State of the Streams in the Great Swamp Watershed

April 2013

Acknowledgements

Many thanks to Roger Edwards, GSWA Volunteer, and Lee Pollock, Professor Emeritus of Biology at Drew University, for their numerous contributions to this report. Thanks also go to the GSWA staff and Stream Team volunteers who gave invaluable input throughout the process. GSWA would also like to thank The Watershed Institute for funding this project to allow us to learn more about our watershed streams.

Executive Summary

The five main streams in the Great Swamp watershed have been monitored since 1999 by the Ten Towns Great Swamp Watershed Management Committee (TTC) and the Great Swamp Watershed Association (GSWA). Data from chemical and macroinvertebrate (MIV) monitoring were analyzed to determine trends in water quality in each stream over time, identify any areas of concern that have previously gone unaddressed, rank the health of watershed streams, and identify future potential actions for GSWA that would improve water quality.

MIVs at each monitoring site were collected and identified annually every spring between 2000 and 2011; the community composition was used to determine a score based on the Benthic Index of Biotic Integrity (B-IBI). The B-IBI was calculated based on eight community characteristics, each of which reflects the degree of environmental stress present. This scoring system ranked each site on a scale from very poor to good, and the scores allow for comparison at the same site over time as well as between sites that have different MIV communities. Average B-IBI scores for all sites on one stream were compared annually. All streams showed an overall upward trend during the sampling period indicating improving water quality across all streams. This is attributed to two factors; a shift in sampling date from early June to late May, and an increase in regional precipitation over the period. Averaged stream B-IBIs also showed differences between the streams with Primrose Brook and the Passaic River consistently having significantly higher average B-IBI scores than Great Brook, Loantaka Brook, and Black Brook.

Chemical monitoring was conducted during 1999-2008 by TTC at six sites around the watershed; one per stream and one at the outlet of the watershed. Additional GSWA monitoring was conducted at multiple sites along Loantaka Brook (2005-2007), Great Brook (2008-2010), and the Passaic River (2011-2012). This data was analyzed for total phosphorus (TP), dissolved reactive phosphorus (DRP), total nitrogen (TN), total dissolved solids (TDS), and total suspended solids (TSS). TP and DRP were both highest during summer at all sites, likely due to fertilizer usage. Fertilizer usage is also the likely cause of high summer TN seen at several sites. Other sites had the highest average TN during the winter, possibly due to an influx from decaying leaves and organic matter during winter snowmelt. TDS values peaked during the winter, but some sites saw increases in TDS again during the summer, illustrating that TDS can bind to soil particles for slow release during precipitation. TSS remained low at all sites with a few spikes due to rain events.

Both MIV and chemical monitoring showed similarities in water quality between the streams. Primrose Brook consistently ranked highest, followed by the Passaic River, and Great Brook, with Black Brook and Loantaka Brook as the poorest quality streams. Topography and development play major roles in this ranking; streams in the western portion of the watershed (the Passaic River and Primrose Brook) have a higher stream gradient and less development, while the remaining three in the eastern portion of the watershed have a lower stream gradient and more development.

Common pressures on streams include golf courses, road salt, stormwater runoff, impoundments, and development. Recommendations to reduce these impacts are given for GSWA, landowners, and watershed municipalities. GSWA should develop relationships with watershed golf courses to reduce their fertilizer and pesticide usage; continue to educate local municipalities and contractors about the benefits of using salt brine and smart road salting techniques; and continue and expand educational programming about controlling stormwater runoff. Landowners are encouraged to install riparian buffers around ponds, lakes, and streams. Municipalities must be vigilant about future development to minimize impacts to watershed streams.

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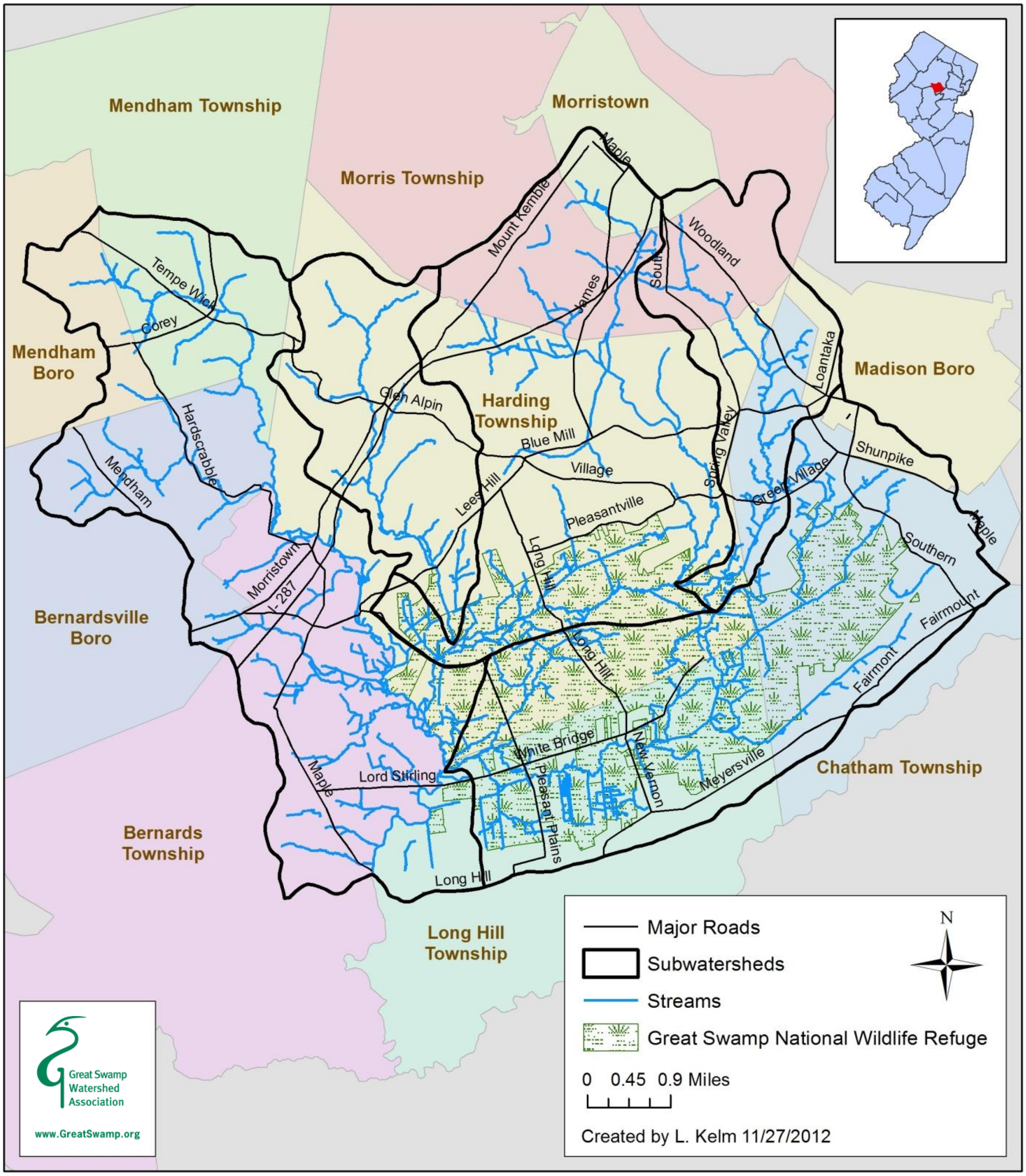

Figure 1. Map of The Great Swamp Watershed
The 55-square mile watershed is at the headwaters of the Passaic River and includes five main streams, parts of ten towns, and the Great Swamp National Wildlife Refuge.

1.0 Introduction

The Great Swamp watershed is a 55-square-mile region in Morris and Somerset Counties, and includes portions of ten different towns. The five main streams in the watershed - the Passaic River, Primrose Brook, Great Brook, Loantaka Brook, and Black Brook - all flow into the Great Swamp National Wildlife Refuge and exit as the Passaic River via Millington Gorge. **Figure 1** shows the location of the Great Swamp watershed, its streams, and municipalities.

Water quality in the five streams has been monitored at sites around the watershed since 1999 by the Ten Towns Great Swamp Watershed Management Committee (TTC) and the Great Swamp Watershed Association (GSWA). This water quality monitoring includes chemical monitoring (1999-present), macroinvertebrate monitoring (2000-present), and visual stream assessments (2004-present). Locations of monitoring sites can be seen in **Figure 2**.

Chemical monitoring data gives information about components in the water, such as nutrients and sediment. This is useful for learning about water quality on a short timescale as monitoring results give a snapshot of the water at the sampling site when the sample was taken.

Macroinvertebrate (MIV) monitoring looks at the MIV community at a site to give an idea of water quality over a broader time scale. MIVs are small and cannot easily move to avoid adverse environmental conditions; therefore the community composition at a site is affected by the water quality over a period of time.

Visual assessments take a holistic approach to stream health looking at factors both in the stream, such as algae, and around the stream, such as nearby land uses.

Although these different types of data have been collected around the watershed for the last 13 years, they have not been looked at comprehensively. This report aims to do that by comparing different types of monitoring data to parse out real causes for water quality decline or improvement.

The goals of this report are to:

- Look for relationships between different types of data. Can visual assessments give clues to changes in a chemical parameter over time? Do changes in the macroinvertebrate community over time reflect changes in a chemical parameter?
- Determine the current quality of the streams within the watershed and how this has changed over time
- Note any pollutants of concern that have previously gone unaddressed
- Rank the health of streams within the watershed. Are some streams of higher quality than others? Why?
- Identify potential future actions for GSWA, including educational programming topics, restoration projects, and areas for future organizational attention.

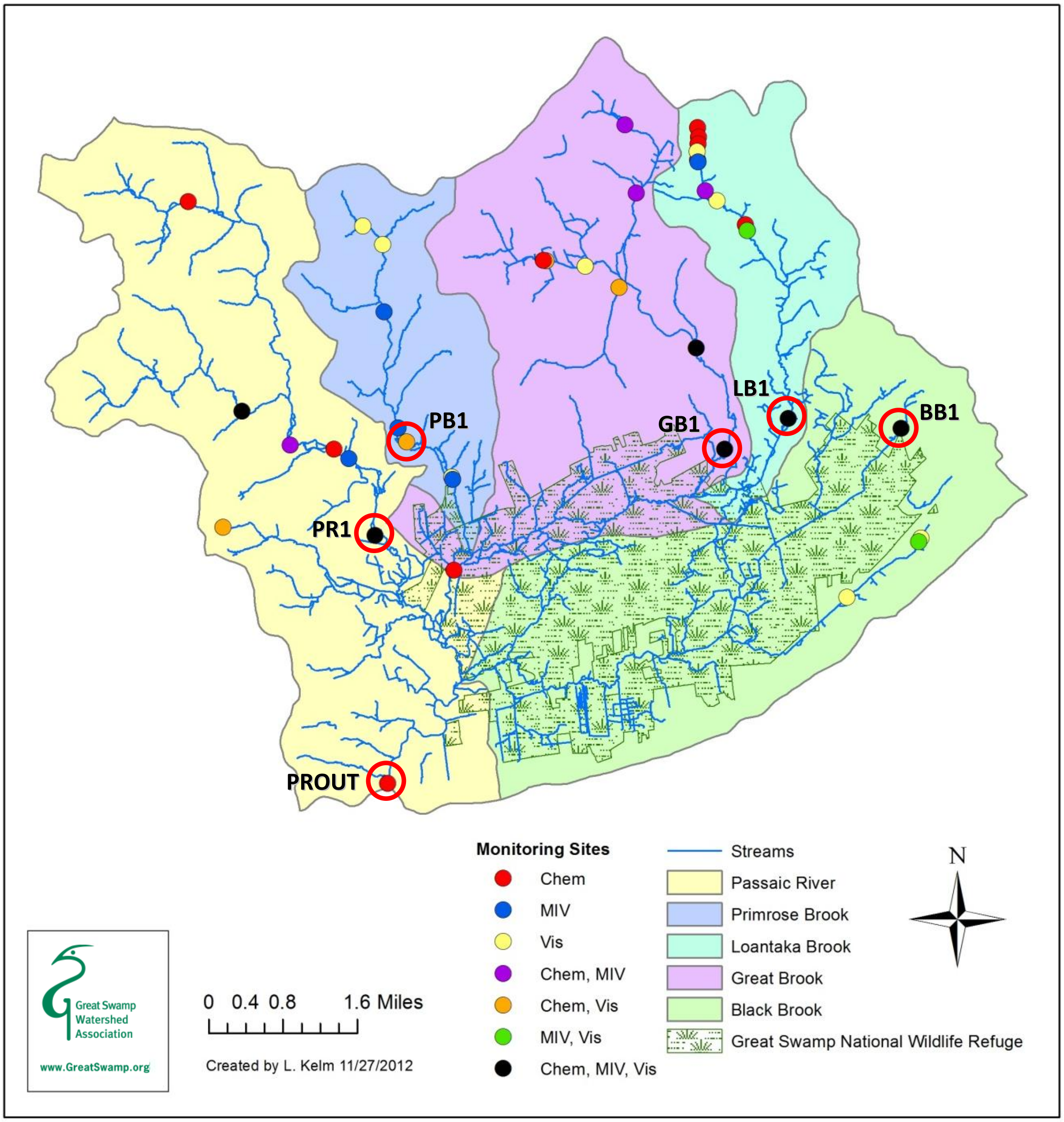

Figure 2. Water Monitoring Sites in the Great Swamp Watershed
There are over 30 stream monitoring sites in the watershed which have been monitored for any combination of chemical, macroinvertebrate, and visual data. The red circles show the 6 sites that are the focus of this report as they are the original TTC monitoring sites and chemical data is available at all these sites dating back to 1999.

2.0 Project Scope

Data analyzed for this report was collected under the auspices of the TTC (1999-2008) and GSWA (2005-2012) at six sites throughout the watershed; one on each of the five streams plus a sixth at the outlet of the watershed at Millington Gorge (**Figure 2**). Data collected at additional sites by GSWA or during the annual MIV survey is included in the analysis when practical to give a more comprehensive understanding of each stream. When available, data collected by the U.S. Geological Survey (USGS) at various sites around the watershed was used to enhance our understanding of long-term trends. USGS discharge data collected at the outlet of the watershed[1] was also incorporated. Data collected during storm flow periods was not included in this report but will be analyzed and incorporated into a future report. (Storm flow conditions result when 0.5 inches of precipitation or more occur during the 48 hours prior to sampling.)

While visual assessment data is extremely useful to GSWA in assessing stream health, it failed to provide insight into changes in the chemical or macroinvertebrate data during analysis. Therefore information collected during visual assessments is not included in this report.

3.0 Macroinvertebrates

One way to monitor overall environmental quality in the Great Swamp watershed is by evaluating the composition of macroinvertebrate communities that occur in the five major streams that drain it. Macroinvertebrates (MIVs) are small animals living on or in stream bottoms such as insect larvae, worms, and crayfish. MIVs live only for a short period of time (a few weeks to a few years depending on the species), and different species have different levels of tolerance for water pollution. These small animals generally have limited or no mobility, so unlike fish, they cannot move to locations with more suitable conditions. Looking at the types and numbers of MIVs found at a stream site reveals a lot about its water quality over a period of time.

Physical (i.e. erosion-delivered sediments) and chemical (i.e. road salts, nutrients, and other pollutants) alterations within the watershed area tend to become focused in streams as precipitation rinses the surrounding terrain and collects in downhill flow patterns. Variability in climatic determinants such as average temperature and rainfall can directly alter in-stream conditions as well. Impoundments and related activities (such as dredging and nutrient enrichment) also influence downstream locations. Conditions that elevate water temperatures, reduce oxygen availability, raise the content of dissolved chemicals, or add fine sediments to streams create stressful conditions for inhabitants like MIVs. Whatever the sources of stress may be, it is the combination of conditions flowing over time past any given stream location that determines which biological organisms will survive and thrive there. Examining the existing MIV community at a given spot over time offers a reflection of the stability or variability in conditions in the upstream terrain. Because survival requires that tolerable conditions exist over the life-span of the resident fauna, one-time biological sampling informs us about a span of recent history in the area. This information can be a valuable supplement to instantaneous information about conditions made available through chemical monitoring.

[1] USGS site 01379000 at Millington Gorge (same as the TTC/GSWA site PROUT)

Macroinvertebrate communities at 17 sites around the watershed (**Figure 2**) have been monitored annually since 2000 using the methods detailed in Pollock 2000 and Pollock 2012. At each site, the collected species are identified and the community composition is used to determine a score based on the Benthic Index of Biotic Integrity (B-IBI). The B-IBI is calculated based on eight community characteristics, each of which reflects the degree of environmental stress present. This scoring system allows for comparison at the same site over time as well as between sites that have different MIV communities. B-IBI scores can range from 8 to 40. Higher B-IBI numbers indicate higher water quality.

To look at B-IBI changes over time and determine if trends are present at a specific site, the score at each site was averaged and the standard deviation calculated. Statistically, 66% of values should fall within one standard deviation from the mean, so any values falling above or below can be considered outliers and can reveal trends or anomalies. Reviewing outlying B-IBI scores shows that low outlying scores occur primarily during earlier sampling years and high outlying scores are more frequent during later sampling years. This suggests an improvement in B-IBI scores at all sites since 2000.

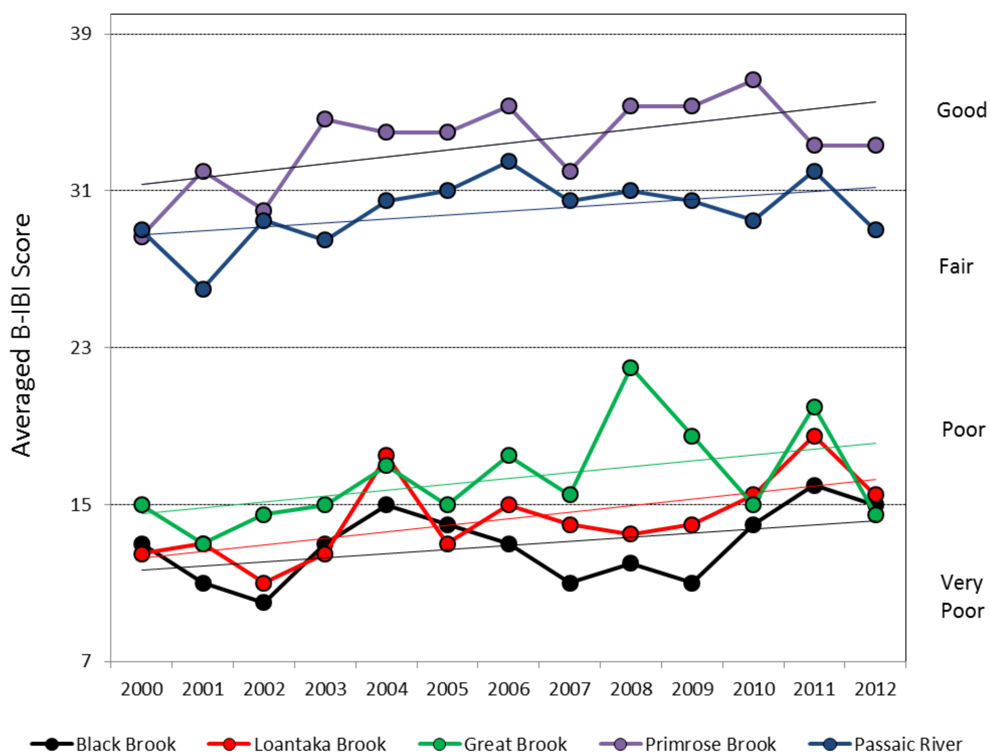

Figure 3. Averaged Annual B-IBI Scores by Stream
The Benthic Index of Biotic Integrity (B-IBI) scores at all sites on the same stream were averaged for each year between 2000 and 2012. All streams show an increasing B-IBI trend over this time period. (Pollock 2013)

Overall, improving B-IBI results are affirmed by looking at the stream-wide averaged B-IBI values over time (**Figure 3**). While average scores for each stream show some variability from year to year, all streams show an improving trend. There are two factors that would impact all streams in the watershed and are likely contributing to this improving trend: precipitation patterns and sampling date. Since 1900, annual precipitation has shown an increasing trend (though shorter-term patterns of drier and wetter weather are present as seen in **Figure 4**). During the period of MIV monitoring (2000-2011) we have transitioned from a relatively dry period during the early 2000s into a distinctly wetter period beginning around 2003. While precipitation events can be spotty and affect small areas, we often see larger storm systems with a regional affect. These regional storms may help improve conditions at sites throughout the watershed by introducing additional fresh water into streams and diluting any pollutants.

In addition to showing overall stream improvement, **Figure 3** also illustrates the disparity between streams in the watershed: streams in the western portion of the watershed (Primrose Brook and the Passaic River) consistently have higher B-IBI scores than their eastern counterparts (Great Brook, Loantaka Brook, and Black Brook). This trend is discussed in greater detail in Section 5.0.

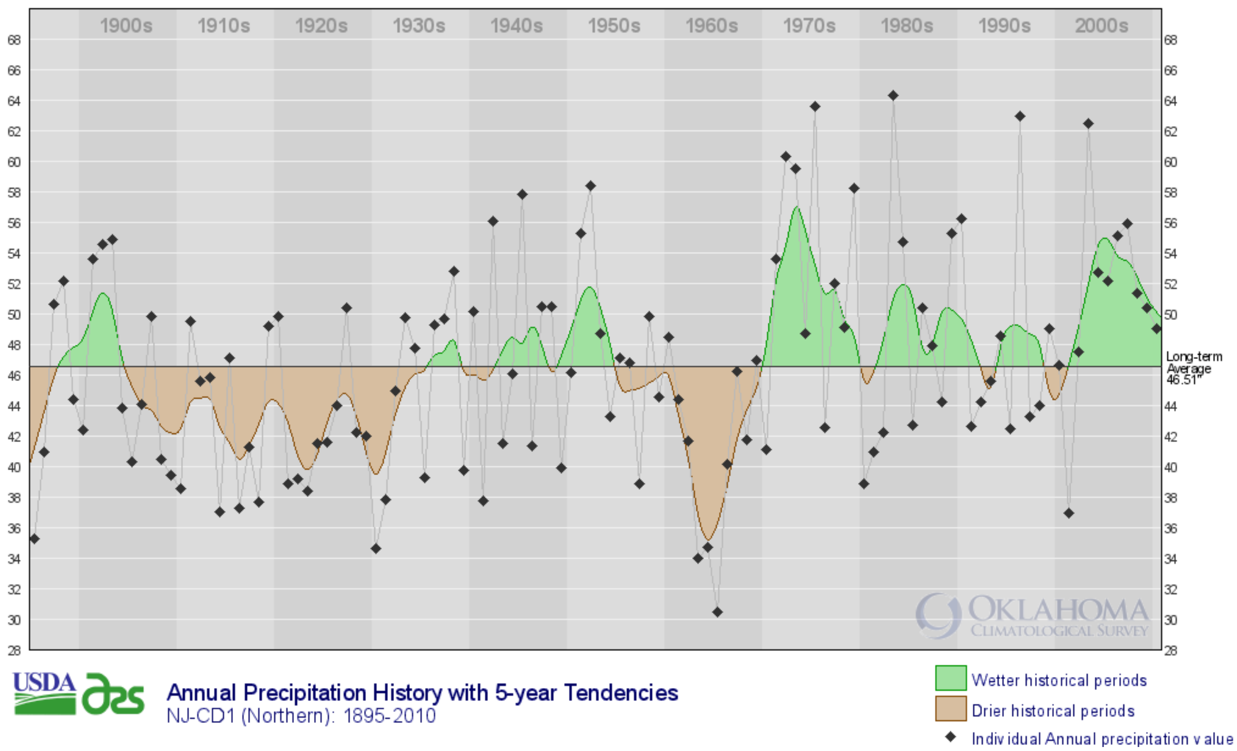

Figure 4. Annual Precipitation in Northern New Jersey, 1900-2010
Increasing precipitation from the beginning of the MIV sampling period in 2000 through 2011 can help explain the improvements seen in macroinvertebrate communities across the watershed. Although the annual precipitation in 2008-2010 declined, it is still above both the long-term average (46.51 inches) and the amounts seen in 2000-2002. (Office of the N.J. State Climatologist 2012)

The MIV sampling date also has the potential to affect B-IBI scores at sites throughout the watershed. From 2000 through 2005, MIV sampling was conducted in early June. Beginning in 2006, the sampling date was shifted to late May. This earlier sampling date may be closer to the varying date when some MIV species metamorphose into adults and leave their stream habitats. Sampling a few weeks earlier may capture additional species before they become terrestrial adults. Trends in outlying B-IBI scores also show evidence of the sampling date shift as most low outlying B-IBI scores occur 2000-2005 and most high outlying B-IBI scores occur 2006-2011. This shift has also been found to be a likely cause of variability in B-IBI scores at Great Brook sites (**Figure 5**).

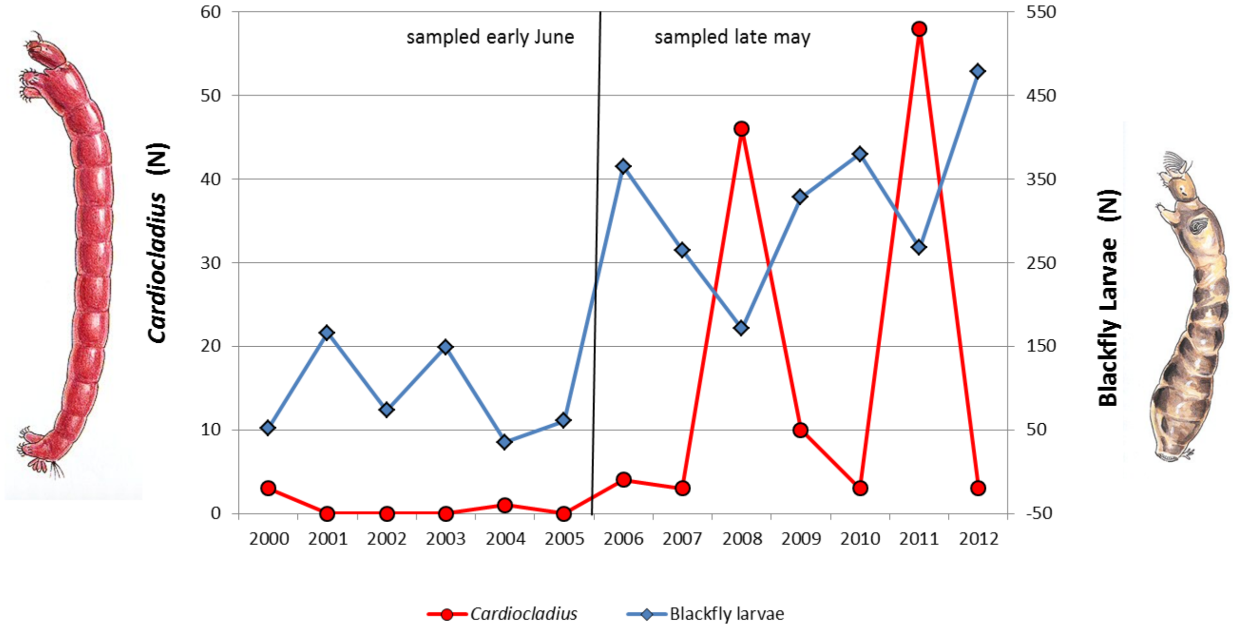

Figure 5. Predator-Prey Relationship at Great Brook Macroinvertebrate Sites
Populations of the predatory midge larvae *Cardiocladius obscurus* and its prey, the blackfly larvae, show an inverse relationship. This is especially evident beginning in 2006 when MIV sampling shifted from early June to late May (closer to the varying point of blackfly metamorphosis from larvae to adults). This means there are more blackfly larvae in samples beginning in 2006, so its relationship to *C. obscurus* is more evident. Graph created by L. Pollock, 2013.

Great Brook is one of the poorer quality streams in the watershed, but its sites' B-IBI scores vary from year to year (variability in average B-IBI scores, especially since 2006, can be seen in **Figure 3**). Investigation into the B-IBI scoring components showed that much of the variability was caused by a relationship between the predatory midge larvae *Cardiocladius obscurus* and its prey, the blackfly larvae. Predator and prey populations tend to show an inverse relationship: when the prey population is large, the predator population increases. The resulting decrease in the prey population, in turn, leads to a population decline among the predators. Over time, the prey population will recover and the cycle will begin again. The relationship between this blackfly and midge larvae show such a pattern (**Figure 5**). This influences several factors used to calculate the B-IBI score, which causes the score to fluctuate[2]. A similar relationship between these two species is also seen at Primrose Brook and somewhat at Passaic River sites, though the numbers of blackfly and midge larvae are much lower. Although the blackfly larvae are present at sites on Black Brook and Loantaka Brook, the midge larvae are not[3], so the relationship is not seen in those streams. Not enough is known about the biology of *Cardiocladius obscurus* to explain why it is missing from Black Brook and Loantaka Brook sites.

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[2] Periods of rising predator and falling prey numbers impact the B-IBI score positively, while the converse occurs as predators decline permitting prey to flourish.

[3] *Cardiocladius obscurus* has never been seen in Black Brook MIV monitoring and only rarely seen in Loantaka Brook MIV monitoring (L. Pollock, personal communication, 2012).

Looking at B-IBI scores at all sampling sites, similarities are seen in areas where low quality MIV communities are located. Common conditions affecting MIVs include golf courses, impoundments, high concentrations of development, and a close proximity to major roads. These can lead to nutrient inputs, high water temperatures, low dissolved oxygen, increased sedimentation, and high levels of total dissolved solids from road salt. Water Pollution Control Utilities (WPCUs, also known as wastewater treatment plants) are found on Loantaka Brook and Black Brook. These utilities likely exert a negative influence on downstream MIV communities, but it is difficult to discern their exact impact as opposed to other environmental factors (including poor quality MIV habitat and pressures from road salting). This will be discussed in more detail in concert with the chemical monitoring results in Section 6.0, *Ranking the Streams*.

4.0 Chemical Monitoring

Monitoring of the chemical conditions in surface waters in the watershed began in 1999 and continued through 2008 under the guidance of the Ten Towns Great Swamp Watershed Management Committee (TTC 2008). GSWA staff and volunteers actively participated in several phases of this program, including sample collection from 1999-2005, as well as other on-site tasks. This monitoring was conducted at six sites in the watershed, one on each of the five main streams and one at the outlet of the watershed (**Figure 2**). Initial monitoring focused on components of nitrogen and phosphorus and total suspended solids. The concentration of total dissolved solids was added to this suite of parameters in 2006-2008.

Beginning in 2005, GSWA began its Adopt-a-Stream program where one stream in the watershed was "adopted" for intensive quarterly monitoring for a three-year period. Streams monitored under this GSWA program had multiple monitoring sites located throughout the reach of the stream and included TTC and MIV monitoring sites when possible. Loantaka Brook was monitored under this program during 2005-2007 (GSWA 2008), then Great Brook was monitored in 2008-2010 (GSWA 2011), and Passaic River monitoring began in 2011 and will be completed Nov. 2013 (GSWA 2012). GSWA has not yet conducted any Adopt-a-Stream chemical monitoring on Black Brook or Primrose Brook.

This report looks at the following parameters: total nitrogen, total phosphorus, dissolved reactive phosphorus, total suspended solids, and total dissolved solids. **Table 1** shows the average values for each parameter at each of the six TTC sites and the number of times each site exceeded the NJ State Surface Water Quality Standard for each parameter (N.J. Admin. Code 2011).

Parameters were analyzed separately for each of the six TTC monitoring sites, with values above or below one standard deviation from the mean being used to determine trends. Outlying values were compared to stream flow data to look for correlations between parameters and recent precipitation patterns. Data was also broken down monthly to see where seasonal variations exist.

Finally, data was compared across streams and with other monitoring data (i.e. GSWA's data at additional sites on Loantaka Brook, Great Brook, and the Passaic River, and USGS data gathered at various sites around the watershed) to look for regional or stream-specific patterns.

Monitoring Parameter		Monitoring Site					
		Loantaka Brook 1	Great Brook 1	Black Brook 1	Passaic River 1	Primrose Brook 1	Passaic River Outlet
Total Phosphorus	Average	0.167 mg/l	0.055 mg/l	0.084 mg/l	0.039 mg/l	0.037 mg/l	0.097 mg/l
	NJ State Standard	0.1 mg/l	0.1 mg/l	0.1 mg/l	0.1 mg/l	0.1 mg/l	0.1 mg/l
	No. of Exceedances	34/52 (65.4%)	1/62 (1.6%)	12/49 (24.5%)	1/55 (1.8%)	3/51 (5.9%)	21/50 (42%)
Dissolved Reactive Phosphorus	Average	0.113 mg/l	0.020 mg/l	0.035 mg/l	0.012 mg/l	0.014 mg/l	0.036 mg/l
Total Nitrogen	Average	5.926	1.217	1.037	.904	.855	1.01
Total Suspended Solids	Average	9 mg/l	6 mg/l	10 mg/l	4 mg/l	3 m/l	10 mg/l
	NJ State Standard	40 mg/l	40 mg/l	40 mg/l	40 mg/l	40 mg/l	40 mg/l
	No. of Exceedances	1/51 (2.0%)	0/60	3/46 (6.5%)	0/53	0/46	0/48
Total Dissolved Solids	Average	560 mg/l	303 mg/l	433 mg/l	188 mg/l	163 mg/l	226 mg/l
	NJ State Standard	500 mg/l	500 mg/l	500 mg/l	500 mg/l	500 mg/l	500 mg/l
	No. of Exceedances	17/27 (63.0%)	3/36 (8.3%)	5/24 (20.8%)	0/31	0/26	0/26

Table 1. Overview of Chemical Monitoring Results
Average results for each of five parameters were calculated at each of six monitoring sites in the Great Swamp watershed. The number of times that each site exceeded the NJ State Surface Water Quality Standard (NJ State Standard) provides valuable information about the water quality there. The data used to calculate the averages and number of exceedances was collected under the Ten Towns Great Swamp Watershed Management Committee (1999-2008) and Great Swamp Watershed Association (2005-2012) monitoring programs.

4.1 Nutrients

4.1.1 Nutrients: Introduction

Total nitrogen (TN), total phosphorus (TP), and dissolved reactive phosphorus (DRP) are commonly referred to as nutrients. They are essential to sustain plant and animal life, but can be problematic in high concentrations. Nutrients are often found in soils, decaying organic matter, fertilizers, and waste (both human and animal), and can be conveyed to streams through stormwater runoff, failing septic systems, effluent from wastewater treatment plants, and direct deposition (from animals such as geese or from contact with soils or decaying organic matter). Once in streams, nutrients act as fertilizers, potentially causing excessive growth of aquatic vegetation. This can make the area inhospitable to aquatic life by blocking sunlight from entering the stream and leading to low dissolved oxygen levels (a consequence of the decomposition of excess vegetation).

TP is composed of DRP and particulate phosphorus. DRP, the largest component of TP, is the amount of phosphorus dissolved in water. Particulate phosphorus is from soil particles or plant or animal matter suspended in the water. DRP is the form of phosphorus most readily available for uptake by plants so its levels are often very low but can fluctuate rapidly. TP gives a more stable measure of the phosphorus level in a stream over time.

TN includes nitrate, nitrite, and total Kjeldahl nitrogen (TKN)[4]. During the nitrogen cycle, various processes are constantly converting nitrogen between several forms including ammonia, nitrate, nitrite, and atmospheric nitrogen. During TTC and GSWA sampling, TN components have been monitored in different ways[5], so the most effective way to look at the changes in nitrogen levels over time is through changes in TN[6]. Nitrate and nitrite can become toxic to warm blooded animals at higher concentrations, decreasing the ability of blood to transport oxygen. Infants are particularly susceptible, with symptoms often referred to as "blue baby syndrome."

4.1.2 Phosphorus Results

Nutrients show seasonal variation at each site, reflecting the local conditions. Both TP and DRP are highest during the summer months at all sites (**Figure 6** and **Figure 7**). This is likely caused by fertilizer usage in the spring and summer months; excess fertilizer can be carried from lawns to nearby streams by stormwater runoff. The lowest TP values tend to occur in winter with one exception: BB1 has slightly lower TP values during spring than during winter. DRP values are lowest at all sites during winter or spring.

Figure 6 and **Figure 7** also illustrate the comparative levels of TP and DRP between sites. From these graphs it is obvious that LB1 has the highest average values of both TP and DRP with PROUT and BB1 following. As a result, LB1 exceeded the NJ State Surface Water Quality Standard (NJ State Standard; N.J. Admin. Code 2011) for total phosphorus most frequently, with 65% of samples above the standard. High rates of exceedance were also seen at PROUT (42%) and BB1 (24%). Total phosphorus is the only nutrient analyzed for this report with an NJ State Standard.

LB1, PROUT and BB1 had the majority of TP exceedances during summer months[7], further supporting the idea that spring and summer fertilizer usage is a main contributing factor to high summer phosphorus levels.

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[4] TKN includes organic nitrogen, ammonia, and ammonium.

[5] In 1999-2005, nitrates plus nitrites and TKN were monitored by TTC. In 2006-2008, nitrate, TKN, and ammonia were monitored by TTC. In 2005-2012, nitrate, nitrite, and TKN were monitored by GSWA.

[6] During 2006-2008 TTC monitoring, nitrite was not monitored. GSWA has found nitrite levels to be very low (often less than 0.1 mg/l) so TN during this time period was calculated as TKN plus nitrate.

[7] At LB1, TP exceedances occurred during every month of the year with 100% of samples taken in June through August exceeding the NJ State Standard. At PROUT, all exceedances occurred in April through September with 100% of samples taken in June through August exceeding the standard. At BB1, all exceedances occurred in May through September with 66% of samples taken in June through August exceeding the standard.

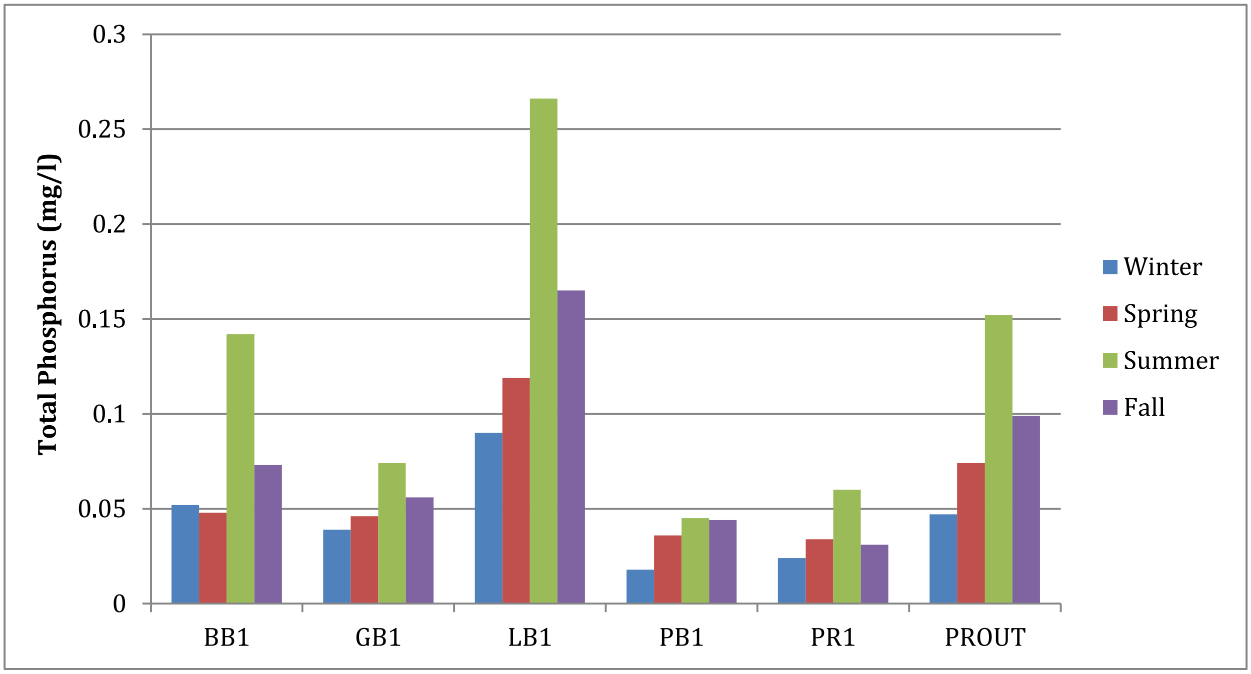

Figure 6. Seasonal Variation of Total Phosphorus
Average values for total phosphorus during each season at sites in the Great Swamp watershed. Data used to calculate average values was collected under the Ten Towns Great Swamp Watershed Management Committee (1999-2008) and Great Swamp Watershed Association (2005-2012).

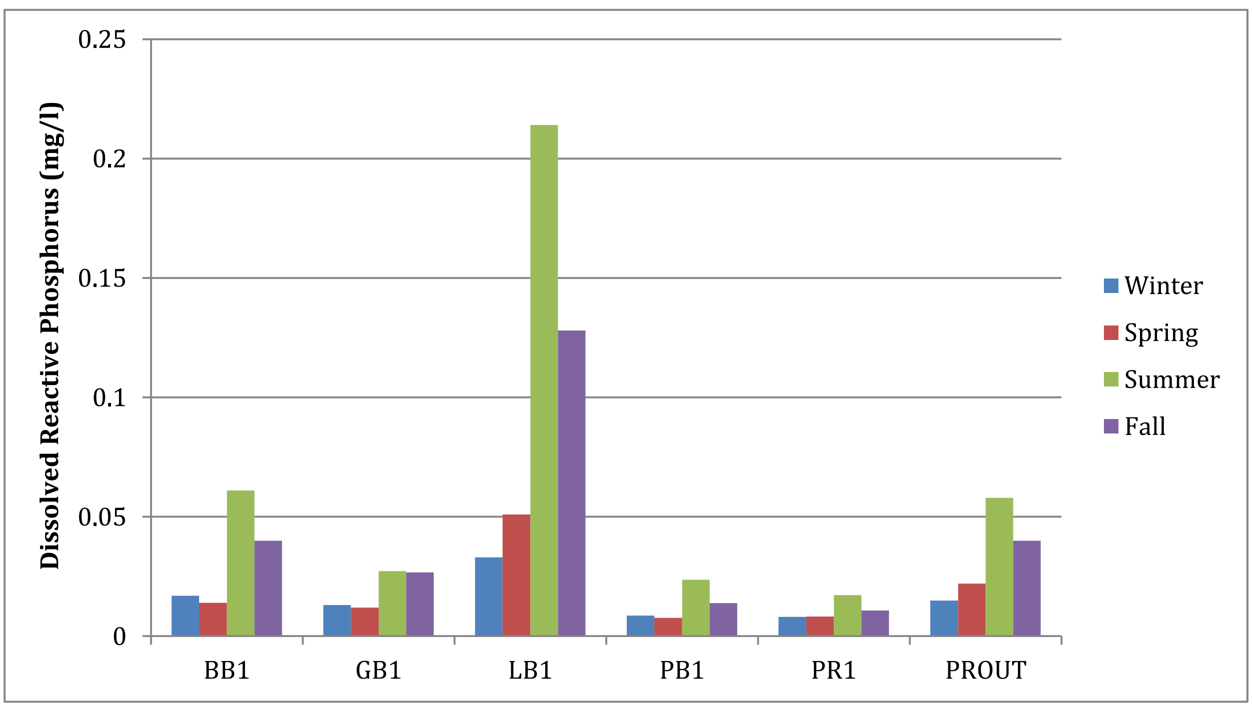

Figure 7. Seasonal Variations of Dissolved Reactive Phosphorus
Average values for dissolved reactive phosphorus during each season at sites in the Great Swamp watershed. Data used to calculate average values was collected under the Ten Towns Great Swamp Watershed Management Committee (1999-2008) and Great Swamp Watershed Association (2005-2012).

In the case of BB1, high summer TP may be increased by two factors: low stream volume and a golf course immediately upstream. The monitoring site is not far downstream from its origin in the Fairmount Country Club, so it is likely subjected to greater fertilizer runoff than other monitoring sites. Furthermore, the site has a low flow volume due to its location near the headwaters, so there is little dilution. A similar situation exists at GSWA's monitoring site GB5 on Great Brook; that site is located near the stream's origin in the Spring Brook Country Club (though there is an impoundment, Foote's Pond, between GB5 and the country club). Monitoring in 2008-2010 demonstrated that the highest levels of TP seen in Great Brook were generally at GB5 and the next site downstream (GSWA 2011). At GB5, the highest TP levels were observed during August, with two August monitoring rounds exceeding the NJ State Standard for TP and the third round just meeting the standard. In contrast, GSWA monitoring on Loantaka Brook found the lowest TP and DRP concentrations at headwaters sites where there is relatively low flow, but no golf course upstream (GSWA 2008).

Golf courses are not the only cause of TP levels in excess of the NJ State Standard. All sites exceeded this standard on at least one occasion. Primrose Brook, often considered the cleanest stream in the watershed, exceeded the TP standard at PB1 in 3 out of 51 samples taken; these can all be attributed to rain events (USGS 01379000).

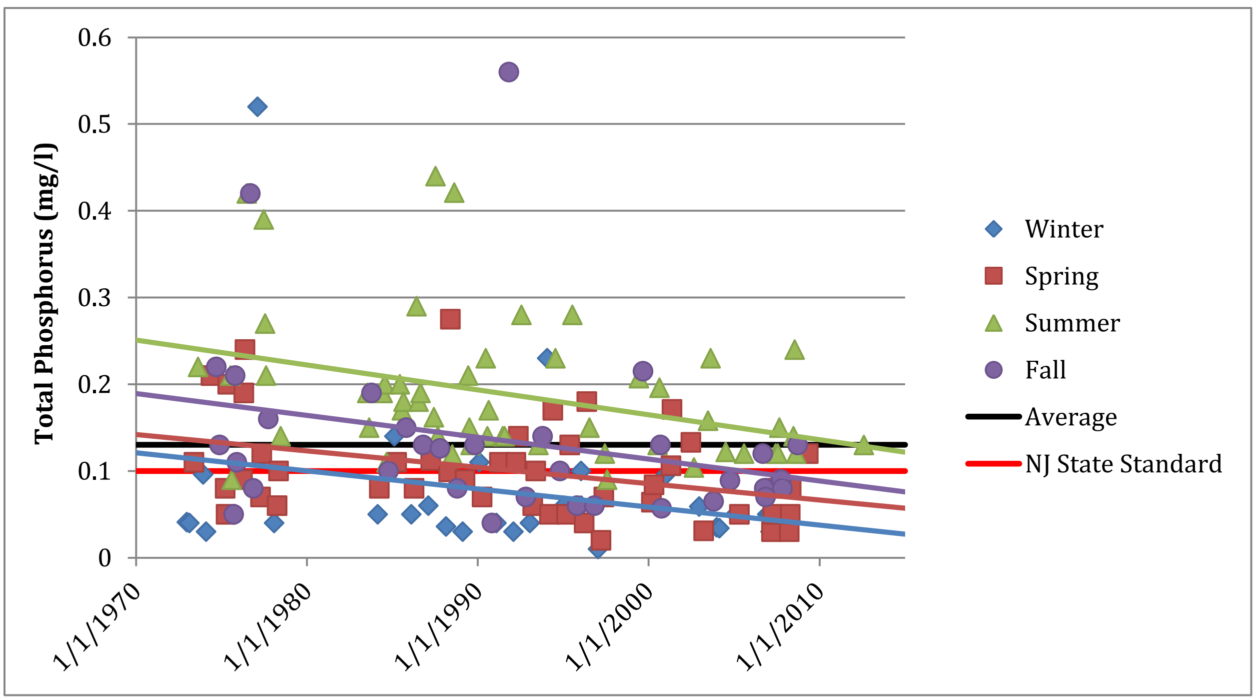

Figure 8. Decreasing Total Phosphorus at PROUT, 1972-2012
Total phosphorus is declining during all seasons at the outlet to the Great Swamp watershed between 1972-2012. This graph shows data collected by USGS (1972-2009), TTC (1999-2008), and GSWA (2012).

Looking at trends over the entire period of data collected, TP is decreasing at both PROUT[8] (**Figure 8**) and LB1 (**Figure 9**). This decrease at LB1 is occurring during all seasons except summer (when it is not increasing or decreasing), indicating some influence from fertilizer usage. DRP at LB1 shows the same pattern of decrease during all seasons except summer. DRP is also decreasing at PB1 during the fall and winter and at GB1 during the winter. DRP is increasing slightly during the fall at PR1. This trend of decreasing phosphorus during fall and winter and steady or increasing phosphorus during summer and fall further show the influence of fertilizer usage on streams throughout the watershed.

One interesting trend of note is that LB1, GB1, and PROUT tend to have higher TP before 2006 and lower TP after that period. Similarly, all sites except PR1 have higher DRP values prior to 2006 with an increased frequency of lower DRP after that. Further investigation into these recent declines is needed to determine potential causes.

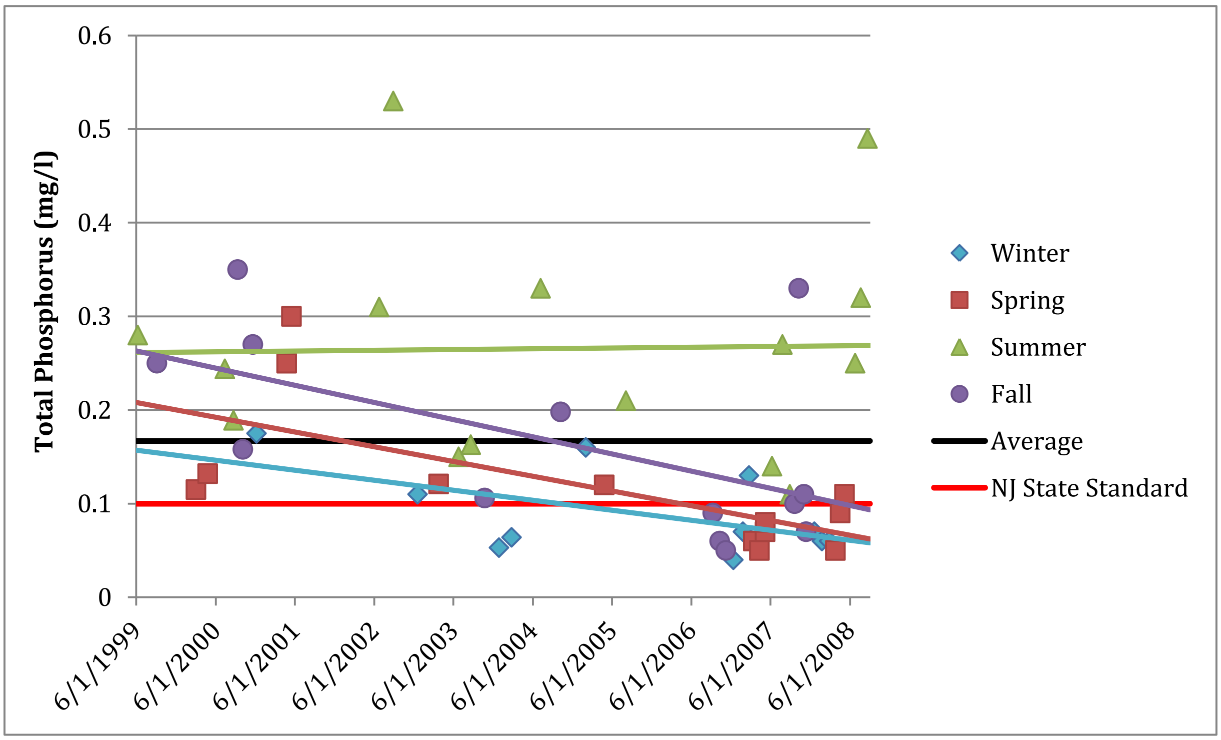

Figure 9. Seasonal Total Phosphorus Trends at LB1
Trend lines show that total phosphorus is decreasing during all seasons except summer at LB1 on Loantaka Brook. Data used to calculate average values was collected under the Ten Towns Great Swamp Watershed Management Committee (1999-2008) and Great Swamp Watershed Association (2005-2012).

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[8] The TP decreasing at PROUT is evident when looking at TTC and GSWA data from 1999-20012 and when combining this with USGS data from 1972-2009. USGS does not differentiate between baseflow and stormflow data, and since TP can increase during storm conditions, the USGS data may be skewing the TP levels and exacerbating the downward trend seen in **Figure 8.**

4.1.3 Nitrogen Results

TN has more complex seasonality than TP and DRP; some sites have similar patterns of high and low TN while others do not (**Figure 10**). At BB1, GB1, and PROUT, TN is highest during the winter and lowest during the fall. As trees lose their leaves and organic matter decays (a source of nitrogen[9]), TN is carried to streams by precipitation. This may be more pronounced during winter snowmelt and continue throughout the year. It should be noted that average TN at BB1 during the summer is only slightly lower than during the winter. High summer TN may be caused by spring and summer fertilizer usage at the upstream golf course and the limited dilution at this site (as discussed previously in Section 4.1.2).

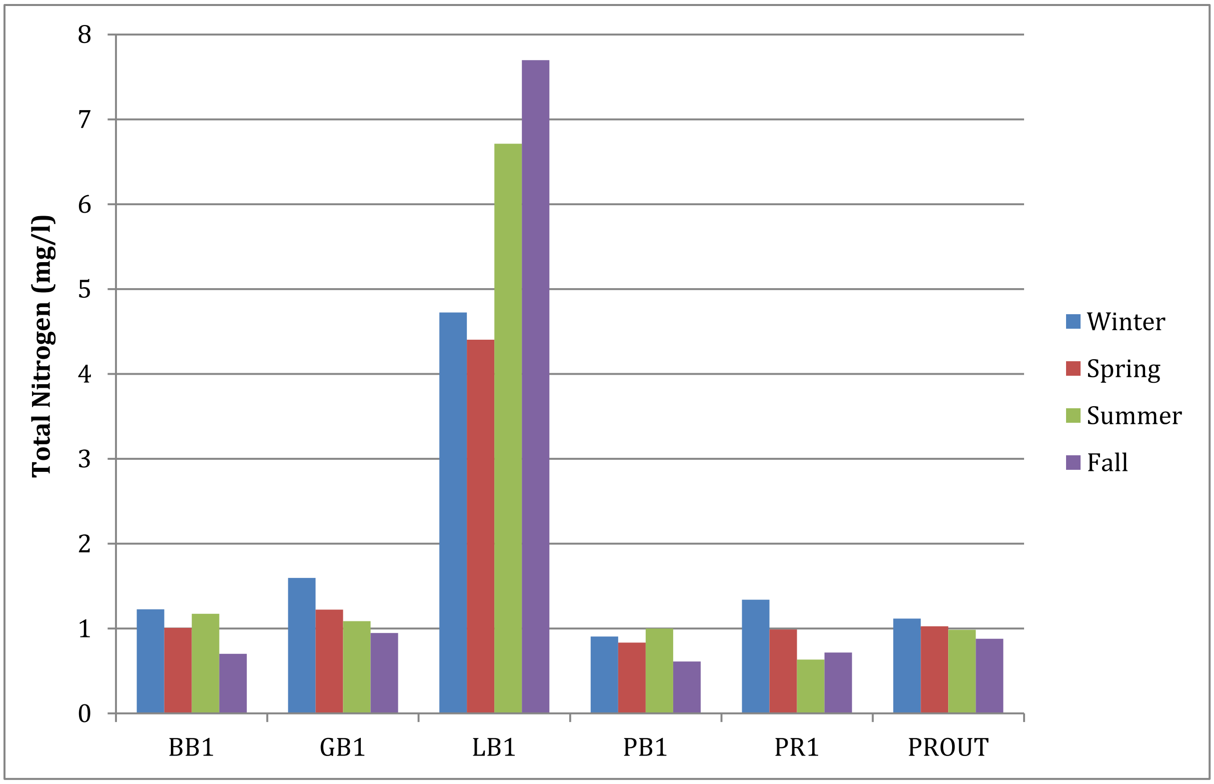

Figure 10. Seasonal Variations of Total Nitrogen
Average values for total nitrogen during each season at sites in the Great Swamp watershed. Data used to calculate average values was collected under the Ten Towns Great Swamp Watershed Management Committee (1999-2008) and Great Swamp Watershed Association (2005-2012).

PR1 also has high winter TN, but average TN is lowest during the summer. Summer TN at GB1 is also fairly low (though slightly greater than during the fall). Low summer TN values have been seen at additional GSWA stream monitoring sites along the Passaic River (GSWA 2012) and Great Brook (GSWA 2011). This has been attributed to denitrification, a process where bacteria convert nitrate (a component of TN) in the soil into atmospheric nitrogen. The bacteria responsible for denitrification are thought to be more active during the summer when temperatures are warmer.

[9] Leaf litter is a source of total Kjeldahl nitrogen, a component of TN.

PROUT does not show much seasonal variation in TN. Since water flowing here is an accumulation from all other streams in the watershed, it reflects the cumulative TN from all streams: If different streams have their highest TN values during different seasons, PROUT is less likely to have higher TN during one particular season. Furthermore, PROUT is impacted by TN inputs in the Great Swamp National Wildlife Refuge, such as decaying organic matter in swamps.

Aside from having a season of significantly lower TN, PB1 does not show the level of seasonal TN variation that some other sites do. The reasons for this are less clear than at PROUT: Primrose Brook is thought to be under the smallest influence from human activities, and a large portion of its subwatershed is undeveloped. Chemical and macroinvertebrate monitoring results frequently group Primrose Brook and the Passaic River as being similar in terms of development and water quality. Why does PB1 experience different TN seasonality than PR1? To answer this question, further analysis is needed into the components of TN (where that data is available), as well as land use patterns.

Average TN at LB1 is lowest during the spring and highest during the fall (though both spring and winter values are significantly lower than summer and fall). Elevated summer TN may be due to increased fertilizer use during the spring and summer, but Loantaka Brook is also influenced by other possible sources of TN. As is the case with both TP and DRP, LB1 has significantly higher TN values than any other site. This site is located a few miles downstream from the outfall of the Morris Township Woodland Water Pollution Control Utility (WPCU, also known as a wastewater treatment plant), Seton Hackney Stables, and Kitchell Pond. GSWA monitoring on Loantaka Brook showed elevated TP, DRP, and TN in the effluent from the WPCU when compared with upstream sites (GSWA 2008). The levels of these nutrients decreased further from the WPCU. Across Loantaka Brook from the Woodland WPCU is Seton Hackney Stables. Preliminary monitoring in 2010 indicated that Seton Hackney Stables is a likely source of nutrients into Loantaka Brook. Additionally, Canada geese are often found in and around Kitchell Pond (downstream of the WPCU and Seton Hackney Stables), and elsewhere along the length of the stream. The nutrients in goose dropping make their way into a stream from stormwater runoff or direct deposition. Any or all of these factors may be the cause of high nutrients at LB1.

4.2 Total Suspended Solids

Total suspended solids (TSS) is a measure of the sediment suspended in the stream. Water with lower levels of TSS will be clear; the higher the TSS, the cloudier the water. Water with very high TSS can be compared to chocolate milk. Sources of TSS vary, but most commonly soil erosion is involved (such as streambank erosion or stormwater runoff from a construction site with exposed soils). High levels of TSS can be harmful to aquatic life by clogging gills, burying streambed habitat, and blocking sunlight from reaching submerged aquatic vegetation.

Overall, levels of TSS at all sites were found to be low (well below the NJ State Standard). There were only a few instances where sites exceeded the NJ State Standard for TSS; once at LB1 and three times at BB1. There does not appear to be a good explanation for the TSS exceedance at LB1. The three exceedances at BB1 can all be attributed to recent rainstorms (USGS 01379000). The effects of a rainstorm at BB1 can be exacerbated by the low stream volume at the site, resulting in little dilution.

4.3 Total Dissolved Solids

Natural, undisturbed streams often contain small amounts of total dissolved solids (TDS), such as magnesium, bicarbonate, and sulfate, which can enter the water from soils and rocks that the stream comes in contact with. GSWA's stream monitoring has shown unnaturally high levels of sodium and chloride in streams, with the highest levels generally seen in winter, leading to the conclusion that high TDS in the watershed is due to road salting (Edwards 2008). High levels of TDS can be problematic for drinking water supplies as there is no cost-effective method to remove TDS from water (Cywinski 2011). Excessive chloride can impair drinking water taste and excessive sodium can be problematic for individuals on a low-sodium diet. Although there is no drinking water treatment facility within the Great Swamp watershed, there are such facilities downstream on the Passaic River. Aside from potential human health impacts, there are major ecological implications for high TDS levels including growth impairment of many freshwater plants and animals as the streams they depend on increase in salinity.

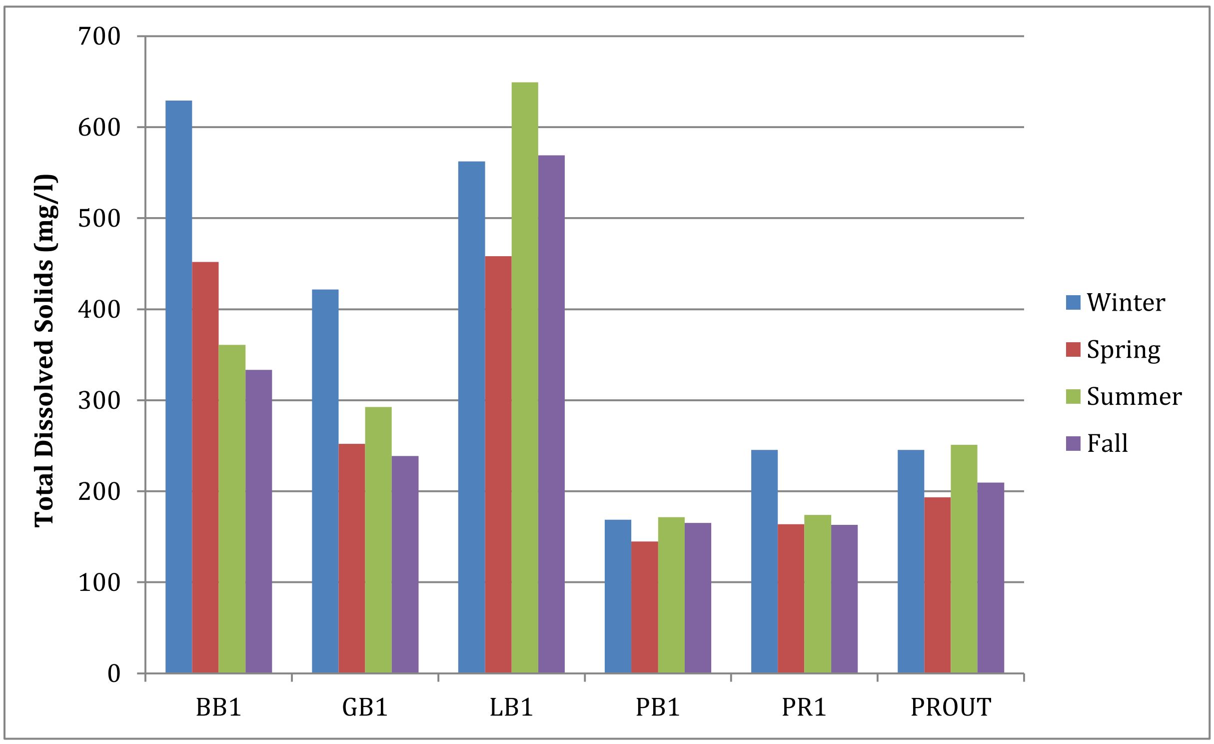

Figure 11. Seasonal Variations of Total Dissolved Solids
Average values for total dissolved solids during each season at sites in the Great Swamp watershed. Data used to calculate average values was collected under the Ten Towns Great Swamp Watershed Management Committee (1999-2008) and Great Swamp Watershed Association (2005-2012).

At BB1, GB1, and PR1, TDS values were highest in winter, with fall having the lowest average TDS at BB1 and GB1 and no single season showing the lowest average TDS at PR1 (**Figure 11**). GSWA stream monitoring on Loantaka Brook (GSWA 2008) and Great Brook (GSWA 2011) demonstrated that TDS levels often spike in the winter due to road salt (generally carried to streams by stormwater runoff, including snowmelt). After the initial winter input, TDS can bind to particles in the soil, slowly leeching out during the remainder of the year with precipitation events.

Looking at **Figure 11**, PB1 on Primrose Brook does not appear to have much seasonal variation in TDS, however 50% of TDS values above the average occurred in the summer. Similarly, LB1 has the highest average TDS during the summer. As a general principle, warmer water temperatures allow for increased solution of ions in water, which may explain higher summer TDS values. Additionally, winter snow cover or frozen ground could block the infiltration of precipitation or snow melt into the soil where it could interact with and dissolve ions en route to the stream. Frozen and snow covered ground would therefore increase surface runoff, which would serve to dilute any TDS in the stream already. This is supported by GSWA data on the TDS components measured during Loantaka Brook monitoring[10] and USGS data from a monitoring site on the Passaic River in Mendham Township (USGS 01378660) and one on Primrose Brook in Harding Township (USGS 01378780).

As with nutrients, when compared to other streams LB1 had the highest average TDS values (though average winter TDS at BB1 exceeded that at LB1). LB1 also had the highest percentage of samples above the NJ State Standard (63%). These exceedances were seen in almost every month of the year, with all samples collected in June-August exceeding the standard. GSWA's Loantaka Brook monitoring in 2005-2007 (GSWA 2008) found that the highest values of TDS were at the most upstream sites, which are located in or close to Morristown where the stream faces the most pressure from development and proximity to major roads (at that point it is a very low volume stream and more susceptible to these outside influences because of a lack of dilution). Just downstream of those sites, effluent from the Woodland WPCU enters the stream. While GSWA monitoring in 2006-2007 showed the effluent to have lower TDS than the upstream sites, it still exceeded the NJ State Standard on all 4 baseflow monitoring dates (in February, May, and twice in November; GSWA 2008). Although the TDS at upstream sites was found to be higher than that of the effluent, the levels measured in the effluent are cause for concern as they are still contributing to the high TDS levels downstream. Since the water being treated by the WPCU is coming from household wastewater, not surface runoff, this is not likely due to road salting[11]. Additional possible sources of TDS in the WPCU effluent include brine from water softeners and household cleaning materials. The TDS from road salting in the upper reaches and closer to the monitoring site as well as the WPCU effluent may be contributing to high TDS levels at LB1.

[10] GSWA (2008) shows that at the two most upstream monitoring sites, the lowest TDS values seen occurred during a February sampling date. On this date (February 7, 2006), sodium and chloride levels accounted for a high percentage of TDS, but other components of TDS being measured at the time were lower including calcium, magnesium, and potassium.

[11] There may be some infiltration of surface runoff and road salt into wastewater conveyance pipes, but the vast majority of water treated by the WPCU comes from household and business wastewater, such as sinks, toilets, showers, and washing machines.

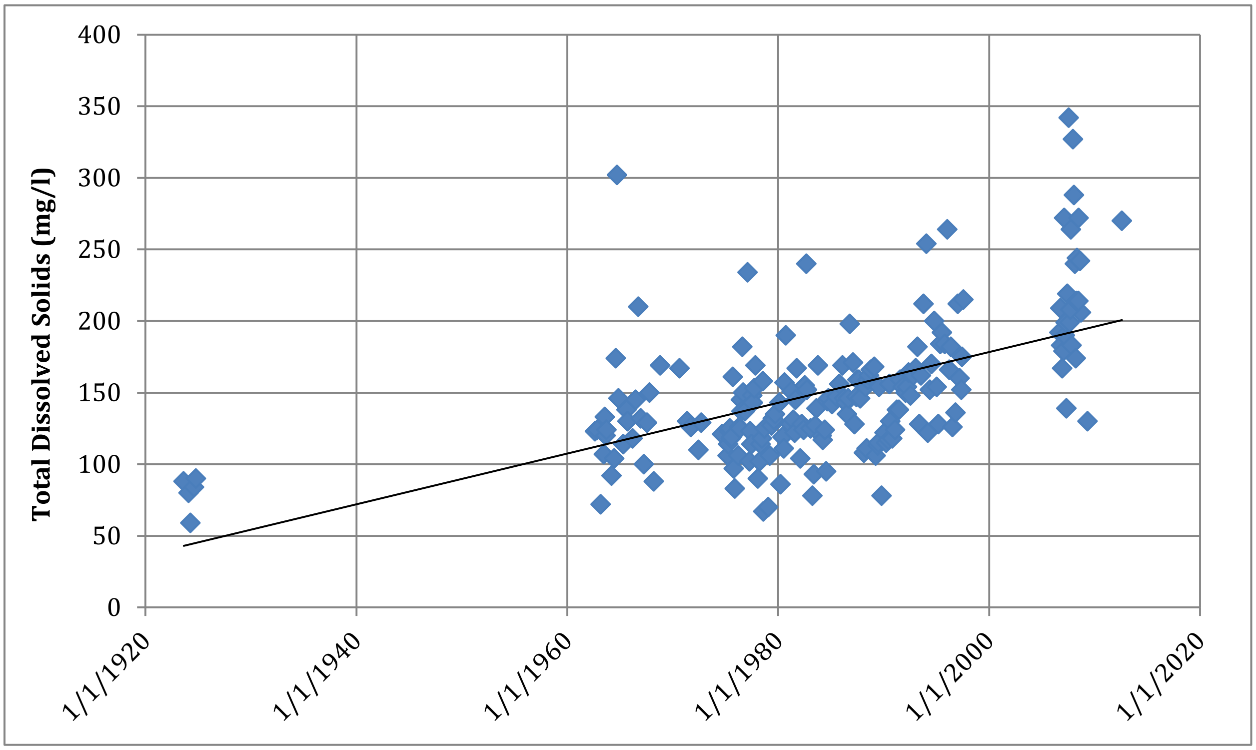

Figure 12. Increasing Total Dissolved Solids at PROUT
Total dissolved solids have been measured periodically by USGS at the outlet of the Great Swamp watershed from 1923-2008. This graph also shows monitoring data from TTC and GSWA 2006-2012. An increasing trend in TDS is evident over this time period. Graph created by R. Edwards, 2012.

As seen with TN, PROUT does not show much seasonal variation in TDS. This is expected when a parameter does not show consistent seasonal variations across all sites as values seen at PROUT are the combined result of those seen at all other sites. However, when examining TDS data collected at PROUT by USGS, TTC, and GSWA, an overall increase in TDS is evident (**Figure 12**). One assumption is that road salt usage has increased with added road miles and people increasingly demand the ability to drive in any weather condition. Future investigation into this trend will include looking at the amount of road salt used by watershed towns over the years, the increase in road miles, the number of snow storms each winter and their associated accumulation (a likely driver of the amount of road salt used each winter). **Figure 13** gives an idea of the relationship between snowfall and TDS levels: Results from GSWA's Passaic River monitoring (GSWA 2012) show TDS levels during a year of heavy snowfall (2010-2011) followed by a year of light snowfall (2011-2012). The resulting TDS levels were very high at all monitoring sites in February 2011 and continued to decline through August 2012.

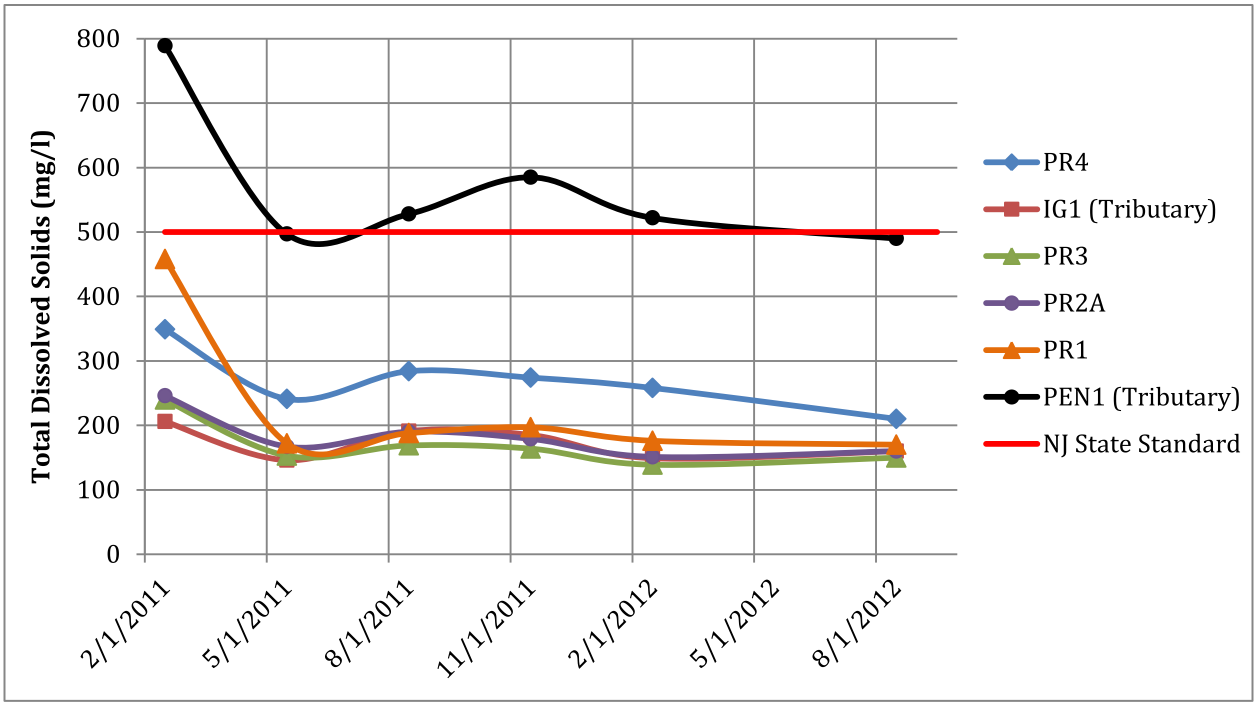

Figure 13. Impact of Snow on Total Dissolved Solids
The winter of 2010-2011 saw heavy snowfall leading to high total dissolved solids (TDS) at all GSWA Passaic River monitoring sites in February 2011. After a spring 2011 decline, TDS remained steady at almost all sites during the winter of 2011-2012 when there was very little snow. PEN1 on Penn's Brook, a tributary of the Passaic River, has consistently had TDS levels near or above the NJ State Standard due to stormwater runoff from nearby shopping center parking lots. Graph created by R. Edwards, 2013.

5.0 Ranking the Streams

Both macroinvertebrate and chemical data have revealed disparities between streams in the watershed (Section 3.0 and Section 4.0). Based on these results (including the average B-IBI values, average values of chemical parameters, and the frequency that each site exceeds the NJ State Standards) the streams can be ranked from best to poorest water quality:

1. Primrose Brook
2. Passaic River[12]
3. Great Brook
4. Black Brook
5. Loantaka Brook

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[12] This does not include results from PROUT. Since that site is at the outlet of the watershed, the water quality there expresses the cumulative effects from all streams and therefore gives an idea of the overall health of all watershed streams.

This ranking is supported by past studies and reports conducted under the auspices of TTC including the *Loantaka Brook Watershed Report* by Princeton Hydro, LLC (July 2009), and *Great Swamp Watershed Water Quality Monitoring Report* by F.X. Browne, Inc. (June 2002).

Streams in the western portion of the watershed (Primrose Brook and the Passaic River) consistently have higher water quality than their eastern counterparts (Great Brook, Black Brook, and Loantaka Brook). There are several likely reasons for this difference including topography and land use patterns (i.e. the concentration of development and the presence of undeveloped lands). Primrose Brook and the Passaic River follow a steeper topographical gradient through closed-canopy forests, leading to faster flow rates, cooler water temperatures, and higher dissolved oxygen content making the streams more hospitable to MIVs. Faster stream flow also leads to better flushing of sediments, debris, and potential causes of impairment (such as fertilizer inputs). Additionally, there are large areas of protected natural lands and less development in the western portion of the Great Swamp watershed leading to fewer human inputs. All of these factors contribute to overall higher water quality in these streams than their eastern counterparts.

In comparison, Great Brook, Black Brook, and Loantaka Brook have poorer water quality as a result of several causes. These eastern streams have a slower flow rate due to a lower topographical gradient, and more exposure to sunlight and heating resulting from less tree cover over the streams. These factors, in turn, reduce oxygen availability in the streams. More development in these subwatersheds compared to the Passaic River and Primrose Brook can increase pollutant inputs (such as road salt) which can further stress the streams and their MIV communities.

When looking at sites on the same stream, both Primrose Brook and the Passaic River show decreasing MIV community quality from upstream to downstream, and GSWA's Passaic River monitoring showed the same for chemical parameters on that stream (GSWA 2012). This pattern counteracts the common saying "the solution to pollution is dilution." This is because coalescing tributaries add cumulatively to sedimentation and chemical buildup, and wider reaches lose canopy protection from warming sunlight. In other words, the saying is true when the pollutant input remains constant but the volume of water in the stream increases. However, what we see in these watersheds is that the pollutant input also increases downstream (and disproportionately due to human influences).

On the other hand, poorer quality streams, including Black Brook, Loantaka Brook, and Great Brook, show roughly equal MIV community quality throughout, suggesting that conditions are stressful enough even upstream to prevent higher quality macroinvertebrate communities from forming. GSWA's chemical monitoring on Loantaka Brook (GSWA 2008) and Great Brook (GSWA 2011) show a pattern opposite to that of the Passaic River; the upstream sites have the highest concentration of pollutants and downstream sites are progressively improved (though only slightly for some parameters and sampling dates). This suggests that the factors affecting Loantaka Brook and Great Brook are originating in the headwaters where development is likely negatively impacting the streams and the low volume of water in these areas is not sufficient to dilute any pollutants (though they are diluted as the water progresses downstream).

6.0 Results by Stream

6.1 Loantaka Brook

Loantaka Brook is the most impaired stream when looking at the chemical monitoring results with Black Brook slightly less impaired. Black Brook has the poorest quality macroinvertebrate communities with Loantaka Brook only somewhat better. There are several possible reasons for these streams to be in such poor condition overall. Both streams have relatively low flow volumes so even a small amount of a potential pollutant can have a big impact. Both streams are the recipients of outflow from WPCUs (the chemical monitoring site on Black Brook, BB1, does not receive effluent from the WPCU, however one MIV monitoring site does). While those plants must meet certain criteria for their effluent, during periods of low stream flow there may not be enough receiving water in the stream for sufficient dilution.

The headwaters of Loantaka Brook are in or near Morristown and the stream faces pressure from its close proximity to development and major roads. High concentrations of impervious surfaces convey stormwater runoff to the stream, carrying any pollutants in the way such as road salt, animal waste, and excess fertilizer. Just downstream from the stream's origin is Seton Hackney Stables where GSWA is currently working to remediate stormwater runoff pollution from the stables into the stream. When this project is completed, it should reduce the levels of nutrients and sediment entering the stream from that site which can only help to improve water quality further downstream. The Woodland WPCU is across Loantaka Brook from Seton Hackney Stables and has been shown by GSWA monitoring to significantly impact water quality at downstream sites (GSWA 2008). The plant has recently been given stricter permit limitations on the nitrate level of effluent, which may improve TN levels and therefore water quality for MIVs at downstream sites.

Kitchell Pond in Loantaka Brook Reservation, downstream from Seton Hackney and the WPCU, has large mowed areas which are very desirable for Canada geese. Around 2004-2005, a riparian buffer was created around the pond which blocked access for the geese and provided some filtering of runoff from the mowed lawn and parking lot into the pond. Although no formal study has been completed as to the impacts of this buffer on geese numbers or water quality, Morris County Park Commission, which manages the park, indicated that there are fewer geese frequenting the park since this buffer was installed (D. Helmer, personal communication, 2013). This may also be one of the reasons for the TP decrease observed at LB1 beginning after 2006 (Section 4.1.2). In 2011, a stormwater management project was installed to reduce stormwater runoff from the parking lots including the installation of two bioretention basins, reduction in paved area, and other measures to trap and treat stormwater runoff. Chemical monitoring has not been conducted on Loantaka Brook since this installation, but macroinvertebrate monitoring, particularly at the site immediately downstream from Kitchell Pond, should reveal water quality improvements from this project.

6.2 Black Brook

The Black Brook chemical monitoring site is close to the headwaters of the stream but lies just downstream of the Fairmount Country Club and Southern Boulevard, a major road. Golf courses are known for their fertilizer and pesticide use. While the Country Club's practices with regards to these chemicals is unknown at this time, these inputs are likely affecting the water quality in Black Brook as evidenced by its average total phosphorus levels (second highest when compared with other streams) and a poor quality MIV community just downstream. Furthermore, as the stream flows through the golf course, it has minimal shading from vegetation (Google Maps 2013a). This exposure to sunlight can lead to increased water temperatures and low dissolved oxygen, creating stressful conditions for MIVs. The addition of vegetated buffers with shrubs and trees along the stream would provide shading to help lower water temperatures and increase dissolved oxygen levels. Additionally, vegetated buffers can act as filters for stormwater runoff (as they have at Kitchell Pond on Loantaka Brook, mentioned above), thus helping reduce the potential input of fertilizer and other pollutants into the streams. Though the Country Club may be adversely impacting Black Brook at BB1, the site's close proximity to Southern Boulevard is also a likely source of stormwater runoff, particularly road salt. BB1 has the highest average winter TDS levels and the second-highest levels during all other seasons.

While there is no chemical monitoring site on Black Brook downstream of the Chatham Township WPCU, MIV monitoring downstream shows poor MIV communities. The WPCU effluent contributes significantly to the volume of water in Black Brook so elevated levels of any inputs from the WPCU would not undergo much dilution as the effluent enters the stream. Water quality meter measurements taken during MIV monitoring reveal high levels of TDS downstream of the WPCU. Similar to the Woodland WPCU on Loantaka Brook, these TDS may be due to water softeners, household chemicals, or other inputs coming into the plant in the influent. Additionally, higher levels of nutrients may also be in the effluent (but this has not been monitored). Further investigation is needed to determine the true impacts from this WPCU on downstream water quality.

6.3 Great Brook

Great Brook ranks in the middle of all the streams though MIV and chemical monitoring results place it closer in ranking towards Black Brook than the higher quality Passaic River. The headwaters of Great Brook lie in Morristown and Morris Township, making it vulnerable to the same development pressures as Loantaka Brook (stormwater runoff carrying road salt, fertilizer, animal waste, and other inputs into the stream). This is seen in GSWA's Great Brook monitoring results (GSWA 2011) where upstream sites have poorer water quality than downstream sites (similar to Loantaka Brook; discussed in the previous section, *Ranking the Streams*). As in the case of Black Brook, a golf course (Spring Brook Country Club) lies along the upper reaches of Great Brook and may be similarly impacting water quality there and at downstream sites. Additionally, there are several large office parks near the upper reaches of Great Brook. The large parking lots associated with these complexes are likely sources of auto-related inputs into the stream including road salt. Impoundments along Great Brook (Foote's Pond, Bayne Pond (on a tributary), and Silver Lake, to name a few) may also be contributing excess nutrients to the stream while elevating the water temperatures and decreasing dissolved oxygen.

6.4 Passaic River

Similar to Great Brook, Loantaka Brook, and Black Brook, the headwaters of the Passaic River face pressures from a nearby major road (Tempe Wick Road). GSWA's water quality monitoring on the Passaic River has found that the most upstream monitoring site (PR4, off Tempe Wick Road in Mendham Township) tends to have higher levels of TP, TN, and TDS (GSWA 2012). Since the site is in close proximity to a major road, it is susceptible to stormwater runoff, and particularly road salt.

All of these parameters decrease at successively further downstream monitoring sites while the stream flows through large areas of protected and forested land and cleaner water is added to the stream, providing dilution. PR1 sees an increase in nutrients, TSS, and TDS, which is attributed to a larger drainage area than upstream (and therefore more potential sources of these inputs). PR1 is also downstream from large office complexes, Interstate 287, and a large impoundment (Osborn Pond), all of which may be adversely affecting the water quality there. MIV monitoring results agree: PR1 shows the lowest community quality of the three Passaic River MIV sites with B-IBI increasing progressively at upstream sites (there is no MIV site as far upstream as the chemical monitoring site off Tempe Wick Road). Downstream of PR1 the river skirts the Basking Ridge Country Club and all other watershed streams drain into the Passaic River. Once the Passaic River reaches PROUT, there are many possible sources of each parameter discussed and it is impossible to tell where each originated.

6.5 Primrose Brook

Primrose Brook, a NJDEP-designated Category One stream[13] for much of its length, is generally thought to be the cleanest stream within the watershed. This has been demonstrated through both MIV and chemical monitoring. The stream originates just beyond Jockey Hollow and flows through the park in its upper reaches. Beyond the confines of Jockey Hollow, Primrose Brook flows through a largely rural area into the Great Swamp National Wildlife Refuge. Mt. Kemble Lake feeds into Primrose Brook and may have adverse impacts on water quality downstream including nutrient inputs. However, this is not readily seen because GSWA has not yet conducted extensive monitoring along Primrose Brook, so the water quality differences between sites upstream and downstream of the lake's input are unknown. Additionally, the higher quality water in Primrose Brook may dilute the water coming from Mt. Kemble Lake and negate any adverse impacts it may otherwise have. MIV monitoring has noted an increase in sedimentation at sites along Primrose Brook. While Primrose Brook is considered to be the best quality stream in the watershed, it is still vulnerable to human impacts.

7.0 Recommendations

It is obvious that there are some common factors with the potential to impact all streams in the watershed, including:

- Stormwater runoff from impervious surfaces and large mowed areas
- Road salting from major roads and commercial parking lots
- Nutrient inputs from geese
- Nutrient inputs, low dissolved oxygen, and elevated water temperatures from impoundments
- Nutrient inputs from golf courses

[13] Category One (C1) waters are protected from any measurable changes to the existing water quality.

In light of these common impacts, the following recommendations can be made:

1. Golf Courses
   GSWA has not worked directly with local golf courses in the past, but considering their potential impact on streams in the watershed, GSWA should develop these relationships. Specifically, discussions about existing fertilizer and pesticide practices and ways to reduce the use of these chemicals would be beneficial to sites downstream. Additionally, golf courses tend to have minimal buffers around the streams and ponds on their property. Working with golf courses to install vegetated riparian buffers would help to reduce stormwater runoff impacts on the streams, and also make the area less attractive to geese (thereby reducing water pollution from goose droppings). Buffers that include taller vegetation (large shrubs and trees) can also serve to shade the stream and decrease water temperatures which may help increase dissolved oxygen. This would make the streams more suitable for macroinvertebrates and other aquatic life.

2. Road Salt
   Since 2009, GSWA has reached out to local departments of public works in watershed towns and surrounding communities to educate them about the impacts of road salt on water quality and smarter salting practices. In 2011, contractors and large private landowners (such as apartment complexes and strip malls) were added to the target audience for this education. Total dissolved solids due to road salting practices continue to impair watershed streams so it is important to continue and expand this outreach and education. On a positive note, an increasing number of towns in northern New Jersey are beginning to use salt brine instead of rock salt for some or all of their winter roads maintenance. A significant move towards brine and the use of smarter salting practices[14] will surely improve TDS levels in streams.

3. Stormwater Runoff
   Many of the factors impacting streams are due to stormwater runoff. Fertilizer, animal waste, road salt, and sediment are all conveyed to streams by runoff when precipitation cannot infiltrate a surface. Impervious surfaces, such as roads, sidewalks, and roofs, all increase stormwater runoff and can therefore increase the damage that runoff can cause in streams. While it is not practical to replace roads and sidewalks with vegetation, pervious pavement options exist and can be used in certain circumstances (such as parking lots and sidewalks). Local governments and developers should be urged to consider pervious pavement alternatives for future development and when routine maintenance requires re-paving these areas. Furthermore, low impact development techniques, such as rain gardens, rain barrels, and riparian buffers, can be implemented to reduce the quantity of stormwater runoff leaving a property and the quality of runoff flowing into a waterbody. GSWA already holds regular programming to educate individuals about the benefits of capturing and storing stormwater on their own properties and installing riparian buffers: These programs should continue and expand to include large landowners (such as businesses, apartment complexes, and local and county government).

[14] Many new technologies exist to make the use of traditional rock salt more efficient and reduce the total amount needed per storm. One example is automated technology that controls the amount of salt released based on the speed of the spreading vehicle.

4. Impoundments

   Impoundments can be sources of nutrients for downstream sites, and also serve to raise water temperatures and slow water movement (thereby reducing dissolved oxygen concentrations). On the other hand, impoundments can serve to trap sediment, reducing downstream sediment loading. It is unrealistic to suggest that all dams in the watershed be removed. However, landowners should be encouraged to install riparian buffers around ponds and lakes to provide shade and reduce pollutant loading from stormwater runoff.

5. Development

   Several of the factors influencing water quality in the region are due to development; stormwater runoff and road salt may be the most obvious but there are others (reduced tree cover over streams, for example). While the impacts of development may be more apparent in the poorer quality streams, chemical and MIV data have shown that it is impacting downstream sites in the higher quality streams (Section 5.0). Therefore, it is imperative for watershed towns to be vigilant about future development in the region in terms of both how and where it occurs.

8.0 Next Steps

1. The analysis in this report was limited to baseflow data. Similar analyses should be completed for stormflow data and results compared to baseflow data analysis for a more thorough understanding of watershed streams.

2. Only five parameters were analyzed in this report. Additional parameters have been measured inconsistently since 1999 and it is important to analyze those parameters and incorporate results with the results found in this report. For example, data on dissolved oxygen and pH may further inform the MIV results. TKN and nitrate data may enhance our understanding of TN sources and impacts.

3. Past monitoring has focused on nutrients and sediment with recent attention on TDS; there may be other parameters (such as e. coli) which have not been monitored in the past and would enhance GSWA's understanding of watershed streams and factors affecting the water quality.

4. Water pollution control utilities are negatively impacting water quality in Loantaka Brook and may be adversely impacting water quality in Black Brook. WPCU influent and effluent should be monitored and compared with data collected by the plants. This monitoring should reveal whether elevated parameters noted in the plant effluent (such as TDS) still exist today and whether they are due to processes at the WPCU or the condition of the influent.

5. Finally, assumptions were made for this report for Black Brook and Primrose Brook because the only data that has been considered for those streams is from one TTC chemical monitoring site and the MIV sites on each stream. Additional chemical monitoring sites would allow for a better understanding of those streams. This is planned for the future for both Black Brook and Primrose Brook as part of GSWA's ongoing Adopt-a-Stream program.

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