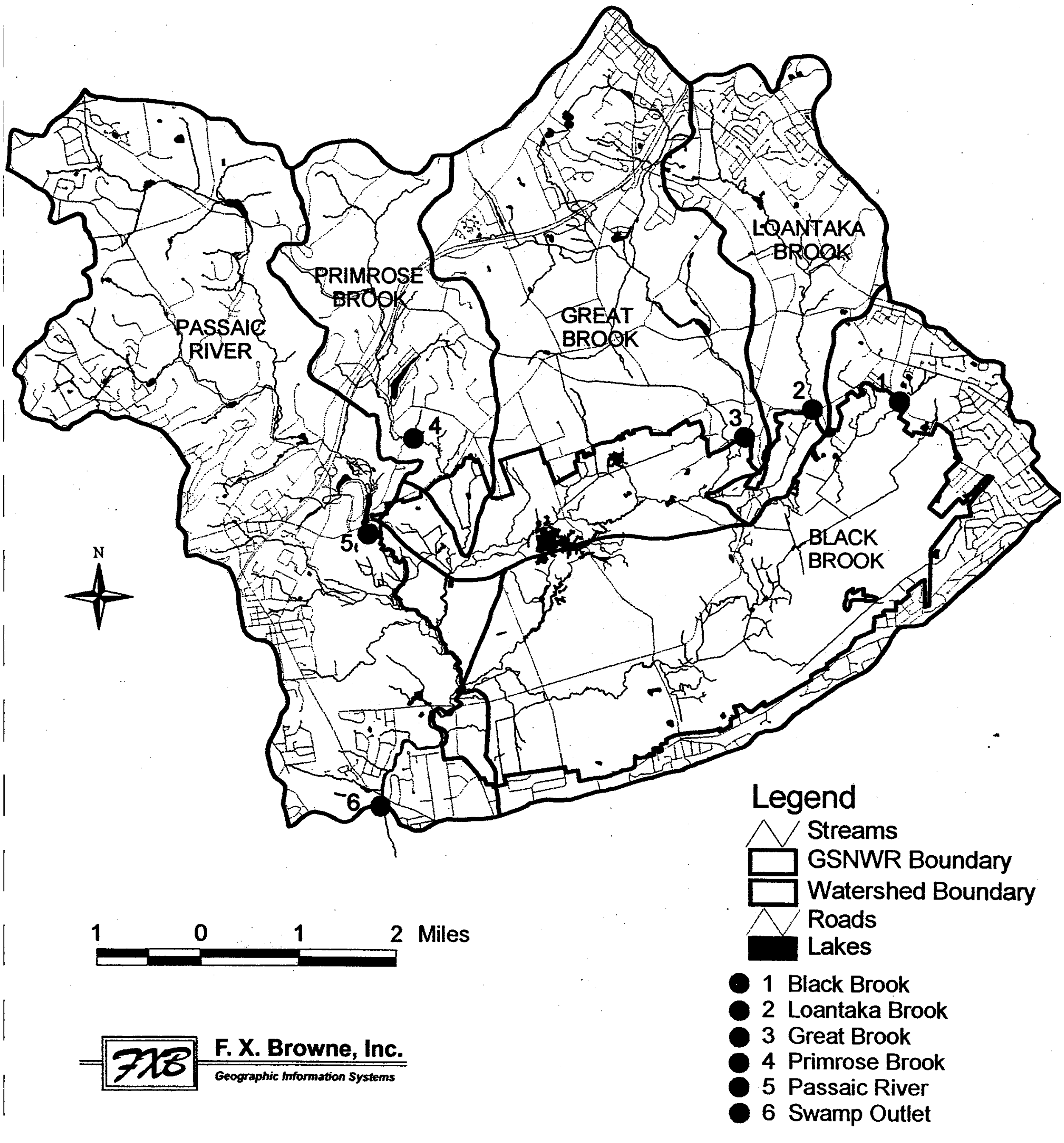

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Table 1: Subwatershed Areas of the Tributaries and their Monitoring Stations

Stream	Entire Subwatershed Areas (acres)	Subwatershed Areas of Monitoring Station (acres)	Impervious Surface Cover (%)
Black Brook	9,090	238	23.2
Loantaka Brook	3,238	2,797	16.5
Great Brook	8,198	5,154	13.5
Primrose Brook	3,354	2,724	5.6
Passaic River	10,813	6,485	8.0
Great Swamp Outlet	34,693	34,693	9.2

The submerged probe at each station was calibrated to the in-stream staff gage and records a relative water surface elevation every fifteen minutes. The recorded data were then used to create storm and monthly hydrographs, which graphically depict the rise and fall of the stream flow. The hydrographs were used to characterize flow as either storm flow or base flow and to develop the water quality sampling programs.

2.2 Development of Rating Curves

By manually collecting velocity data and calculating discharges at various stream gage heights, rating curves have been developed that relate the stream depth to discharge. The developed stage-discharge relationships have been used in conjunction with the recorded stage data to calculate average flow rates for each fifteen-minute interval.

There have been some challenges associated with the development of rating curves at two of the sites. At the monitoring site, Black Brook is small and has low banks. The stream floods its banks even during relatively minor rain events, so it has been difficult to develop a rating curve for the site. Furthermore, at the Black Brook site, the measurements are taken in the stream channel rather than from a bridge, which makes the collection of data from higher flows more difficult. Similar challenges have been encountered at the Primrose Brook site. The measurements at this site are also taken from within the stream channel rather than from a bridge. Additionally, the channel cross section seems to be shifting and changing with time, which affects the rating curve and flows calculated for the stream. Unfortunately, at the time of installation, there was construction planned for both bridges that span the stream, which made these locations ill-suited for the installation of a monitoring station. Now that the repairs and construction are complete, it is recommended that the station be moved upstream to the Baileys Mill Road Bridge. It is hoped that this location will provide a more stable cross-section and a more reliable rating curve.

2.3 Hydrologic Loading

The instantaneous level readings have been used to calculate the hydrologic loading to the Great Swamp. The flow recorded at each fifteen-minute interval is considered to be the flow for the entire fifteen-minute interval and is used to calculate an interval volume. These volumes are then summed to determine monthly baseflow, stormflow, and total flow volumes for each of the tributary streams and for the Passaic River as it leaves the Great Swamp.

Two years of flow data are presented for all five of the tributary streams that were monitored and for the Great Swamp Outlet recorded by USGS. The two hydrologic year intervals were selected to correspond with the two-year period during which most of the sampling occurred. The first hydrologic year lasts from June 1999 to May 2000. Major hydrologic events of that year included a drought in the summer of 1999 followed by the floods of Hurricane Floyd in September 1999, during which approximately eight inches of rain fell during the course of one storm. This amounted to about 20% of the year's total rainfall. During hydrologic year one, the Black Brook rain gage recorded 39.69 inches of rainfall and the Passaic River rain gage recorded 37.33 inches of rainfall. Despite a relatively wet summer during year 2000, the second hydrologic year also posted lower rainfall totals than normal for the region; the Black Brook rain gage recorded 35.83 inches and the Passaic River gage recorded 32.89 inches of rainfall. Table 2 shows the measured flow totals into and out of the swamp for the two calculated hydrologic years.

Table 2: Hydrologic Loading to the Great Swamp June 1999 – May 2001

Stream	Year 1: June 1999 – May 2000			Year 2: June 2000 – May 2001		
	Baseflow (mgal)	Stormflow (mgal)	Total (mgal)	Baseflow (mgal)	Stormflow (mgal)	Total (mgal)
Black Brook	148	36	184	133	58	191
Loantaka Brook	1,651	823	2,474	1,982	968	2,950
Great Brook	1,928	1,273	3,201	1,929	1,479	3,408
Primrose Brook	614	747	1,361	1,281	574	1,855
Passaic River	5,554	2,484	8,038	5,639	2,072	7,711
Tributary Total	9,895	5,363	15,258	10,964	5,151	16,115
Great Swamp Outlet	–	–	16,810	–	–	15,550

These totals show that comparable volumes of water flowed into and out of the swamp during the two hydrologic years. This reflects the comparable rainfall totals during the two years. It is not necessarily expected that the sum of the flows from the tributary streams will be equal to the flow at the outlet due to groundwater contributions, rainfall downstream of the monitoring stations, ungaged tributaries to the Great Swamp, and hydrologic losses due to plant evapotranspiration and evaporation from open water areas. However, these totals show that for the two hydrologic years, the sum of the flows from the monitored tributaries is remarkably close to the total flow from the outlet of the Great Swamp.

The data also provide an indication as to the percentage of flow that results from stormflow versus the percent that results from baseflow. This is an important indicator of the effect of urbanization and impervious surfaces on the hydrologic response of streams. Development and increased impervious surface lead to higher stormwater runoff volumes and reduced baseflow during dry weather due to the reduced capacity for infiltration. Table 3 shows the percentages of baseflow and stormflow for the different streams.

Table 3: Baseflow and Stormflow Percentages for June 1999 – May 2001

Stream	Year 1: June 1999 – May 2000		Year 2: June 2000 – May 2001		Overall	
	Baseflow	Stormflow	Baseflow	Stormflow	Baseflow	Stormflow
Black Brook	80.4%	19.6%	69.6%	30.4%	74.9%	25.1%
Loantaka Brook	66.7%	33.3%	67.2%	32.8%	67.0%	33.0%
Great Brook	60.2%	39.8%	56.6%	43.4%	58.4%	41.6%
Primrose Brook	45.1%	54.9%	69.1%	30.9%	58.9%	41.1%
Passaic River	69.1%	30.9%	73.1%	26.9%	71.1%	28.9%
Tributary Total	64.9%	35.1%	68.0%	32.0%	66.5%	33.5%

The baseflow and stormflow percentages from Black Brook and Primrose Brook are different from what we would expect for the land composition of these streams, particularly for the first year of data collection. As previously mentioned, the development of rating curves has been difficult at these sites and may have affected the results. Secondly, the events of Hurricane Floyd might have influenced the results more severely at these two sites than at the other three. There was a power failure at the Black Brook station near the beginning of the storm and much of the flow data was lost for this event. Since the eight-inch storm represented about one fifth of the year's rainfall, the loss of this data would affect the stormflow percentages for the stream.

The second year percentages for Black Brook and Primrose Brook and the percentages from the other streams are closer to what is expected based on watershed land use. In the second year, the Passaic River had the highest percentage of flow from baseflow. The relatively undeveloped watershed allows for the infiltration of stormwater and greater moderation between baseflow and stormflow. Great Brook is more developed and posts a lower percentage of flow from baseflow. This means that more of the water flows directly into the stream and there is less recharge of groundwater. The hydrologic alterations can lead to increased flooding, reduction of stream flow during baseflow conditions, and a reduction in the filtration and treatment of pollutants associated with stormwater runoff. Finally, the Loantaka Brook baseflow percentage is higher than might be expected based on the level of development in the watershed. However, the wastewater treatment facility that flows into Loantaka Brook provides baseflow to the stream even during time of drought, and increases the proportion of the total flow that occurs during baseflow.

3.0 Water Quality Monitoring

3.1 Nutrient Enrichment

According to the Environmental Protection Agency, "nutrient enrichment frequently ranks as one of the top causes of water resource impairment" (EPA, 2000b). Nutrients are essential for plant growth, but overenrichment can lead to the excess growth of algae and aquatic plants, can alter the composition and species diversity of the aquatic community, and can even lead to human health problems.

When physical conditions such as light and temperature are suitable, the availability of nutrients is most likely the factor that controls the rate of photosynthesis and plant growth. The nutrients that are in shortest supply relative to the demand for those nutrients are considered to be the limiting nutrients. Phosphorus, nitrogen, and potassium are the three primary nutrients that are essential to plant growth. Trace amounts of quite a few other elements are also necessary, however, they are not generally found to be in short enough supply to limit growth in a natural stream (Hynes, 1970). Likewise, there is sufficient potassium present in all but the most mineral-poor waters, and it is generally not considered to be a limiting nutrient in aquatic systems. Phosphorus and nitrogen are the least available elements, are the most likely to control plant growth, and are therefore the two nutrients of greatest concern in freshwaters.

One of these two nutrients usually serves as the limiting nutrient in algal and plant growth. Phosphorus is often found to be the limiting nutrient in lakes, but nitrogen may play a greater role as a limiting nutrient in streams than in lakes (EPA, 2000b). There are some indications that nitrogen is also usually the limiting nutrient in swamps, however, it is likely that the limiting nutrient varies in wetland systems and that nitrogen and phosphorus play different roles during different seasons (Horne and Goldman, 1994). Due to the importance of both nutrients, analysis of both nitrogen and phosphorus has been included in the Great Swamp Water Quality Monitoring Program.

3.1.1 Nitrogen

Nitrogen can exist in organic and inorganic, particulate and soluble forms. Generally, the soluble, inorganic forms are the most available for plant growth. Soluble, inorganic nitrogen can exist as ammonium, nitrite, or nitrate. Although ammonium can be an important source of nitrogen for bacteria, algae, and larger plants, nitrate is the fully oxidized form of nitrogen and is usually the form of inorganic nitrogen that occurs in lakes and streams (Hynes, 1970; Horne and Goldman, 1994; Schwoerbel, 1987).

Particulate and dissolved organic fractions of nitrogen are generally not immediately available for plant growth. However, they can be converted to ammonium by bacteria and fungi and oxidized to form nitrites then nitrates. Biologic availability of organic nitrogen can range widely depending on the complexity of the structure. Urea and proteins are readily available, whereas complex humic acids are essentially biologically inert and become a nitrogen sink when deposited (Horne and Goldman, 1994). In lakes and reservoirs, and potentially in slower moving streams, much of the particulate nitrogen present is live algal biomass. In fast-flowing systems, much of the algal growth is in the benthic region, and is probably not included in a water column sample. In these systems, the particulate component includes more detritus and less live biomass.

Sources of Nitrogen

Nitrogen can enter an aquatic system in a variety of ways and from a variety of sources.

- Rainfall—Precipitation contributes some nitrates to aquatic systems. Acid rain contains nitric acid. Levels of nitric acid in precipitation tend to be higher when there are more automobiles present.
- Overland runoff—Surface runoff can contain nitrogen in various forms including inorganic nitrogen from fertilizers and organic nitrogen from animal waste.
- Groundwater—Nitrate does not adsorb to soil particles as easily as phosphorus or ammonium ions. Nitrate ions move easily through the soil to the groundwater, become inaccessible and unavailable for uptake by terrestrial plants, and can result in high groundwater concentrations of nitrates.
- Nitrogen fixation—Some types of plants can convert gaseous nitrogen into a usable form for plant growth. Blue-green algae are capable of nitrogen fixation in aquatic systems as are some wetlands plants, including alder and *Ceanothus* (e.g. New Jersey Tea).
- Point sources—Wastewater treatment facilities can be sources of nitrates. Generally, effluent undergoes aeration to convert ammonia to nitrate, however, many treatment facilities lack denitrification processes and export nitrogen as nitrates.

Sinks/Losses of Nitrogen

- Deposition—Complex humic acids containing nitrogen become biologically inert and are deposited in the benthic region.
- Denitrification—Denitrification is the bacterial reduction of nitrate to the gaseous form of nitrogen, which occurs in oxygen-depleted bottom sediments. Nitrates are often lost through denitrification in wetlands.

Nitrogen Cycling

In addition to nitrogen sources and sinks, nitrogen is constantly being converted to different forms and is being recycled within the aquatic system. Urea from aquatic animal excretions is quickly broken down to ammonia. Ammonium ions are quite reactive and if they are not oxygenated, they are rapidly taken up by plants and algae. Nitrates are also taken up by plants fairly easily. Particulate organic nitrogen can exist in the water column as phytoplankton, become part of benthic algal growth, and disappear from water column samples. This nitrogen can later appear as particulate organic nitrogen in decomposing plants that become part of the water column.

The continuous cycling of nitrogen leads to variations in the distribution of nitrogen fractions and changes in total nitrogen concentrations depending on season, stream level, and other conditions.

Nitrogen Analysis

There is disagreement within the scientific community over whether to use total nutrient concentrations or soluble nutrient concentrations when establishing nutrient criteria in streams. Much of the total nitrogen concentration is not immediately available to plants and algae, but can be converted to usable forms. Soluble fractions are immediately available, but may be kept at low levels due to biological production (EPA, 2000b). The EPA *Ambient Water Quality Recommendations for Rivers and Streams in Nutrient Ecoregion IX* provides reference concentrations of total Kjeldahl nitrogen (TKN), which is a measure of organic nitrogen plus ammonia; nitrates plus nitrites (NO_3 + NO_2); and total nitrogen – calculated (TN), which calculated from the measured total Kjeldahl nitrogen and nitrates plus nitrites fractions.

In order to quantify the soluble and total nitrogen fractions, the samples collected as part of the Great Swamp Water Quality Monitoring Program have been analyzed for two different nitrogen parameters: nitrates plus nitrites (often referred to simply as nitrates) and total Kjeldahl nitrogen. Although the biologically available, soluble, inorganic component of nitrogen includes both nitrates and ammonia, nitrates were selected for measurement because they have been found to be the most common, biologically available form of nitrogen in stream systems. The detection limit for the nitrates plus nitrites analysis is 0.01 mg/l. Total Kjeldahl nitrogen was selected for analysis because this fraction can be added to the nitrate concentration to yield the total nitrogen concentration in the stream. This is essential for determining the total nitrogen loading to the Great Swamp and for comparison to literature values. The detection limit for the total Kjeldahl nitrogen analysis is 0.1 mg/l. Future water quality monitoring will include analysis for ammonia nitrogen to verify the hypothesis that nitrates are the primary biologically available form of nitrogen in the Great Swamp tributaries.

3.1.2 Phosphorus

Phosphorus can also be found in several forms in freshwater, including soluble inorganic phosphate as orthophosphate and polyphosphates, soluble organic phosphate, and particulate organic phosphate (Schwoerbel, 1987). The biologically available form of phosphorus is soluble, inorganic orthophosphate. Algae have some mechanisms for storing phosphorus and for breaking the bond between phosphates and organic material, however, for the most part, bound phosphorus is considered to be biologically unavailable. Phosphates quickly bind to soil particles and plant roots as they pass through the soil, and consequently, much of the phosphorus in aquatic systems is bound and moves as sediment particles. Some phosphorus is also found in living cells of aquatic organisms.

There is no gaseous form of phosphorus, therefore there is no addition or loss of phosphorus through the atmosphere. However, bound phosphorus can be released from bottom sediments under anoxic conditions and can increase the concentration of biologically available phosphates. Wetland plants can also modify the phosphorus cycle. Rooted aquatic plants take up the majority of their phosphorus from bottom sediments. Phosphorus is then released to the water when the plants die and decay.

Sources of Phosphorus

Phosphorus can enter a water body from several watershed sources.

- Erosion—The inflow of large amounts of total phosphorus into aquatic systems results mainly from the erosion of soil particles from steep slopes and disturbed ground (Horne and Goldman, 1994). Stream channel erosion also adds sediment and consequently bound phosphorus to the water column. Changes in patterns of erosion and sedimentation transport strongly influence the overall phosphorus transport process in aquatic systems.
- Surface runoff—Orthophosphates are applied to agricultural, residential, and commercial land as fertilizers and can reach a stream via overland runoff if they do not bind to soil particles.
- Point sources—Wastewater treatment facilities are sources of total and soluble phosphate.
- Internal loading—Under anoxic conditions, phosphate can be released from bottom sediments.

Sinks of Phosphorus

- Sediment—Although some phosphorus is released from sediment or is taken up by aquatic plants and converted to soluble phosphate, some phosphorus becomes biologically inert once it is bound to sediment.

Phosphorus Cycling

Much of the phosphorus used by aquatic plants is recycled. Decomposition releases phosphates that can then be reused by algae. Phosphorus in sediment is slow to recycle into the water column, but there is some internal loading of phosphorus from sediment. Under anoxic (zero oxygen) conditions, soluble phosphorus is released from sediments in a stream, lake, or wetland. These soluble phosphates then become biologically available for algae. Wetland plants also modify the phosphorus cycle. Rooted aquatic plants take up some soluble phosphorus through their leaves, but generally obtain about 85% of their phosphorus from sediment pore water. When the plants die and decay some of this phosphorus is returned to open water as soluble inorganic phosphate (Horne and Goldman, 1994).

Phosphorus Analysis

As with nitrogen, there is disagreement over whether to use total nutrient concentrations or soluble nutrient concentrations when establishing nutrient criteria in streams. The EPA *Ambient Water Quality Recommendations for Rivers and Streams in Nutrient Ecoregion IX* provides reference concentrations for total phosphorus. Dr. G. Fred Lee, in his critique of the USEPA Nutrient Criteria Technical Guidance Manual, advocates that algal available phosphorus be estimated using soluble orthophosphate plus about 20% of the particulate phosphorus in agricultural and urban runoff (Jones-Lee, 2002). There are other claims that the fertility of turbulent water is best measured in terms of total phosphorus, since bound phosphate is continuously released by bacterial action (Hynes, 1970).

Soluble, inorganic phosphorus and total phosphorus concentrations have both been measured as part of the Great Swamp Water Quality Monitoring Program. The dissolved reactive phosphorus (DRP) component approximates the soluble inorganic phosphorus fraction. In this analysis, the sample is filtered to separate the dissolved component of phosphorus. The analysis of the filtered sample is largely a measure of orthophosphate, but a small fraction of any condensed phosphate that is present in the sample is usually included in the measured concentration. The detection limit for the dissolved reactive phosphorus analysis is 0.001 mg/l. Total phosphorus (TP) measures all of the organic and inorganic, particulate and dissolved phosphorus in the water column. Therefore dissolved reactive phosphorus is a fraction of the total phosphorus. The detection limit for the total phosphorus analysis is 0.002 mg/l.

3.1.3 Suspended Solids

Surface erosion and stream channel erosion add sediments to surface water. Particles from the eroded sediment cause turbidity in the stream water, which can have a detrimental effect on aquatic life. Sediment can clog fish gills and impair respiration, smother spawning areas, attenuate light, and affect plant growth. Turbidity has been shown to reduce both the abundance and diversity of benthic invertebrates. This reduction has been attributed, in part, to the adverse effect on the production of periphyton, which is a food source for aquatic invertebrates (Quinn et al, 1992). Sediment is also important because of its role in transporting phosphates and other compounds, including toxic substances.

The measurement of total suspended solids includes all particulate matter in the water, including algae, detritus, and sediment. The detection limit for the analysis of total suspended solids is 1.0 mg/l.

3.2 New Jersey Surface Water Quality Standards

Despite the extent of the nutrient enrichment problem across the country, most states have little more than vague language that recommends that they maintain natural nutrient levels and avoid nutrient enrichment. The New Jersey Water Quality Standards address nutrients both quantitatively and qualitatively, depending on the situation. The criteria for the higher quality “FW1” waters are qualitative, while “FW2” waters have quantified limits for some nutrients that are based partly on toxicity and partly on ecological health. “FW1” waters are fresh waters “that are to be maintained in their natural state of quality (set aside for posterity) and not subjected to any man-made wastewater discharges or increases in runoff from anthropogenic activities” (NJDEP 1998). However, the DEP does not offer any reference concentrations that represent this natural state. “FW2” is the general surface water classification for most other surface water bodies in the state, and includes all of the Great Swamp tributaries. The numeric criteria include limits for bacteria, metals, toxic substances, sediments, and some nutrients. Within the FW2 classification, a distinction is made between trout production and nontrout waters. The Passaic River upstream of Osborne Pond and Primrose Brook upstream of the Lees Hill Road Bridge are both considered to be trout production waters. Another distinction is made between Category One and Category Two waters. All reaches of stream within the Great Swamp National Wildlife Refuge Boundary are considered to be Category One waters. According to the water quality standards, "Category One waters shall be protected from any measurable changes to the existing water quality. Water quality characteristics that are generally worse than the water quality criteria, except as due to natural conditions, shall be improved to maintain or provide for the designated uses where this can be accomplished without adverse impacts on organisms, communities, or ecosystems of concern" (NJDEP 1998). However, because the natural condition varies from region to region, there are no numeric criteria that quantify exactly what those conditions should be.

The list of New Jersey surface water quality criteria includes limits for total phosphorus, nitrates, and total suspended solids. According to these standards, total phosphorus should not exceed 0.05 mg/l in lakes, ponds, reservoirs, or in tributaries at the point where they enter lakes, ponds, or reservoirs, except where site-specific criteria are developed. Total phosphorus concentrations should not exceed 0.1 mg/l in all other streams, unless it can be proven that total phosphorus is not the limiting nutrient. The limit for total suspended solids is 25.0 mg/l in trout production waters and 40.0 mg/l in nontrout waters. The nitrate limit of 10 mg/l is based on human health standards (NJDEP 1998). There are no listed limits for total Kjeldahl nitrogen or total nitrogen in the New Jersey Water Quality Standards. Additionally, there is no mention as to whether the phosphorus and total suspended solids standards apply to baseflow or stormflow nutrient and sediment concentrations.

3.3 EPA Nutrient Criteria

The EPA is advocating the development of refined numeric criteria to reduce ambiguity and provide distinct interpretations of acceptable and unacceptable nutrient conditions. The EPA is in the preliminary stages of developing ecoregional nutrient criteria for different types of water bodies including lakes and reservoirs, rivers and streams, and wetlands. Ecoregional recommendations for rivers and streams have been made for the two causal variables, total phosphorus and total nitrogen. The EPA intends that the criteria be used to develop nutrient management programs for watersheds that are contributing to water quality problems.

The EPA has divided the country into fourteen aggregate ecoregions. Each of these ecoregions is then divided into numerous smaller level III ecoregions. The Great Swamp Watershed is located in EPA's Aggregate Ecoregion IX - Southeastern Temperate Forested Plains and Hills and in Level III Ecoregion 64 - Northern Piedmont. The Northern Piedmont is a transitional region of low rounded hills, irregular plains, and open valleys in contrast to the low mountains to the north and west and the flat coastal plains of the ecoregion to the east (EPA, 2000a).

Ambient Water Quality Recommendations for Rivers and Streams in Nutrient Ecoregion IX provides reference concentrations for total phosphorus and total nitrogen in the ecoregion. The concentrations were derived using the procedures described in EPA's *Technical Guidance Manual for Developing Nutrient Criteria for Rivers and Streams*. *Ambient Water Quality Recommendations for Rivers and Streams in Nutrient Ecoregion IX* also provides reference concentrations for Level III Ecoregion 64.

The manual describes two methods for establishing reference conditions. One method is to choose the upper 25^{th} percentile (75^{th} percentile) of a reference population of streams. Reference streams are those that are relatively undisturbed and are believed to represent the natural condition of the region. Use of data from reference streams is the preferred way to establish a reference condition. The 75th percentile was chosen by the EPA since it is likely associated with minimum impact conditions, will be protective of designated uses, and provides management flexibility. When reference streams are not identified, the alternative method is to determine the lower 25th percentile of the population of all streams within a region. The 25th percentile of the entire population was chosen by EPA to represent a surrogate for an actual reference population.

The following table contains a summary of the reference conditions for the level III ecoregion in which the Great Swamp Watershed is located. These reference conditions are based on the 25th percentile of all streams rather than on the 75th percentile of reference streams. As shown in Table 4, the reference concentration for total phosphorus is slightly lower than the New Jersey Standard for total phosphorus. The New Jersey Standard for total phosphorus was developed based on the role of phosphorus in the eutrophication of lakes, ponds, and reservoirs. This indicates that total phosphorus in reference streams are low enough that they do not result in eutrophication of water bodies. The reference concentration for nitrate is significantly lower than the New Jersey Standard for nitrate. The New Jersey Standard is based on human health concerns and toxicity rather than on ecological considerations. The Standard reflects a threshold concentration above which water is not considered to be safe for consumption, however, it does not reflect a level that is healthy for the aquatic ecosystem.

Table 4: Reference Nutrient Concentrations for Aggregate Ecoregion IX – Level III Ecoregion 64

Nutrient Parameters	Aggregate Nutrient Level III Ecoregion 64 Reference Conditions
Total Phosphorus (mg/l)	0.04
Total Nitrogen – calculated (mg/l)	1.295
Total Kjeldahl Nitrogen (mg/l)	0.3
Nitrate/Nitrite (mg/l)	0.995

3.4 Great Swamp Watershed Nutrient and Suspended Solids Concentrations

Over a two and a half year period baseflow and stormflow samples were collected at each of the five tributary monitoring stations and at the outlet monitoring station. Baseflow sampling was initiated in June 1999 and ended in May 2001. The baseflow samples were collected as grab samples at all of the monitoring locations. During this period, twelve samples were collected at each of the five tributary stations and eleven baseflow samples were collected at the outlet station. The two hydrologic years included in this report correspond to the period of baseflow sampling. The first stage of stormflow sampling was the First Flush sampling conducted from February through November of 1999. The First Flush Sampling Program monitored four storm events at each of the five tributary streams. The outlet station was not included in the First Flush Sampling Program. Although the samples were collected as time-weighted discrete samples, a flow-weighted composite concentration was calculated using the flow data from the monitoring stations, and the calculated composite concentrations are used in this report. The composite stormflow sampling program was performed from March 2000 to November 2001. During this period, eleven to thirteen stormflow flow-weighted composite samples were collected at each of the five tributary stream stations. Three stormflow events were monitored at the outlet site by collected grab samples twice per day during the rise and fall of the Passaic River Outlet's hydrograph. These samples were then composited based on flow data downloaded from the USGS website to provide a flow-weighted composite sample.

3.4.1 Assessment of Baseflow Concentrations

Application of the New Jersey surface water quality standards for nitrates and total suspended solids to the baseflow concentrations of the Great Swamp tributary streams and the outlet of the Great Swamp is fairly straightforward. However, the application of the New Jersey Standard for total phosphorus is more ambiguous. Each of the sampled streams flows into a lake, pond, or reservoir either upstream or downstream of the sampled location. However, none of the sampling locations is located at the point where the stream enters a lake or pond. Nonetheless, due to the significance of the downstream receiving body, the lower concentration is used as the recommended criterion for all of the sampled tributary streams.

There are several ways in which the EPA Ecoregional Nutrient reference data can be used to classify streams. One way is to use the reference condition as a threshold for nutrient acceptability. Streams that have concentrations lower than the reference concentration are considered to be acceptable and streams that have concentrations greater than the reference concentration are considered to be impaired. This approach assumes that 75% of all streams in the ecoregion are impaired, which may or may not be the case, depending on the ecoregion.

A second approach is to compare the stream concentration to both the reference concentration and a second threshold concentration that is higher than the reference concentration. Streams with concentrations lower than the reference concentration are considered to be reference streams. Streams with nutrient concentrations between that of the reference stream and the second threshold are considered to be acceptable quality streams. Streams with concentrations higher than the second threshold are considered to be impaired streams. EPA has not identified where that higher threshold should be, and it is probably subject to change depending on the ecoregion. However, since there is concern with the quality of Category One waters downstream, the measured concentrations will be compared to the reference conditions.

Appendix B includes a series of tables and graphs that provide the average, median, and range of baseflow concentrations for all of the parameters sampled as part of the Great Swamp Water Quality Monitoring Program. The tables and graphs also show the New Jersey Standards and EPA reference conditions for each parameter where available. There is an empty space on the graphs in situations where there is no standard or reference condition available. A discussion of the baseflow nutrient concentrations is presented in section 3.4.3.

3.4.2 Assessment of Stormflow Concentrations

Neither the New Jersey Water Quality Standards nor the EPA Nutrient Criteria data mention whether the limits, standards, and concentrations should apply to baseflow or stormflow conditions. The *Nutrient Criteria Technical Guidance Manual* acknowledges that stream flow can affect the concentration and distribution of nutrients, however, there is no record as to whether the concentrations used in the development of the reference conditions were from baseflow or stormflow sampling. Likewise, the New Jersey Surface Water Quality Standards do not mention whether the limits should be applied to baseflow or stormflow conditions. Based on the lack of information, and the historic focus on dry weather sampling, it is likely that the reference conditions and water quality standards represent baseflow conditions.

The historic focus on sampling baseflow conditions makes it difficult to find reference stormflow concentrations. The sampling that was completed as part of the Nationwide Urban Runoff Program (NURP) provides some of the only available data on nutrient and sediment concentrations from samples collected during stormflow conditions. However, even these data are of somewhat limited use in their comparison to Great Swamp Watershed data. Most of the sites included in the NURP study have drainage areas much smaller and much more developed than those of the Great Swamp tributaries studied in this program. However, there are five sites that can be used as references for the Great Swamp watershed. Two sites are located in Michigan, have mixed land use, have impervious surface coverage of 21% and 26%, and have watershed areas of 2,001 and 2,871 acres. The watersheds of the other three sites are composed predominantly of open space and provide something closer to a reference condition. One of the sites is located in Michigan and the other two are located in New York. They have drainage areas of 2,303, 5,248, and 5,338 acres and have impervious surface coverages of 6%, 1%, and 1%. The tables below show the ranges of mean stormflow concentrations and the ranges of median stormflow concentrations for the sites.

Table 5: Stormflow Nutrient Concentrations for Mixed Land Use (from NURP Study)

Parameter	Range of Means (mg/l)	Range of Medians (mg/l)
Total Phosphorus	0.103 – 0.268	0.093 – 0.243
Nitrates	0.284 – 0.469	0.256 – 0.456
Total Kjeldahl Nitrogen	0.845 – 1.056	0.811 – 1.031
Total Suspended Solids	46 – 68	43 – 61

Table 6: Stormflow Nutrient Concentrations for Open Space (from NURP Study)

Parameter	Range of Means (mg/l)	Range of Medians (mg/l)
Total Phosphorus	0.027 – 0.091	0.017 – 0.085
Nitrates	0.240 – 1.108	0.206 – 1.096
Total Kjeldahl Nitrogen	0.340 – 0.889	0.305 – 0.883
Total Suspended Solids	17 – 64	6 – 26

As is seen in the storm flow data collected as part of the Great Swamp Monitoring Program, there is a wide range in the concentrations among sampling locations and even at a single site. Although these concentrations are not established guidelines or standards, comparison to the range of concentrations measured in this national study helps to put the measured Great Swamp data into a larger context.

Great Swamp stormflow concentrations were also compared to the New Jersey Water Quality Standards and EPA reference concentrations, even through it is unclear whether it is appropriate to apply these reference conditions to stormflow conditions. In the absence of clearly defined state or national standards for stormwater quality in streams, the best reference data available are the concentrations measured at the Passaic River tributary station located upstream of the Great Swamp. Baseflow conditions in the Passaic River are comparable to a reference stream in the Great Swamp's ecoregion, and the stormflow concentrations were lower in Passaic River than in any of the other monitored streams.

Appendix C includes a series of tables and graphs that provide the average, median, and range of stormflow concentrations for all of the parameters sampled as part of the Great Swamp Water Quality Monitoring Program. The tables and graphs also show the New Jersey Standards, EPA reference conditions, and Nationwide Urban Runoff Program (NURP) Mixed Land Use and Open Space ranges for each parameter where available. Bars on the mixed Land Use and Open Space columns of the graph indicate the range of averages. There is an empty space on the graphs in situations where there is no standard or reference condition available. A discussion of the stormflow nutrient concentrations is presented in the next section.

3.4.3 Discussion of Great Swamp Water Quality

Black Brook

Black Brook baseflow total phosphorus concentrations do not meet the New Jersey total phosphorus standard for streams entering lakes and ponds. Only one of the twelve sampled concentrations is lower than the 0.05 mg/l standard, and one third of the sampled baseflow concentrations are also higher than the 0.1 mg/l limit for all streams. Likewise, only one of the baseflow total phosphorus concentrations is lower than the EPA reference condition for total phosphorus. Black Brook stormflow total phosphorus concentrations are all much higher than both the New Jersey standard and the EPA reference condition. The lowest Black Brook stormflow total phosphorus concentrations falls within the range of the Mixed Land Use NURP concentrations, but for the most part, they are higher than the NURP Mixed Land Use and Open Space Concentrations.

All measured Black Brook baseflow and stormflow nitrates concentrations are much lower than the New Jersey limit of 10 mg/l and all but one are also lower than the EPA ecoregional reference concentration for nitrates.

Black Brook baseflow and stormflow total Kjeldahl nitrogen concentrations are higher than the EPA reference value of 0.3 mg/l. Some of the measured stormflow concentrations fall within the ranges of the Mixed Land Use and Open Space concentrations, but overall, most of the Black Brook total Kjeldahl nitrogen concentrations are greater than the NURP concentrations.

Black Brook baseflow total suspended solids concentrations are lower than the New Jersey Standards for both nontrout and trout production waters. However, the stormflow concentrations are much higher than the 40.0 mg/l standard for nontrout waters. Overall, the stormflow concentrations are also much higher than the NURP concentrations.

Dr. Leland Pollock of Drew University conducted macroinvertebrate sampling at two locations in the Black Brook Subwatershed during the same timeframe as the water quality monitoring. Dr. Pollock's BB1 macroinvertebrate sampling station is in the same location as the Black Brook water quality monitoring station. Water quality at this station has been ranked "very poor" based on the biological monitoring that was conducted during the period of the monitoring in this study. The BB1 site was one of the two most biologically impaired of the five macroinvertebrate sampling sites corresponding to the water quality monitoring stations. (Pollock 2001)

Evaluation of Black Brook Water Quality

The overall baseflow water quality in Black Brook is somewhat impaired based on the New Jersey Standards, EPA reference criteria, and in comparison to the watershed's more pristine streams. The biological assessment also indicates that the water quality in this tributary is poor. The small watershed of the sampling station is dominated by impervious surface, urbanized land, and a golf course immediately upstream of the station. It appears that the intensive land use has had a noticeable impact on the water quality in the stream. The impact is particularly noticeable in the stormflow concentrations measured in the stream.

Overall, this portion of the tributary does not have a major impact on the Great Swamp due to its small volume of flow, but it is problematic that the headwaters of one the major streams flowing through the swamp are degraded. It should also be noted that there is a wastewater treatment facility on another arm of Black Brook that is not being monitored as part of this monitoring program. Spot sampling should be conducted on the other tributary to determine the impact that treatment facility has on water quality.

Loantaka Brook

Loantaka Brook total phosphorus concentrations do not meet the New Jersey Standards for total phosphorus. None of the concentrations is below the 0.1 mg/l limit. Likewise, all of the total phosphorus concentrations are much higher than the EPA ecoregional reference criteria. Although there are no New Jersey DEP or EPA standards for dissolved reactive phosphorus, it is worth noting that average Loantaka Brook dissolved reactive phosphorus concentrations are three to twelve times higher than any of the other streams. Loantaka Brook stormflow total phosphorus concentrations are even higher than the baseflow concentrations and fall above the range of concentrations measured during the NURP study.

The baseflow nitrate concentrations in Loantaka Brook approach the New Jersey 10 mg/l limit during periods of low flow, although none exceeds the limit. All of the Loantaka Brook baseflow and stormflow nitrate concentrations exceed the EPA ecoregional reference criterion of 0.995 mg/l, and all of the stormflow concentrations are higher than the NURP nitrate concentrations.

Loantaka Brook total Kjeldahl nitrogen concentrations are higher than the EPA reference concentrations during baseflow and stormflow. Only two of the measured baseflow concentrations and none of the stormflow concentrations are lower than the 0.3 mg/l criterion. Total nitrogen concentrations also exceed the EPA reference concentrations.

Loantaka Brook total suspended solids concentrations are lower than the New Jersey Standards for both nontrout and trout production waters during baseflow, but exceed the 40.0 mg/l standard for nontrout streams during stormflow.

Dr. Leland Pollock of Drew University conducted macroinvertebrate sampling at four locations in the Loantaka Brook Subwatershed during the timeframe of the water quality monitoring study. The LB1 macroinvertebrate sampling station is in the same location as the Loantaka Brook water quality monitoring station. Water quality at this station has been ranked "very poor" based on the biological monitoring that was conducted at the site during the period of monitoring in this study. Along with the BB1 site, the LB1 site was one of the two most biologically impaired of the five macroinvertebrate sampling sites corresponding to the water quality monitoring stations (Pollock 2001).

Evaluation of Loantaka Brook Water Quality

The overall water quality in Loantaka Brook during baseflow and stormflow is impaired based on New Jersey Water Quality Standards, EPA reference criteria, and nutrient concentrations in the other watershed streams. The high concentrations of soluble, inorganic nutrients in Loantaka Brook probably result from the treatment plant that discharges into the stream. The concentrations are inversely correlated with flow, which indicates that they may result from a point source, and are diluted by either groundwater or surface water runoff at higher flows. There is also a possibility that nitrate concentrations may exceed the 10 mg/l limit farther upstream from the monitoring station, where there is less dilution. Spot sampling should be undertaken to verify the source of these high nutrient concentrations. In addition to the treatment facility, there is fairly intensive development in the headwaters of the Loantaka Brook watershed that is impacting the water quality in the stream and is leading to the elevated stormflow concentrations of total phosphorus, total Kjeldahl nitrogen, and total suspended solids.

Great Brook

Great Brook total phosphorus baseflow and stormflow concentrations do not meet the New Jersey Standard for total phosphorus in streams entering lakes and ponds. Only two of the twelve baseflow sample concentrations are lower than the 0.05 mg/l standard, but none of the sampled concentrations exceeds the higher 0.1 mg/l limit. None of the stormflow concentrations is lower than the 0.05 mg/l standard, and most also exceeded the 0.1 mg/l standard. Likewise, the Great Brook baseflow and stormflow total phosphorus concentrations exceed the EPA reference criterion. Although the Great Brook stormflow total phosphorus concentrations are higher than the Open Space stormflow concentrations, they are comparable to the Mixed Land Use stormflow concentrations recorded in the NURP study.

All measured Great Brook nitrates concentrations are much lower than the New Jersey limit of 10 mg/l and are also lower than the EPA ecoregional reference concentrations for nitrates. Great Brook baseflow and stormflow total Kjeldahl nitrogen concentrations are all higher than the EPA reference concentrations for this parameter. The stormflow total Kjeldahl nitrogen concentrations fall into the upper range of the NURP Mixed Land Use concentrations. For the most part, the total nitrogen concentrations in Great Brook are lower than the EPA reference criterion.

Great Brook total suspended solids concentrations are lower than the New Jersey Standards for both nontrout and trout production waters during baseflow. About half of the stormflow total suspended solids concentrations exceed the nontrout standard of 40.0 mg/l, and about half meet the standard. The average total suspended solids concentrations fall within the range of the Mixed Land Use NURP concentrations and even in the upper range of the NURP open space concentrations.

Dr. Leland Pollock of Drew University conducted macroinvertebrate sampling at four locations in the Great Brook Subwatershed during the same timeframe as the water quality monitoring program. The GB2 macroinvertebrate sampling station is in the same location as the Great Brook water quality monitoring station. Overall, water quality at this station was ranked “very poor” based on the biological monitoring that was conducted at the site during the period of monitoring in this study. Biological monitoring conducted in the fall of 2000 indicated slightly better water quality, with a ranking of “poor,” but the quality then declined again according to the sampling conducted in the summer of 2001 (Pollock 2001).

Evaluation of Great Brook Water Quality

The overall water quality in Great Brook is slightly impaired based on the New Jersey Standards, EPA reference criteria, and comparison to the watershed’s more pristine streams. However, Great Brook baseflow concentrations are closer to the standards than those of Black Brook or Loantaka Brook. Similarly, even though Great Brook’s biological rating is “very poor,” the Benthic Index of Biological Integrity indicates that the water quality at the Great Brook site is slightly better that the water quality at either the Black Brook or Loantaka Brook sites. Stormflow concentrations are comparable to the concentrations measured in mixed land use areas during the NURP stormflow water quality study.

There is quite a bit of development in the headwaters of Great Brook including impervious surfaces, golf courses, and residential developments. There is also some agricultural land within the watershed. The intensive land use seems to have had an impact on the baseflow water quality in Great Brook, but the impact does not seem to be as severe as in Black Brook and Loantaka Brook.

Primrose Brook

Primrose Brook baseflow total phosphorus concentrations meet the New Jersey Standard for streams entering lakes and ponds. Two of the sampled concentrations exceed the 0.05 mg/l limit and one of those two also exceeds the 0.1 mg/l limit, however the mean and median concentrations fall below the 0.05 mg/l New Jersey Standard as well as the EPA ecoregional criterion for total phosphorus. Stormflow concentrations of total phosphorus vary widely in Primrose Brook, but for the most part exceed the New Jersey standards.

Primrose Brook baseflow and stormflow nitrate, baseflow total Kjeldahl nitrogen, and baseflow total nitrogen concentrations are all lower than the New Jersey Water Quality Standards and the EPA reference criteria for these parameters. However, like the stormflow total phosphorus concentrations, the stormflow total Kjeldahl nitrogen concentrations vary widely. Several fall below or very close to the EPA reference criterion of 0.3 mg/l, but most exceed that concentration. Likewise, some of the stormflow total nitrogen concentrations exceed the EPA reference and some fall below it.

Primrose Brook total suspended solids concentrations are lower than the New Jersey Standards for both nontrout and trout production waters during baseflow. In all but two cases, stormflow total suspended solids exceeded the 25.0 mg/l standard for trout production waters.

Dr. Leland Pollock of Drew University conducted macroinvertebrate sampling at three locations in the Primrose Brook Subwatershed during the timeframe of the water quality monitoring. The PB2 macroinvertebrate sampling station is in approximately the same location as the Primrose Brook water quality monitoring station. Based on the biological monitoring that was conducted at the site during the period of monitoring in this study, water quality at this station has been ranked “fair to good”. The Benthic Index of Biological Integrity (B-IBI) calculated for the sampling conducted in fall of 1999 and summer of 2000 places the water quality in the upper end of the “fair” classification and the B-IBI index for the sampling conducted in summer 2001 places water quality in the lower end of the “good” range. Biological sampling conducted in fall 2000, however, indicated that water quality was poor (Pollock 2001).

Evaluation of Primrose Brook Water Quality

Primrose Brook baseflow nutrient concentrations represent nutrient reference conditions for the Great Swamp Watershed, and based on the biological monitoring, the water quality in Primrose Brook was the best of the five macroinvertebrate sampling sites corresponding to the water quality monitoring stations. The Primrose Brook watershed has the least amount of impervious surface coverage and the least amount of developed land of any of the monitored subwatersheds.

However, in spite of its relatively pristine condition, there is some significant development upstream of the monitoring station, which impacts the water quality. There is also residential development and agricultural land downstream of the monitoring station that might be adversely affecting the swamp. According to some of the biological surveys, the water quality was considered “good,” however according to other biological surveys water quality was poor. Primrose Brook also seems to have some of the most dramatic differences between baseflow and stormflow concentrations. While the baseflow concentrations can be considered reference quality, the stormflow concentrations are more comparable with and sometimes higher than the concentrations in Great Brook. The total phosphorus, total Kjeldahl nitrogen, and total suspended solids concentrations all vary widely during stormflow. The first three sampled first flush storms yielded the highest concentrations of these parameters. All three were fairly high intensity storms that occurred while there was construction on a bridge upstream of the monitoring station. The high measured concentrations may have resulted from this construction, but some high concentrations were observed at subsequent storms, so the high concentrations may have resulted independently of the construction activity. The fluctuations between baseflow and stormflow concentrations in this watershed should be monitored closely in future studies.

Passaic River

Passaic River baseflow total phosphorus concentrations meet the New Jersey Standard for streams entering lakes and ponds. Two of the sampled concentrations exceed the 0.05 mg/l limit, but are below the 0.1 mg/l standard. Likewise, most of the measured baseflow total phosphorus concentrations fall below the EPA reference criterion. The stormflow total phosphorus concentrations exceed the New Jersey standard of 0.05 mg/l and the EPA reference criterion, but almost all are lower than the New Jersey standard of 0.1 mg/l for all streams. The stormflow total phosphorus concentrations are lower than the Mixed Land Use concentrations and are in the upper end of the Open Space Range.

Passaic River baseflow and stormflow nitrates concentrations are lower than the New Jersey Water Quality Standard and the EPA reference criterion. Baseflow total Kjeldahl nitrogen concentrations are scattered above and below the EPA reference criterion, and the average and median concentrations are slightly higher than the 0.3 mg/l criterion. Most of the stormflow total Kjeldahl nitrogen concentrations are greater than the EPA reference. The Passaic River total Kjeldahl nitrogen concentrations are lower than the NURP Mixed Land Use concentrations and comparable with the NURP Open Space Concentrations. For the most part Passaic River baseflow and stormflow total nitrogen concentrations are lower than the EPA criterion.

Passaic River total suspended solids concentrations are lower than the New Jersey Standards for both nontrout and trout production waters during baseflow. Stormflow total suspended solids concentrations were less than the 25.0 mg/l standard for trout production waters during all but two storms included in the sampling program.

Dr. Leland Pollock of Drew University conducted macroinvertebrate sampling at four locations in the Passaic River Subwatershed during the timeframe of the water quality monitoring program. The PR1 macroinvertebrate sampling station is in the same location as the Passaic River water quality monitoring station. Based on the biological monitoring that was conducted at the site during this study’s sampling period, water quality at this station has been ranked “very poor to poor”. The Benthic Index of Biological Integrity (B-IBI) calculated for the sampling conducted in fall of 1999, summer of 2000, and summer 2001 places the water quality in the “poor” category and the B-IBI index for the sampling conducted in fall 2000 places water quality in the “very poor” category. (Pollock 2001)

Evaluation of Passaic River Water Quality

Although the Passaic River baseflow concentrations are slightly higher than the Primrose Brook concentrations, Passaic River nutrient concentrations are also reference conditions for the Great Swamp Watershed. The Passaic River watershed is relatively undeveloped and has less impervious surface than the Black Brook, Loantaka Brook, or Great Brook watersheds. Passaic River also has much lower stormflow nutrient concentrations than any of the other streams. The concentrations are closer to the New Jersey Standards and EPA reference criteria. They are also comparable with the concentrations recorded from Open Space watersheds in the NURP study. The Passaic River stormflow concentrations should serve as a reference for the Great Swamp Watershed in the absence of any well-defined stormflow standards. It is particularly important to maintain concentrations in the Passaic River, because it contributes such a large volume of the water that flows into the Great Swamp according to the hydrologic monitoring done as part of this study.

Based on the biological monitoring, the water quality in Passaic River is considered impaired, even though the water chemistry data indicate that the Passaic River is a reference stream. The poor biological water quality could be the result of the sampling site's location downstream of Osborne Pond. *Macroinvertebrate Communities of the Great Swamp Watershed* notes that sites located just below impoundments (where waters stall and heat and photosynthetically driven pH rises during the daytime) are found to have the worst water quality of the sampled sites on a stream. (Pollock 2001) The effects of Osborne Pond might be overriding the ostensibly good water quality in the Passaic River.

Great Swamp Outlet

The total phosphorus concentrations in the Passaic River flowing out of the Great Swamp do not meet the New Jersey Water Quality Standard. Four of the sampled concentrations are lower than the 0.1 mg/l standard for all streams, but none of the sample concentrations is lower than the 0.05 mg/l standard. Likewise, the total phosphorus concentrations exceed the EPA ecoregional criteria. Only three stormflow samples were collected at the outlet. Two sampled concentrations meet the 0.1 mg/l standard and one of those also meets the 0.05 mg/l standard. Based on these limited stormflow results, it does not seem as though the total phosphorus concentrations fluctuate as much in the outlet as they do in the tributary streams.

The baseflow and stormflow nitrate concentrations in the Great Swamp Outlet are much lower than either the New Jersey Water Quality Standard or the EPA reference. Almost all of the total Kjeldahl nitrogen concentrations were higher than the EPA reference criterion, but most of the total nitrogen concentrations were lower than the EPA reference for total nitrogen.

The baseflow and stormflow total suspended solids concentrations were lower than the New Jersey Standards for both nontrout and trout production waters.

Evaluation of Outlet Water Quality

The outlet nutrient concentrations seem to show different patterns than those of the tributary streams. Baseflow total phosphorus concentrations are higher than those in many of the tributary streams, but the concentrations do not appear to fluctuate as much between baseflow and stormflow based on the limited stormflow data for the outlet. Nitrate concentrations are very low and total Kjeldahl nitrogen concentrations are relatively high, indicating that much of the nitrogen is present as organic nitrogen and that nitrates are probably being taken up and used by plants in the wetland. Total suspended solids also seem to be high during baseflow, but like total phosphorus concentrations, they do not appear to fluctuate as much during stormflow based on the limited data. The solids suspended in the water column during baseflow are more likely associated with plant material than sediment.

3.5 Great Swamp Watershed Nutrient and Suspended Solids Loads

The nutrient concentrations measured during the baseflow and stormflow sampling programs have been used in conjunction with the monitored stream flows to estimate nutrient and suspended solid loading to the Great Swamp. When the hydrologic budget was calculated, each interval volume was characterized as baseflow or stormflow. These same characterizations were used to assign nutrient and suspended solids concentrations for the calculation of nutrient loads.

3.5.1 Allocation of Sampled Concentrations to Develop Loads

Baseflow sampling was conducted on a regular basis during the two hydrologic years included in this report. To calculate baseflow loading, the baseflow concentration measured on a particular day was used as the baseflow concentration for all baseflow intervals during the period from sampling midpoint to sampling midpoint. More baseflow samples were collected during the second year than the first year. Therefore, the baseflow totals calculated for the second year probably reflect the actual loading better than the first year totals.

The allocation of stormflow concentrations proved to be a more complex task. It is not appropriate to allocate stormflow concentrations in the same way baseflow concentrations were allocated due to variations in rainfall, intensity, and other storm features, so another alternative had to be identified. One option was to develop equations relating each stream’s chemical parameters and a storm characteristic such as rainfall. Several of the streams showed correlations between rainfall and total phosphorus and rainfall and total suspended solids. Loantaka Brook showed an inverse correlation between flow and nitrates. However, the lack of relationships between storm-related variables and other parameters precludes the use of this method for all parameters and all streams. As a result, median stormflow concentrations were used to develop the stormflow loadings. Medians were selected rather than the averages, because the averages can be skewed by the extreme values.

Only three storm events were sampled at the Outlet of the Great Swamp, which did not provide enough data to arrive at a reliable central tendency for the stormflow concentrations. As a result, the sampled baseflow concentrations were allocated to all flow leaving the swamp.

The tables and graphs in Appendix D show the nutrient loads for each of the chemical parameters for each of the two monitoring years. The tables and graphs include baseflow, stormflow, and total loads for each of the tributary streams; the tributary totals; and the total load leaving the swamp. Black Brook's relatively small contribution to the nutrient and suspended solids loading results from its significantly smaller watershed area and consequently its lower flow volumes. The tables also include a column showing the pounds per acre per year, which normalizes the loading rates based on the contributing area to each subwatershed.

3.5.2 Total Phosphorus Loads

Based on the measured data, the total phosphorus contributed by the five monitored streams is comparable to the total phosphorus load leaving the swamp. The first year's data shows a net export of total phosphorus from the swamp, while during the second year total phosphorus loads in and out of the swamp were almost the same. It was expected that the swamp was acting as more of a phosphorus sink than it appears from the data, and the results of the monitoring merit some additional analysis and attention in the next phase of the water quality monitoring program. There is probably a significant baseflow total phosphorus contribution from the Black Brook tributary on which the watershed's second wastewater treatment facility is situated. This tributary is not monitored, so those nutrient loads are not accounted for in this budget. Future nutrient budgets should incorporate data from the treatment facility's Discharge Monitoring Reports (DMRs) or should include spot sampling to assess the impact of this load. Secondly, based on the limited stormflow data collected at the outlet of the Great Swamp, it appears that baseflow and stormflow total phosphorus concentrations are comparable; however, it is important to collect additional outlet stormflow samples to provide a better assessment of what is leaving the swamp. The revision and improvement of the rating curves during the next phase of monitoring will also help to clarify the results of the total phosphorus loading by refining the hydrologic totals that form the basis of the nutrient load calculations. Finally, since there were some correlations noted between total phosphorus concentrations and storm parameters, it may be advisable to develop a relationship between the variables and estimate total phosphorus concentrations for each storm rather than using the median concentration. This process would be time-intensive, but may serve to refine the estimates of total phosphorus entering the swamp.

The normalization of the nutrient loads with the contributing watershed areas indicates which watersheds are contributing the greatest loads based on their size. The Loantaka Brook watershed has the highest total phosphorus and dissolved reactive phosphorus loading rates, and Black Brook watershed has the second highest loading rates for those parameters. According to impervious surface cover statistics, the Black Brook watershed is more developed than the Loantaka Brook watershed, but the Loantaka Brook total phosphorus loading rate is twice that of Black Brook. This is a result of the high baseflow nutrient concentrations in Loantaka Brook. The total phosphorus and dissolved reactive phosphorus loading rates of the other three streams are in the same range even though there is some variation in the development levels of these watersheds. Although slightly higher than the Primrose Brook and Passaic River loading rates, the Great Brook watershed loading rates are not as high as might be expected based on the level of development in this watershed and on the disparity in nutrient concentrations. Although the Great Brook watershed is comparable in size to the Passaic River watershed, the flow rates and flow volumes are much lower in this stream, which lead to overall lower loading rates even though the actual concentrations are higher.

3.5.3 Dissolved Reactive Phosphorus Loads

The relationships between the tributary and outlet dissolved reactive phosphorus loads are similar to the total phosphorus loads. The first year showed a net export of dissolved reactive phosphorus, while the second year showed an overall retention of dissolved reactive phosphorus in the swamp. It might be expected that dissolved reactive phosphorus loads leaving the swamp would be lower than those entering the swamp, because the soluble, inorganic phosphorus is biologically available and can be utilized by algae and other aquatic plants. However, other wetland conditions encourage the conversion of bound phosphorus to the soluble, reactive form and these factors may play a role in the Great Swamp. Wetland plants can recycle phosphorus from bottom sediments back into the water column, and the anoxic conditions in wetlands are favorable for phosphorus liberation. The input and export of this component of phosphorus should also be closely watched during the next phase of the water quality monitoring. The phosphorus dynamics may vary with season, so it will be particularly important to collect samples regularly. The collection of only four samples during the first sampling year might not have provided enough information to account for the fluctuations in the swamp's behavior.

3.5.4 Nitrogen Loads

Based on the nitrate, total Kjeldahl nitrogen, and total nitrogen loads into and out of the swamp, it appears that the Great Swamp is changing the composition and total amount of the system's nitrogen components. The nitrate load into the swamp is much greater than the nitrate export from the swamp, whereas the total Kjeldahl nitrogen export is greater than the total Kjeldahl nitrogen input. There is an overall reduction in total nitrogen during both the first year and the second year of monitoring, with a total nitrogen reduction of more than 50% in the second year. Based on these data, it appears that much of the nitrate-nitrogen is taken up for plant growth, and that nitrogen is exported in an organic form, which then appears as total Kjeldahl nitrogen in the analysis. There is also a loss of nitrogen as the water flows through the swamp, some of which may settle to the bottom as complex humic acids and some of which is lost to the atmosphere through the process of denitrification. Although the Great Swamp appears to be effectively processing and removing nitrogen from the water, these load relationships should be tracked to see if they are changing with time. Additional analyses should account for the discharge from the unmonitored wastewater treatment facility, which probably contributes nitrates to the swamp that have not been included in this budget.

The trends in total Kjeldahl nitrogen loading rates from the tributary streams are similar to the trends in total phosphorus loading rates in the different streams; however, the trends in nitrate loading rates are quite different. The Loantaka Brook watershed posts the highest loading rates for total Kjeldahl nitrogen, and the Black Brook watershed posts the second highest loading rates for this parameter. Passaic River has a higher loading rate than Great Brook in the first hydrologic year, while Great Brook's loading rate is higher in the second hydrologic year. Primrose Brook has the lowest total Kjeldahl nitrogen loading rate for both years.

As expected from the high nitrate concentrations, the nitrate loading rate from the Loantaka Brook watershed is between ten and twenty times greater than all of the other streams' nitrate loading rates. During the first hydrologic year Great Brook and Passaic River had comparable nitrate loading rates, Primrose Brook had a lower loading rate, and Black Brook had the lowest nitrate loading rate. The second hydrologic year posted a similar ranking, but the Primrose Brook loading rate was more comparable to the Passaic River and Great Brook loading rates. Again, Black Brook had the lowest nitrate loading rate that year.

3.5.5 Total Suspended Solids Loads

The Great Swamp also appears to be a sink for solids. There are reductions in the total suspended solids loads during both years. The planned outlet stormflow sampling will be particularly important to verify these results. The tributary streams tend to have higher total suspended solids loads during stormflow than baseflow and much of the total suspended solids loading results from stormflow. If this is also the case in the outlet, the assessment that the Great Swamp is acting as a sink for solids may not be correct. However, based on the limited stormflow data, it does not seem that there is much of a change in total suspended solids concentrations between the baseflow and stormflow samples.

Total suspended solids loading rates for the tributary streams showed patterns similar to those of total phosphorus and total Kjeldahl nitrogen. Loantaka Brook had the highest loading rate, and Black Brook had the second highest loading rate. Primrose Brook had a higher total suspended solids loading rate than Great Brook the first year, while Great Brook had a higher total suspended solids loading rate the second year. Passaic River had the lowest total suspended solids loading rate both years.

4.0 Conclusions and Recommendations

The water quality data indicate that the more developed watersheds have higher nutrient and sediment concentrations during baseflow and stormflow than the less developed watersheds. The best way to prevent further degradation of water quality is to control growth in developed and undeveloped watersheds. Adoption and implementation of watershed sensitive ordinances, particularly the stormwater management model ordinance, is essential to the maintenance of existing water quality levels in all of the subwatersheds.

To assist with the evaluation and control of water quality, water quality standards have been developed for the tributary streams based on the data from the Great Swamp Watershed Water Quality Monitoring Program. Tables showing the water quality standards are included in Appendix E and their development is explained in greater detail in the report *Water Quality Standards for the Great Swamp Watershed*, which was prepared for the Ten Towns Committee by F. X. Browne, Inc. in June 2002. These standards are guidelines and goals and may be refined and changed as more data are obtained from the tributary streams and as water quality monitoring and vegetation mapping are conducted within the Great Swamp National Wildlife Refuge. The standards may also change based on new DEP or EPA water quality criteria.

Table 7 shows a summary comparison of measured stream water quality to the water quality standards. As shown in this table, the water quality in Black Brook does not meet the majority of the standards, particularly during stormflow; Loantaka Brook does not meet any of the established standards; and Great Brook exceeds more standards than it meets as well. Primrose Brook and the Passaic River meet all of the baseflow water quality standards, however, while Passaic River meets all of the stormflow standards, Primrose Brook only meets half of them. This assessment indicates that management strategies described in the Great Swamp Watershed Management Plan must continue to be implemented in order to improve and/or maintain existing water quality in the Great Swamp watershed.

Management of growth is an important way to maintain existing water quality in all streams, however there should be additional and slightly varying management goals in each of the subwatersheds. The Passaic River baseflow and stormflow conditions currently meet the recommended standards, should serve as a reference for the watershed, and should be protected from any further degradation. The Primrose Brook baseflow conditions, which meet the recommended standards, should also be protected from further degradation. Attention should be focused on the identification of the sources and causes of the unusually high stormflow concentrations that are sometimes measured in this otherwise pristine stream and which exceed the developed standards for the stream.

Great Brook is somewhat impaired based on the water quality data and a comparison to the standards. Most measured baseflow and stormflow concentrations exceed the recommended standards, but Great Brook is closer to attainment than either Black Brook or Loantaka Brook. The results of the macroinvertebrate studies have shown impairment in this stream, but recent results indicate that the macroinvertebrate population appears to be slowly improving. New development should be undertaken carefully, and priority should be given to restoration and retrofit efforts.

Loantaka Brook exceeds both baseflow and stormflow recommended standards for every parameter. The major water quality goal for Loantaka Brook should be the confirmation of the source of the high baseflow nutrient concentrations and the reduction of these concentrations that contribute a large portion of the baseflow and total nutrient loads to the Great Swamp. Priority should also be given to the retrofit of stormwater management systems in the developed areas to reduce the high stormflow nutrient and suspended solids loads contributed by Loantaka Brook.

Black Brook exceeds the majority of the baseflow and stormflow recommended standards, however, the problems appear to be more severe during stormflow conditions. Although Black Brook loads are almost negligible compared to the larger streams, the nutrient concentrations are high and should be addressed to improve habitat quality in the stream. Stormwater management and infiltration to improve baseflow water quantity and stormwater quality should be priorities. Most of the restoration in this watershed probably needs to be undertaken as retrofit work, since it is already quite developed. There is also potential for riparian restoration along portions of the stream.

Continued monitoring should focus on the update and improvement of the stream rating curves to improve the accuracy of the hydrologic and nutrient loads. Stormflow outlet monitoring will help to refine the swamp's nutrient budget, as will spot sampling of some of the unmonitored tributaries. Future monitoring should also seek to answer some of the questions that have been raised during the course of this monitoring and should track any positive or negative change in the streams' overall water quality.

Table 7: Comparison of Measured Stream Water Quality and Recommended Standards

Stream	Meets Baseflow Standard*						Meets Stormflow Standard*					
	TP	**DRP**	**NO_3**	**TKN**	**TN**	**TSS**	**TP**	**DRP**	**NO_3**	**TKN**	**TN**	**TSS**
Black Brook	No	No	Yes	No	Yes	Yes	No	No	Yes	No	No	No
Loantaka Brook	No	No	No	No	No	No	No	No	No	No	No	No
Great Brook	No	No	Yes	No	Yes	No	No	No	Yes	Yes	Yes	No**
Primrose Brook	Yes	Yes	Yes	Yes	Yes	Yes	No	No**	Yes	Yes	Yes	No
Passaic River	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes

* Based on median water quality data collected from 1999 to present
**Median value exceeds standard by less than 10%

TP = Total Phosphorus
DRP = Dissolved Reactive Phosphorus
NO_3 = Nitrate
TKN = Total Kjeldahl Nitrogen
TN = Total Nitrogen
TSS = Total Suspended Solids

5.0 References

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APPENDIX A

Glossary of Technical Terms

Anoxic – lacking oxygen

Automated Sampling Unit – machine that is installed and programmed to collect water samples at specified time or volume intervals. The Great Swamp Water Quality Monitoring Program uses ISCO 6700 sampling units to collect water samples.

Baseflow – stream flow during periods of dry weather

Benthic Region – bottom of a stream, lake, or other water body

Biomass – the weight of biologic matter

Composite Samples – samples collected from the same water body at different times and are combined together to form the sample that is analyzed

Detritus – dead and decaying organic matter and debris

Discharge – stream flow (volume per unit time)

Discrete Samples – samples collected at different times and analyzed as individual samples

Eutrophication – the chemical, physical, and biological changes that occur in water bodies as a result of nutrient enrichment, increased organic matter, and sedimentation

Flow-weighted Samples – samples collected at specified volume intervals

Grab Samples – single samples collected at a point in time

Humic Acid – organic compounds that decompose very slowly. Humic acids are very chemically stable.

Hydrologic Load – the total quantity of water that enters another water body from tributaries, precipitation, ground water, direct runoff, and other sources.

Limiting Nutrient – the nutrient that is in shortest supply relative to the quantities needed for plant growth, thereby controlling the growth of the plant.

Nutrient Budget – account and assessment of nutrients flowing into a water body, nutrient accumulation in the water body, nutrient loss from the water body, and nutrients leaving the water body

Nutrient Sink – accumulation of nutrients in a water body such that they become unavailable, are stored, and are essentially removed from the system

Orthophosphate – inorganic phosphorus compound containing the phosphate group (PO_4^{3-}). Orthophosphate is very biologically available when dissolved in water.

Phytoplankton – microscopic algae that float freely in open water

Polyphosphate – inorganic phosphorus compound containing a multiple phosphates groups or a phosphorus/oxygen group with multiple molecules of phosphorus. In water, polyphosphates will gradually revert to the ortho form. This is the form of phosphate found in detergents that contain phosphate.

Reference Concentration –concentration of nutrient or other substance in a reference or natural stream

Reference Stream – stream that best represents natural, undisturbed biological, chemical, and physical conditions

Sampling Unit – see Automated Sampling Unit

Staff Gauge – calibrated metal plate that is installed in the stream and used to measure relative depth of water (i.e., stage)

Stage – relative depth of water

Stormflow – stream flow during and immediately following wet weather

Submerged Probe – instrument that is mounted in-stream and measures depth/stage based on hydrostatic pressure

Time-weighted Samples – individual samples collected at specified time intervals

Tipping Bucket Rain Gage – instrument that measures rainfall in discrete volumes. This type of rain gage can be used to measure interval rainfall totals rather than simply a storm total.

Total Kjeldahl Nitrogen – chemical analysis that measures organic nitrogen plus ammonia in water samples

Turbidity – a measure of the total suspended matter in a body of water

Urea – excretions from animals that can easily be converted to ammonia

Water Column – water between the water/atmosphere interface at the surface and the water/sediment interface at the bottom

APPENDIX B

Table B1: Baseflow Total Phosphorus Concentrations

Stream	Average Concentration (mg/l)	Median Concentration (mg/l)	Range of Concentrations (mg/l)
NJ WQ Standard	0.050	–	–
EPA Reference	0.040	–	–
Black Brook	0.082	0.077	0.027 – 0.137
Loantaka Brook	0.226	0.247	0.115 – 0.35
Great Brook	0.060	0.060	0.043 – 0.084
Primrose Brook	0.046	0.036	0.016 – 0.193
Passaic River	0.040	0.034	0.023 – 0.091
Outlet	0.132	0.130	0.057 – 0.215

Table B2: Baseflow Dissolved Reactive Phosphorus Concentrations

Stream	Average Concentration (mg/l)	Median Concentration (mg/l)	Range of Concentrations (mg/l)
NJ WQ Standard	not available	–	–
EPA Reference	not available	–	–
Black Brook	0.039	0.037	0.007 – 0.082
Loantaka Brook	0.152	0.164	0.035 – 0.280
Great Brook	0.024	0.025	0.008 – 0.035
Primrose Brook	0.018	0.020	0.003 – 0.035
Passaic River	0.013	0.012	0.007 – 0.027
Outlet	0.043	0.035	0.014 – 0.111

Table B3: Baseflow Nitrates Concentrations

Stream	Average Concentration (mg/l)	Median Concentration (mg/l)	Range of Concentrations (mg/l)
NJ WQ Standard	10	–	–
EPA Reference	0.995	–	–
Black Brook	0.13	0.07	<0.01 – 0.42
Loantaka Brook	6.67	6.78	2.90 – 8.89
Great Brook	0.51	0.50	0.08 – 0.92
Primrose Brook	0.40	0.43	0.17 – 0.58
Passaic River	0.26	0.24	0.04 – 0.68
Outlet	0.15	0.06	0.01 – 0.41

Table B4: Baseflow Total Kjeldahl Nitrogen Concentrations

Stream	Average Concentration (mg/l)	Median Concentration (mg/l)	Range of Concentrations (mg/l)
NJ WQ Standard	not available	–	–
EPA Reference	0.3	–	–
Black Brook	0.62	0.69	0.32 – 1.15
Loantaka Brook	0.75	0.70	0.21 – 1.30
Great Brook	0.62	0.53	0.33 – 1.18
Primrose Brook	0.20	0.18	0.11 – 0.30
Passaic River	0.34	0.33	0.16 – 0.83
Outlet	0.88	0.75	0.57 – 1.46

Table B5: Baseflow Total Nitrogen Concentrations

Stream	Average Concentration (mg/l)	Median Concentration (mg/l)	Range of Concentrations (mg/l)
NJ WQ Standard	not available	–	–
EPA Reference	1.295	–	–
Black Brook	0.75	0.81	0.07 – 1.35
Loantaka Brook	7.42	7.49	4.20 – 9.41
Great Brook	1.13	1.13	0.48 – 2.02
Primrose Brook	0.60	0.61	0.27 – 0.87
Passaic River	0.60	0.57	0.27 – 1.23
Outlet	1.03	1.01	0.65 – 1.47

Table B6: Baseflow Total Suspended Solids Concentrations

Stream	Average Concentration (mg/l)	Median Concentration (mg/l)	Range of Concentrations (mg/l)
NJ WQ Standard	25/40	–	–
EPA Reference	not available	–	–
Black Brook	4.9	3.7	1.6 – 13
Loantaka Brook	13	8.1	2.0 – 44
Great Brook	5.3	5.0	1.0 – 11
Primrose Brook	3.4	2.5	<1.0 – 7.2
Passaic River	3.6	3.0	1.2 - 16
Outlet	12	12	1.3 – 27

Figure B1: Baseflow Total Phosphorus Concentrations

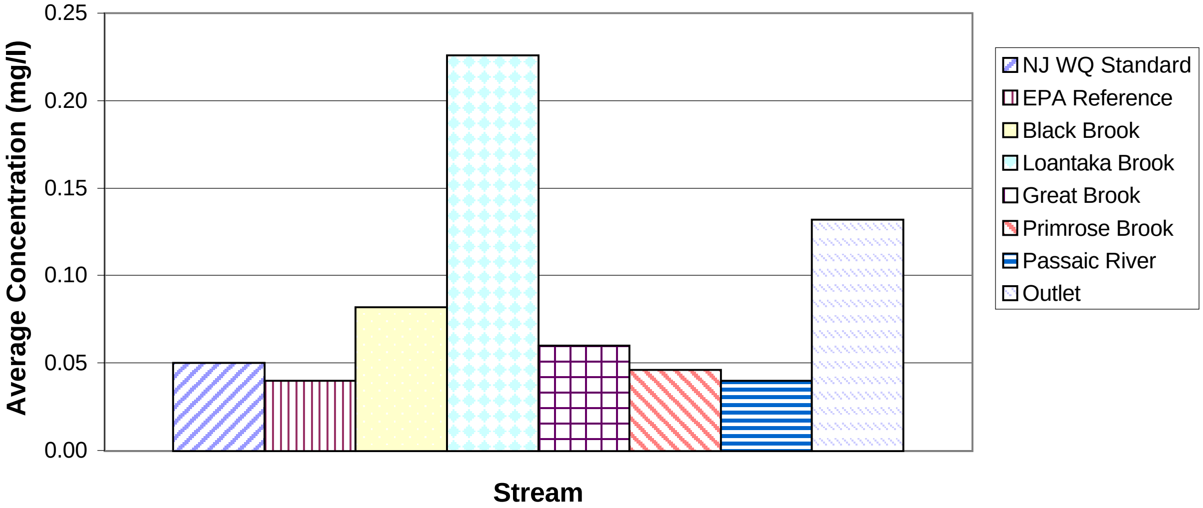
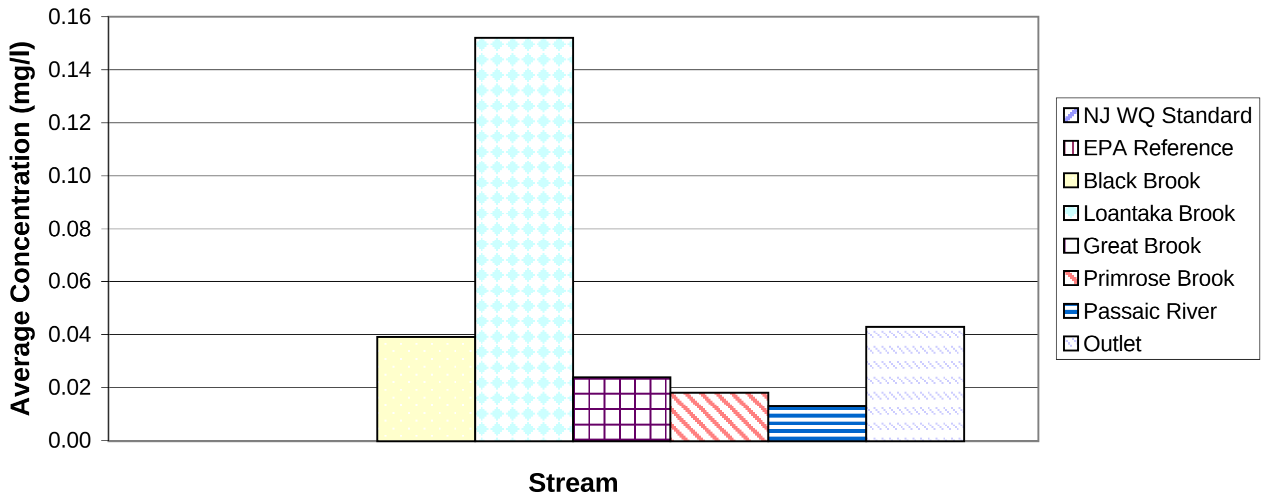


Figure B2: Baseflow Dissolved Reactive Phosphorus Concentrations



There is no New Jersey Water Quality Standard or EPA Reference Criterion for this parameter.

Figure B3: Baseflow Nitrates Concentrations

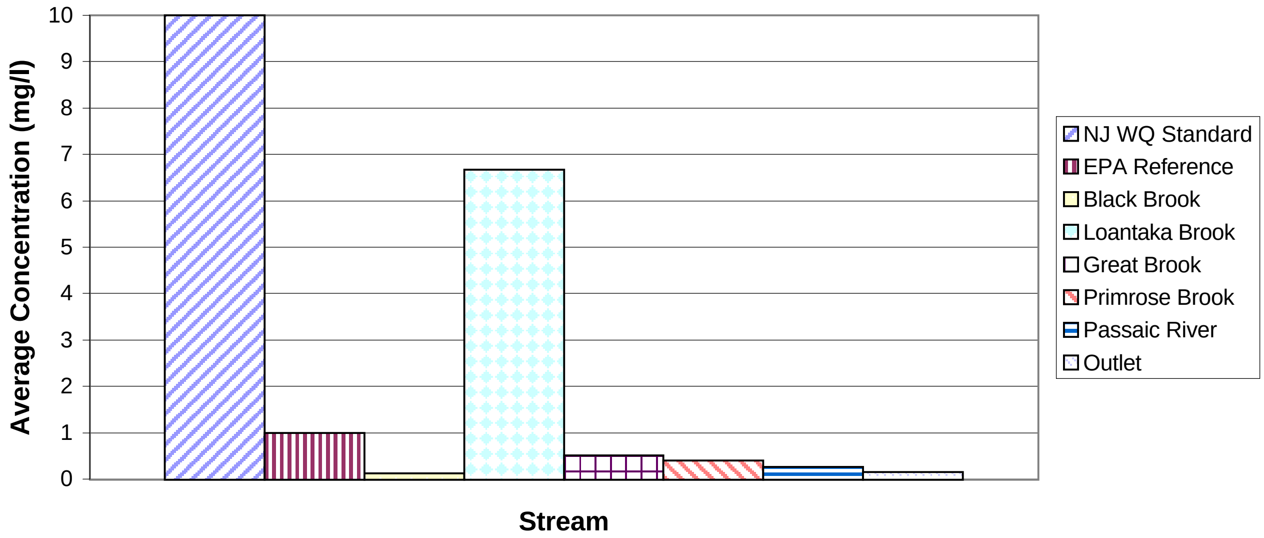
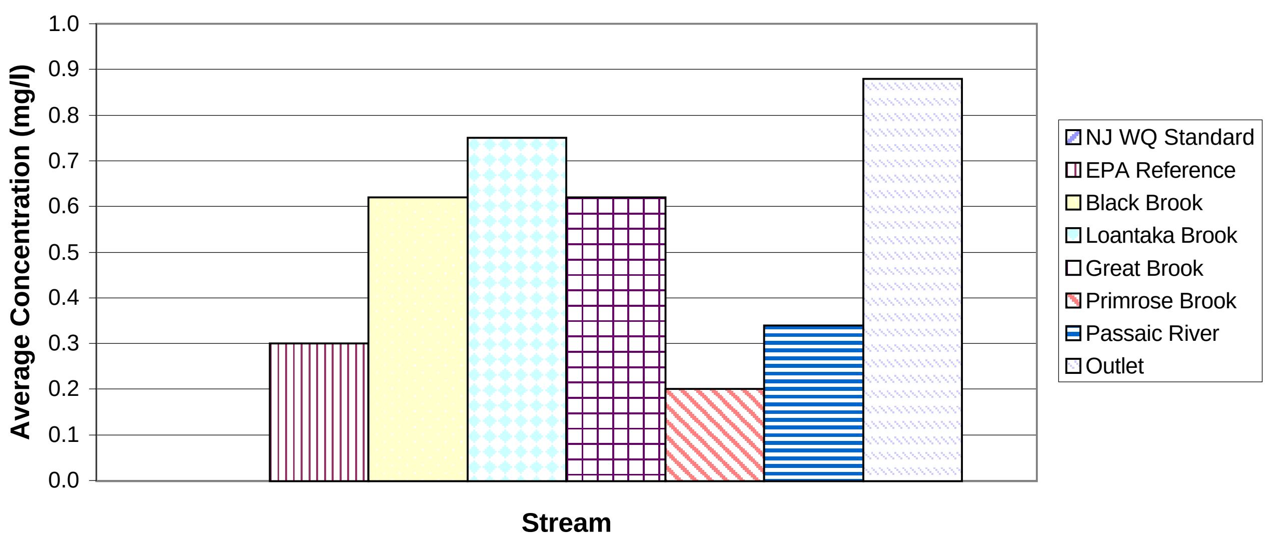
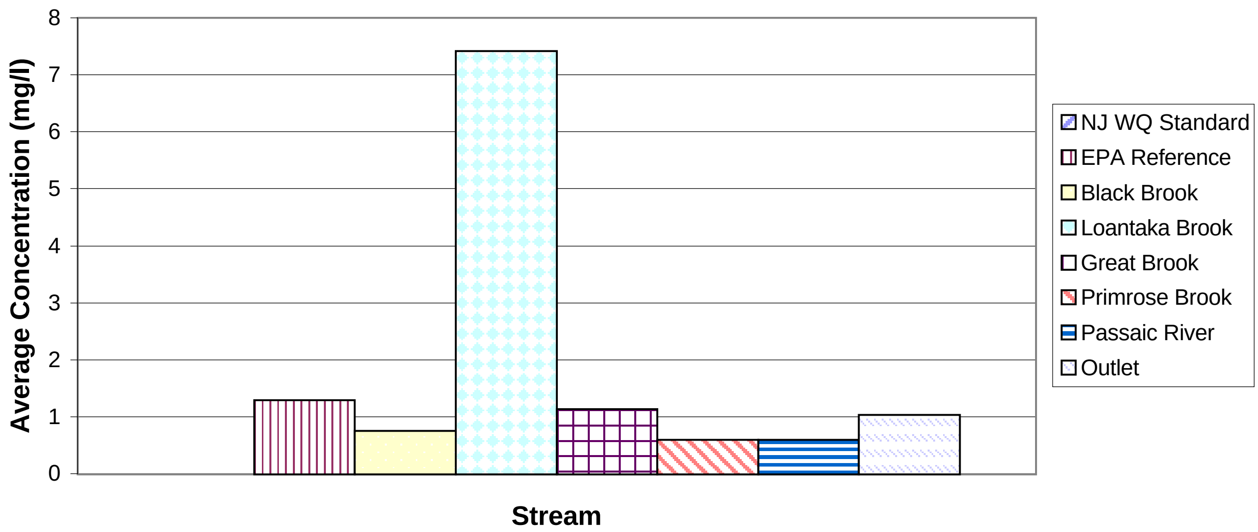


Figure B4: Baseflow Total Kjeldahl Nitrogen Concentrations



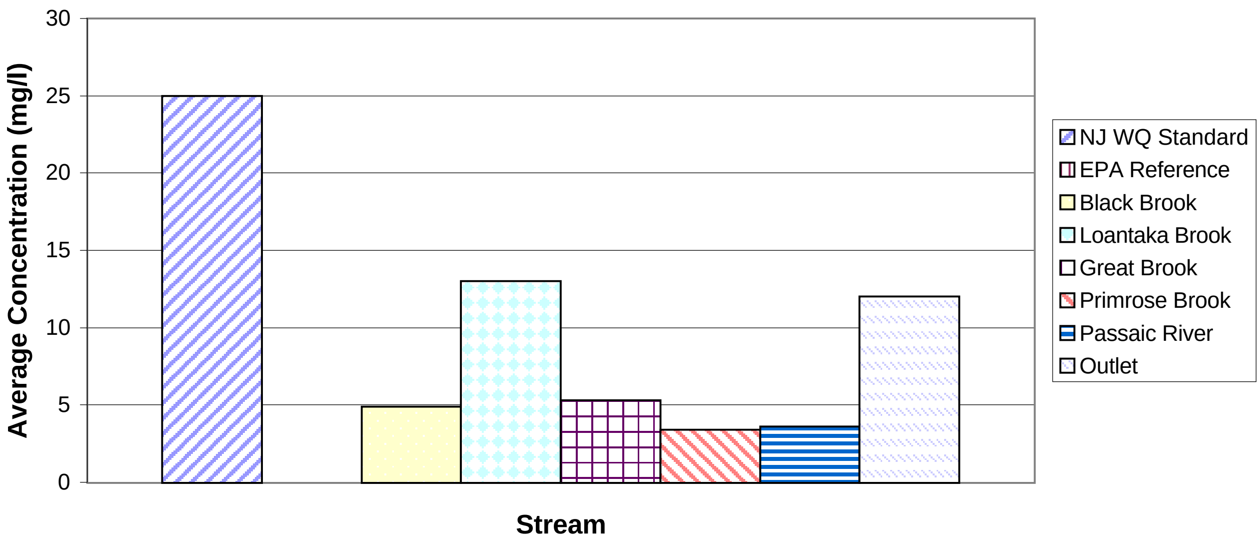
There is no New Jersey Water Quality Standard for this parameter.

Figure B5: Baseflow Total Nitrogen Concentrations



There is no New Jersey Water Quality Standard for this parameter.

Figure B6: Baseflow Total Suspended Solids Concentrations



There is no EPA reference criterion for this parameter.

APPENDIX C

Table C1: Stormflow Total Phosphorus Concentrations

Stream	Average Concentration (mg/l)	Median Concentration (mg/l)	Range of Concentrations (mg/l)
NJ WQ Standard	0.05	–	–
EPA Reference	0.04	–	–
Mixed Land Use (NURP)	0.103 – 0.268	0.093 – 0.243	–
Open Space (NURP)	0.027 – 0.091	0.017 – 0.085	–
Black Brook	0.41	0.42	0.16 – 0.80
Loantaka Brook	0.47	0.38	0.29 – 0.81
Great Brook	0.18	0.16	0.087 – 0.356
Primrose Brook	0.29	0.19	0.048 – 0.768
Passaic River	0.088	0.078	0.050 – 0.16
Outlet	0.104	0.084	0.043 – 0.184

Table C2: Stormflow Dissolved Reactive Phosphorus Concentrations

Stream	Average Concentration (mg/l)	Median Concentration (mg/l)	Range of Concentrations (mg/l)
NJ WQ Standard	not available	–	–
EPA Reference	not available	–	–
Mixed Land Use (NURP)	not available	–	–
Open Space (NURP)	not available	–	–
Black Brook	0.094	0.080	0.037 – 0.254
Loantaka Brook	0.117	0.115	0.046 – 0.218
Great Brook	0.030	0.024	0.004 – 0.062
Primrose Brook	0.022	0.021	0.002 – 0.053
Passaic River	0.015	0.014	0.005 – 0.050
Outlet	0.044	0.044	0.013 – 0.075

Table C3: Stormflow Nitrate Concentrations

Stream	Average Concentration (mg/l)	Median Concentration (mg/l)	Range of Concentrations (mg/l)
NJ WQ Standard	10	–	–
EPA Reference	0.995	–	–
Mixed Land Use (NURP)	0.284 – 0.469	0.256 – 0.456	–
Open Space (NURP)	0.240 – 1.108	0.206 – 1.096	–
Black Brook	0.38	0.34	0.09 – 1.11
Loantaka Brook	3.28	2.73	1.54 – 6.55
Great Brook	0.51	0.48	0.01 – 0.99
Primrose Brook	0.44	0.41	0.01 – 0.81
Passaic River	0.30	0.26	0.15 – 0.61
Outlet	0.15	0.22	<0.01 – 0.32

Table C4: Stormflow Total Kjeldahl Nitrogen Concentrations

Stream	Average Concentration (mg/l)	Median Concentration (mg/l)	Range of Concentrations (mg/l)
NJ WQ Standard	not available	–	–
EPA Reference	0.3	–	–
Mixed Land Use (NURP)	0.845 – 1.056	0.811 – 1.031	–
Open Space (NURP)	0.340 – 0.889	0.305 – 0.883	–
Black Brook	1.64	1.38	0.64 – 3.94
Loantaka Brook	1.63	1.50	0.69 – 3.36
Great Brook	1.01	0.95	0.56 – 2.36
Primrose Brook	1.06	0.71	0.19 – 3.86
Passaic River	0.64	0.52	0.22 – 1.21
Outlet	0.85	0.58	0.24 – 1.72

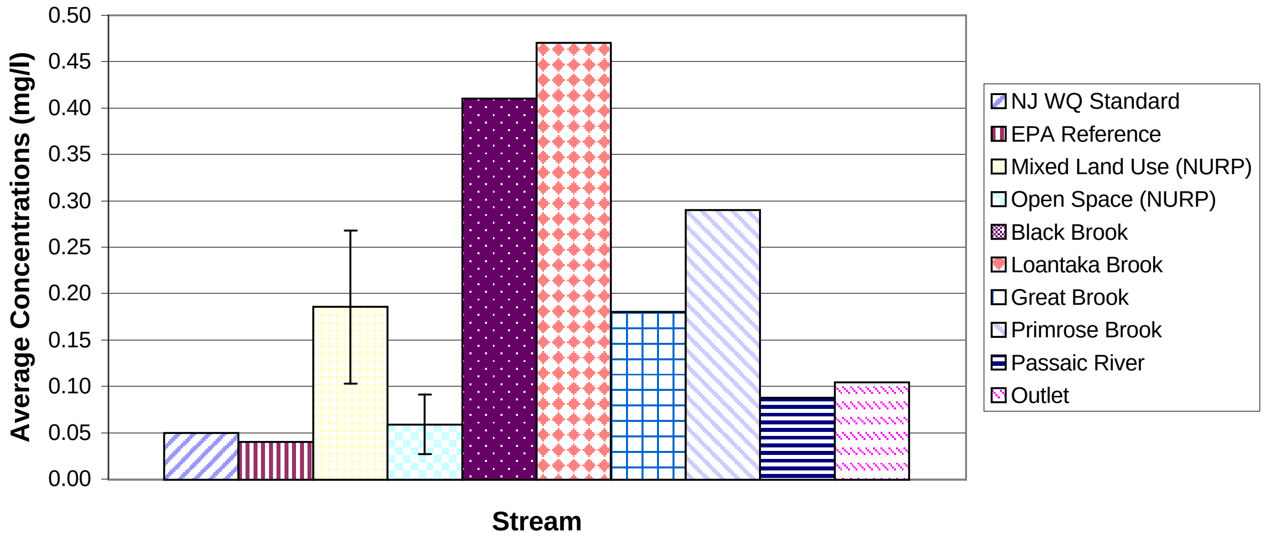
Table C5: Stormflow Total Nitrogen Concentrations

Stream	Average Concentration (mg/l)	Median Concentration (mg/l)	Range of Concentrations (mg/l)
NJ WQ Standard	not available	–	–
EPA Reference	1.295/2.225	–	–
Mixed Land Use (NURP)	not available	–	–
Open Space (NURP)	not available	–	–
Black Brook	2.02	1.88	0.73 – 4.43
Loantaka Brook	4.91	4.58	2.29 – 8.15
Great Brook	1.52	1.48	0.89 – 3.06
Primrose Brook	1.50	1.20	0.20 – 4.48
Passaic River	0.93	0.75	0.39 – 1.78
Outlet	0.99	0.90	0.36 – 1.72

Table C6: Stormflow Total Suspended Solids Concentrations

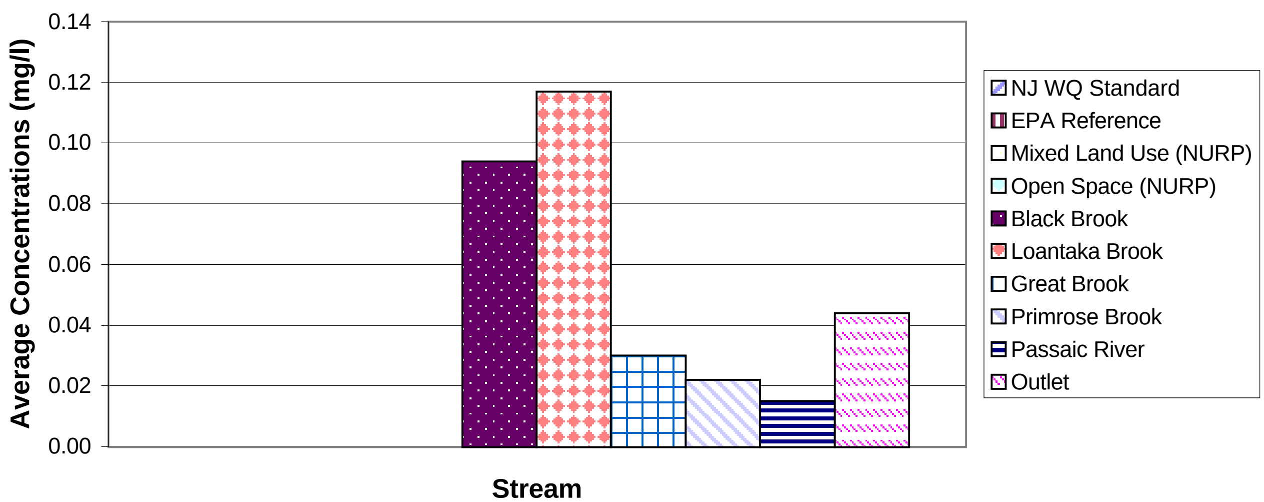
Stream	Average Concentration (mg/l)	Median Concentration (mg/l)	Range of Concentrations (mg/l)
NJ WQ Standard	25/40	–	–
EPA Reference	not available	–	–
Mixed Land Use (NURP)	46 – 68	43 – 61	–
Open Space (NURP)	17 – 64	6 – 26	–
Black Brook	119	100	18 – 277
Loantaka Brook	136	108	27 – 276
Great Brook	55	43	12 – 137
Primrose Brook	148	61	10 – 738
Passaic River	23	19	3 – 100
Outlet	10	10	7.5 – 13

Figure C1: Stormflow Total Phophorus Concentrations



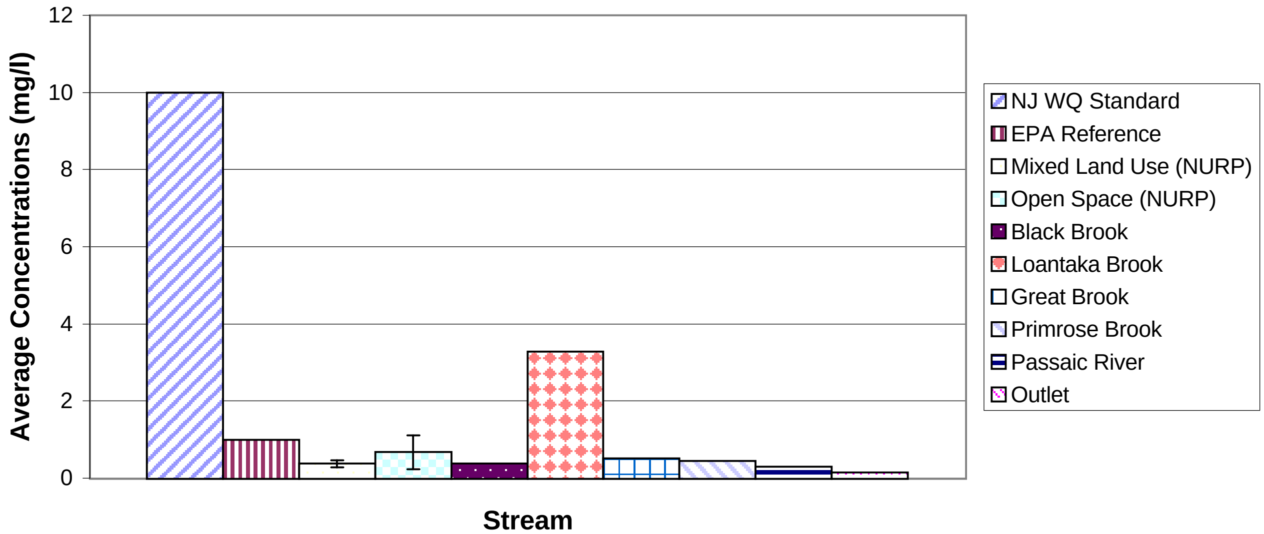
Bars indicate the ranges of NURP concentrations.

Figure C2: Stormwater Dissolved Reactive Phosphorus Concentrations



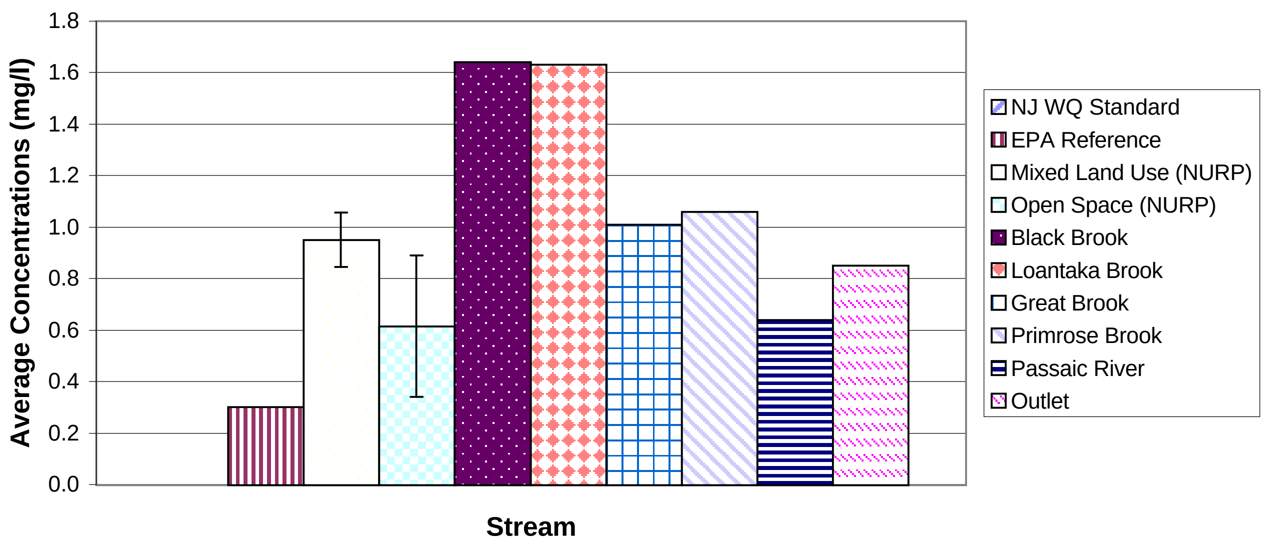
There are no New Jersey Water Quality Standard, EPA Reference Criterion, or NURP concentrations for this parameter.

Figure C3: Stormflow Nitrate Concentrations



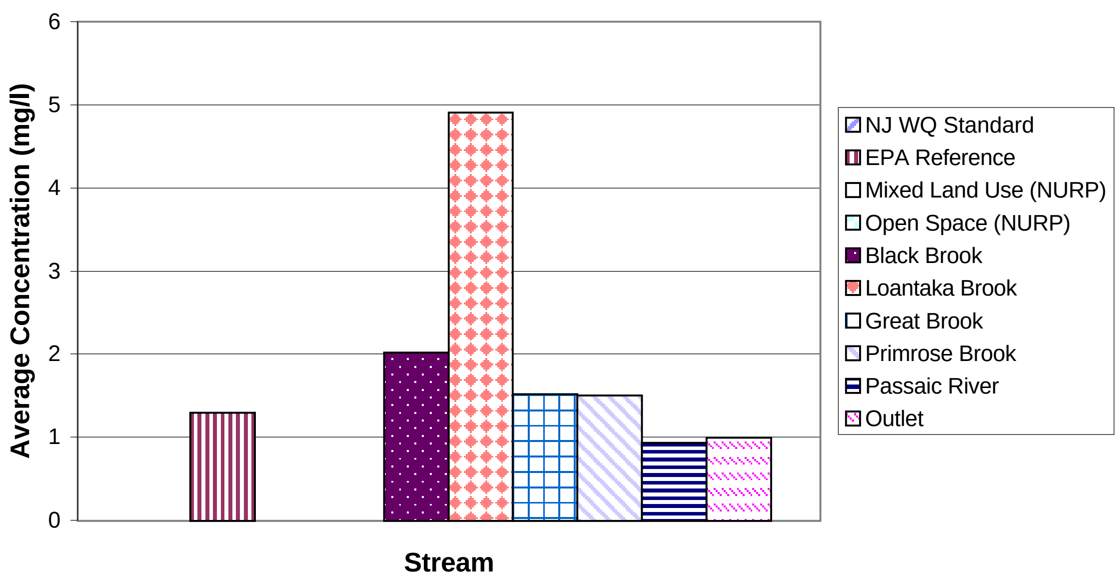
Bars indicate the ranges of NURP concentrations.

Figure C4: Stormflow Total Kjeldahl Nitrogen Concentrations



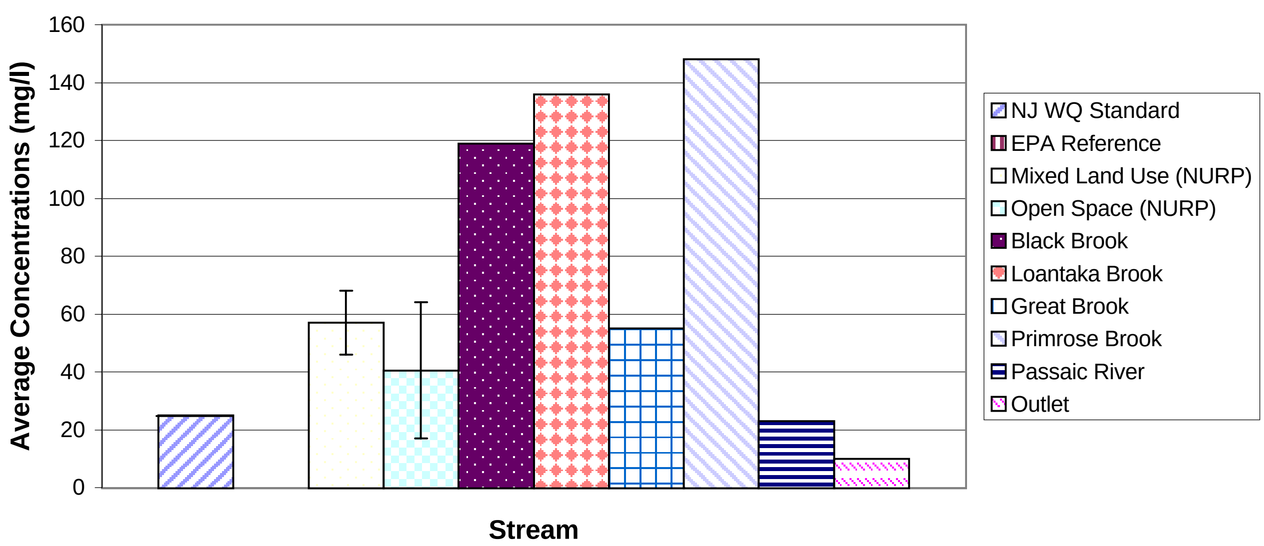
There is no New Jersey Water Qualtiy Standard for this parameter.
Bars indicate the ranges of NURP concentrations.

Figure C5: Stormflow Total Nitrogen Concentrations



There are no New Jersey Water Qualtiy Standard or NURP concentrations for this parameter.

Figure C6: Stormflow Total Suspended Solids Concentrations



There is no EPA reference criterion for this parameter.
Bars indicate the ranges of NURP concentrations.

APPENDIX D

Table D1: Year One Total Phosphorus Loads

Stream	Baseflow Load (lbs)	Stormflow Load (lbs)	Total Load (lbs)	Loading Rate (lbs/acre/year)
Black Brook	85	127	212	0.891
Loantaka Brook	2,384	2,609	4,993	1.785
Great Brook	953	1,700	2,653	0.515
Primrose Brook	150	1,184	1,334	0.490
Passaic River	1,578	1,616	3,194	0.493
Tributary Total	5,150	7,236	12,386	0.712
Outlet	–	–	17,798	0.513

Table D2: Year Two Total Phosphorus Loads

Stream	Baseflow Load (lbs)	Stormflow Load (lbs)	Total Load (lbs)	Loading Rate (lbs/acre/year)
Black Brook	88	203	291	1.223
Loantaka Brook	3,723	3,069	6,792	2.428
Great Brook	991	1,974	2,965	0.575
Primrose Brook	591	910	1,501	0.551
Passaic River	1,997	1,348	3,345	0.516
Tributary Total	7,390	7,504	14,894	0.856
Outlet	–	–	14,588	0.420

Table D3: Year One Dissolved Reactive Phosphorus Loads

Stream	Baseflow Load (lbs)	Stormflow Load (lbs)	Total Load (lbs)	Loading Rate (lbs/acre/year)
Black Brook	42	24	66	0.277
Loantaka Brook	1,480	790	2,270	0.812
Great Brook	278	255	533	0.103
Primrose Brook	66	131	197	0.072
Passaic River	460	290	750	0.116
Tributary Total	2,326	1,490	3,816	0.219
Outlet	–	–	7,707	0.222

Table D4: Year Two Dissolved Reactive Phosphorus Loads

Stream	Baseflow Load (lbs)	Stormflow Load (lbs)	Total Load (lbs)	Loading Rate (lbs/acre/year)
Black Brook	38	39	77	0.324
Loantaka Brook	2,288	929	3,217	1.150
Great Brook	356	296	652	0.127
Primrose Brook	224	101	325	0.119
Passaic River	692	242	934	0.144
Tributary Total	3,598	1,607	5,205	0.299
Outlet	–	–	4,666	0.134

Table D5: Year One Nitrate Loads

Stream	Baseflow Load (lbs)	Stormflow Load (lbs)	Total Load (lbs)	Loading Rate (lbs/acre/year)
Black Brook	100	103	203	0.853
Loantaka Brook	81,438	18,742	100,181	35.817
Great Brook	11,460	5,099	16,560	3.213
Primrose Brook	2,330	2,555	4,886	1.794
Passaic River	16,085	5,388	21,474	3.311
Tributary Total	111,413	31,887	143,304	8.237
Outlet	–	–	21,202	0.611

Table D6: Year Two Nitrate Loads

Stream	Baseflow Load (lbs)	Stormflow Load (lbs)	Total Load (lbs)	Loading Rate (lbs/acre/year)
Black Brook	201	164	366	1.54
Loantaka Brook	107,163	22,051	129,214	46.20
Great Brook	7,297	5,922	13,220	2.57
Primrose Brook	4,484	1,963	6,447	2.37
Passaic River	14,637	4,494	19,131	2.95
Tributary Total	133,782	34,594	168,378	9.68
Outlet	–	–	18,463	0.53

Table D7: Year One Total Kjeldahl Nitrogen Loads

Stream	Baseflow Load (lbs)	Stormflow Load (lbs)	Total Load (lbs)	Loading Rate (lbs/acre/year)
Black Brook	806	417	1,223	5.14
Loantaka Brook	11,827	10,298	22,125	7.91
Great Brook	8,126	10,092	18,218	3.54
Primrose Brook	1,251	4,425	5,676	2.08
Passaic River	18,947	10,777	29,723	4.58
Tributary Total	40,957	36,009	76,966	4.42
Outlet	–	–	153,859	4.44

Table D8: Year Two Total Kjeldahl Nitrogen Loads

Stream	Baseflow Load (lbs)	Stormflow Load (lbs)	Total Load (lbs)	Loading Rate (lbs/acre/year)
Black Brook	703	667	1,370	5.76
Loantaka Brook	14,033	12,116	26,149	9.35
Great Brook	10,544	11,721	22,266	4.32
Primrose Brook	2,223	3,399	5,622	2.06
Passaic River	15,722	8,989	24,711	3.81
Tributary Total	43,225	36,892	80,117	4.60
Outlet	–	–	95,063	2.74

Table D9: Year One Total Nitrogen Loads

Stream	Baseflow Load (lbs)	Stormflow Load (lbs)	Total Load (lbs)	Loading Rate (lbs/acre/year)
Black Brook	906	520	1,426	5.99
Loantaka Brook	93,265	29,040	122,305	43.73
Great Brook	19,586	15,191	34,777	6.75
Primrose Brook	3,581	6,980	10,561	3.88
Passaic River	35,032	16,165	51,197	7.90
Tributary Total	152,370	67,896	220,266	12.66
Outlet	–	–	175,061	5.05

Table D10: Year Two Total Nitrogen Loads

Stream	Baseflow Load (lbs)	Stormflow Load (lbs)	Total Load (lbs)	Loading Rate (lbs/acre/year)
Black Brook	904	831	1,735	7.29
Loantaka Brook	121,196	34,167	155,363	55.55
Great Brook	17,841	17,643	35,484	6.88
Primrose Brook	6,707	5,362	12,069	4.43
Passaic River	30,359	13,483	43,842	6.76
Tributary Total	177,007	71,486	248,493	14.28
Outlet	–	–	113,526	3.27

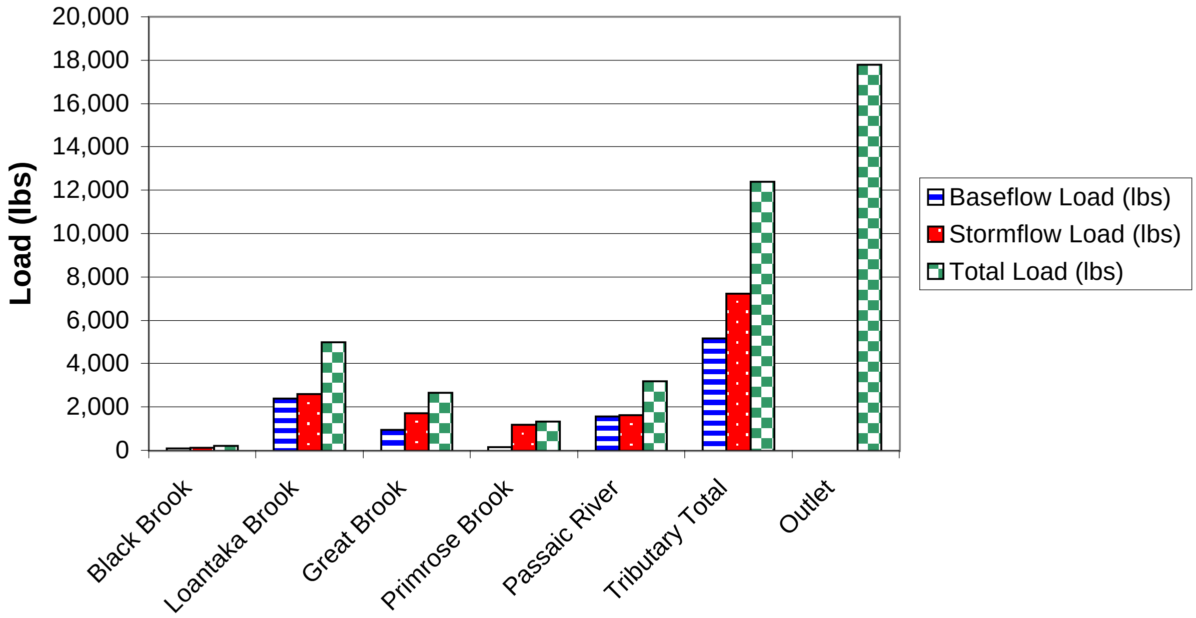
Table D11: Year One Total Suspended Solids Loads

Stream	Baseflow Load (lbs)	Stormflow Load (lbs)	Total Load (lbs)	Loading Rate (lbs/acre/year)
Black Brook	5,845	30,187	36,031	151.39
Loantaka Brook	95,784	741,457	837,241	299.34
Great Brook	75,723	456,799	532,522	103.32
Primrose Brook	20,011	380,181	400,191	146.91
Passaic River	156,576	393,760	550,336	84.86
Tributary Total	353,939	2,002,384	2,356,321	134.44
Outlet	–	–	1,342,129	38.69

Table D12: Year Two Total Suspended Solids Loads

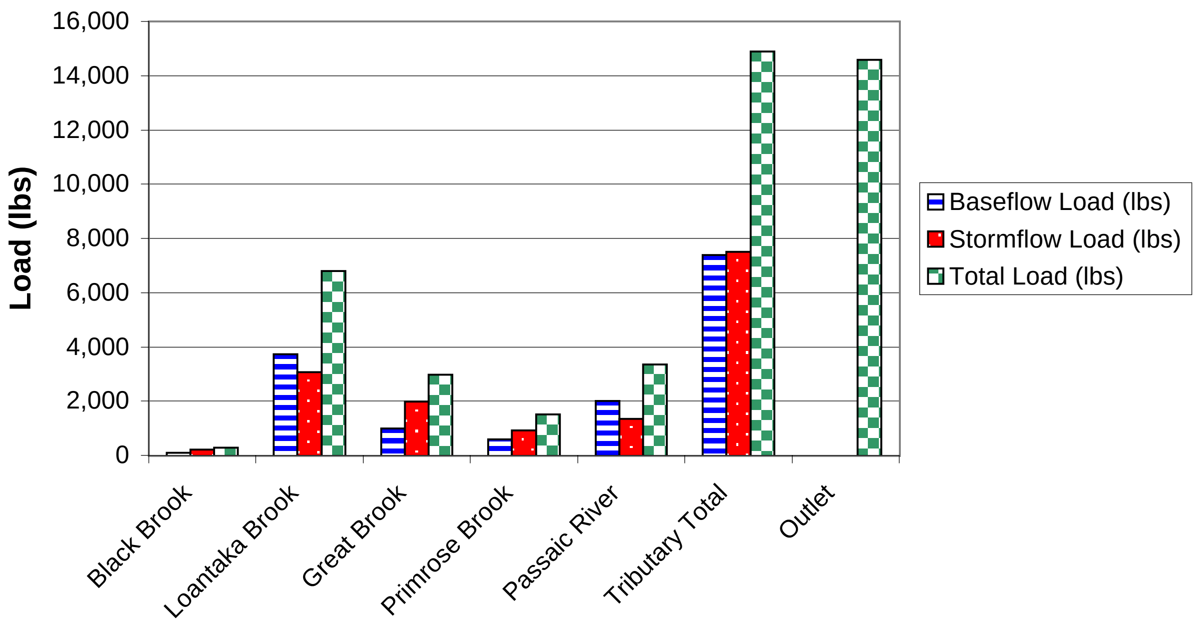
Stream	Baseflow Load (lbs)	Stormflow Load (lbs)	Total Load (lbs)	Loading Rate (lbs/acre/year)
Black Brook	4,675	48,361	53,036	222.84
Loantaka Brook	221,727	872,347	1,094,074	391.16
Great Brook	86,375	530,535	616,910	119.70
Primrose Brook	20,301	292,037	312,338	114.66
Passaic River	201,904	328,434	530,339	81.78
Tributary Total	534,982	2,071,714	2,606,697	149.83
Outlet	–	–	1,348,126	38.86

Figure D1: Year One Total Phosphorus Loads



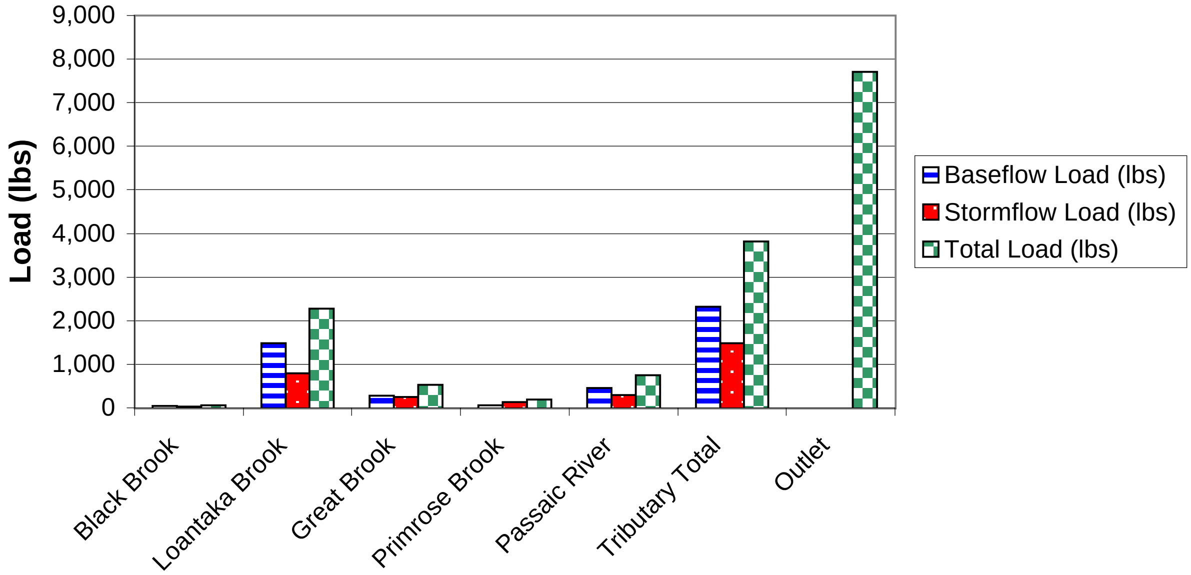
Note: Black Brook's small contribution to loading rates results from its small watershed area.

Figure D2: Year Two Total Phosphorus Loads



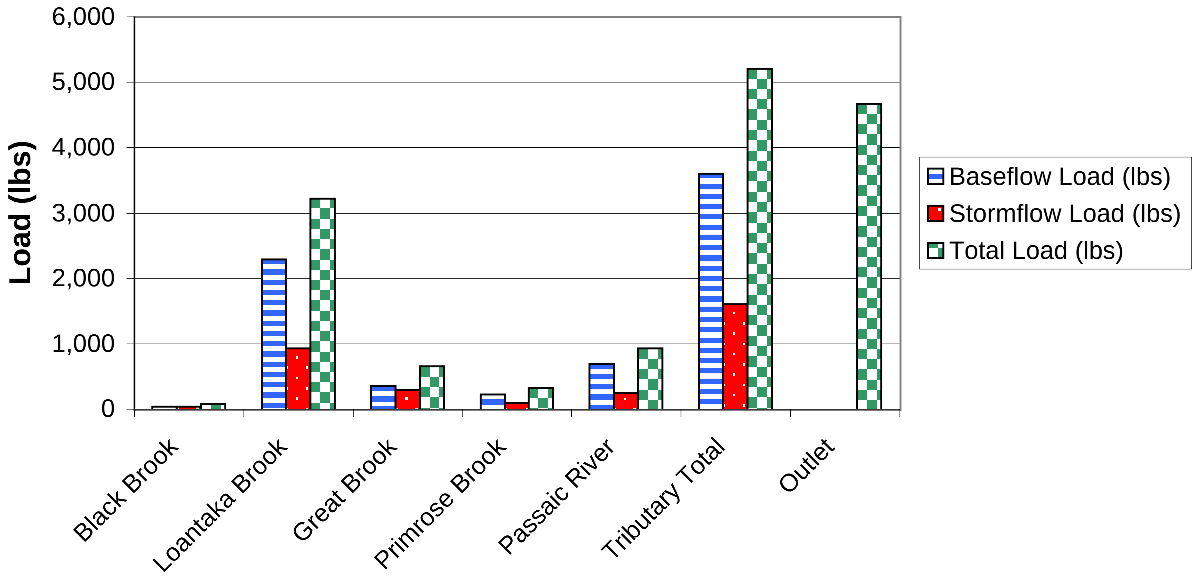
Note: Black Brook's small contribution to loading rates results from its small watershed area.

Figure D3: Year One Dissolved Reactive Phosphorus Loads



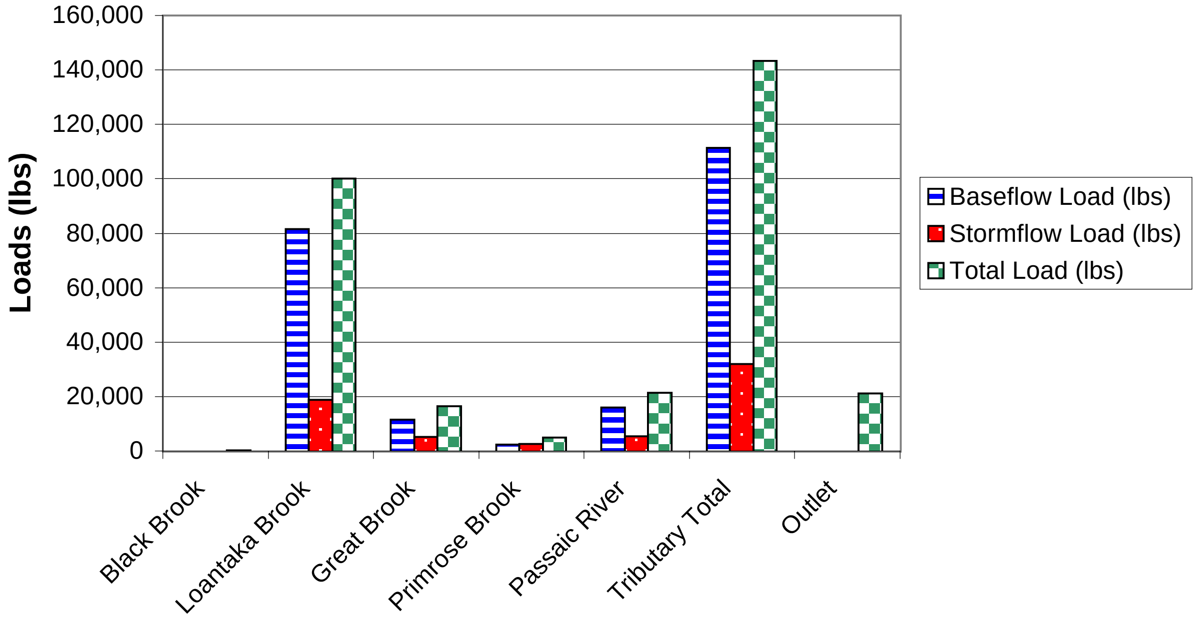
Note: Black Brook's small contribution to loading rates results from its small watershed area.

Figure D4: Year Two Dissolved Reactive Phosphorus Loads



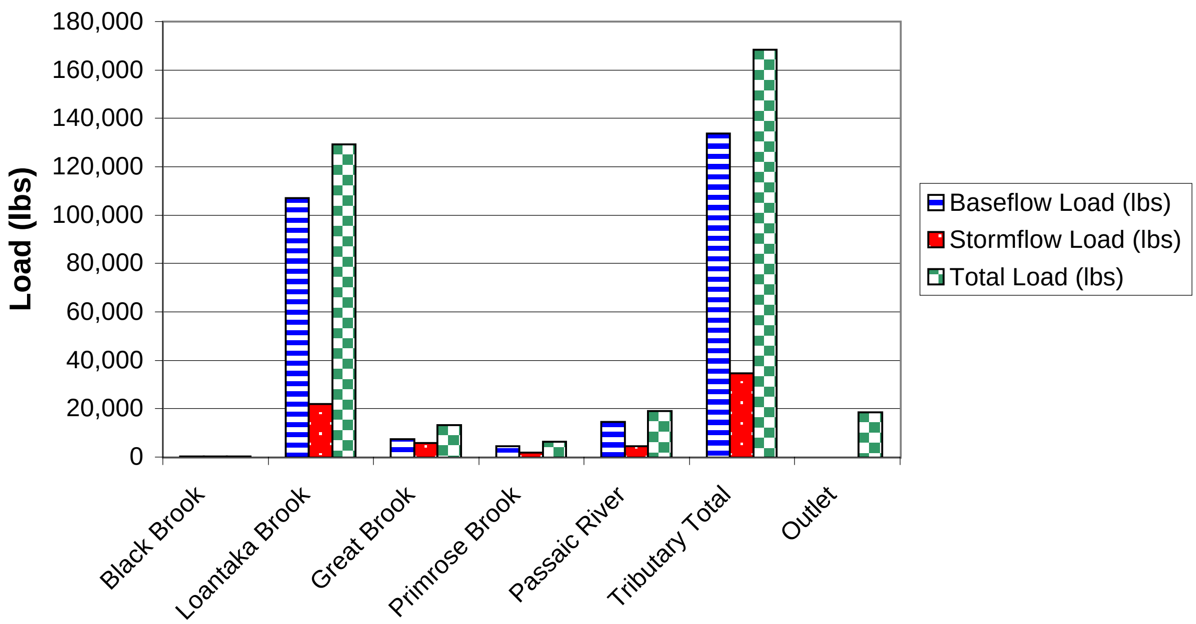
Note: Black Brook's small contribution to loading rates results from its small watershed area.

Figure D5: Year One Nitrate Loads



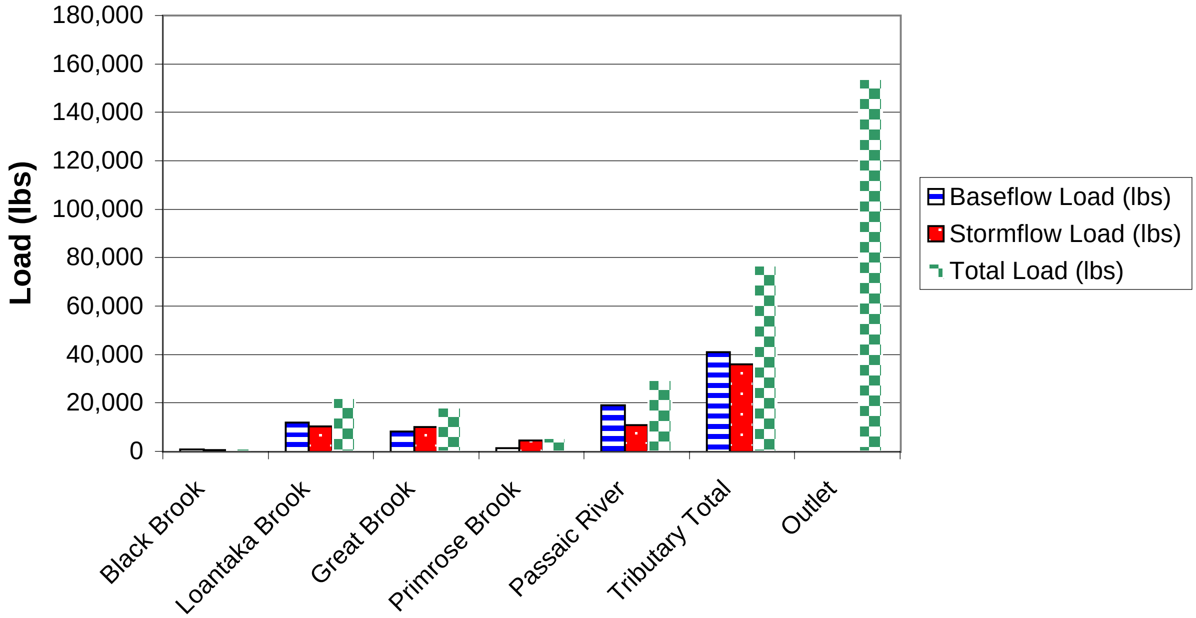
Note: Black Brook's small contribution to loading rates results from its small watershed area.

Figure D6: Year Two Nitrate Loads



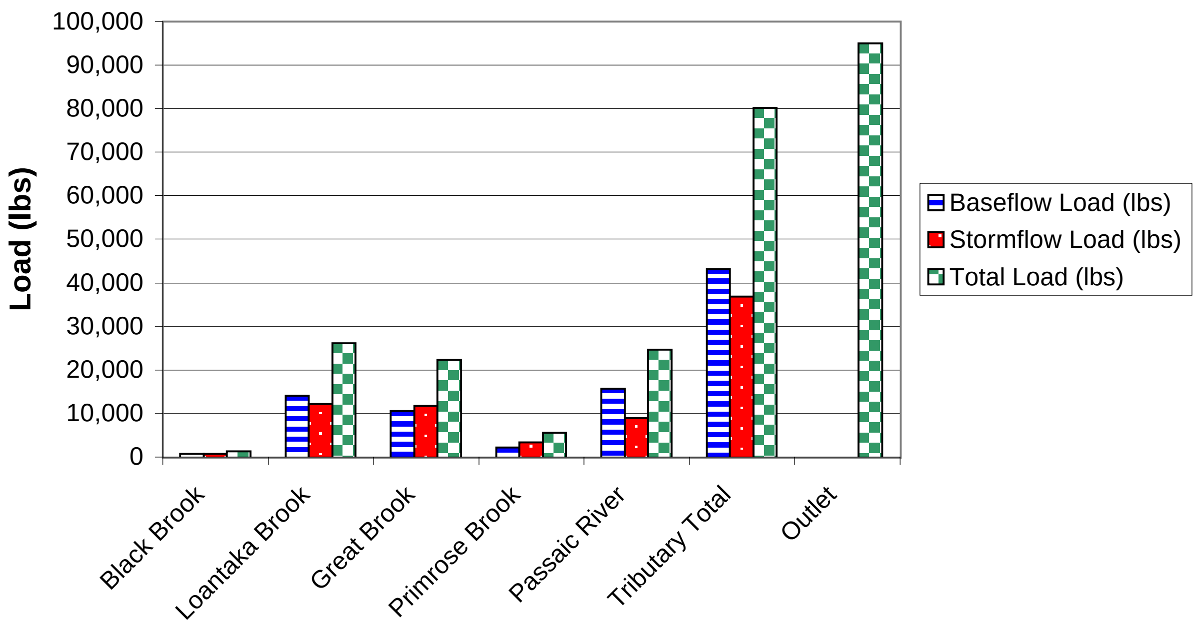
Note: Black Brook's small contribution to loading rates results from its small watershed area.

Figure D7: Year One Total Kjeldahl Nitrogen Loads



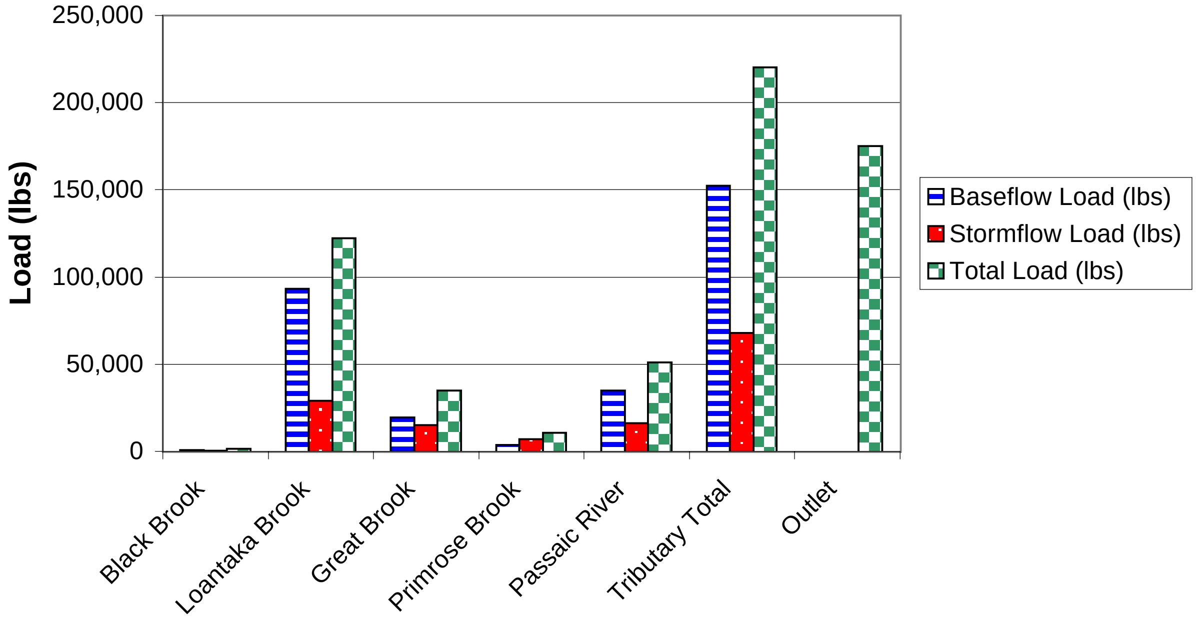
Note: Black Brook's small contribution to loading rates results from its small watershed area.

Figure D8: Year Two Total Kjeldahl Nitrogen Loads



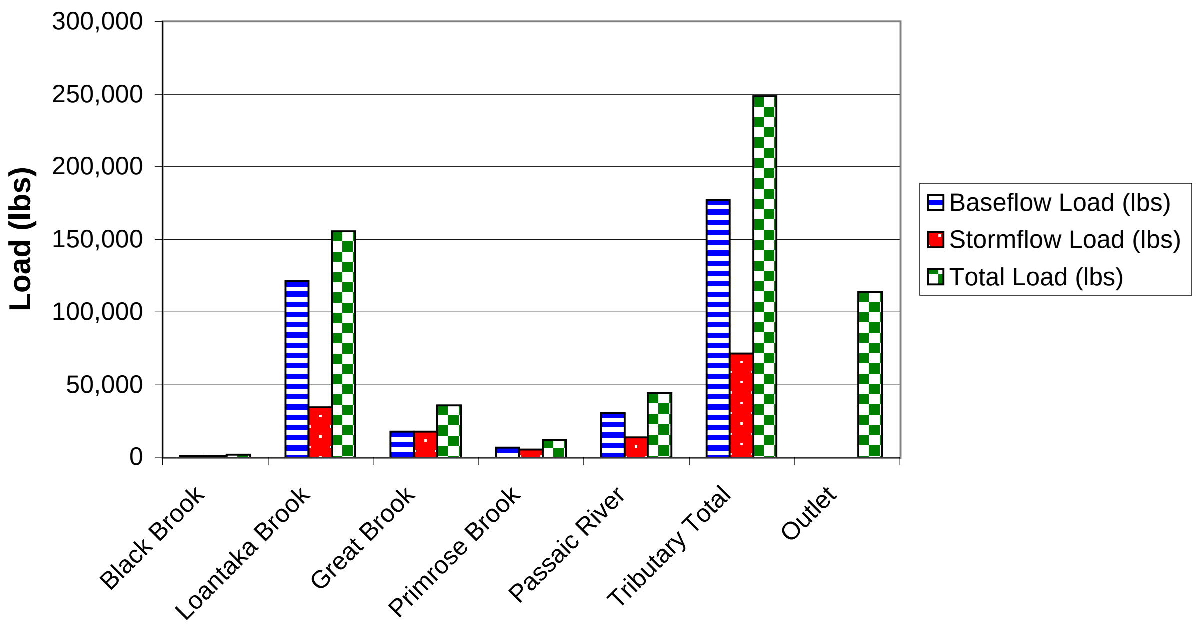
Note: Black Brook's small contribution to loading rates results from its small watershed area.

Figure D9: Year One Total Nitrogen Loads



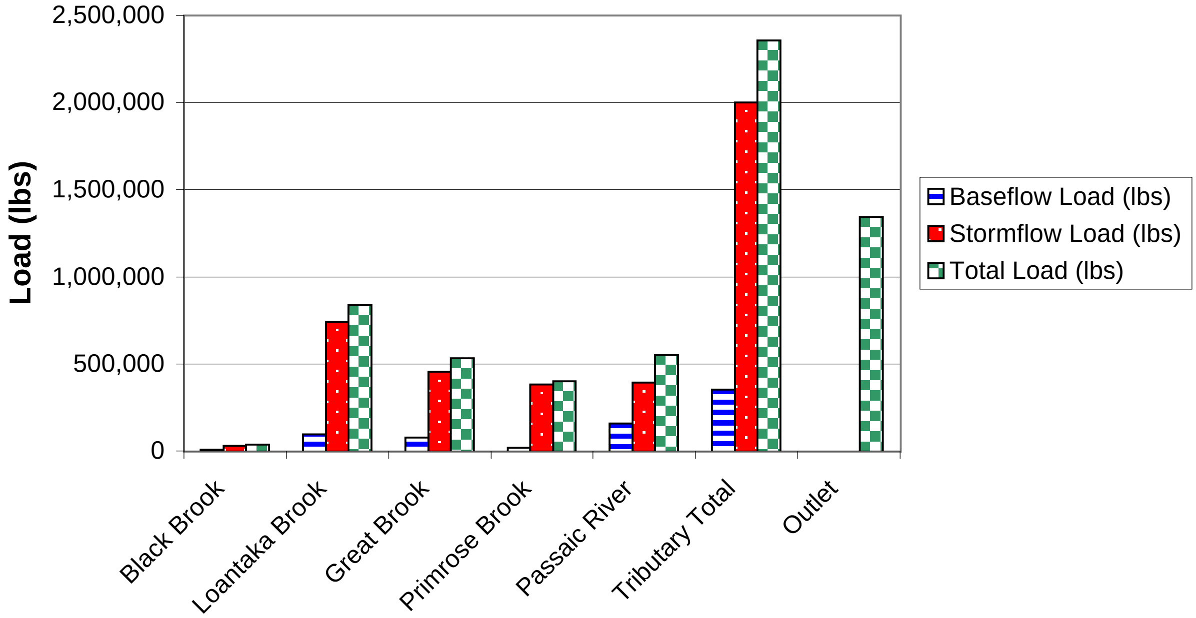
Note: Black Brook's small contribution to loading rates results from its small watershed area.

Figure D10: Year Two Total Nitrogen Loads



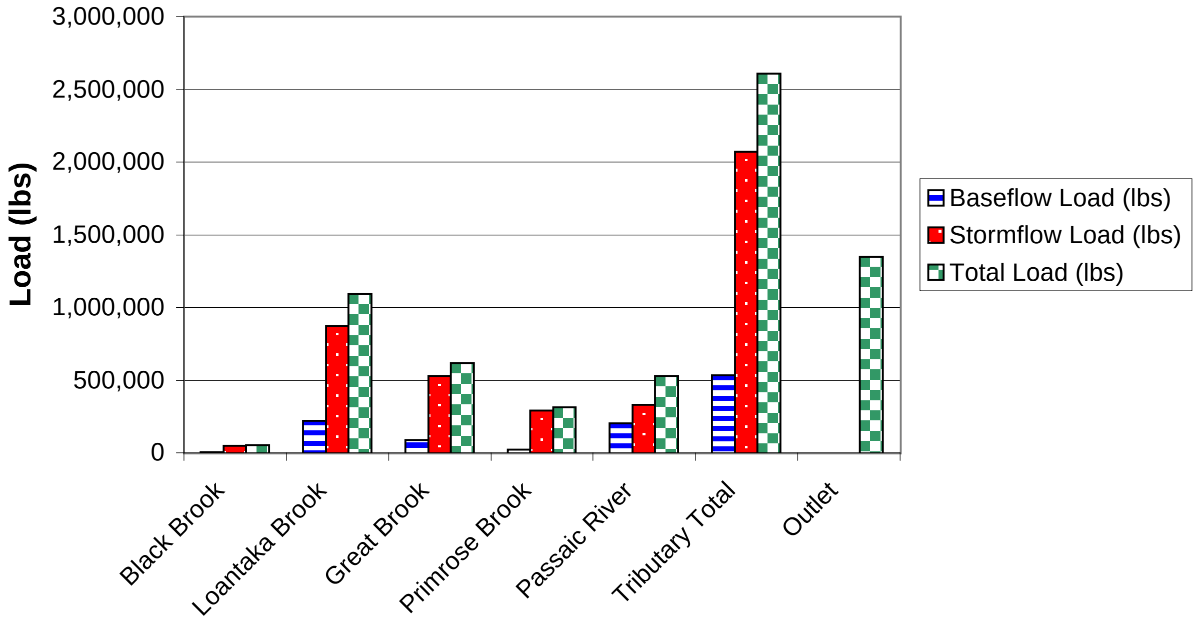
Note: Black Brook's small contribution to loading rates results from its small watershed area.

Figure D11: Year One Total Suspended Solids Load



Note: Black Brook's small contribution to loading rates results from its small watershed area.

Figure D12: Year Two Total Suspended Solids Load



Note: Black Brook's small contribution to loading rates results from its small watershed area.

APPENDIX E

Table E.1: Great Swamp Total Phosphorus Standards

Stream	Baseflow Criterion (mg/l)	Median Measured Baseflow (mg/l)	Stormflow Criterion (mg/l)	Median Measured Stormflow (mg/l)
Black Brook	0.05	0.077	0.1	0.42
Loantaka Brook	0.05	0.247	0.1	0.38
Great Brook	0.05	0.060	0.1	0.16
Primrose Brook	0.04	0.036	0.1	0.19
Passaic River	0.04	0.034	0.1	0.078

Table E.2: Great Swamp Dissolved Reactive Phosphorus Standards

Stream	Baseflow Criterion (mg/l)	Median Measured Baseflow (mg/l)	Stormflow Criterion (mg/l)	Median Measured Stormflow (mg/l)
Black Brook	0.02	0.037	0.02	0.080
Loantaka Brook	0.02	0.164	0.02	0.115
Great Brook	0.02	0.025	0.02	0.024
Primrose Brook	0.02	0.020	0.02	0.021
Passaic River	0.02	0.012	0.02	0.014

Table E.3: Great Swamp Nitrate Standards

Stream	Baseflow Criterion (mg/l)	Median Measured Baseflow (mg/l)	Stormflow Criterion (mg/l)	Median Measured Stormflow (mg/l)
Black Brook	0.2	0.07	0.5	0.34
Loantaka Brook	2.0	6.78	2.0	2.73
Great Brook	0.7	0.50	0.8	0.48
Primrose Brook	0.5	0.43	0.6	0.41
Passaic River	0.4	0.24	0.4	0.26

Table E.4: Great Swamp Total Kjeldahl Nitrogen Standards

Stream	Baseflow Criterion (mg/l)	Median Measured Baseflow (mg/l)	Stormflow Criterion (mg/l)	Median Measured Stormflow (mg/l)
Black Brook	0.4	0.69	1.0	1.38
Loantaka Brook	0.4	0.70	1.0	1.50
Great Brook	0.4	0.53	1.0	0.95
Primrose Brook	0.3	0.18	1.0	0.71
Passaic River	0.4	0.33	1.0	0.52

Table E.5: Great Swamp Total Nitrogen Standards

Stream	Baseflow Criterion (mg/l)	Median Measured Baseflow (mg/l)	Stormflow Criterion (mg/l)	Median Measured Stormflow (mg/l)
Black Brook	1.0	0.81	1.5	1.88
Loantaka Brook	2.4	7.49	3.0	4.58
Great Brook	1.3	1.13	1.8	1.48
Primrose Brook	0.8	0.61	1.6	1.20
Passaic River	0.8	0.57	1.4	0.75

Table E.6: Total Suspended Solids Standards

Stream	Baseflow Criterion (mg/l)	Median Measured Baseflow (mg/l)	Stormflow Criterion (mg/l)	Median Measured Stormflow (mg/l)
Black Brook	4.0	3.7	40	100
Loantaka Brook	4.0	8.1	40	108
Great Brook	4.0	5.0	40	43
Primrose Brook	4.0	2.5	25	61
Passaic River	4.0	3.0	25	19