NJ Department of Environmental Protection
Water Monitoring and Standards
Bureau of Freshwater and Biological Monitoring

Stressor Identification of Drakes Brook

AMNET Station AN0311 @ Emmans Road
Roxbury Township, Morris County, New Jersey

September 2014

NJ Department of Environmental Protection
Water Monitoring and Standards
Bureau of Freshwater and Biological Monitoring

September 2014

Stressor Identification Of Drakes Brook AMNET Station AN0311 @ Emmans Road Roxbury Township, Morris County, New Jersey

Cover photo- AN0311 Drakes Bk @ Emmans Rd., looking upstream, April 2009

Table of Contents

Acknowledgements

The following current and former NJDEP personnel assisted in the study and/or preparation of this report: Dean Bryson, William Honachefsky, Anna Signor, Alfred Korndoerfer Jr., Leigh Lager, Leslie McGeorge, Alena Baldwin-Brown, Anthony Altieri, Richard Fenton, Robert Maruska, Raymond Bousenberry, Amy Rowan and Pat Gardner.

Executive Summary

A Stressor Identification (SI) study was conducted on a segment of Drakes Brook, located in Roxbury Township, Morris County, New Jersey from 2006-2009. This segment was found to be biologically impaired based on the results of benthic macroinvertebrate sampling performed at station AN0311, Drakes Brook at Emmans Rd., as part of the NJDEP's Ambient Biomonitoring Network (AMNET). The benthic macroinvertebrate community was assessed using a multi-metric index called the New Jersey Impairment Score (NJIS). The benthic community at this site was rated as being moderately impaired and therefore not meeting the Aquatic Life Use goals of the federal Clean Water Act. Based on the impairment, this segment of Drakes Brook was listed in the 2004 Integrated Water Quality Monitoring and Assessment Report (includes 305(b) report and 303(d) list).

One of the requirements of federal clean water legislation is to identify, and then where possible, remediate impaired waterbodies. The goal of this SI study was to determine the probable cause or causes of this biological impairment, whether it be a chemical pollutant or a non-chemical stressor such as flow alteration or siltation. The ability to accurately identify stressors and support those findings is a critical step in developing appropriate strategies and corrective measures that will improve the quality of aquatic resources.

The general protocol followed for this SI study was based on USEPA's Stressor Identification Guidance Document (USEPA, 2000) and their Causal Analysis/Diagnosis Decision Information System (CADDIS). Following the USEPA framework, the steps used in this study included first defining the impairment. Next, after a thorough review of available data for the watershed and field reconnaissance, a list of candidate causes was developed. Additional monitoring was then performed, which included chemical sampling of the water column and sediment, sediment toxicity testing, and additional benthic macroinvertebrate sampling, targeted to fill identified data gaps. Lastly, using a weight-of-evidence approach, the probable cause or causes were determined by thoroughly evaluating those on the candidate list.

Approximately 5.6 square miles of the Drakes Brook watershed drain to site AN0311. This contributing watershed has experienced a high degree of development, and as a result, urban land use and impervious cover (based upon 2002 aerial photography) are now at 40.3% and 16.8% respectively. Typically in lotic ecosystems, there is a strong association of upstream land use and water quality characteristics with macroinvertebrate community condition. Generally, statistical analysis has shown that severe community impairment was most significantly and positively related to the amount of urban land and total flow of municipal effluent, and most significantly and negatively related to the amount of forested land (Kennen, 1999). Some researchers have suggested that significant impairment begins at around 10% impervious cover and a second threshold appears to be present at around 25-30% impervious cover, where most indicators of stream quality shift to the poor condition (Kennen and Ayers, 2002). Streams in urban and urbanizing areas are affected by many anthropogenic factors that directly or indirectly modify stream geomorphology, chemistry, and aquatic-assemblage structure (Kennen and Ayers, 2002). Stormwater runoff from urban areas typically contains a mixture of pollutants including sediment, nutrients (nitrogen and phosphorus), chlorides, trace metals, petroleum hydrocarbons, microbial pollution, and organic chemicals (pesticides, herbicides, and industrial)(Shaver *et al*., 2007).

Additional benthic macroinvertebrate sampling for this study has revealed that the biological impairment is not limited to AN0311. Upstream of AN0311, portions of Ledgewood Brook, Drakes Brook, and its southern tributary were found to have similarly, if not more, degraded populations of benthic macroinvertebrates, which are presumably nearer to likely sources of stress in the watershed. Any stressor known to be present in a stream, and known to cause biotic degradation, is a probable, and indeed a likely contributor to the observed biological degradation and impairment (Gerritsen *et al*., 2004). Most benthic metrics respond to most stressor types. Therefore, disentangling the individual effects of each stressor is usually not possible.

Based on this additional benthic macroinvertebrate sampling, as well as chemical monitoring (both water column and sediment) and sediment toxicity testing at several stations in the watershed, the probable causes of the impairment were determined to be the following: 1. Ionic strength variations. Ionic Strength, as measured by Total Dissolved Solids (TDS), specific conductivity, and chloride, and the likely extreme fluctuations during times of road salt application and melting, can exert stress on the biota. Increased ionic strength can cause shifts in community composition rather than mortality (CADDIS). While our sampling was performed during non-winter months, a sampling station on the southern tributary exceeded criteria for both TDS and chloride (NJDEP, 2008). 2. Sedimentation. The effects of sedimentation cannot be conclusively ruled out. Upstream portions of the watershed are more clearly impacted by sediment but the effect is not as definitive at AN0311, based on field observations, the benthic community composition, water chemistries, and habitat assessments. The sources of sediment which exist in the watershed include stormwater runoff from impervious areas and construction sites, bank erosion caused by high stream flows, and re-suspension of bed sediments. Therefore, the additive effects of sedimentation are also considered a potential cause of the impairment.

Also, this study found that the Fenimore Landfill does not appear to be a major contributor to the impairment of the benthic macroinvertebrate communities in the downstream reaches of Drakes Brook covered by this investigation. This finding is based on the benthic macroinvertebrate sampling conducted at a station located on an unnamed tributary downstream of the landfill near Ledgewood Pond (DR-LB2) during this study which indicated a Good rating (including 30% sensitive taxa).

Introduction

One of the requirements of state and federal Clean Water Act legislation is to identify, and then, where possible, remediate impaired waterbodies. While the focus of management actions associated with the Act was initially on chemical-related impairments, biological impairments have become equally as important. The types of biological impairments can include fish kills, excessive algal blooms, loss of biological diversity or shifts in biological assemblages. Remediating impaired waterbodies requires that the probable cause or causes of impairment first be identified - an often difficult undertaking, especially when the sources of impairment are not solely the result of piped discharges.

This report describes a Stressor Identification Study conducted on a portion of the Drakes Brook watershed from 2006-2009, focusing on the biological impairment identified at AMNET station AN0311, Drakes Brook at Emmans Rd., located in Roxbury Township, Morris County, New Jersey (see Study Area, Figure 1). The benthic macroinvertebrate community at this site was rated as being moderately impaired and, therefore, not meeting the Aquatic Life Use goals of the federal Clean Water Act. Based on the impairment, this segment of Drakes Brook was listed in the 2004 Integrated Water Quality Monitoring and Assessment Report (includes 305(b) report and 303(d) list).

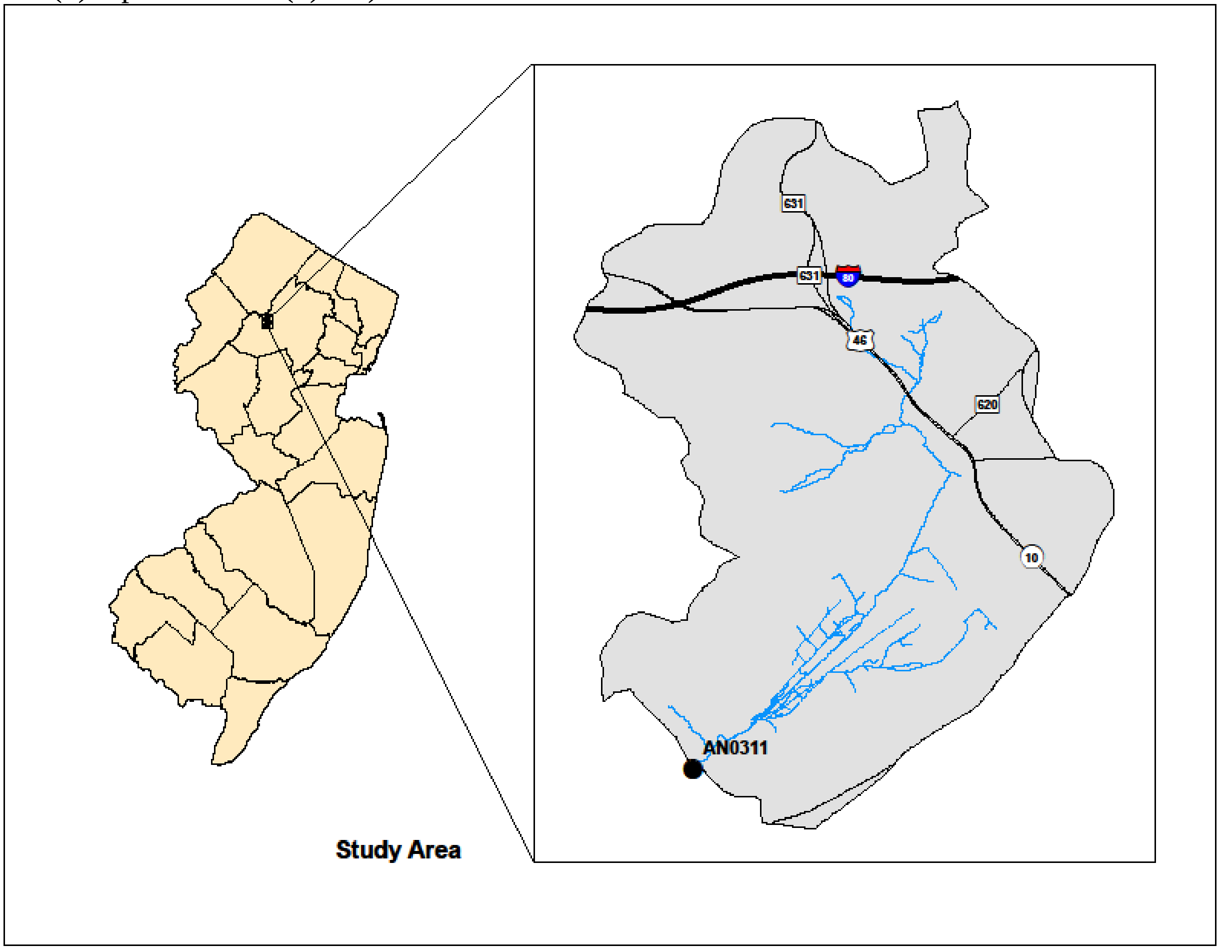


Figure 1. Study Area

The general protocol followed for this SI study was based on USEPA's Stressor Identification Guidance Document (USEPA, 2000) and their Causal Analysis/Diagnosis Decision Information System (CADDIS). Following the USEPA framework, the steps used in this study included first defining the impairment. Next, after a thorough review of available data for the watershed and field reconnaissance, a list of candidate causes was developed. Additional monitoring was then performed, targeted to fill identified data gaps. Lastly, using a weight-of-evidence approach, the probable cause or causes were determined by thoroughly evaluating those on the candidate list.

Approximately 5.6 square miles of the Drakes Brook watershed drain to site AN0311. This contributing watershed has experienced a high degree of development, particularly during the 1970's with the significant commercial development along the Rt. 10 corridor. As a result, urban land use and impervious cover (based upon 2002 aerial photography) are now at 40.3% and 16.8% respectively (see Figure 2). Typically in lotic ecosystems, there is a strong association of upstream land use and water quality characteristics with macroinvertebrate community condition. Generally, statistical analysis has shown that severe community impairment was most significantly and positively related to the amount of urban land and total flow of municipal effluent, and most significantly and negatively related to the amount of forested land (Kennen, 1999). Some researchers have suggested that significant impairment begins at around 10% impervious cover and a second threshold appears to be present at around 25-30% impervious cover, where most indicators of stream quality shift to the poor condition (Kennen and Ayers, 2002). Streams in urban and urbanizing areas are affected by many anthropogenic factors that directly or indirectly modify stream geomorphology, chemistry, and aquatic-assemblage structure (Kennen and Ayers, 2002). Stormwater runoff from urban areas typically contains a mixture of pollutants including sediment, nutrients (nitrogen and phosphorus), chlorides, trace metals, petroleum hydrocarbons, microbial pollution, and organic chemicals (pesticides, herbicides, and industrial)(Shaver *et al*., 2007). The goal of this study was to pinpoint, if possible, the stressor or stressors causing the biological impairment observed at AN0311, thereby providing policy makers with information necessary to develop potential strategies for possible remediation.

Defining the Impairment

At the time of this investigation, NJDEP personnel had conducted benthic macroinvertebrate sampling at AN0311 as part of the AMNET network on three (3) occasions – 1994, 1999, and 2004. This data was analyzed using a multi-metric index called the New Jersey Impairment Score (NJIS). The NJIS uses family-level taxonomy, of a randomly selected 100-organism subsample, and is comprised of five metrics, or measureable characteristics of the benthic community - Total Taxa; percent Ephemeroptera, Plecoptera, and Trichoptera (%EPT); number of EPT taxa; modified Hilsenhoff Biotic Index (HBI); and percent Contribution of the Dominant Family (%CDF). For each of the three sampling events, the NJIS was 21, which indicated Drakes Brook at this site was moderately impaired, but at the high end of the moderately impaired range, 9-21.

The metrics at this site that have consistently scored deficient are:

- %EPT
- Number of EPT taxa
- %CDF

EPT (commonly known as mayflies, stoneflies, and caddisflies) are generally regarded as sensitive to a variety of stressors, with a greater abundance and taxa richness indicating better conditions. The %CDF is a measure of community structure, with an excessive dominance of one taxon indicating a shift in the benthic community composition as a response to a stressor or stressors. In the case of AN0311, the dominant taxon have varied with each sample, but have consistently been relatively pollution tolerant taxa, including the caddisfly Hydropsychidae, the amphipod Gammaridae, and the Diptera (true fly) Chironomidae (midge flies).

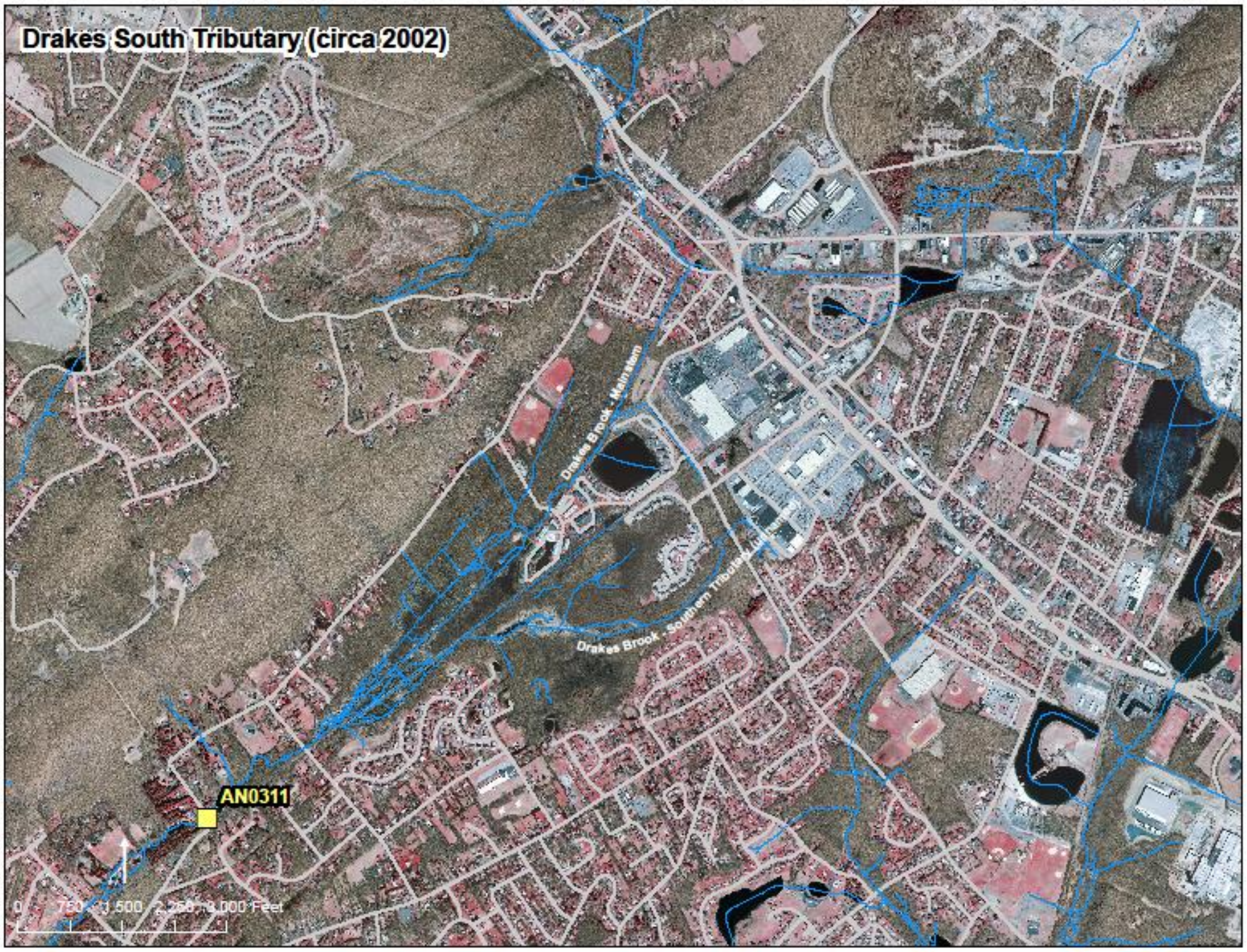


Figure 2. Aerial photograph of study area with hydrology and AMNET Station AN0311 (circa 2002)

Stressor Identification Process

Desktop Investigation

All water quality and other environmental data and information for the Drakes Brook watershed, which could be acquired, were reviewed to determine potential sources and causes of the impairment. NJDEP's Geographic Information System (GIS) was utilized to map and display pertinent features in the study area such as hydrology, permitted discharges, aerial photography, known contaminated sites, and stations with existing water quality data collected by the NJDEP, and other governmental agencies, or consultants. Also using GIS, the current and past land use and land cover (LU/LC) were analyzed to calculate the percentage of the contributing watershed classified as urban, forest, or agriculture, and in determining the percentage of the watershed occupied with impervious cover (%IC).

Field Reconnaissance

Using the list of suspected sources identified through the desktop investigation, NJDEP staff performed a thorough reconnaissance of Drakes Brook and Ledgewood Brook to ground-truth information from the desktop investigation, gather field measurements, photographs, and acquire GPS locations of suspected sources of pollution.

Identification of Candidate Causes and Sources

With the degree of urbanization in the Drakes Brook watershed, and consequently a high level of impervious surfaces contributing runoff, the list of potential stressors included those normally associated with urban LU/LC. Along with the typical urban stressors, the presence of potential impacts of landfill leachate and effluent from a sewage treatment plant also needed to be considered. Therefore, based on information and data gathered as part of the desktop investigation, and observations made as part of the field reconnaissance, the following candidate causes and potential sources of the biological impairment were identified:

1. Stormwater runoff from urban areas and/or construction sites contributing-
    - i. Toxic compounds such as PAHs, petroleum hydrocarbons and metals.
    - ii. Ionic strength (TDS and chloride).
    - iii. Physical habitat alterations by sedimentation and the effects of channel modifications.
    - iv. Nutrient (nitrogen and phosphorus) and/or organic enrichment.

2. Nutrient and/or organic enrichment from the effluent, and/or leachate.

3. Toxic compounds such as volatile organic compounds, semi-volatile organic compounds (base neutral/acid extractables, BN/AE), and metals potentially from leachate.

The linkage between likely sources, stressors, and effects is presented as a conceptual diagram (see Figure 3, below). Each of these candidate causes was thoroughly evaluated to determine if the defined pathway to the biological effects was present or not, using a weight-of-evidence approach. As part of this process, additional chemical, physical, and biological data were collected to fill identified data gaps.

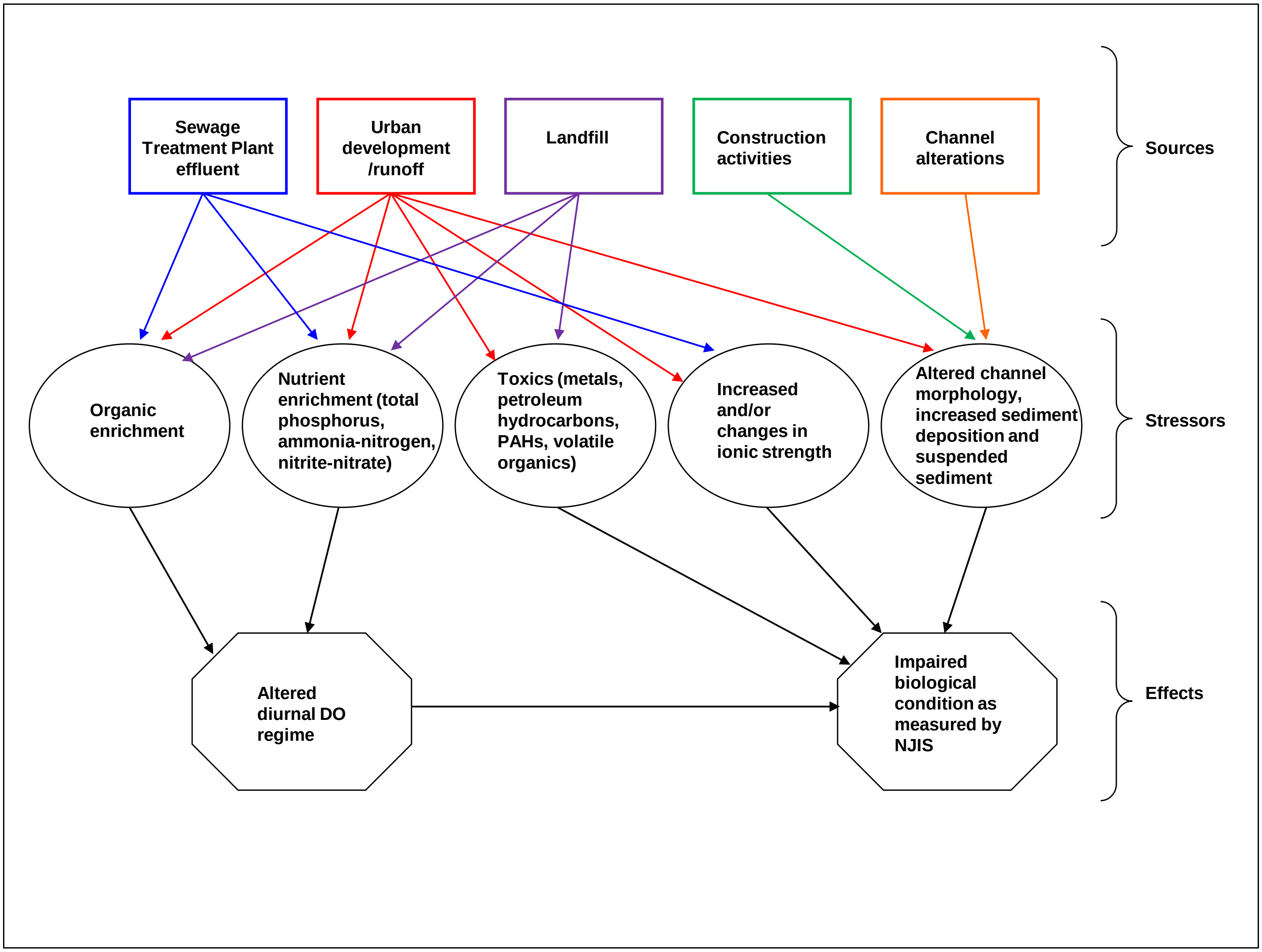


Figure 3. Conceptual Diagram of Candidate Causes

Additional Monitoring

Sampling Station and Parameter Selection

Based on the findings of the desktop investigation and field reconnaissance, a monitoring plan was developed to fill data gaps. Three sites in the watershed were established to collect water quality and sediment data- AMNET site AN0311, Drakes Brook southern tributary near Tania Court (DR-S1), and Drakes Brook in the Willow Walk development (DR-2). In addition, benthic macroinvertebrate samples were also collected at these three stations, as well as at three others - an unnamed tributary upstream of Ledgewood Pond just downstream of Fenimore Landfill (DR-LB2), Ledgewood Brook below Ledgewood Pond outfall (DR-LB1), and Drakes Brook just upstream of the low head dam at Emmans Rd. (AN0311up)(see Figure 4). The purpose of these additional biological monitoring stations was to trace how far upstream from AN0311 the biological degradation was actually occurring, and to rule out contributing portions of the Drakes Brook sub-watershed as sources of stress to the stream biota. A partial sampling site was also established at the Roxbury Mall stormwater outfall to the Drakes Brook southern tributary (DR-SHW), where only Petroleum Hydrocarbons (in sediment and water), and Polycyclic Aromatic Hydrocarbons (PAHs) in sediment were collected.

The following water quality parameters were selected to be sampled at all sites except DR-SHW:

Phenols, Ammonia-Nitrogen, Nitrate+Nitrite-Nitrogen (NO_2+NO_3), Total Phosphorus, pH, Temperature, Dissolved Oxygen (DO), Hardness, Total Dissolved Solids (TDS), Total Suspended Solids (TSS), Chlorides, Sulfate, Sulfides, Biochemical Oxygen Demand, 5-day (BOD_5), and Total Petroleum Hydrocarbons (TPH). Base Neutral/Acid Extractable (BN/AE) compounds (USEPA Method 625) and Purgeables (USEPA Method 624) were sampled at just AN0311.

The following non-aqueous (sediment) parameters were also collected at all sites except DR-SHW:

Metals (Fe, Mn, Cd, Cr, Cu, Hg, Pb, Ni, As, Zn), Total Petroleum Hydrocarbons, and Total Phosphorus.

Additionally, sediment toxicity test samples were also collected at sampling stations AN0311, DR-2, and DR-S1.

Flow Requirements

One dry weather flow sampling event (preceded by at least 72 hours with no rainfall) and one wet weather flow sampling event (2-8 hours after the onset of precipitation) were conducted at each of the stations. Non-aqueous parameters were only sampled during the dry weather event.

Sample Collection Timeline

Chemical sampling at the three (3) pre-selected stations plus the partial station at the Roxbury Mall took place on September 20, 2006 (dry weather sampling) and April 4, 2007 (wet weather sampling). Only aqueous samples were collected on April 4, 2007.

Benthic macroinvertebrate samples were collected at the three (3) pre-selected chemical sampling stations, as well as AN0311up, concurrent with the chemical sampling on September 20, 2006. The additional two stations, DR-LB1 and DR-LB2 were sampled on April 25, 2007.

Sediment toxicity samples were collected on April 25, 2007**.**

Based on the results of the above sampling, additional sediment chemical samples were collected on November 30, 2007 at AN0311up (PAHs and Metals), and at DR-SHW (PAHs only).

Additional follow up sediment toxicity test samples were collected at AN0311up and at the Roxbury Mall storm water outfalls, DR-SHW, on February 21 and 25**,** 2008. Due to ambiguous results of these samples, however, an additional set of sediment toxicity samples were again collected at the same two (2) sites on April 2, 2008.

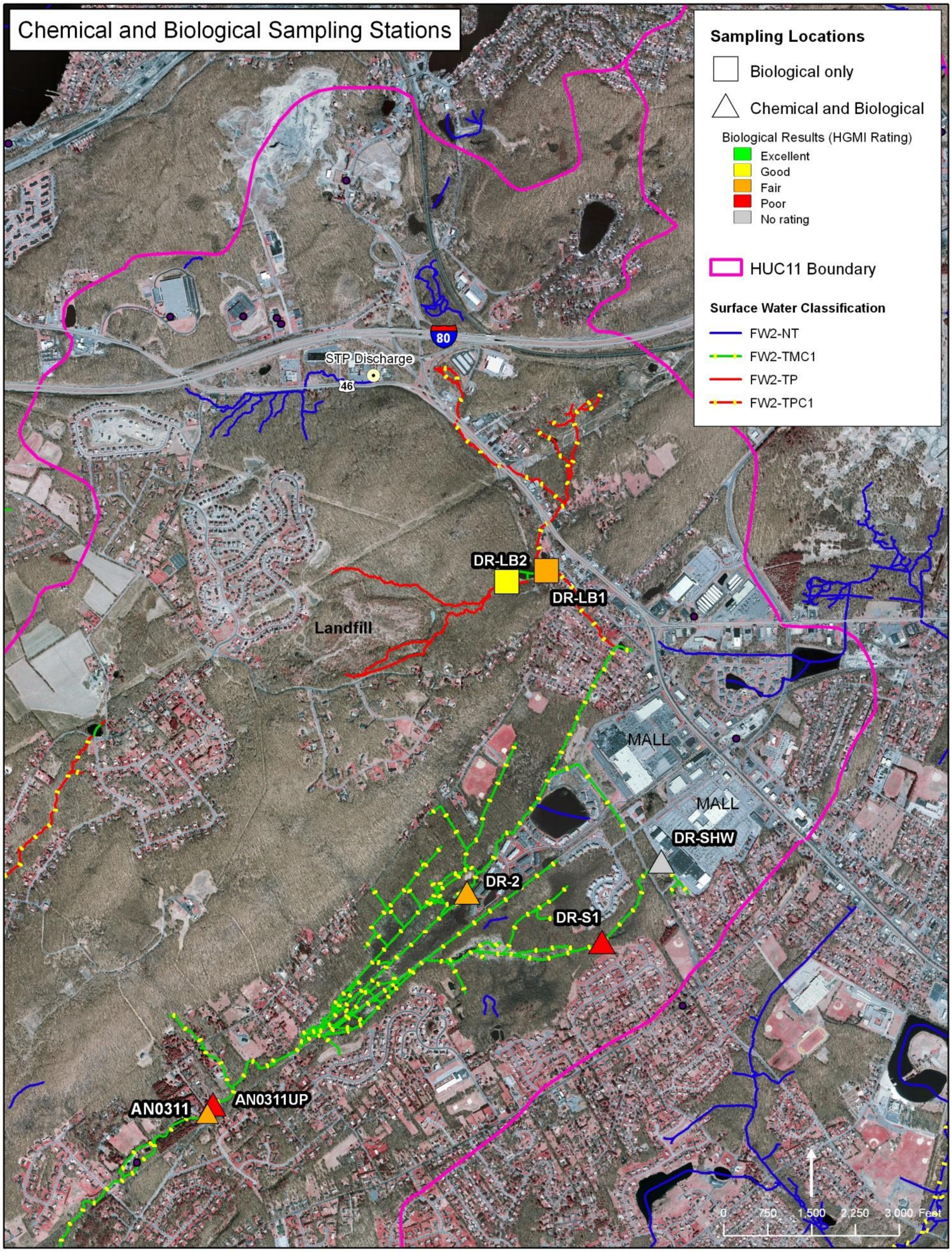


Figure 4. Stream Classifications and Additional Monitoring Stations

Sampling Results and Discussion

Benthic Macroinvertebrate Sampling Results

The NJIS uses family-level taxonomy and three rating categories - non-impaired, moderately impaired and severely impaired. The NJIS was found to be limited in its ability to detect subtle degrees of impairment, as compared to other biological assessments with more detailed taxonomy (Jessup, 2007). A new tool was developed to identify biological degradation in New Jersey streams called the High Gradient Macroinvertebrate Index (HGMI) (Jessup, 2007). The HGMI, also a multi-metric index, uses genus-level taxonomy with seven metrics and four rating categories - Excellent, Good, Fair, and Poor, with Fair and Poor considered to be impaired. The benthic macroinvertebrate data collected for this study was evaluated using the HGMI.

The additional benthic macroinvertebrate samples were collected to trace how far upstream from AN0311 the biological degradation was actually occurring, and to rule out contributing portions of the Drakes Brook sub-watershed and/or sites therein as significant sources of stress to the stream biota reflected at station AN0311. For comparison, data for two nearby minimally-disturbed AMNET sites is also included - AN0313 Stony Brook and AN0318 Spruce Run. See Table 1 below.

Station AN0311 received a score of 37.68 and a rating of Fair, but scored higher than DR-2, and DR-S1. Presumably, this would indicate that DR-2 and DR-S1 are nearer to the sources of stress in the watershed, and therefore exhibiting a greater effect on the biota. These two stations also had the worst habitat assessment ratings of the sites sampled, Marginal.

Station AN0311up, the station closest to and upstream of AN0311 (approximately 135 feet), received the lowest HGMI score of 15.98 and a rating of Poor. This station is just upstream of a low head dam on Drakes Brook, which may serve as a trap for sediment and potentially some legacy toxic substances associated with this sediment. Consequently, additional sediment samples were collected here for PAHs, metals, and toxicity testing (see discussion of results below).

Station DR-LB2, located on a tributary just upstream of and flowing into Ledgewood Pond, but below the Fenimore Landfill, received a HGMI score of 62.58 and a rating of Good.

Station DR-LB1, located on Ledgewood Brook (a tributary to Drakes Brook) but below the Ledgewood Pond outfall, received a HGMI score of 39.54 and a rating of Fair. While scoring slightly better than the sites downstream on Drakes Brook, the results still indicate an impaired benthic community, and show that the impairment observed in Drakes Brook extends into the Ledgewood Brook sub-watershed.

In examining the responses of the individual metrics, no Attribute 2 taxa were present in any of the mainstem or southern branch of Drakes Brook samples. This metric is a tolerance metric, developed specific to New Jersey, which measures the presence of the most sensitive taxa indigenous to the state. While station AN0311 had 23% sensitive EPT, none of these EPTs are designated as Attribute 2 taxa, and therefore are not considered the most sensitive taxa. The Hilsenhoff Biotic Index (HBI) is also a tolerance metric, with values ranging from 0, assigned to the most pollution intolerant taxa, to 10, assigned to very pollution tolerant taxa. The HBI score at AN0311, 5.66, is slightly better than HBI scores at the upstream sites, DR-2, DR-S1, and DR-LB1, and indicates a benthic community composed of a few more pollution intolerant organisms. The number of scraper taxa is the number of taxa that scrape their food (periphyton) from the surface of a fixed object, such as a rock, log, leaf, etc. Taxa with this feeding designation, known as functional feeding group, are typically more intolerant of stressors such as sediment. The data suggests, with more of these scraper taxa present, that in-stream habitat conditions are better (less sedimentation) at AN0311 than DR-2, DR-S1, and DR-LB1. As with the total index score, this metric also seems to indicate worse conditions at some of the upstream reaches, nearer the presumed source or sources of stress to the biota. While the benthic community at AN0311 is impaired, there appears to be some recovery occurring, when compared to upstream stations, DR-2 and DR-S1, in particular. Table 1 (below) summarizes metric results and index scores. For comparison purposes, 2004 benthic macroinvertebrate sampling data from sites in two relatively undeveloped watersheds was included in Table 1- AN0318 Spruce Run in Lebanon Twp., Hunterdon Co. and AN0313 Stony Brook in Washington Twp., Morris Co.

Table 1 Results of Benthic Macroinvertebrate Sampling

Metric	AN0311	AN0311up	DR-2	DR-S1	DR-LB1	DR-LB2	AN0318	AN0313
Date	9/20/2006	9/20/2006	9/20/2006	9/20/2006	4/25/2007	4/25/2007	4/7/2004	4/6/2004
# of taxa	23	11	18	13	22	36	19	24
% non-insect taxa	34.8	54.5	27.8	53.8	22.7	16.7	5.56	16.7
%sensitive EPT	23	0	4	0	29	30	64	48
#scraper taxa	4	4	2	1	1	1	4	3
HBI	5.66	5.96	6.01	7.61	5.92	4.85	4.07	3.53
#attribute 2 taxa	0	0	0	0	2	9	4	8
#attribute 3 taxa	3	0	1	0	3	6	8	8
HGMI score	37.68	15.98	25.57	12.63	39.54	62.58	73.04	76.19
HGMI rating	Fair	Poor	Fair	Poor	Fair	Good	Excellent	Excellent
Habitat Score	149	121	107	90	146	167	178	164
Habitat Rating	Suboptimal	Suboptimal	Marginal	Marginal	Suboptimal	Optimal	Optimal	Optimal

Water Chemistry Results

The results of the water column chemistry samples collected during this investigation can be found in Appendix E, Table 1, with the results summarized in the following charts.

Total Phosphorus (see Figure 5)

Nutrients such as phosphorus are essential for plant growth, but over-enrichment can stimulate excessive plant and algal growth (eutrophication). This excessive growth can alter in-stream food resources and habitat structure, and lead to oxygen depletion during nighttime hours when photosynthetic activity ceases. Values at all sites trended higher during the wet sampling event compared to the dry event, indicating stormwater runoff was a source of phosphorus in the watershed. There was only one station (DR-S1) that exceeded the Surface Water Quality Standards' (SWQS) Total Phosphorus criterion of 0.10 mg/L (NJDEP, 2008), and that occurred only marginally during the wet weather sampling event.

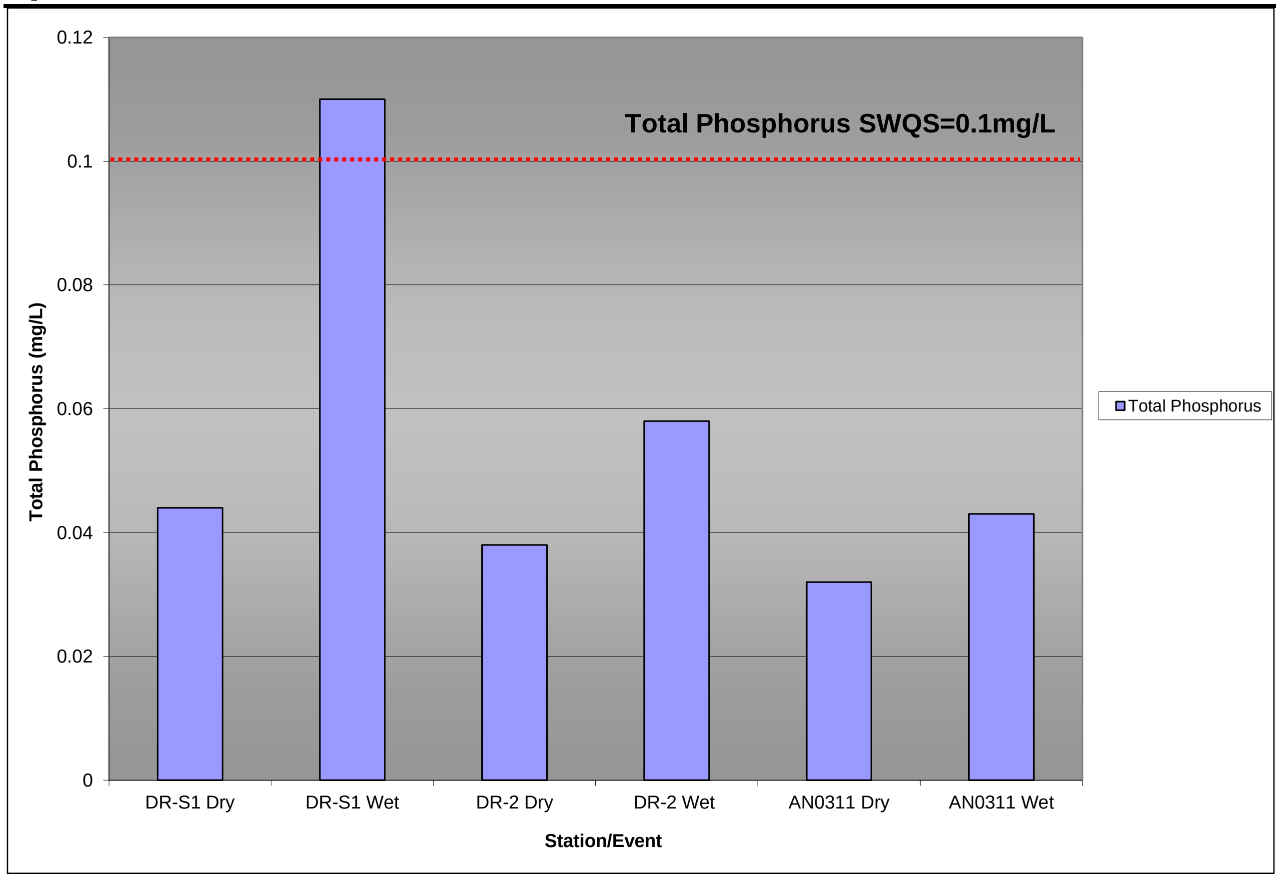


Figure 5. Total Phosphorus Results

Nitrogen - Ammonia and Nitrate-Nitrite

Like phosphorus, nitrogen is also an essential element for living organisms, which at elevated levels can cause excessive plant and algal growth. Total Ammonia Nitrogen (TAN) was measured at the 3 sampling stations. The more toxic form of ammonia, Un-ionized Ammonia (UIA) was not measured directly, but calculated from formulas using the variables of pH, temperature, and conductivity. These calculated UIA values were then compared with the calculated summer (March 1-October 31) criteria in the SWQS (See Appendix E, Table 2). No value of UIA exceeded the SWQS. However, the acute UIA SWQS is expressed as a three-hour average using the "minimum average one day flow with a statistical recurrence interval of 10 years" (MA1CD10), and these samples were instantaneous grabs. As such, these values of UIA may not reflect conditions found on a larger temporal scale. There could be times when UIA values in this stream are higher or lower. A value of UIA above 0.05 mg/L has been cited (Floyd *et al*., 1996) as a level of concern for stream biota, particularly fish. No sampling station exceeded that value.

At present, there are no aquatic life criteria in the SWQS for both nitrate and nitrite (see Figure 6), but none of the results in this sampling are considered excessive.

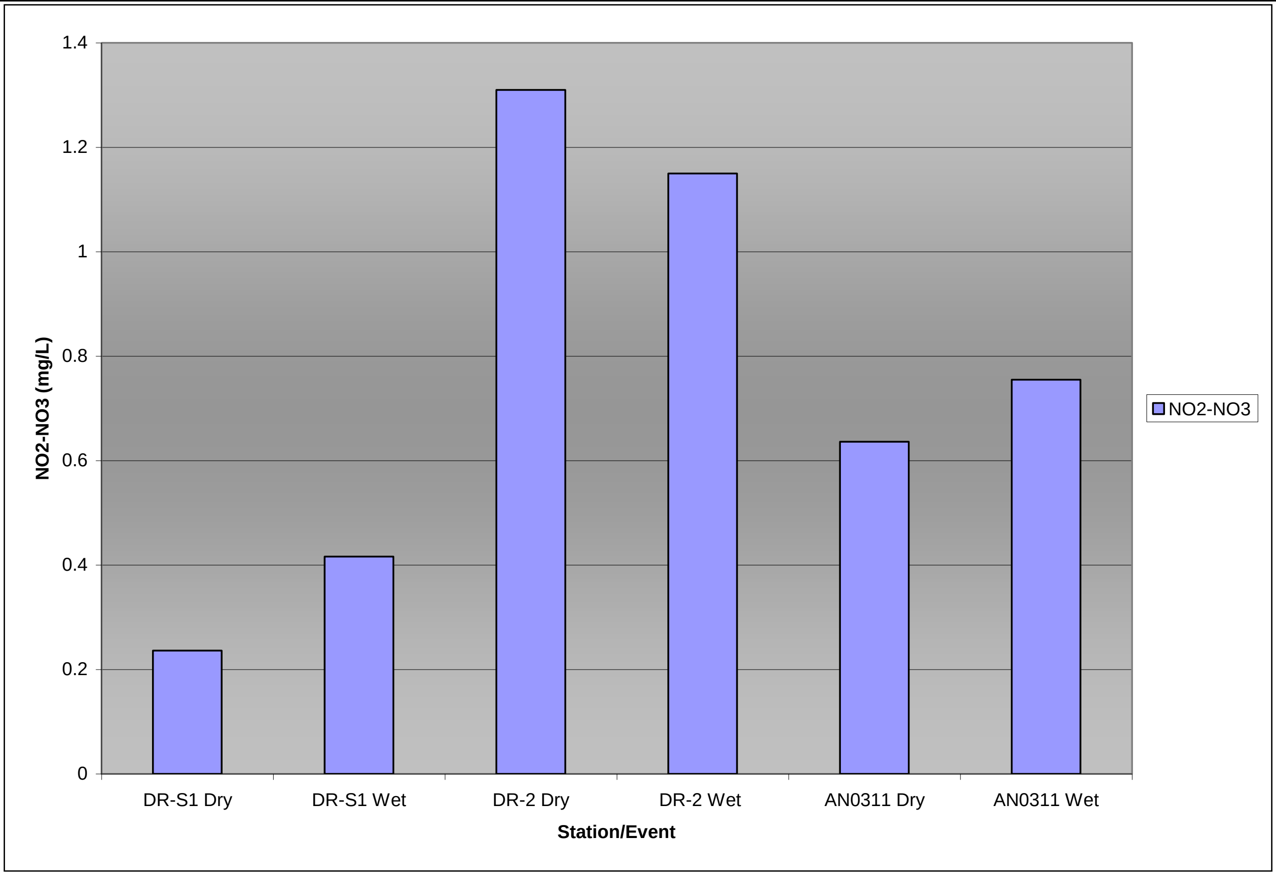


Figure 6. Nitrate-Nitrite Sampling Results

Biochemical Oxygen Demand (BOD) and Dissolved Oxygen

BOD is a measure of the potential oxygen consumption by microbial respiration. Inputs of organic matter to a stream, such as animal waste, municipal treatment plant effluent, or from failing septic systems, can lead to increases in BOD, and in-stream oxygen depletion. No extreme BOD_5 values were observed at any sites sampled.

There was one station (DR-S1) that exceeded the SWQS for dissolved oxygen (SWQS for FW2-TM of “not less than 5.0 mg/L at any time”), with a dry weather concentration of 2.0 mg/L. It should be noted that this grab sample was collected during daylight hours. Measurements taken over a diurnal cycle were not taken, and could have resulted in additional exceedances.

Specific Conductivity, Total Dissolved Solids, and Chloride

These three parameters are indicators of ionic strength. A review of the dry weather results for Specific Conductivity, TDS, and Chloride (see Figure 7, below) reveals the highest value for each occurring at DR-S1. The TDS SWQS criteria of 500 mg/L was exceeded at DR-S1 during the dry weather sampling with a level of 695 mg/L. The Chloride SWQS, FW2 Aquatic (chronic) criteria of 230 mg/L was also exceeded at DR-S1 with a result of 279 mg/L. There is no standard for Specific Conductivity, but it is an indicator of overall ionic strength.

The baseflow chloride results from the mainstem of Drakes Brook stations within the study area were significantly higher than the levels found in 1996 by Coastal Environmental Services, with the highest level of 75 mg/L in 1996, compared with 107 mg/L in 2006. Similarly, higher Specific Conductivity readings were made in sampling for this study than recorded by Coastal Environmental Services in 1996, for stations on both Drakes Brook and Ledgewood Brook within the study area.

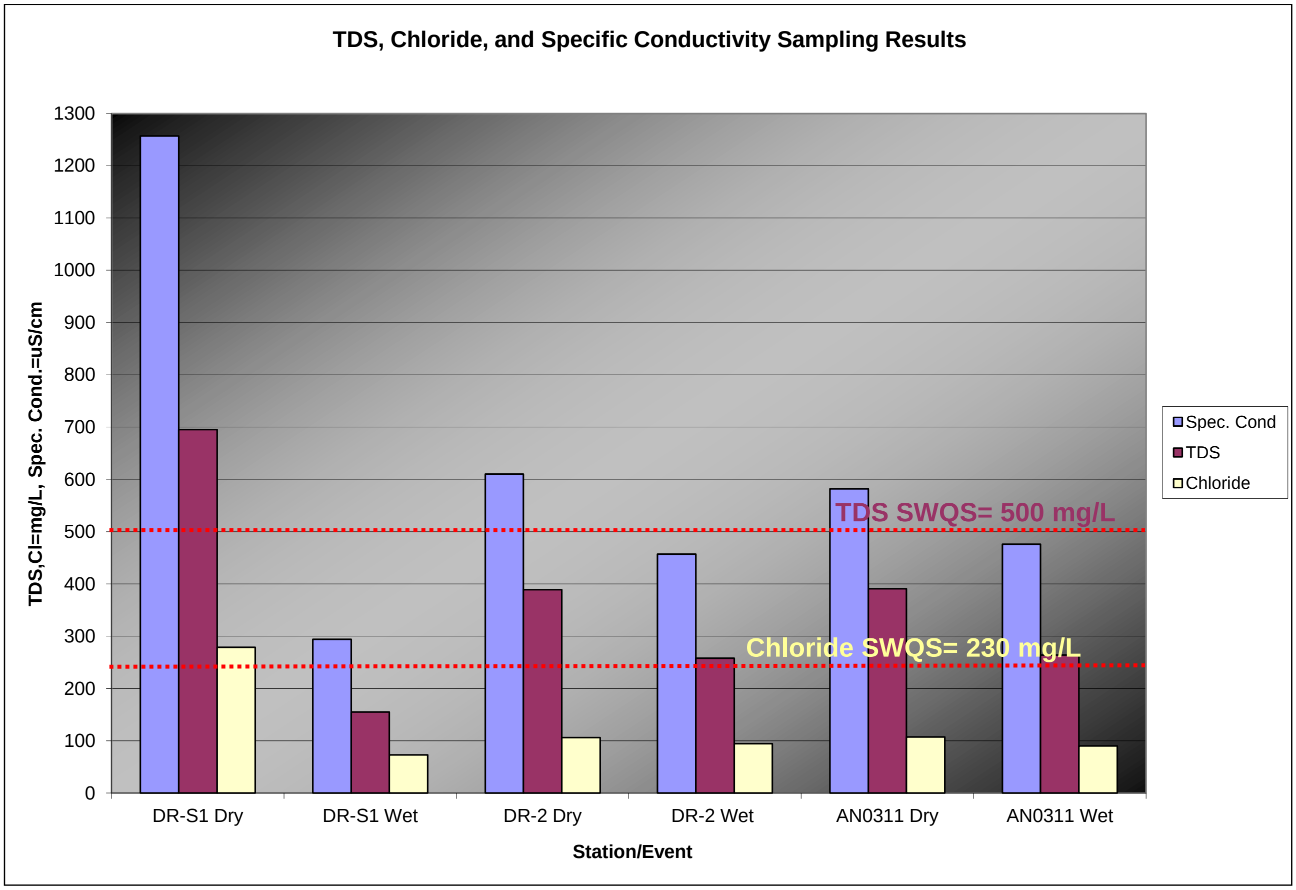


Figure 7. TDS, Chloride and Specific Conductivity Sampling Results

<u>Hardness</u>
Hardness is a measure of the dissolved mineral content of water. Calcium and magnesium ions are the most common sources of hardness. There are no SWQS criteria for hardness. Dry weather results (see Figure 8) indicated the water at all stations sampled was quite hard, with all being above 150 mg/L. Based on analysis of the data by New Jersey Geological and Water Survey (NJGWS) personnel, these readings are not likely the result of the underlying dolomite limestone of the Leithsville Formation, but indicative of the urban LU/LC of the watershed. All hardness values were lower during the wet weather sampling, with DR-S1 being significantly lower, as a result of dilution by rainwater. The wet weather hardness at DR-S1 was less than a tenth of the dry weather hardness, indicating that a high proportion of the wet weather flow was rainwater presumably running off the impervious surfaces of the mall complexes located not far upstream. Rainwater is naturally soft, having little or no dissolved minerals.

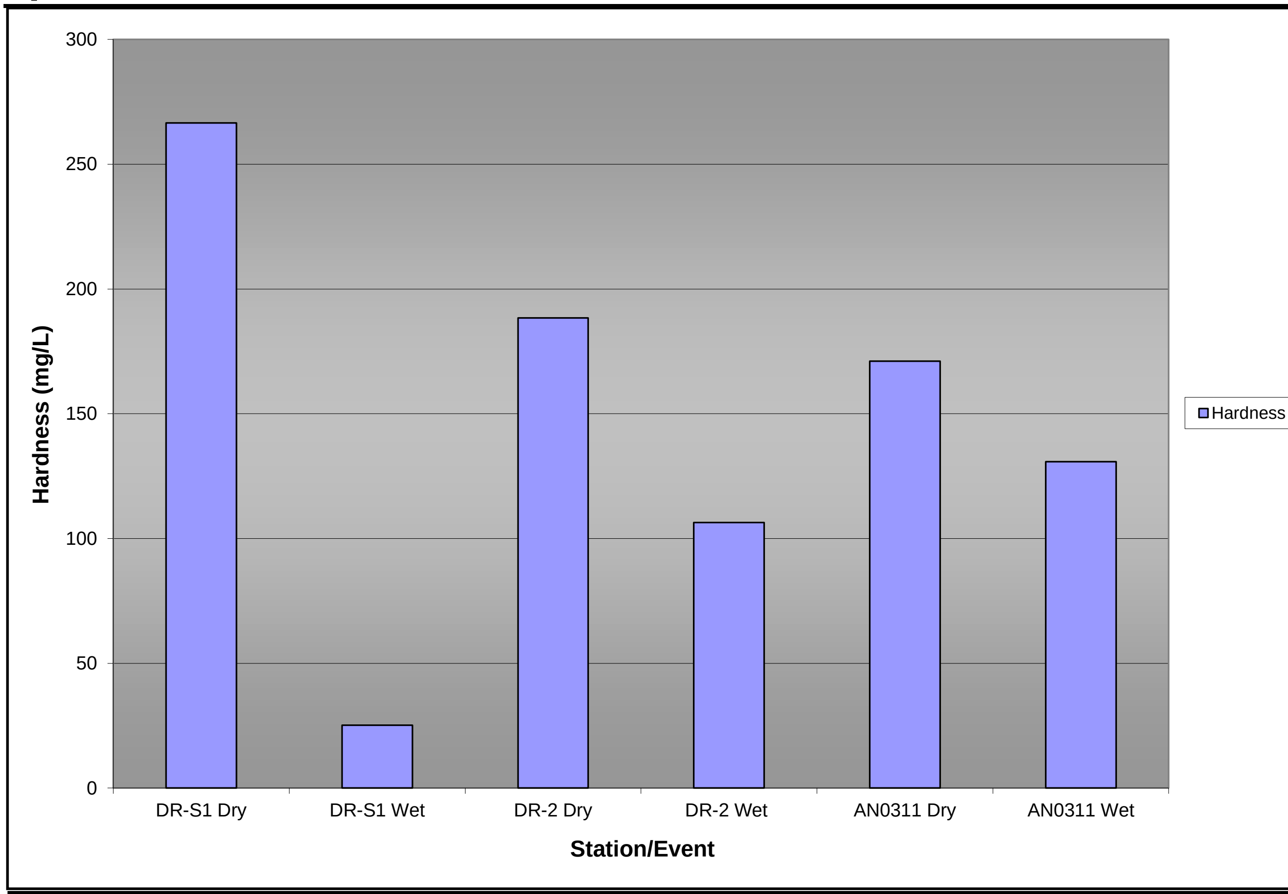


Figure 8. Hardness Results

Total Suspended Solids and Turbidity (See Figure 9, below)

Suspended solids are particulate matter carried in the water column and turbidity is a measure of the scattering effect the suspended solids have on light. Station DR-S1 exceeded the SWQS criteria for TSS of 25 mg/L. This occurred during the wet weather sampling with a measured level of 28 mg/L. None of the sampling locations exceeded the SWQS criteria for turbidity of a maximum of 50 NTU (Nephelometric Turbidity Unit) measured at any time. The highest turbidity measurement also occurred at station DR-S1, which had a wet weather value of 31.1 NTU. These wet weather results at DR-S1 suggest that stormwater runoff from the upstream impervious surfaces is contributing a significant amount of silt and sediment to the southern tributary and/or elevated flows are causing bank erosion and re-suspension of the streambed sediment. As part of the habitat assessment performed with the benthic macroinvertebrate sampling, bank stability was noted as being below optimal at AN0311, as well as the upstream mainstem site, DR-2, and the Ledgewood Brook site, DR-LB1.

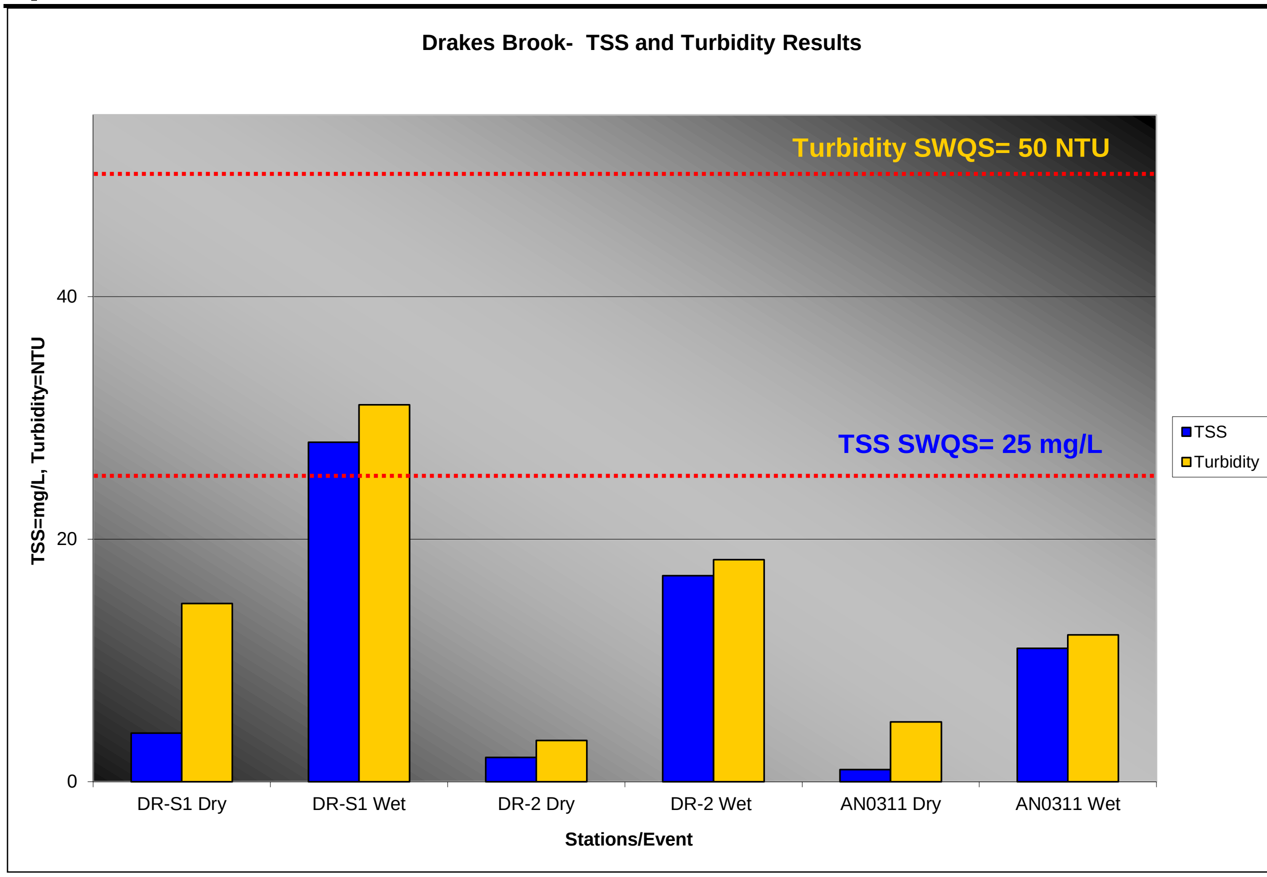


Figure 9. TSS and Turbidity Results

Sulfate, Sulfide, and Total Petroleum Hydrocarbons (TPH)

There were no exceedances of the 250 mg/L SWQS for sulfate at any of the sampling stations, wet or dry. Sulfide was not detected (ND) at any stations, wet or dry. There is no numerical SWQS for petroleum hydrocarbons, other than a narrative "none noticeable." No petroleum hydrocarbons were detected in the water column at AN0311 during both dry and wet weather samplings. Petroleum hydrocarbons, however, were measured, albeit at low levels, at sample locations upstream of AN0311, which are progressively closer to the more urbanized areas of the watershed (see Figure 10). Station DR-2 had dry and wet weather values of 1.2 mg/L and 0.57 mg/L, respectively. This dry weather level is interesting in that Coastal Environmental, as part of their 1997 study, reported the highest petroleum hydrocarbon result (1.27 mg/L) from their sampling station on Ledgewood Brook, not far upstream of DR-2. This was attributed to oil-tainted runoff to Ledgewood Brook somewhere near the sampling location. Station DR-S1 had dry and wet weather values of non-detect (ND) and 1.33 mg/L, respectively. The highest value, 3.1 mg/L, was found at DR-SHW during the wet weather event, indicating stormwater runoff is carrying hydrocarbons from the impervious surfaces of the Roxbury Mall parking lot.

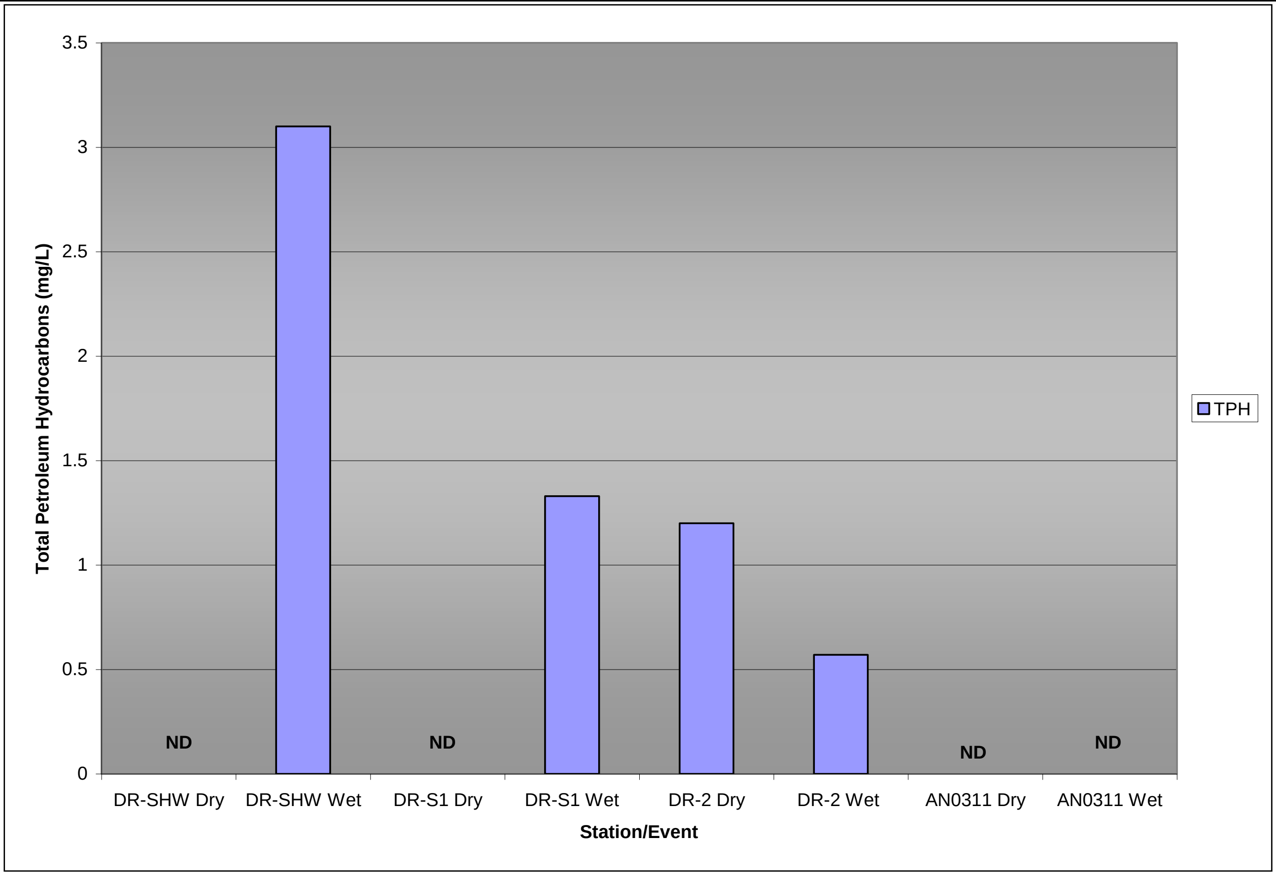


Figure 10. Total Petroleum Hydrocarbons Results

Phenols

Phenols were a potential fugitive pollutant which had been identified in prior studies of the Drakes Brook watershed. Phenols are a class of chemical compounds similar to alcohol, with many laboratory and industrial uses. All sampling stations had non-detects (ND) for phenolic compounds, in this sampling, for both wet and dry weather events.

Purgeables (USEPA 624) Water Chemistry Results (see Appendix E, Table 4)

This analysis measures water column concentrations of compounds also known as volatile organic compounds, such as benzene and chloroform. All values reported by the laboratory were less than their Method Detection Limit (MDL), and thus had either a qualifier of “K” or “U”. The MDL is the minimum concentration at which an analyte can be measured and reported with 99% confidence that the concentration is greater than zero. All values were below the MDLs, thus their value in identifying potential stressors here is limited.

Extractable Base/Neutrals and Acids (USEPA 625) Water Chemistry Results (see Appendix E, Table 4)

This analysis measures water column concentrations of compounds also known as semi-volatile organic compounds, some of which are PAHs. All values reported by the laboratory were less than their MDLs. Similar to the USEPA 624 Purgeables, their value in identifying potential stressors here is limited.

Sediment Chemistry Results

The results of the bed-sediment chemistry samples collected during this investigation for petroleum hydrocarbons, total phosphorus, sulfate, and heavy metals can be found in Appendix E, with the results summarized in the following charts.

Total Petroleum Hydrocarbons (see Appendix E, Table 1)
The concentrations of total petroleum hydrocarbons (TPH) observed in the samples collected are graphed in Figure 11, below. The highest value for TPH was at the Roxbury Mall stormwater outfall (DR-SHW), which had a value of 1430 mg/kg. Stations AN0311, DR-2 and DR-S1 had values of 129, 181, and 425 mg/kg, respectively, indicating a diminution of sediment-borne petroleum hydrocarbons in a downstream direction. There is at present no standard for TPH in sediment by which to estimate adverse biological effects, although the literature (Pettigrove and Hoffmann 2005 and Anson *et al*. 2007) suggests a possible threshold of 840 mg/kg. Using this level, the higher sediment concentration at the Roxbury Mall stormwater outfalls would appear to be of some concern, but the concentration at AN0311 is well below this level.

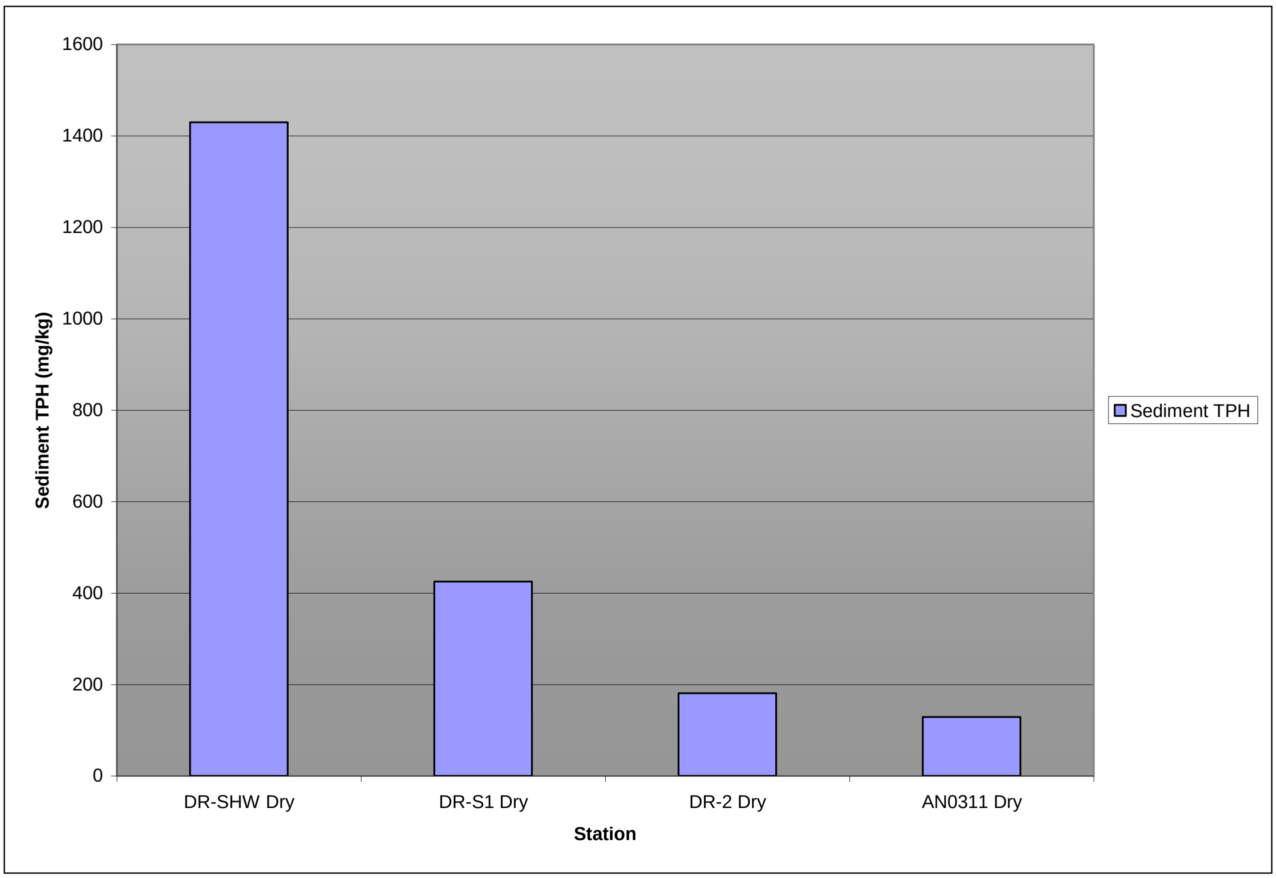


Figure 11. Sediment Total Petroleum Hydrocarbons Results

Total Phosphorus (see Appendix E, Table 1)
The amount of total phosphorus in the sediment at each of the three (3) sampling stations was fairly uniform with values for AN0311, DR-2, and DR-S1 of 165, 194, and 169 mg/kg, respectively.

Sulfate (see Appendix E, Table 1)
Sulfate was not detected in the sediment samples at any of the sampling stations.

Heavy Metals (see Appendix E, Table 5)
Arsenic, cadmium and mercury were not detected (ND) at all sampling stations. Other sampled metals (Cr, Cu, Fe, Mn, Ni, Pb, and Zn) all had measurable values, but none exceeded the NJDEP Ecological Screening Criteria's Lowest Effect Level (LEL) (www.state.nj.us/dep/srp/guidance/ecoscreening/) for freshwater sediments. The LEL represents the concentration at which adverse benthic impacts may begin to occur (level tolerated by most benthic organisms). The lowest concentration of all detected metals was at AN0311, except Manganese (Mn).

PAHs (see Appendix E, Table 3)
The results of the bed-sediment chemistry samples collected during this investigation for PAHs can be found in Appendix E, Table 3. Sediment samples were collected for PAH analyses at sample stations AN0311up and the Roxbury Mall storm water outfall (DR-SHW). The samples were analyzed for 17 PAH compounds. Only one compound (fluoranthene) was found at AN0311up, although the result had a "J" qualifier. The "J" indicates that the mass spectrophotometer has identified the chemical as present but the quantity is estimated, since it is below the first point on the calibration curve. Ten (10) PAHs, including fluoranthene, however, were identified as being in the sediments at station DR-SHW. Of these ten compounds, nine (9) were "J" valued, while one (1), fluoranthene, at a concentration of 1,690 µg/kg (or 1.690 mg/kg), was not "J" valued and represents a real concentration. This concentration of fluoranthene did exceed NJDEP's Ecological Screening Criteria (ESC) suggested LEL, but did not exceed the Severe Effects Level (SEL) of 1,020 mg/kg. The SEL indicates the level where severe impacts to the benthic community were observed in most cases studies. The remaining nine (9) PAHs identified do show some exceedances of NJDEP ESC-LELs, but because their quantity is only estimated, stating specific exceedances of the criteria is not possible. The fact, however, that so many have been identified as present near a stormwater outfall is of some significance, although there is no evidence that these compounds are migrating downstream in concentrations likely to affect the biota at AN0311.

Sediment Toxicity Testing Results

Three rounds of sediment toxicity testing using test organism, *Hyalella azteca*, were conducted in the study area; one set of tests in 2007 and two sets in 2008. Test conditions established during all of the toxicity tests were: 23°C(+/- 1); age of test organisms at start was 7-14 days; renewal of overlying water was two (2) volumes daily, every twelve (12) hours; and overlying culture water, which came from Round Valley Reservoir, was alkalinity and hardness adjusted. There were ten (10) test organisms per replicate and four (4) replicates per treatment. All treatments were fed 1.0 ml YCT daily, and light was maintained at sixteen (16) hours of light and eight (8) hours of dark.

A ten (10) day sediment toxicity test was performed starting on June 19, 2007 and ending June 29, 2007 using the amphipod *Hyalella azteca*, cultured in-house. Samples were collected on April 25, 2007 at the following locations:

AN0311 Drakes Brook at Emmans Road below footbridge;
DR-2 Drakes Brook at Willow Walk; and
DR-S1 South Branch Drakes Brook near Tania Court.

A reference sediment sample was also collected on the same day at a nearby non-impaired AMNET site (AN0313 – Stony Brook @ Fairview Road). Percent survival per treatment (defined by the number of test organisms recovered at the end of the test) were as follows:

AN0313 –90% Control
AN0311 –65%
DR-2 – 60%
DR-S1 – 45%

The test was considered valid since there was greater than 80% survival in the control (reference) site. Using a pairwise t-test (reference and test site) the survival at DR-S1 was determined to be significantly reduced (P=0.003) from the control and therefore the sediment at this site is acutely toxic. The survival of test organisms at other two sites, DR-2 and AN0311, was not significantly reduced when compared to the control site, using the same pairwise t-test.

A second round of ten (10) day sediment toxicity testing was conducted from February 26, 2008 through March 7, 2008. This testing was conducted on samples collected at the following stations:

AN0311up (upstream of the footbridge @ AN0311);
DR-SHW (the outfall of the Roxbury Mall into the southern tributary of Drakes Brook); and
Reference control site AN0313.

The tests did not achieve the required 80% recovery of test organisms at the reference control site (33 out of 50 or 66% recovery was noted). The reason for the control mortality was unknown. Given the questionable results of the reference control site, a follow up sampling and testing at the same three (3) sites was recommended.

Accordingly, on April 2, 2008, sediment toxicity testing samples were again collected at sites AN0311up, DR-SHW and the reference control site AN0313. A ten (10) day sediment toxicity test was conducted on these samples from April 15, 2008 through April 25, 2008. The percent survival (recovery) for sites AN0313, AN0311up and DR-SHW were: 86%, 70%, and 26%, respectively. This test met the criteria for control survival and was a valid test.

Comparing AN0313 and DR-SHW (reference and test site), the survival at DR-SHW was determined to be significantly reduced (P=<0.001) from the reference site using the pairwise t-test. Survival at other test site, AN0311up, was determined to be not significantly different.

Results seem to indicate that sediment in the southern tributary is acutely toxic, possibly with contaminants emanating from the mall complex outfalls just above DR-SHW. But, this toxicity is not evident in the sediment downstream at AN0311, nor is it evident at the upstream Drakes Brook site, DR-2.

Evaluation of Candidate Causes and Sources

In evaluating both water column and sediment chemistry results collected for this study at AN0311, comparisons were compared with data collected at a minimally-disturbed AMNET site, AN0318, Spruce Run @ Newport Rd. (01396550), where physical/chemical sampling was also conducted as part of the Ambient Surface-Water Quality Monitoring Network (ASWQMN), a NJDEP/USGS cooperative monitoring program (see Table 2, below). ASWQMN water quality data was downloaded from USGS's National Water Information System (nwis.waterdata.usgs.gov/nwis).

Table 2. Comparison of Drakes Brook with Spruce Run

	AN0318 Spruce Run @ Newport	AN0311 Drakes Bk @ Emmans Rd.	
	Median	**Dry**	**Wet**
Spec. Conductivity, µS/cm	136.5	582	476
Chloride, mg/L	10.8	107	90.4
TDS, mg/L	88	391	264
Total Suspended Solids, mg/L	2.5	1	11
Turbidity (NTU)	1.45	4.93	12.1
Total Phosphorus, mg/L	0.010	0.032	0.043
Ammonia-N, mg/L	<0.030	0.041	0.0315 J-R
NO_3+NO_2, mg/L	0.46	0.636	0.755
Sed. Chromium, mg/kg	13	3.3	
Sed. Copper, mg/kg	5	2.47	
Sed. Manganese, mg/kg	235	205	
Sed. Nickel, mg/kg	3.9	2.01	
Sed. Lead, mg/kg	5.95	5.75	
Sed. Zinc, mg/kg	33.5	31.3	

Spruce Run median for NO_3+NO_2, and Chloride is a filtered sample

Stormwater runoff from urban areas contributing:

Toxic compounds such as PAHs, petroleum hydrocarbons, and metals - While there is evidence, per the results, that various PAHs are being carried by runoff from paved surfaces, such as the parking lots of the Ledgewood and Roxbury Malls. However, there is no evidence that these compounds have migrated downstream to AN0311 in concentrations to cause toxicity. Likewise, all of the sediment metals at AN0311 were below levels which could cause negative aquatic life effects, and were at or below concentrations found in Spruce Run. Sediment metal concentrations were progressively higher at other stations in the watershed, located closer to sources of runoff from paved surfaces, including metals usually associated with parking lot runoff- zinc, copper, lead, and chromium. Lastly, petroleum hydrocarbons were not detected in the water column at AN0311 during both sampling events, and were in the sediment at a concentration well below the level of concern. Therefore, petroleum hydrocarbons, as well as metals and PAHs carried by stormwater runoff from urban areas are not likely causes of the impairment.

Ionic strength, as measured by TDS, chloride, and specific conductivity, was clearly higher in the Drakes Brook watershed, than a less developed watershed, such as the Spruce Run watershed (AN0318). The median specific conductivity of Spruce Run was 136.5 µS/cm and median chloride value was 10.8 mg/L. Roy et al. (2003) observed consistently strong relationships between biotic indices and specific conductance which indicated that increased specific conductance may lead to biotic impairment of surface waters. Increased ionic strength can cause shifts in community composition rather than mortality (CADDIS). Specific conductivity and chloride levels throughout the watershed, including AN0311, are comparable to those of other urbanized watersheds in New Jersey. TDS has the ability to cause benthic macroinvertebrate impairment by chronic non-lethal effects (Bodkin, 2007). Bodkin, quoting from Kennedy (2002), further suggests that the rate of change in TDS concentration may be more toxic to benthic macroinvertebrates than the TDS concentration alone. A technical paper authored by SETAC (2004) noted that the stress caused by the energy expenditure of organisms trying to regulate water and ions can affect growth and reproduction. Such ionic balancing, if conducted over a significant portion of an organism's life cycle, can result in the replacement of less tolerant organisms with more salinity tolerant organisms, such as amphipods. Ephemeroptera (mayflies) appear to be highly sensitive to TDS (Bodkin et al., 2007), explained perhaps by the fact that mayflies have more exposed cells that are not protected by an epithelial layer making them more permeable than many other benthic macroinvertebrates (Kennedy, 2002 in Bodkin et al., 2007). Including the benthic macroinvertebrate sampling as part of this study, and the 3 rounds of sampling performed as part of the AMNET program, less than 1% of the organisms collected at AN0311 were Ephemeroptera, compared with Spruce Run (AN0318), which had a benthic community composed of almost 40% Ephemeroptera in the 2004 sampling. Even though TDS levels did not exceed criteria (SWQS) at AN0311, extreme fluctuations and/or pulses, not measured definitively as part of this study, likely occur during winter months when de-icing salts are applied to paved surfaces. Chloride, which is a component of the elevated TDS and specific conductivity, was found to be above the freshwater chronic aquatic criteria for FW2 streams at DR-S1. The effect of elevated chloride levels on aquatic organisms is similar to that of elevated TDS and high specific conductivity, disruption of osmoregulation leading to impaired survival, growth, and/or reproduction (Evans and Frick, 2001). As with the TDS and specific conductivity results, this chloride value was from sampling performed in September, far removed from the time of year where road salting would occur. High concentrations of chloride that occur in late spring and summer when there are no deicing activities may be due to the discharge of groundwater containing high concentrations of chloride (Eldridge *et al*., 2010).

The wet event results for all three parameters - specific conductivity, TDS, and chloride - were significantly lower compared to the dry event (baseflow). Therefore, during this sampling in April, stormwater runoff was not contributing to the ionic strength as a cause of the biological impairment. But, the sampling results indicated that baseflow (dry event) levels of TDS, specific conductivity, and chloride are similar to median levels found in urban groundwater wells installed into glacial sediments (Raymond Bousenberry, NJGWS, personal communication, 2011) affected by decades of land use associated non-point source pollution. Groundwater tends to have the most impact on surface water quality during the summer months. Therefore, the dry event sampling results are more indicative of the groundwater quality. It seems likely that the levels of all three of these parameters would be much higher at times of snow melt. Ionic strength may partially explain the dearth of EPT taxa at AN0311, DR-2 and DR-S1, and consequently the depressed index scores, but other factors such as habitat quality could also cause a similar biological response. Ionic strength is, therefore, considered to be a contributing cause, but a cause which cannot be fully evaluated with the current data. More data during winter months is needed to definitively link ionic strength as the cause of the biological impairment.

<u>Habitat alterations caused by sedimentation</u> - Sediment is one of the most common and potentially damaging pollutants found in urban runoff (Shaver et al., 2007). For benthic macroinvertebrates, sedimentation means loss of habitat variability, quality, and quantity (Logan, 2007). Sediment deposition changes the abundance and species composition of benthic macroinvertebrate communities, with some taxa more tolerant and better adapted to the effects (Logan, 2007). Sources of sediment can be classified as channel (includes banks subjected to erosion, fine streambed materials, mid-channel or point bars) or non-channel (includes urban areas which markedly increase the volume and timing of runoff), both of which occur in the Drakes Brook watershed (Wood and Armitage, 1997). As impervious surfaces in a watershed increase, a higher proportion of rainfall is received into streams as runoff, increasing the frequency of bankfull flows (Shaver et al, 2007). These bankfull flows increase stream bank erosion, fine sediment production, streambed scour, and fine sediment deposition. And with channel straightening, which has occurred particularly with the southern tributary, movement of runoff from the upstream impervious surfaces to the downstream reach is facilitated. Runoff from construction sites is also a potential source of sediment, particularly if erosion control measures are not adequate or properly maintained. Water column data generated for this study showed much higher TSS results during the wet weather sampling compared to baseflow conditions, with the highest concentrations nearer the higher density of impervious surfaces, such as the shopping malls. Moving downstream toward AN0311, the TSS concentration is reduced, as the water velocity slows, and particulates are deposited. Logan (2007) suggested that the

responses of five (5) benthic macroinvertebrate metrics correlated and responded consistently to increasing fine sediment deposition. The metrics % burrower and % Chironominae of Chironomidae responded positively to increasing sediment deposition. The metrics % EPT, EPT taxa abundance, and % Orthocladiinae of Chironomidae responded negatively to increasing fine sediment deposition. Benthic metrics, such as %EPT, are often correlated with one or more other environmental variables.

Therefore, distinguishing the effects of fine sediment and other perturbations may be a problem (Logan, 2007). An evaluation of the macroinvertebrate data collected as part of this study, compared with data from AN0318 (2004), finds that three sites - AN0311up, DR-S1, and DR-2 - had metric responses inferring that sedimentation is impacting the sites, ranked in order from greatest to least, respectively. AN0311 was ranked next, but only one of the five metrics responded as would be expected if impacted by sediment deposition. Two of the others responded in a manner opposite to the expected response, and two responded inconclusively. The low head dam between AN0311 and AN0311up appears to be trapping much of the sediment, as evident by the different metric responses from these two sites on Drakes Brook, separated by only several hundred feet. The in-stream habitat assessment parameters for AN0311 which would respond negatively to sedimentation (epifaunal substrate/available cover, embeddedness, and sediment deposition) were reviewed for the 1999, 2004, and 2006 samplings. All three parameters were in the high suboptimal to low optimal range, indicating that sedimentation was not observed to be significantly altering the in-stream habitat at AN0311. Ephemeroptera (mayflies) appear to be a promising order that contains sediment tolerant and sediment intolerant taxa from which several indicator species can be drawn (Relyea *et al*., 2000). But the macroinvertebrate data from Drakes Brook shows an almost complete absence of Ephemeroptera, due likely to the overriding effects of another stressor or stressors. Relyea et al. (2000) categorized a list of selected taxa into four levels of sediment tolerance. No taxa present at AN0311 were included in the "Sediment Intolerant to Fine Sediments" or "Moderately Sediment Intolerant to Fine Sediments" categories. So while sediment deposition seems to be impacting some portions of Drakes Brook significantly, as far downstream as AN0311up, the effect below the dam at AN0311 is not conclusive and may be masked by other stressors.

<u>Nutrient and organic enrichment</u> - Evidence of organic and nutrient enrichment contributed by urban runoff was not observed or detected in the data for this study at levels which would likely affect the biota at AN0311 through nighttime dissolved oxygen depressions. Nitrogen and phosphorus levels at AN0311 were not considered excessive, and BOD results were not extraordinary. All dissolved oxygen measurements were recorded as instantaneous readings during daylight hours. Diurnal dissolved oxygen measurements were not conducted as part of this study. Additional nutrient samples, taken seasonally, along with diurnal dissolved oxygen measurements, would enable a more definitive assessment of the role that nutrient levels are playing in the impaired benthic community.

Nutrient and organic enrichment from the Quality Inn effluent and/or Fenimore landfill leachate: While the Quality Inn effluent and Fenimore landfill leachate were not directly sampled for this study, their effects on the benthic community at AN0311, at the time of this investigation, seem limited at best, based on results of stream nutrient and BOD sampling in the watershed.

Toxic compounds such as phenols, volatile organic compounds, semi-volatile organic compounds (BN/AE), and metals emanating from the now closed Fenimore landfill: Again, while the landfill leachate was not directly sampled, the benthic macroinvertebrate sampling of the tributary downstream of the landfill did not indicate any significant degradation of the biological community, nor did water quality parameters show any levels of concern in Drakes Brook. Therefore, any impacts of toxic compounds from the landfill at AN0311 would also be considered unlikely.

Conclusions

Onsite visual observations at AN0311 initially performed for this investigation showed that there were no readily identifiable sources or stressors in the immediate vicinity of this station, other than some adjoining groomed lawns. This station located on Emmans Road is in a suburban/rural watershed and sits downstream of a substantial, linear, palustrine forested wetlands complex. The external boundaries of that forested wetlands complex have been encroached upon by various land development projects. In some instances, the interior portions of those upstream forested wetlands have also been encroached upon by residential land development projects. Nevertheless, this expanse of forested wetlands, between the concentrated impervious cover around the malls and AN0311, may be providing some remedial effects, even with the past channelization on both the mainstem and southern tributary. Forest and wetlands help mitigate many adverse effects of human-induced landscape alterations (Kennen and Ayers, 2002).

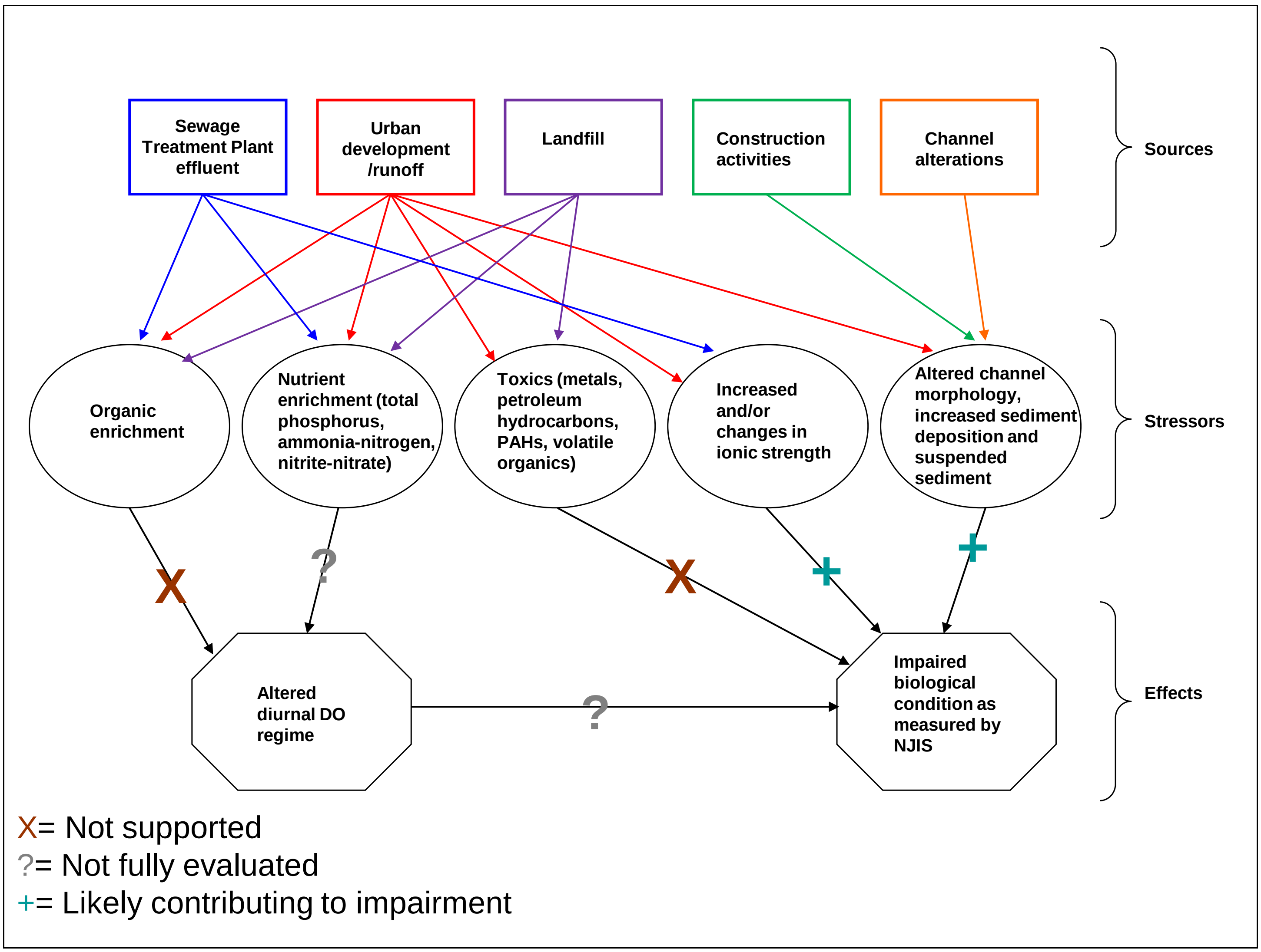


Figure 12. Conceptual Diagram of Candidate Causes - supported, disproven, or not fully evaluated

The benthic macroinvertebrate sampling for this study supports these observations and revealed that the biological impairment is not limited to AN0311, with portions of Ledgewood Brook, Drakes Brook upstream of AN0311, and its southern tributary having similarly, if not more, degraded populations of benthic macroinvertebrates. There appears to be some recovery in the benthic macroinvertebrate community at AN0311 when compared to these upstream sites which are nearer to the apparent sources of stress. The results of this benthic macroinvertebrate sampling, along with field observations, guided and focused efforts toward the potential sources of the impairment, which were not in close proximity to AN0311.

Any stressor known to be present in a stream, and known to cause biotic degradation, is a probable, and indeed a likely contributor to the observed biological degradation and impairment (Gerritsen *et al*., 2004). Most benthic metrics respond to most stressor types. Disentangling the individual effects of each stressor is usually not possible. For Drakes Brook (see Figure 12, above), these stressors include ionic strength, particularly with the likely extreme fluctuations not captured fully by monitoring in support of this study, as well as the potential additive effects of sedimentation. The effects of the sedimentation appear to be ameliorated to a degree by the low head dam at AN0311, but enough suspended material continues to pass over to possibly alter the benthic community composition. Even though the field observations and chemistry data do not conclusively support this theory, the presence/absence of indicator taxa suggests a possible sedimentation effect.

Additionally, this study finds that the Fenimore Landfill does not appear to be a major contributor to the impairment of the benthic macroinvertebrate communities in the downstream reaches of Drakes Brook covered by this investigation. This is based upon the benthic macroinvertebrate sampling conducted at a station located on an unnamed tributary upstream of Ledgewood Pond (DR-LB2) which indicated a Good rating (including 30% sensitive EPT taxa). This is contrary to previous NJDEP studies from 1975-76 which indicated significant degradation to Drakes Brook being caused by the landfill.

Possible effects caused by a stressor or stressors not monitored or fully captured in this study cannot be conclusively ruled out, such as those which might be contributed by an intermittent discharge, an episodic event, or diurnal dissolved oxygen fluctuations. But, based on the diligence and thoroughness applied to all aspects of this study, the probable stressors stated herein, are the likely causes of the biological impairment at AN0311, Drakes Brook at Emmans Rd.

References

1. Anson, Jennifer R., Vincent Pettigrove, Melissa Carew and Ary A. Hoffmann, 2007. High molecular weight petroleum hydrocarbons differentially affect freshwater benthic macroinvertebrate assemblages. Society of Environmental Toxicology and Chemistry. Vol.27, No.5 07-414.

2. Bodkin, Rod, James Kern, Phillip McClellan, Arthur J. Butt, and Charles Martin, 2007. Limiting total dissolved solids to protect aquatic life. Journal of Soil and Water Conservation, May/June 2007, Vol.62, Number 3.

3. Bode, Robert W., Margaret A. Novak, Lawrence E. Abele, L. Heitzman, and Alexander J. Smith, 2002. Quality Assurance Work Plan for Biological Stream Monitoring in New York State. NYS Dept. of Environmental Conservation, Albany, NY.

4. Eldridge, William H., David B. Arscott, and John K. Jackson, 2010. Expert Report on the Proposed Ambient Water Quality Criteria for Chloride in PA Waters. Report #2010004, Stroud Water Research Center, Avondale, PA.

5. Evans, M and C. Frick, 2001. The effects of road salts on aquatic ecosystems. NWRI Contribution Series No. 01-000. National Water Research Institute, Saskatoon, Saskatchewan.

6. Floyd, Ruth–Francis, Craig Watson, Denise Petty, and Deborah B. Pouder, 1996. FA – 16 Ammonia in Aquatic Systems. Department of Fisheries and Aquatic Sciences, Florida Cooperative Extension Service, Institute of Food and Agricultural Services, University of Florida.

7. Gerritsen, Jeroen, Benjamin Jessup, and Erik Leppo, 2004. Effects of Multiple Stressors on Aquatic Ecosystems. Final Technical Report, WERF 96-IRM-2. Prepared for Water Environment Research Foundation, Alexander, VA by Tetra Tech Inc., Owings Mills, MD.

8. Jessup, Benjamin, 2007. Development of the New Jersey High Gradient Macroinvertebrate Index (HGMI). Tetra Tech Inc., Owings Mills, Maryland. (www.nj.gov/dep/wms/bfbm)

9. Kennedy, A.J., 2002. An Ecotoxicological Assessment of a Treated Coal-mining Effluent in the Leading Creek Watershed, Meigs County, Ohio. MS Thesis, Virginia Polytechnic Institute and State University, Blacksburg, VA.

10. Kennen, Jonathan G., 1999. Relation of Macroinvertebrate Community Impairment to Catchment Characteristics in New Jersey Streams. Journal of the American Water Resources Association, Vol. 35, No. 4.

11. Kennen, Jonathan G. and Mark A. Ayers, 2002. Relationship of Environmental Characteristics to the Composition of Aquatic Assemblages along a Gradient of Urban Land Use in New Jersey, 1996-98. U.S. Geological Survey Investigations Report 02-4069, West Trenton, NJ.

12. Logan, Olivia A., 2007. Effects of Fine Sediment Deposition on Benthic Invertebrate Communities. Master's Thesis, University of New Brunswick, Saint John.

13. NJDEP, 2009. Ecological Screening Criteria. NJDEP Site Remediation Program, www.nj.gov/dep/srp/guidance/ecoscreening

14. NJDEP, 2001. Background Investigation Report, Fenimore Sanitary Landfill, Roxbury Township, Morris County, N.J., Facility No. 1436A. Prepared by H2M Assoc. Inc., Parsippany, NJ.

15. NJDEP, 2009. New Jersey Stormwater Best Management Practices Manual. Revised, September 2009. NJDEP, Division of Watershed Management, Trenton, NJ.

16. NJDEP, 2005. Immediate Environmental Concern Assessment Report, Fenimore Sanitary Landfill, Morris County, N.J. Prepared by Louis Berger Group Inc., Morristown, NJ.

17. NJDEP, 2008. Surface Water Quality Standards. N.J.A.C 7:9B. Trenton, New Jersey.

18. Pettigrove V., and A. Hoffman, 2005. Effects of long-chain hydrocarbons-polluted sediment on freshwater macroinvertebrates. Environ. Toxicol Chem 24:2500-2508.

19. Relyea, Christina D., D. Wayne Minshall, and Robert J. Danehy, 2000. Stream Insects as Bioindicators of Fine Sediment. Water Environment Federation, Watershed Management 2000 Conference.

20. Riva-Murray, Karen, Robert W. Bode, Patrick J. Phillips, and Gretchen L. Wall, 2002. Impact source determination with biomonitoring data in New York state: concordance with environmental data. Northeast Naturalist 9(2):127-162.

21. SETAC (Society of Environmental Toxicology and Chemistry), 2004. Whole effluent toxicity testing: Ion imbalance. Technical issue paper. Pensacola, FL: SETAC.

22. Shaver, Earl, Richard Horner, Joseph Skupien, Chris May, and Graeme Ridley, 2007. Fundamentals of Urban Runoff Management: Technical and Institutional Issues, 2nd Ed. North American Lake Management Society, Madison, WI.

23. Township of Roxbury, 1997. A Report on the Existing Environmental Status of Drake's Brook and Ledgewood Brook, Township of Roxbury, N.J. Project No.41-043.01. Prepared by Coastal Environmental Services, Hamilton, NJ.

24. Township of Roxbury, 2002. Natural Resource Inventory Update for the Township of Roxbury, Morris County, N.J. Prepared by Amy S. Greene Environmental Consultants, Flemington, NJ.

25. Township of Roxbury, 2003. Drakes Brook Restoration Plan, A Headwaters of The South Branch of the Raritan River. Prepared by Aqua-Niche, Marysville, PA.

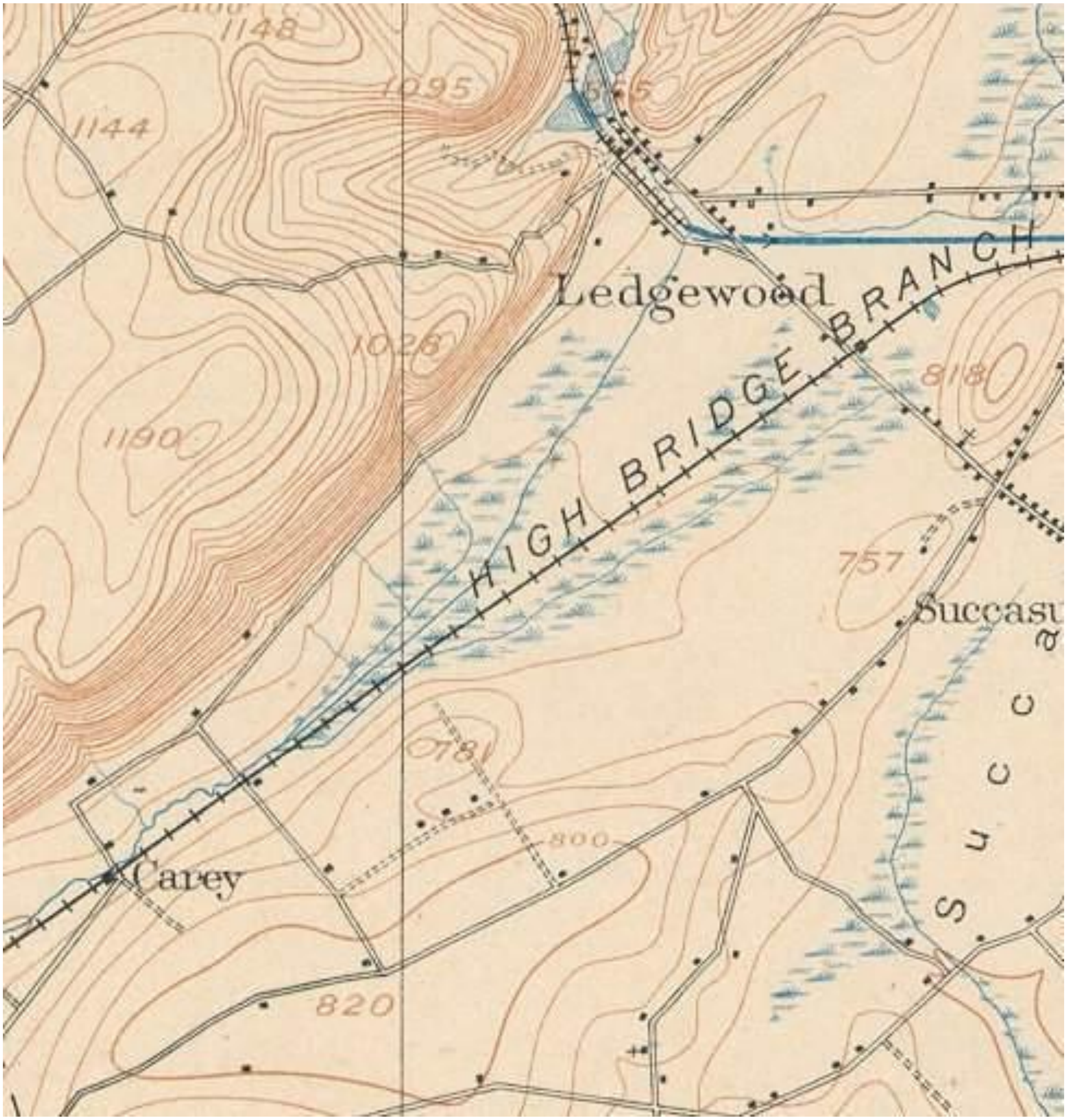
26. USEPA, 1999. Rapid bioassessment protocols for use in streams and wadeable rivers: periphyton, benthic macroinvertebrates and fish, 2nd edition. US Environmental Protection Agency, Office of Water, Washington, DC. EPA 841-B-99-002

27. USEPA, 2000. Stressor Identification Guidance Document. US Environmental Protection Agency, Office of Water, Washington, DC. EPA 822-B-00-025.

28. USEPA. Causal Analysis/Diagnosis Decision Information System (CADDIS). www.epa.gov/caddis.

APPENDIX A

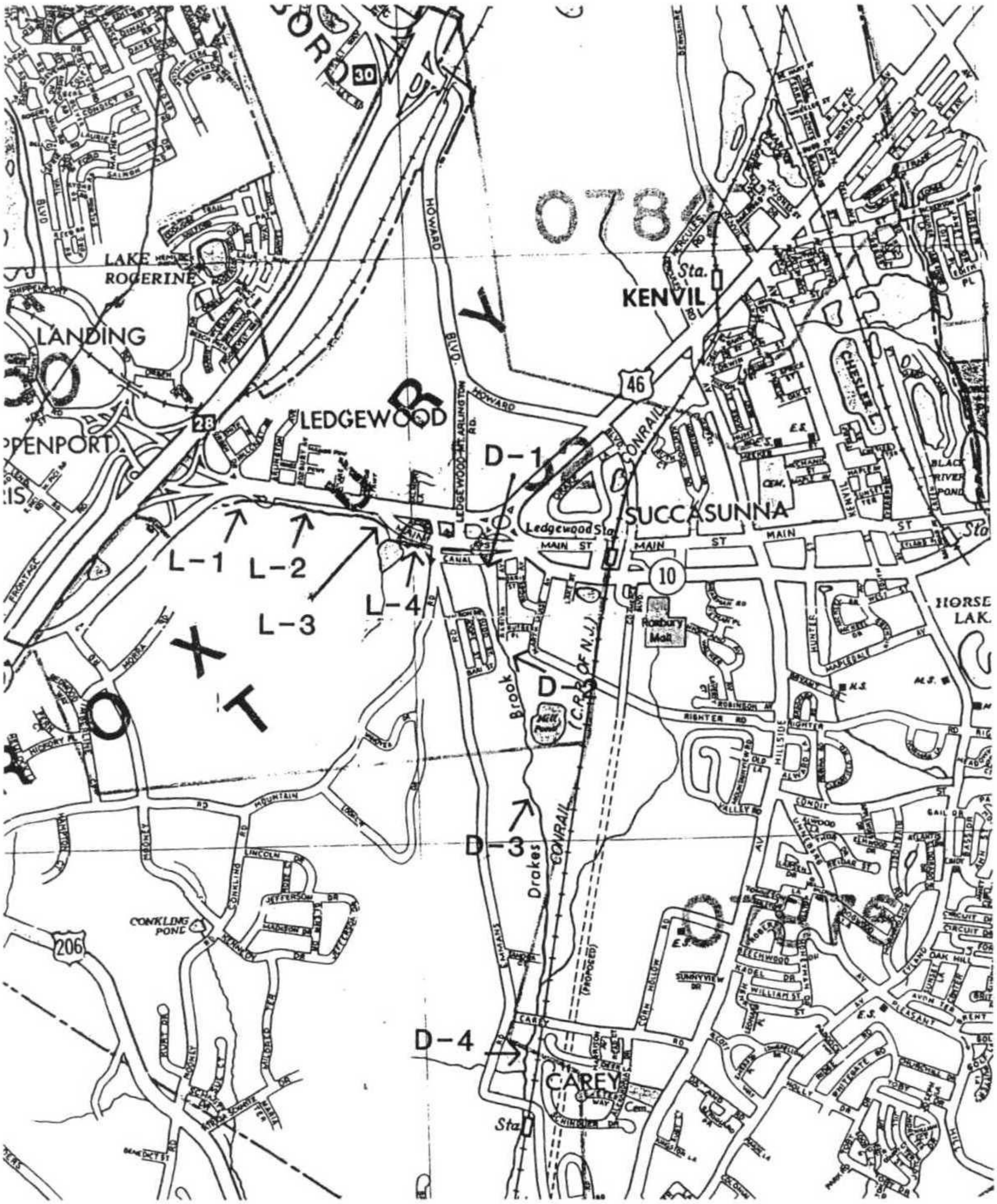
U.S. Geological Survey Map (circa 1881)



Triangulation by the U.S.Coast and Geodetic Survey.
Topography by the Geological Survey of New Jersey.
Surveyed in 1881.
Revised in 1903 under direction of H.M.Wilson, Geographer, and
Hersey Munroe, Topographer in charge, by Robert Coe
and Ira M.Flocker.

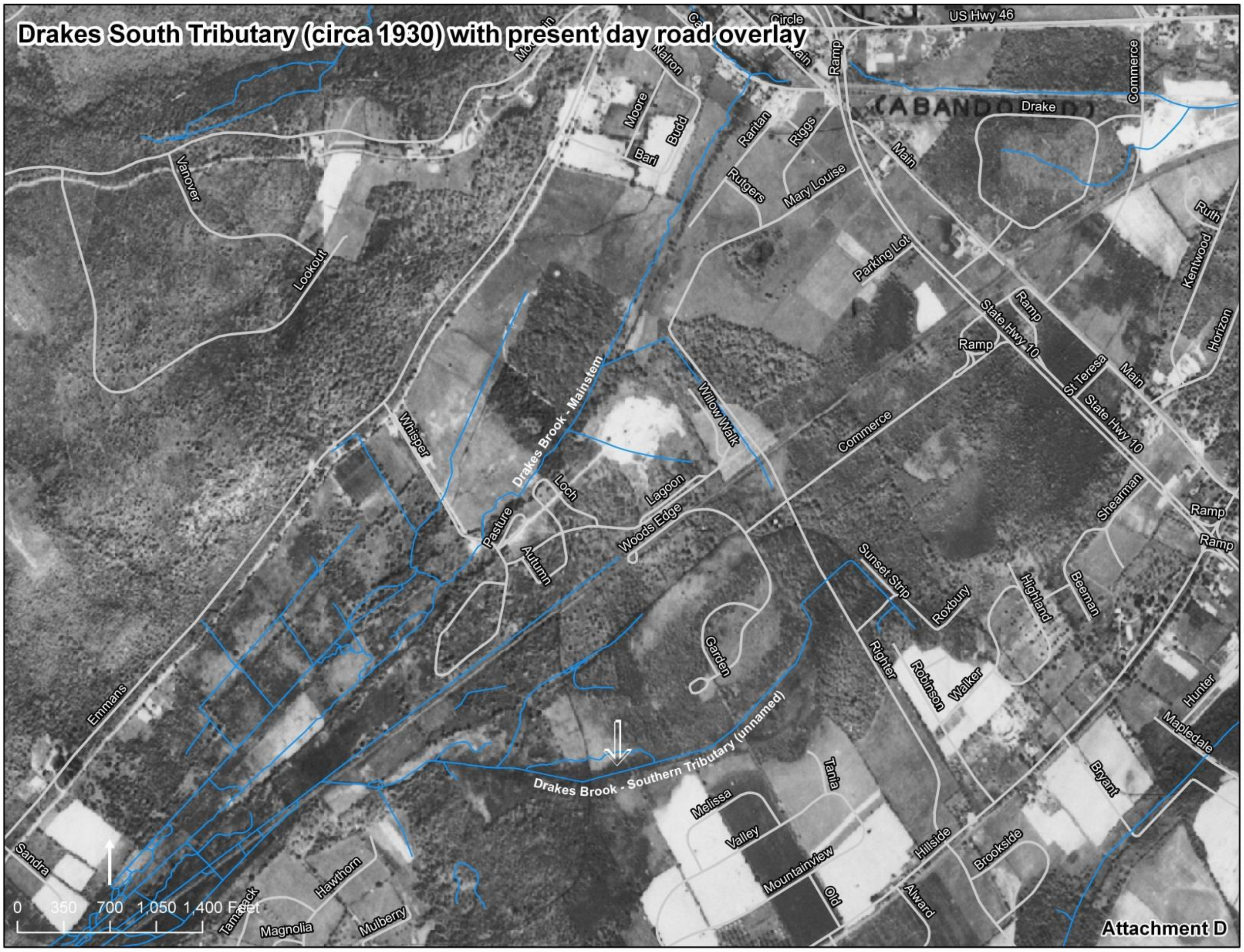
APPENDIX B

Coastal Environmental Stream Sampling Locations, March 1997



APPENDIX C

Drakes South Tributary Aerial Photo (circa 1930)



APPENDIX D

Drakes South Tributary Aerial Photo (circa 2002)

APPENDIX E

Table 1 - Chemistry Results

Site ID		DR-SHW			DR-S1		DR-2		AN0311		AN0311up
Site Description	RL	S Br Drakes Bk@ Roxbury Mall			S Br Drakes Bk@ nr. Tania Ct.		Drakes Bk@Willow Walk		Drakes Bk@ Emmans Rd.		Drakes Bk@Emmans Rd. (upstream of footbridge)
Event		Dry	Wet	Dry	Dry	Wet	Dry	Wet	Dry	Wet	Dry
Date		9/20/2006	4/4/2007	11/30/2007	9/20/2006	4/4/2007	9/20/2006	4/4/2007	9/20/2006	4/4/2007	11/30/2007
Time		1245	1255	1240	1100	1215	1100	1330	0945	1115	1140
Sample ID		169504	161656	171064	169503	161655	169502	161654	169501	161653	171063
Water Temp.,°C				10.5	16.4	5.8	14.7	6.4	15.5	7.2	2.9
DO				6.09	2.00	9.80	8.74	9.90	6.95	9.70	11.35
pH				7.28	7.27	7.58	7.7	7.74	7.59	7.76	7.66
Turbidity, NTU				7.12	14.7	31.1	3.39	18.4	4.93	12.1	3.86
Spec. Cond., µS/cm				1022	1257	294	610	457	582	476	454
NO2+NO3	0.012				0.236	0.416	1.31	1.15	0.636	0.755	
Ammonia-N	0.01				0.769*	0.244*	0.048	0.248*	0.041	0.0315*J-R	
TSS	1				4	28	2	17	1	11	
TDS	1				695	155	389	258	391	264	
BOD5	see below				2.9	2.1	1.2 K	2.4	1.3 J	1.1 K	
Chloride	2				279	72.8	106	94.3	107	90.4	
Hardness	0.085				266.521	25.114	188.447	106.339	171.135	130.779	
Phenol	0.00500				ND	ND	ND	ND	ND	ND	
Sulfate	5.00				17.8	5.01	19.5	12.9	16.1	14.6	
Sulfide	0.100				ND	ND	ND	ND	ND	ND	
Total P	0.0100				0.044	0.11	0.038	0.058	0.032	0.043	
Pet. Hydroc	0.500	ND	3.1		ND	1.33	1.2	0.57	ND	ND	
Sed. Total P	4				169		194		165		
Sed. Pet. Hydroc.	20	1430			425		181		129		
Sed. Sulfate	50				ND		ND		ND		
Sed. As	1				ND		ND		ND		ND
Sed. Cd	0.4				ND		ND		ND		ND
Sed. Cr	1				7.83		3.9		3.3		4.52
Sed. Cu	1				8.86		3.29		2.47		2.58
Sed. Fe	5				6090		5930		5930		
Sed. Mn	1				51.7		68.1		205		57.3
Sed. Ni	1				3.98		2.39		2.01		1.56
Sed. Pb	2				14.1		7.61		5.75		7.67
Sed. Zn	1				58.9		38		31.3		29.5
Sed. Hg	0.1				ND		ND		ND		ND
Sed. % Solids	0.01%	74.9			68.3		79.9		73.55		

All water column results are in mg/L (ppm), except metals which are in ug/L
All sediment results are in mg/kg dry
J-R= Approximate value, result below the reporting level
JMI= Approximate value due to matrix interferences
K= Value below detection limit
"ND" indicates the concentration of the analyte tested was either not detected or below the RLs.
* Analysis performed with distillation (RL=0.05)
For BOD: J=Depletion is less than 2.0 or Final DO is >1.0 and <2.0. K=Depletion is less than 1.0

Table 2 - Un-ionized Ammonia Calculations

Site ID	Date	TAN	UIA	UIA Summer Acute Criteria (calc.)
AN0311	4/4/2007	0.0315	0	0.090
DR-2	4/4/2007	0.248	0.002	0.084
DR-S1	4/4/2007	0.244	0.001	0.070
AN0311	9/20/2006	0.041	0	0.126
DR-2	9/20/2006	0.048	0.001	0.133
DR-S1	9/20/2006	0.769	0.004	0.098

All results in mg/L
TAN = Total Ammonia Nitrogen
UIA = Unionized Ammonia

Table 3 - Sediment PAH Results

Site ID	DR-SHW	AN0311up	NJDEP ESC- LEL
Site Description	S Br Drakes Bk@ Roxbury Mall	Drakes Bk@Emmans Rd. (upstream of footbridge)	
Event	Dry	Dry	
Date	11/30/2007	11/30/2007	
Time	1240	1140	
Sample ID	171064	171063	
Naphthalene	ND	ND	176
2-Methylnaphthalene	ND	ND	20.2
Acenaphthyene	ND	ND	5.87
Acenaphthene	ND	ND	6.71
Fluorene	ND	ND	77.4
Phenanthrene	668 J	ND	204
Anthracene	119 J	ND	57.2
Fluoranthene	1690	49.8 J	423
Pyrene	1250 J	ND	195
Benzo(A)Anthracene	596 J	ND	108
Chrysene	728 J	ND	166
Benzo(B)Fluoranthene	698 J	ND	10400
Benzo(k)Fluoranthene	817 J	ND	240
Benzo(A)Pyrene	771 J	ND	320
Ideno(1,2,3-CD)Pyrene	387 J	ND	200
Dibenz(A,H)Anthracene	ND	ND	33
Benzo(G,H,I)Perylene	410 J	ND	170
Total PAHs	8134		4000

All values are µg/kg, dry weight
NJDEP ESC-LEL - NJDEP's Ecological Screening Criteria - Lowest Effect Level

Table 4 - Purgeables (EPA624) and Base Neutral and Acid Extractable (EPA625) Water Chemistry

EPA 624	**AN0311dry**	**AN0311wet**
Chloromethane	0.27(K)	0.390(K)
Vinyl chloride	0.28(K)	0.400(K)
Bromomethane	0.53(K)	0.480(K)
Chloroethane	0.44(K)	0.420(K)
Trichlorofluoromethane	0.21(K)	0.390(K)
1,1-Dichloroethene	0.28(K)	0.370(K)
Methylene chloride	0.47(K)	0.460(K)
Trans-1,2-dichloroethene	0.23(K)	0.330(KF)
Tert-butyl alcohol	0.85(K)	0.550(K)
Methyl-t-butyl ether	0.16(K)	0.130(K)
1,1-Dichloroethane	0.28(K)	0.320(K)
Chloroform	0.18(K)	0.230(K)
1,1,1-Trichloroethane	0.21(K)	0.360(K)
Carbon tetrachloride	0.43(K)	0.340(K)
Benzene	0.33(K)	0.280(K)
1,2-Dichloroethane	0.22(K)	0.250(K)
Trichloroethene	0.38(K)	0.310(K)
1,2-Dichloropropane	0.20(K)	0.190(K)
2-Chloroethyl vinyl ether	0.29(K)	0.170(K)
Bromodichloromethane	0.10(K)	0.190(K)
Cis-1,3-Dichloropropene	0.31(K)	0.180(K)
Toluene	0.24(K)	0.250(K)
Trans-1,3-Dichloropropene	0.35(K)	0.150(K)
1,1,2-Trichloroethane	0.29(K)	0.110(K)
Tetrachloroethene	0.40(K)	0.350(K)
Dibromochloromethane	0.21(K)	0.110(K)
Chlorobenzene	0.26(K)	0.160(K)
Ethylbenzene	0.17(K)	0.280(K)
m/p-Xylene	0.46(K)	0.560(K)
o-Xylene	0.44(K)	0.250(K)
Bromoform	0.15(K)	0.120(K)
1,1,2,2-Tetrachloroethane	0.26(K)	0.190(K)
1,3-Dichlorobenzene	0.27(K)	0.200(K)
1,4-Dichlorobenzene	0.22(K)	0.240(K)
1,2-Dichlorobenzene	0.22(K)	0.150(K)
Naphthalene	0.15(K)	0.190(K)
EPA 625		
N-Nitrosodiethylamine	2(U)	2(U)
Phenol	3(U)	2(U)
Bis(2-Chloroethyl) ether	2(U)	2(U)
2-Chlorophenol	2(U)	2(U)
1,3-Dichlorobenzene	2(U)	2(U)
1,4-Dichlorobenzene	2(U)	2(U)
1,2-Dichlorobenzene	2(U)	2(U)
Bis(2-Chloroisopropyl) ether	2(U)	2(U)
N-Nitrosopyrrolidine	2(U)	2(U)
N-Nitroso-di-n-propylamine	2(U)	2(U)
Hexachloroethane	2(U)	2(U)
Nitrobenzene	2(U)	2(U)
Isophorone	2(U)	2(U)

2-Nitrophenol	3(U)	2(U)
2,4-Dimethylphenol	4(U)	4(U)
Bis(2-Chloroethoxy) methane	2(U)	2(U)
2,4-Dichlorophenol	3(U)	2(U)
1,2,4-Trichlorobenzene	2(U)	2(U)
Naphthalene	2(U)	2(U)
Hexachlorobutadiene	2(U)	2(U)
N-Nitroso-di-n-butylamine	2(U)	2(U)
4-Chloro-3-methylphenol	3(U)	2(U)
Hexachlorocyclopentadiene	1(U)	2(UF)
2,4,6-Trichlorophenol	3(U)	2(U)
2,4,5- Trichlorophenol	2(U)	2(U)
2-Chloronaphthalene	2(U)	2(U)
Dimethyl phthalate	3(U)	2(U)
2,6-Dinitrotoluene	2(U)	2(U)
Acenaphthylene	2(U)	2(UF)
Acenaphthene	2(U)	2(U)
2-4-Dinitrophenol	5(U)	8(U)
Pentachlorobenzene	2(U)	2(U)
4-Nitrophenol	2(U)	6(U)
2,4-Dinitrotoluene	2(U)	2(U)
Diethyl phthalate	3(U)	2(U)
Fluorene	2(U)	2(U)
4-Chlorophenyl phenyl ether	2(U)	2(U)
4,6-Dinitro-2-methylphenol	7(U)	4(U)
N-Nitrosodiphenylamine	2(U)	2(U)
4-Bromophenyl phenyl ether	2(U)	2(U)
Hexachlorobenzene	2(U)	2(U)
Pentachlorophenol	4(U)	4(U)
Phenanthrene	2(U)	2(U)
Anthracene	2(U)	2(U)
Di-n-butyl phthalate	3(U)	2(U)
Fluoranthene	2(U)	2(U)
Pyrene	2(U)	2(U)
Butyl benzyl phthalate	4(U)	2(U)
Benzo(a)anthracene	2(U)	2(U)
3,3'-Dichlrobenzidine	2(U)	6(U)
Chrysene	2(U)	2(U)
Bis(2-Ethylhexyl) phthalate	2(U)	2(U)
Di-n-octyl phthalate	2(U)	2(U)
Benzo(b)fluoranthene	2(U)	2(U)
Benzo(k)fluoranthene	2(U)	2(U)
Benzo(a)pyrene	1(U)	2(U)
Indeno(1,2,3-cd)pyrene	2(U)	4(U)
Dibenzo(a,h)anthracene	3(U)	2(U)
Benzo(g,h,i)perylene	2(U)	2(U)

All results are in ug/L
(U)=(K)= less than the MDL
(F)= Compound did not pass QC check criteria

Table 5 - Comparison of Sediment Metals to NJDEP Ecological Screening Criteria

	AN0311	DR-2	DR-S1	AN0311up	NJDEP ESC-LEL	RL
As	ND	ND	ND	ND	6	1.46
Cd	ND	ND	ND	ND	0.6	0.586
Cr	3.30	3.90	7.83	4.52	26	1.46
Cu	2.47	3.29	8.86	2.58	16	1.46
Fe	5930	5930	6090	-	NA	7.32
Hg	ND	ND	ND	ND	0.174	0.136
Mn	205.00	68.1	51.7	57.30	630	1.46
Ni	2.01	2.39	3.98	1.56	16	1.46
Pb	5.75	7.61	14.1	7.67	31	2.93
Zn	31.30	38	58.9	29.50	120	2.93

ND= Non-detect
All results in mg/kg dry

NJDEP ESC-LEL= NJDEP's Ecological Screening Criteria-Lowest Effects Levels (LELs) indicate concentrations at which adverse benthic impact may begin to occur (level tolerated by most benthic organisms)

RL= Laboratory Reporting Limit- The lowest concentration at which an analyte can be detected in a sample and its concentration can be reported with a reasonable degree of accuracy and precision

NA= Not available