# Report as of FY2006 for 2006NY83B: "Effect of urban runoff on seasonal and spatial trends in the water quality of the Saw Mill River"

## Publications

Project 2006NY83B has resulted in no reported publications as of FY2006.

## Report Follows

# Effect of urban runoff on seasonal and spatial trends in the water quality of the Saw Mill River
# Report submitted to the New York State Water Resources Institute

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## Project Overview

The Saw Mill River is a tributary to the Hudson River in the Lower Hudson River Drainage Basin. The headwaters of the River are located in the Village of Chappaqua in the town of New Castle. The River has several designated uses over its entire stretch, indicating diverse surroundings as it travels from Chappaqua to Yonkers, NY where it eventually discharges into the Hudson River. Additionally, along the Yonkers stretch, the river has been severely altered over the past 30 years by flood control projects and re-routing (Pearce, 1999). The most extreme case of this is in south Yonkers, where the river has a concrete bottom (at Old Nepperhan Rd.) and eventually flows underground (at Elm St.) for its final 800 feet before reaching the Hudson.

Urban runoff is one of the leading sources of water quality impairment in surface waters (Usepa, 2000b). According to USGS estimates (Wall et al., 1998), the Saw Mill River watershed of 23.8 $mi^2$ is 63.4% urban, 35.4% forested, and 1.0% agricultural. This high percentage of urban areas makes the Saw Mill susceptible to contamination from urban runoff. Pollutants usually associated with urban runoff include nutrients (nitrogen and phosphorous), metals (cadmium, copper, lead and zinc), and coliform bacteria (Usepa, 2005).

The primary objective of this work was to conduct a year-long continuous monitoring program for the entire stretch of the Saw Mill River. The following water quality parameters related to urban runoff were monitored: surface water nutrients (ammonia, nitrate and total phosphorous) and fecal coliform bacteria. Temperature, conductivity, pH, total suspended solids and turbidity were also measured. This data is being made available on the Saw Mill River Coalition website (http://www.sawmillrivercoalition.com) via our partnership with Groundwork Yonkers.

Our final objective of this project was to measure the spatial profile for sediment-bound metals in the Saw Mill River. This work is being conducted this summer through matching funds provided by the Saw Mill River Coalition/Groundwork Yonkers. Ten to twelve sediment samples will be collected at sites along the entire stretch of the Saw Mill River and analyzed for concentrations of the toxic metals of copper, lead, nickel, cadmium, zinc, arsenic, and chromium.

The results of this work will be presented at the New York Water Environment National Meeting University (student) symposium in February 2008. Additional conferences highlighting the efforts of undergraduate research will be targeted for poster and/or platform presentations. Follow-up work on the Saw Mill River is been perused through a collaborative USEPA Targeted Watershed Grant proposal that was submitted in Fall 2006 by the Saw Mill River Coalition/Groundwork Yonkers.

**Personnel**

This work included partnerships with Groundwork Yonkers and Saunders Trade and Technical High School in Yonkers. Groundwork Yonkers is a non-profit organization developed in 1999 dedicated to revitalizing, greening, and connecting people to the urban environment in lower Westchester County. It follows a model developed nearly twenty years ago in the United Kingdom (UK) designed to regenerate towns with long histories and aging infrastructures. Groundwork Yonkers is the coordinator of the Saw Mill River Coalition, a partnership of non-profit groups, government agencies, and businesses, aimed to revitalize and protect the Saw Mill watershed. Saw Mill River Coalition/Groundwork Yonkers was periodically updated on progress and key findings throughout the duration of the project.

Another key partner in the project is the environmental science and technology program at Saunders High School in Yonkers which has been working with junior and senior classes for more than two years on water quality monitoring efforts along the Saw Mill. Two students, Nicole Kerrison and Leslie Guadron were involved in field sampling and laboratory analysis of water quality parameters through a paid summer internship. Nicole and Leslie worked in the environmental engineering laboratories at Manhattan College three days a week for eight weeks. They were trained in the laboratory analyses for nutrients and assisted in all analytical work. After the conclusion of her work on the project Nicole Kerrison has been working in our labs on her senior project.

Two undergraduate students, Jason Lumish and Erica Hanley worked approximately six to eight hours per week throughout the school year and thirty-five hours a week for ten weeks from June 1 to August 15 as paid undergraduate research assistants (URAs). They were trained in all aspects of sample analysis, and performed the majority of the analytical work for the project. Two graduate students, Michael Lynch and Eric Spargamino worked approximately 6 hours per week on the project. They were utilized to collect samples and perform some limited sample analysis. All personnel listed in Table 1 were trained in all aspects of sampling and analysis prior to work on the project.

**Table 1:** Personnel on this project

| | **Level** | **Field of Study** | **Institution** | **Role** |
|---|---|---|---|---|
| Jason Lumish | Undergraduate (Junior) | Civil Engineering (major; Environmental Engineering (minor) | Manhattan College, Riverdale, NY | Field sampling, sample analysis |
| Erica Hanley | Undergraduate (Sophomore) | Environmental Engineering | Manhattan College, Riverdale, NY | Sample analysis |
| Christopher Fanelli | Undergraduate (Sophomore) | Environmental Engineering | Manhattan College, Riverdale, NY | Database management |
| Eric Spargamino | Graduate student | Environmental Engineering | Manhattan College, Riverdale, NY | Field sampling, sample analysis |
| Michael Lynch | Graduate student | Environmental Engineering | Manhattan College, Riverdale, NY | Field sampling, sample analysis |
| Nicole Kerrison | Junior | Environmental technology | Saunders Trades and Technical School, Yonkers NY | Sample analysis |
| Leslie Guadron | Sophomore | Environmental technology | Saunders Trades and Technical School, Yonkers NY | Sample analysis |

**Methods**

Water samples were collected in 1 L acid-washed polypropylene bottles. After collection, they were stored in a cooler filled with ice until arrival in the lab. Samples were transferred to a refrigerator and stored at 4 °C prior to analyses.

Sample pH was measured using a pH meter (Accumet Model 15, Fisher Scientific, Hampton, NH) employing a combination hydrogen ion electrode (Model 910600, Thermo Orion, Boston, MA). Sample conductivity and temperature were determined using Oakton CON 200 Series total dissolved solids/ conductivity/ temperature probe. Turbidity was measured using a Hach Turbidimeter (Model 2100P, Loveland, CO).

HACH spectrophotometric (Spectrophotometer Model DR 2010) test methods were used to measure nitrate (cadmium reduction method), total ammonia (Nessler method) and total phosphorus (ascorbic acid method) on filtered samples. Fecal coliform bacteria levels were determined using the membrane filtration method (Clseceri et al., 1998).

**Sample Site Selection**

Sites were selected along the Saw Mill River so that a representative spatial profile of water quality could be obtained (Table 2). Site-to-site distances along the river were determined using USGS maps and the MapTech mapping software package. We are reporting these distances as "Distance from Elm St.," which is the location at which the Saw Mill River travels underground in Yonkers. It was not possible to find maps detailing the exact geographic position of the river along this final stretch as it flows into the Hudson River. A map of all sites is presented in Figure 1. Sample site S6 (Executive Blvd) is in a small brook that empties into the Saw Mill River in Elmsford, NY. Since it is not along the main stem of the Saw Mil River, we have not reported a distance in Table 2.

**Sampling Frequency**

Samples were collected approximately every one to two weeks over the period of June 26, 2006 to October 23, 2006. In some instances, complete analysis of the data for all parameters was not possible within the EPA recommended holding times. In these instances, only a subset of the water quality parameters was analyzed. The remaining parameters were analyzed for at the following sampling event.

**Table 2: Sampling Locations**

| Site ID | Location | Lat | Long | Distance from Elm St. (mi) |
|---|---|---|---|---|
| S12 | Walsh Rd., Yonkers, NY | 40.9379 | -73.8893 | 0.40 |
| S11 | Torre Pl., Yonkers, NY | 40.9517 | -73.8779 | 2.17 |
| S10 | Hearst, St., Yonkers, NY | 40.9744 | -73.8688 | 4.13 |
| S9 | Lawrence St., Ardsley, NY | 41.0025 | -73.8563 | 6.57 |
| S8 | V.E. Macy Park, Ardsley, NY | 41.0183 | -73.8463 | 8.26 |
| S7 | Woodlands Lake (spillway), Dobbs Ferry, NY | 41.0240 | -73.8452 | 8.62 |
| S6 | Executive Blvd, Elmsford NY | 41.0704 | -73.8082 | N/A |
| S5 | Warehouse Lane, Elmsford NY | 41.0637 | -73.8170 | 12.61 |
| S4 | Saw Mill River Road (Rosedale Nursery), Hawthorne, NY | 41.0952 | -73.8108 | 16.33 |
| S3 | Saw Mill Road, Eastview, NY | 41.0811 | -73.8287 | 14.50 |
| S2 | Pleasantville Rd/Manville Rd., Pleasantville, NY | 41.1332 | -73.7962 | 19.48 |
| S1 | Chappaqua Metro North Station, Chappaqua, NY | 41.1565 | -73.7756 | 22.93 |

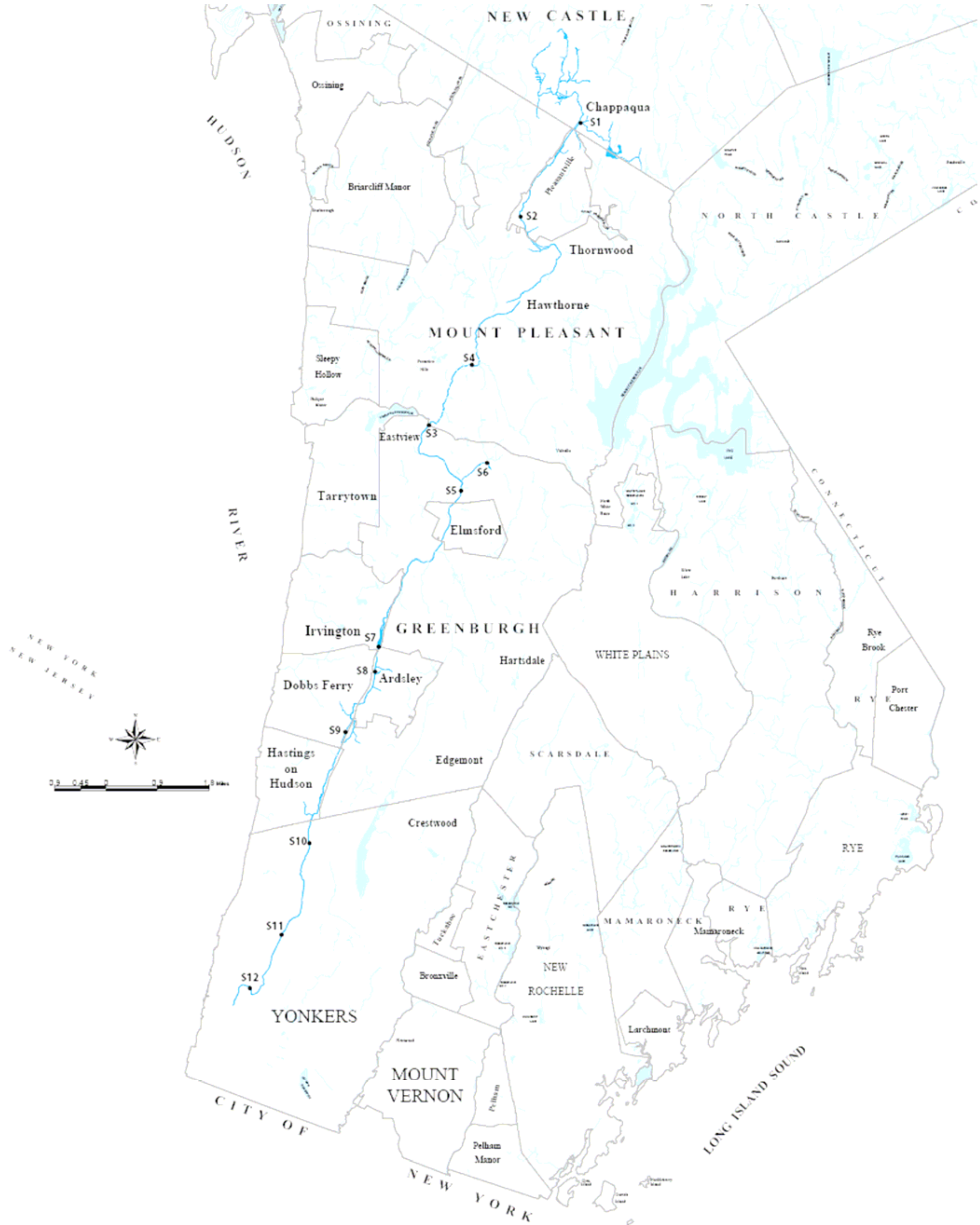


**Figure 1:** Map of all sampling locations (S1 to S12).

## Results

### Basic Water Quality

A summary of basic water quality parameters (pH, conductivity TSS and turbidity) are reported in Table 3. Median, minimum, maximum, and standard deviations are listed. We are in the process of posting the complete database on the Saw Mill River Coalition website.

**Table 3:** Summary of Basic Water Quality Parameters[a]

| Site | pH | Conductivity (µS/cm) | TSS (mg/L) | Turbidity (NTU) |
|---|---|---|---|---|
| S1 | 7.36 (7.10 - 7.70) ; 0.19 | 632 (186 – 891); 190 | 2.9 (1.0 – 17) ; 11 | 3.84 (1.6 - 10.9) ; 3.56 |
| S2 | 7.62 (7.32 - 7.90) ; 0.20 | 605 (190 – 793); 170 | 1.6 (0.5 - 35) ; 18 | 1.87 (0.74 - 18.6) ; 5.09 |
| S3 | 7.60 (7.32 - 7.90) ; 0.19 | 663 (249 – 829); 173 | 2.1 (1.0 - 61) ; 23 | 1.46 (1.02 - 38.9) ; 11.2 |
| S4 | 7.53 (7.16 - 7.80) ; 0.20 | 621 (222 – 795); 176 | 2.1 (0.9 - 46) ; 21 | 2.19 (0.91 - 27.2) ; 7.6 |
| S5 | 7.46 (7.13 - 7.85) ; 0.22 | 755 (190 – 1041); 245 | 2.1 (1.1 - 14) ; 7.6 | 2.52 (2.08 - 16.8) ; 4.48 |
| S6 | 7.64 (7.22 - 7.90) ; 0.22 | 781 (389 – 1005); 165 | 3.2 (1.6 - 64) ; 23 | 2.39 (1.79 - 42.1) ; 11.9 |
| S7 | 7.60 (7.14 – 8.00) ; 0.25 | 674 (198 – 823); 182 | 4.8 (3.7 - 60) ; 17 | 4.88 (2.66 - 59.1) ; 17.3 |
| S8 | 7.70 (7.32 – 8.00) ; 0.20 | 666 (185 – 824); 193 | 4.6 (1.9 - 41) ; 11 | 3.11 (1.97 - 46.9) ; 13.2 |
| S9 | 7.57 (7.23 - 7.90) ; 0.21 | 762 (184 - 846) ; 203 | 3.9 (2.3 - 61) ; 17 | 3.21 (1.00 - 60.1) ; 17.2 |
| S10 | 7.72 (7.17 – 8.00) ; 0.22 | 758 (192 - 869) ; 203 | 4.4 (1.6 - 64) ; 18 | 3.07 (1.50 – 53.0) ; 15.2 |
| S11 | 7.81 (7.28 - 8.17) ; 0.27 | 740 (205 - 826) ; 187 | 6.9 (3.1 - 58) ; 15 | 3.86 (2.73 - 45.6) ; 12.7 |
| S12 | 7.67 (7.31 - 8.02) ; 0.23 | 751 (205 - 862) ; 197 | 4.9 (2.5 - 59) ; 16 | 3.89 (2.33 - 46.1) ; 12.8 |

(a) Data reported as median (min – max); standard deviation

The pH of the Saw Mill River showed very little spatial and temporal variability and is generally within the acceptable levels for freshwater streams. NYS DEC regulations (1999) state that pH shall not be less than 6.5 nor more than 8.5. The median pH of all samples was 7.59 with a standard deviation of 0.23. The lowest and highest pH values reordered were 7.10 and 8.17 respectively.

Electrical conductivity (EC) showed large temporal variability, in part due to very low conductivity readings recorded on 8/28/06 during the middle of a heavy rainfall event. The low conductivity readings are the result of dilution from rainwater. In general, the EC values are on the high side of freshwater streams, and not uncommon for streams impacted by urban runoff.

Factors which can affect EC include the surrounding geology, the size of the watershed area relative to the area of the waterbody, wastewater point and non-point sources, and salt water intrusion. Electrical conductivity estimates the amount of total dissolved salts (TDS), or the total amount of dissolved ions in the water. The TDS concentration can be related to EC of the water, but the relationship is a function of the type and nature of the dissolved cations and anions in the water and possible the nature of any suspended materials. High TDS water can be harmful to fish and plants and may limit biodiversity.

The TDS (in mg/L) usually ranges from 0.5 to 1.0 times the EC (in µS/cm). Assuming a conversion factor of 0.7, the approximate median and maximum TDS of all samples taken from the Saw Mill River are 500 and 700 mg/L respectively. NYS DEC regulations (1999) for the entire stretch of the Saw Mill River streams state that TDS should be kept low to maintain the best usage of waters but in no case shall it exceed 500 mg/L. While there is some uncertainty in our choice of conversion factor for TDS, the river appears to be impacted by dissolved solids.

**Fecal Colform Bacteria**

Monitoring results for fecal coliform bacteria are presented in Figures 3 and 4. In Figure 3, a box plot is used to show spatial variability in fecal coliform bacteria concentrations along the entire stretch of the Saw Mill River. The boundary of the box closest to a value of zero on the y-axis indicates the 25th percentile, a line within the box marks the median, and the boundary of the box farthest from zero indicates the 75th percentile. The error bars above and below the box indicate the 90th and 10th percentiles, respectively. Sample sites S11 (Torre Pl., Yonkers, NY) and S12 (Walsh Rd., Yonkers, NY) had the highest median fecal coliform counts. These two sites are the southernmost sites sampled, and are in a highly urbanized area of downtown Yonkers. Median fecal coliforms of all other sites were extremely constant. Sample site S1 (Chappaqua Metro North Station), does not have a significantly different median than sites S2 – S10, however, the highest single fecal coliform measurements were for this site ($1.2\times10^5$ and $8.4\times10^4$ org/100 mL).

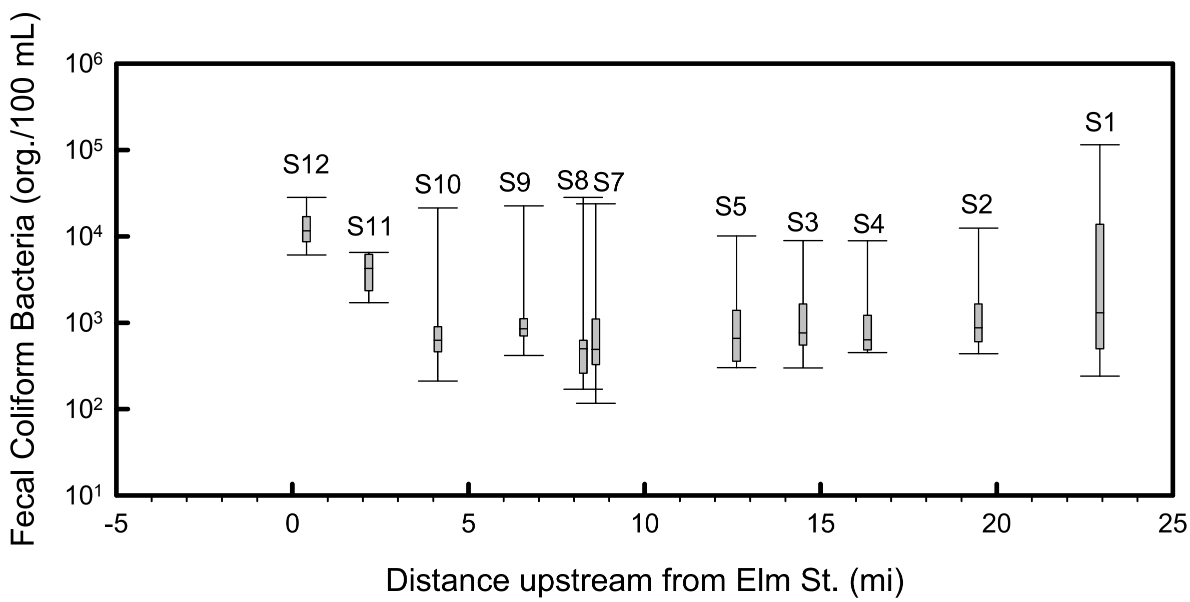


**Figure 3:** Box plot of fecal coliform bacteria as a function of distance upstream from Elm St., Yonkers NY.

In Figure 4, fecal coliform bacteria is shown as a function of time at sample stations S1, S4, S8 and S12. Also indicated on the plot is the daily precipitation recorded at Westchester County Airport. An increase in fecal coliform bacteria seems to be directly related to rainfall. This can be seen in the plots by examining data points that fall in or slightly to the right of significant rainfall events (more than 1.0 inch/day). These data points are consistently higher than baseline for all sample sites.

All median fecal coliform bacteria values were above 200 org./100 mL. This is significant because the NYS DEC criteria (1999) for fecal colifoms states that the monthly geometric mean, from a minimum of five examinations, shall not exceed 200 org./100 mL. Bacterial contamination can originate from point or nonpoint sources. Point sources may include municipal or Industrial discharges of wastewater. Nonpoint sources may include storm water runoff, animal waste, application of manure and biosolids to fields, crop irrigation from contaminated storage ponds, failed septic systems, litter or landfill leakage, or direct discharge of marine-craft sewage. For the Saw Mill River watershed, stromwater runoff, and municipal wastewater discharges are likely causes of the observed high fecal coliform bacteria counts.

Typical pollutant concentrations found in typical urban storm water runoff are on the order of 3600 org./100 mL (Mde, 1999). While fecal coliform bacteria are subject to inactivation upon direct exposure to sunlight, portions of the Saw Mill River are under canopy and rapid die-off is unlikely. It is therefore possible that the high baseline levels of fecal coliform bacteria are the due directly to urban run-off.

Wastewater generated from much of the area of the Saw Mill River is treated by only the Yonkers Wastewater Treatment plant (Mulligan et al., 2005). This plant serves a population of half a million people, a total area of 108 $mi^2$ and receives an average daily flow of 96 million gallons per day (Mulligan et al., 2005). Thus, wastewater generated in the upper Saw Mill River watershed travels south through county trunk lines until it reaches the Yonkers WWTP. While the recorded values at site S1 may seem extremely high ($\approx 10^5$ org/100mL), they are significant less than levels commonly found in raw sewage and sewer overflows. Typical fecal coliform bacteria concentrations in raw sewage are on the order of $10^7$ org/100 mL (Thomann and Mueller, 1987). A 1:100 dilution of raw sewage therefore puts it into the range of our observed values. Coliform bacteria in combined sewer overflows range from $10^5$ to $10^6$ org./100 mL (Thomann and Mueller, 1987). Sewer overflow(s) occurring during wet weather in the upper watershed may therefore be responsible for high fecal coliform bacteria counts at site S1.

For the two sites in Yonkers (S11 and S12), the source of the high coliform levels do not appear to be weather related. The surrounding area is highly urbanized and has the largest density of impervious services. Thus, stormwater runoff may be a contributing a larger load in this area than at the more sub-urban upstream sites. In addition, sewage discharges from homes or businesses tied to storm sewers may be present in this older section of Yonkers. Further investigation is required if such connections exist.

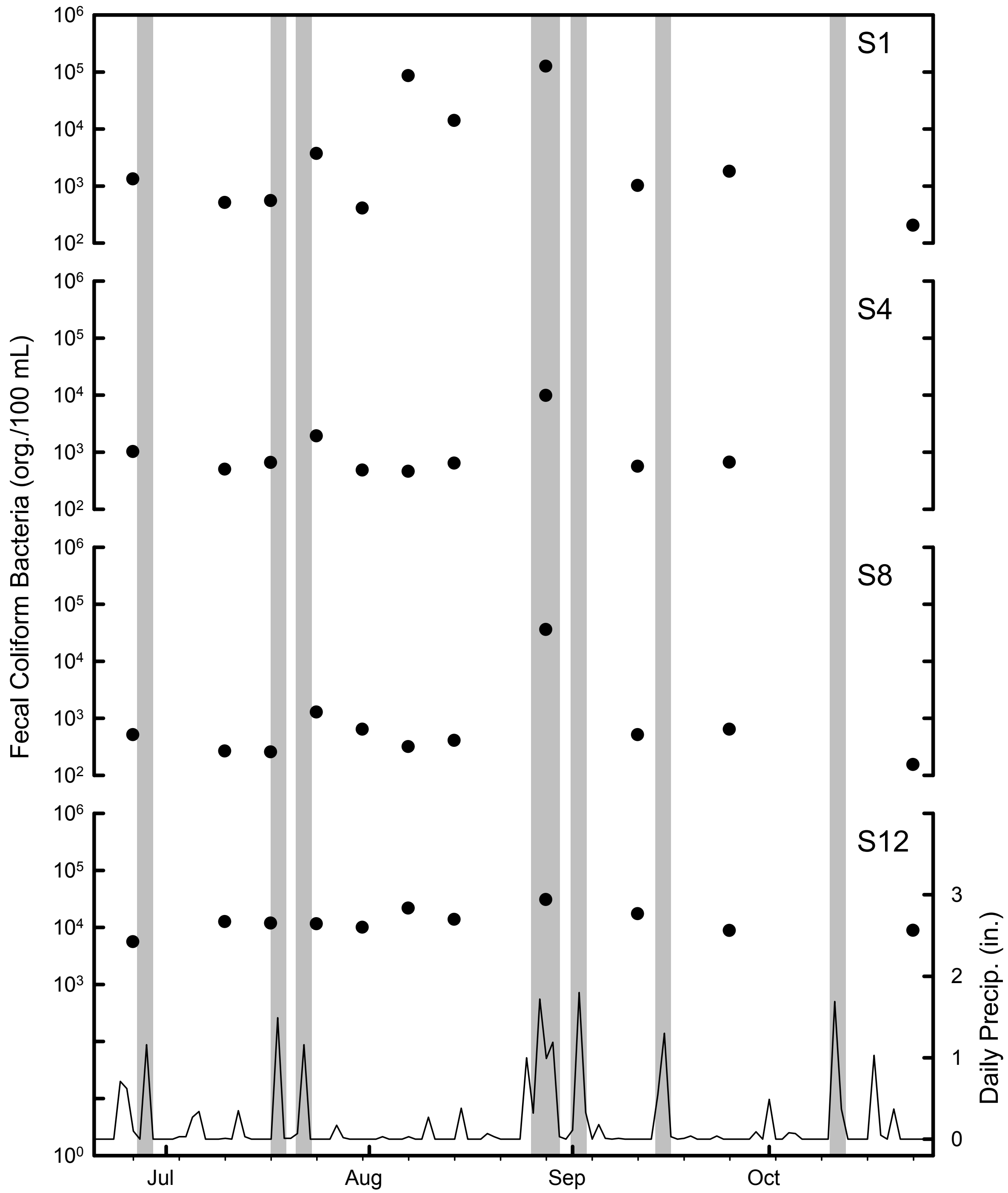


**Figure 4:** Fecal coliform bacteria at sample stations S1, S4, S8 and S12. Also indicated on the plot is the daily precipitation (in.). Grey bars represent days where daily precipitation was greater than 1.0 in.

**Ammonia**

Total ammonia concentrations as a function of time are shown as a box plot in Figure 5. In general, all ammonia concentrations are relatively low with most values falling below 0.4 mg N/L, and the largest value recorded being 0.79 mg N/L. The CCC (chronic criterion concentration) established by EPA for total ammonia is both pH and temperature dependent (Usepa, 1999). All samples collected from this study were considerably lower than their standard determined at their respective temperature and pH. Median total ammonia levels are generally slightly higher during or after storm events as indicated by the daily precipitation record.

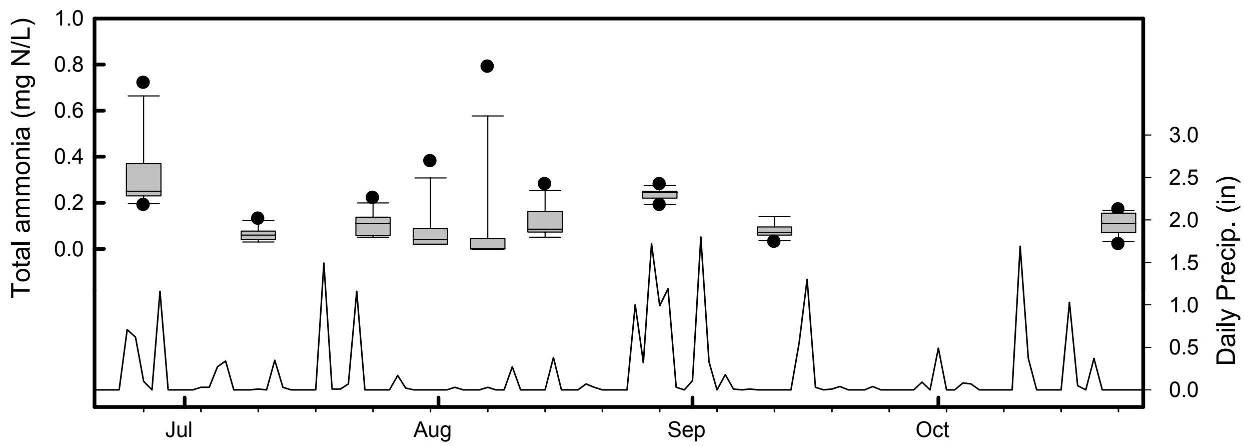


**Figure 5:** Box plot of total ammonia concentrations as a function of time. Also indicated on the plot is the daily precipitation (in.).

A stormwater sampling event performed on August 11, 2004, also showed increases in total ammonia after a significant rainfall event. An ISCO automated sampler was deployed at the Hearst St. (site S10), and programmed to take a series of twenty-four 1.0 L samples at 45 minute intervals. The sampler was deployed at 2:00, the first sample was collected at 2:30 pm. The results of total ammonia and conductivity from this sampling are shown in Figure 6.

We do not have a rainfall estimate for the August 11 storm, however a short period of intense rainfall was observed at 2:45 pm (15 minutes after sampling started) and intermittent rainfall was observed throughout the night starting at 7:00 pm (270 minutes after sampling started). The temporal profile for conductivity appears to give an excellent indication of the rainfall period. The conductivity of the first sample was 755 µS; this value is very consistent with the conductivity at this sampling station during baseline sampling. By the time of the second sample, it had already started raining quite hard. Correspondingly, conductivity had decreased to 448 µS, due to dilution from the input of stormwater to the river. With the next few samples conductivity began to increase until it reached the original baseline conductivity levels. During this period, there was a lack of rain in the area, and the river water upstream of the site was probably not diluted from significant rainfall. After 4.5 hours, the conductivity began to decrease, corresponding with the start of continual rainfall in the area. The conductivity remained low for the remainder of our sampling, indicating that the upstream waters were also receiving significant rainfall. Thus, tracking conductivity levels with time is a viable way of indirectly monitoring stormwater inputs to the river.

Total ammonia levels clearly increase during rainfall. This is evident by comparing the temporal profiles for ammonia and conductivity. Throughout the 18 hour sampling period, increased ammonia levels corresponded to decreased conductivity and vice versa. A cross plot of ammonia versus conductivity yielded a correlation coefficient for ammonia and conductivity of 0.86 (n = 24). Therefore, stormwater runoff is an important non-point source of ammonia to the river.

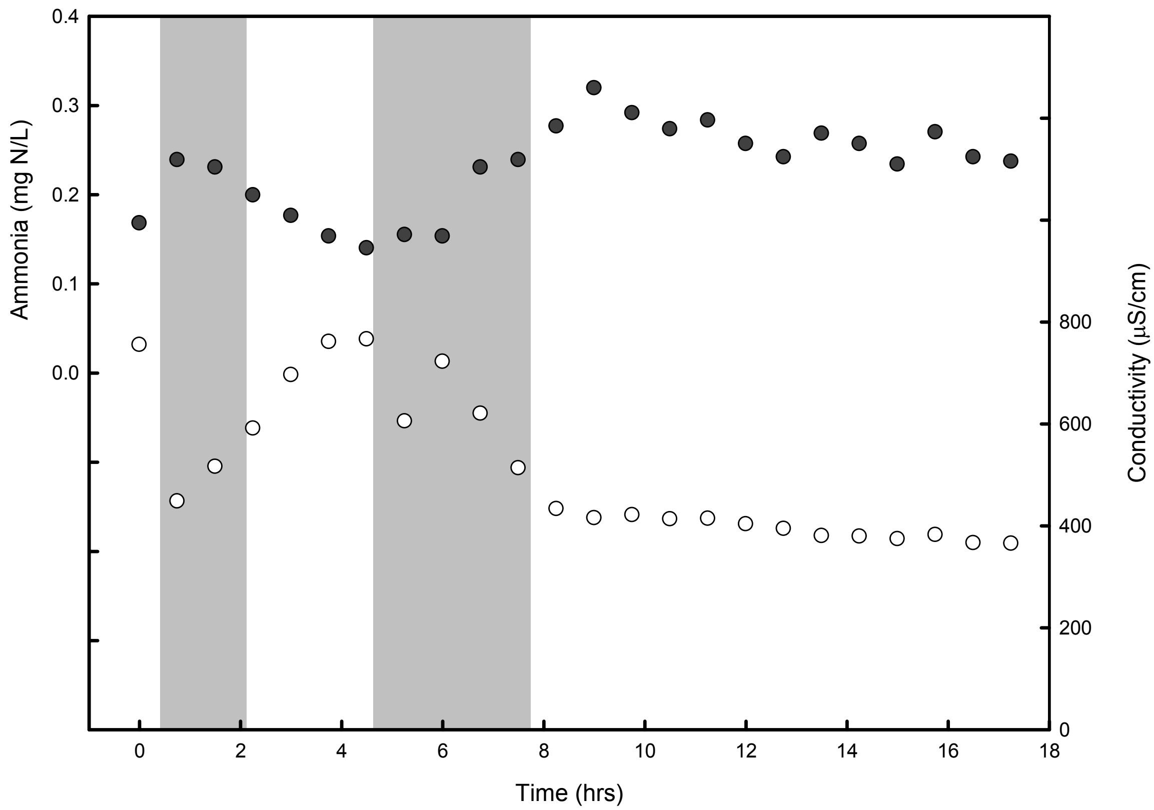


**Figure 6:** Total ammonia (closed circles) and conductivity (open circles) for a storm event captured on August 11, 2004 at site S10 (Hurst St., Yonkers, NY). Grey bars represent periods of significant rainfall.

In Figure 7, total ammonia is plotted versus distance as a box plot. The medians of total ammonia are fairly constant along the entire stretch of the river, however, sites S10, S11 and S12 exhibited higher values during a few sampling events than those observed at the upstream sites. Municipal wastewater, agricultural runoff, fertilizers, and animal feedlots are potential sources of ammonia (and nitrate) to streams. At sites S11 and S12, both ammonia levels and fecal coliform bacteria are higher than that observed at points upstream, both of which can result from municipal wastewater discharges.

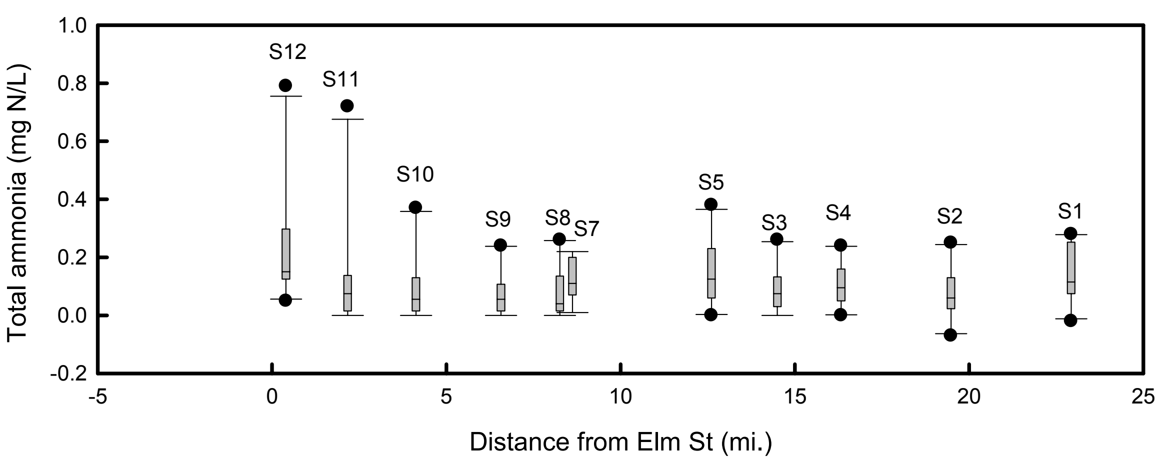


**Figure 7:** Box plot of total ammonia concentrations as a function of distance.

**Nitrate and Phosphorus**

As much as half of the waterbodies surveyed by states do not adequately support aquatic life because of excess nutrients (Usepa, 2002). Furthermore, urban streams are second only to agricultural streams in terms of their nitrate and total phosphorus levels (Barth, 1995). There are several nonpoint sources of nitrate and phosphorus in urban areas: fertilizers in runoff from lawns, pet wastes, failing septic systems, and atmospheric deposition from industry and automobile emissions. Moderately high concentrations of nitrogen and phosphorus can result in excessive plant growth in rivers and streams.

EPA has recently set nutrient criteria for rivers and streams that are based upon conditions observed in unimpacted waterbodies (Usepa, 2000a). As part of this effort, the US was divided into various ecoregions (lower New York being part of Nutrient Ecoregion XIV). These criteria provide recommendations to States agencies for establishing their own water quality standards for nutrients. The aggregate Nutrient Ecoregion XIV reference conditions are 31.25 μg P/L for total phosphorus and 0.71 mg N/L for total nitrogen (Usepa, 2000a).

Nitrate concentrations in the Saw Mill River did not show a large amount of spatial variability. Median and maximum nitrate concentrations from all sample sites did increase however from summer to early fall, and then decreased through to late fall (Figure 8). The small decrease in nitrate observed for the August 28 sampling corresponded with a large rainfall and is probably due to dilution. A summary of nitrate concentration data for each site is presented in Table 4. The median and average of all samples collected was 0.38 mg N/L. All nitrate readings were less than 1.0 mg/L. At these levels, nitrate is not expected to be toxic to aquatic life. Many recorded values for nitrate in late summer/early fall exceeded the EPA reference condition for total nitrogen, even without considering contributions of ammonia and organic nitrogen. If we consider total nitrogen to be the sum of the ammonia and nitrate concentrations, we arrive at a mean total nitrogen of all samples of 0.49 mg N/L.

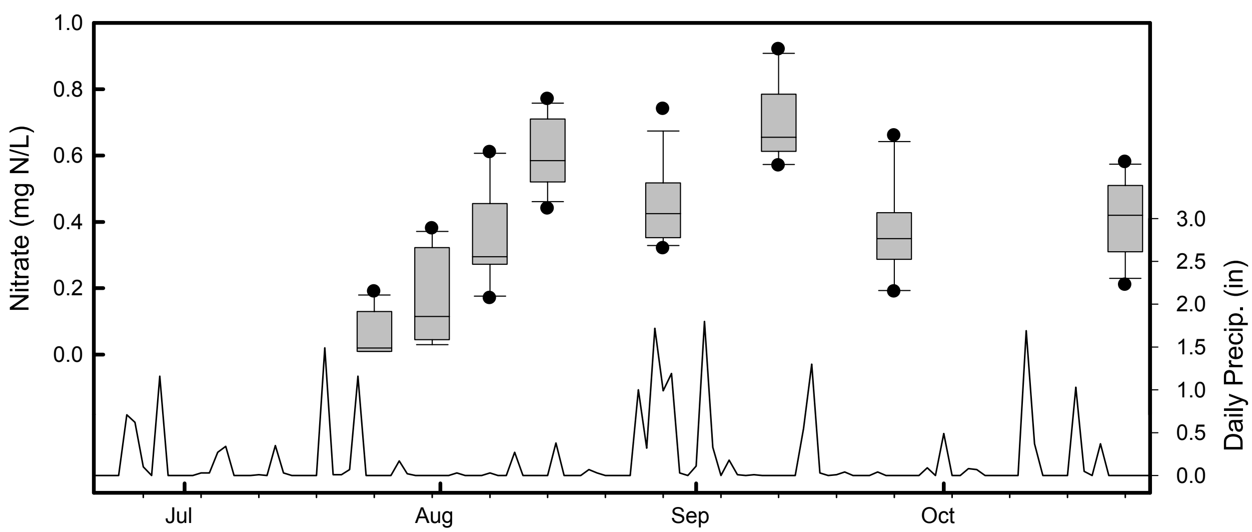


**Figure 8:** Box plot of nitrate concentrations as a function of time.

**Table 4:** Summary of Nitrate and Total Phosphorus[(a)]

| Site | Nitrate (mg N/L) | Total Phosphorus (mg P/L) |
|---|---|---|
| S1 | 0.28 (0.13 - 0.72) ; 0.19 | 0.07 (0.02 - 0.13); 0.03 |
| S2 | 0.52 (<0.10 - 0.92) ; 0.29 | 0.09 (0.02 - 0.83); 0.25 |
| S3 | 0.31 (<0.10 - 0.80) ; 0.27 | 0.08 (0.02 - 0.36); 0.10 |
| S4 | 0.52 (<0.10 - 0.88) ; 0.28 | 0.11 (0.05 - 0.34); 0.08 |
| S5 | 0.38 (<0.10 - 0.74) ; 0.23 | 0.06 (0.04 - 0.27); 0.07 |
| S6 | 0.39 (<0.10 - 0.63) ; 0.22 | 0.07 (<0.02 - 0.18); 0.05 |
| S7 | 0.43 (0.10 - 0.73) ; 0.21 | 0.06 (0.02 - 0.10); 0.03 |
| S8 | 0.37 (<0.10 - 0.74) ; 0.23 | 0.07 (<0.02 - 0.11); 0.03 |
| S9 | 0.39 (<0.10 - 0.66) ; 0.21 | 0.08 (0.06 - 0.13); 0.02 |
| S10 | 0.33 (<0.10 - 0.64) ; 0.23 | 0.09 (0.04 - 0.13); 0.03 |
| S11 | 0.39 (<0.10 - 0.71) ; 0.21 | 0.16 (0.10 - 0.35); 0.08 |
| S12 | 0.41 (0.11 - 0.77) ; 0.22 | 0.12 (0.07 - 0.23); 0.05 |

(a) Data reported as median (min – max); standard deviation

Total phosphorous showed no apparent spatial or temporal trends. A summary of the data is presented in Table 4. Total phosphorus concentrations were quite high for freshwater streams, with average and median values from all samples of 0.10 and 0.08 mg P/L respectively. The N/P ratio (based on the median total N and total P) was equal to approximately 6. Based upon the N/P ratio, the Saw Mill River therefore appears to be N-limited (Thomann and Mueller, 1987).

The total phosphorous values observed here are higher than the USEPA Ecoregion XIV reference conditions, but are in line with levels found for rivers and streams flowing through urbanized areas. Bartsch and Gakstatter (1975) report a mean total P of 0.066 mg P/L from 11 mostly urban areas of the eastern US. Omernik (1977) reports estimated mean total P levels for 75% and 100% urban areas of 0.078 and 0.136 mg P/L, respectively. While freshwater lakes are usually P-limited, freshwater lakes can be either N or P-limited (Thomann and Mueller, 1987).

## References


Barth C. A. (1995) Nutrient Movement from the Lawn to the Stream? *Watershed Protection Techniques* **2**, 239-246.

Bartsch A. F. and Gakstatter J. H. (1975) Management Decisions for Lake Systems on a Survey of Trophic Status, Limiting Nutrients and Nutrient Loadings. American-Soviet Symposium on Mathematical Models to Optimize Water Quality Management. USEPA Gulf Breeze ERL.

Clseceri L. S., Greenberg A. E., and Eaton A. D. (1998) Standard Methods for the Examination of Water and Wastewater, 20th Edition. American Public Health Association Publications.

NYS Department of Environmental Conservation (1999) Surface Water and Groundwater Quality Standards and Groundwater Effluent Limitations.

MDE (1999) Maryland Stormwater Design Manual. Maryland Department of the Environment, Annapolis, MD.

Mulligan G. E., Buroughs E., Lipkin M., Gisondo,P. and Duffy K. (2005) Databook Westchester County. Westchester County Department of Planning, White Plains, NY.

Omernik J. M. (1977) Nonpoint Source Stream Nutrient Level Relationships: A Nationwide Study. U.S. EPA, Environmental Research Laboratory, Corvallis, OR.

Pearce W. H. (1999) Saw Mill River Basin, New York. Reconnaissance study for flood control & ecosystem restoration. Section 905(b) (WDRA 86) preliminary analysis. US Army Core of Engineers.

Thomann R. V. and Mueller J. A. (1987) *Principles of Surface Water Modeling and Control*. Harper Collins, New York, NY.

USEPA (1999) 1999 Update of Ambient Water Quality Criteria for Ammonia. USEPA, Washington, D.C.

USEPA (2000a) Ambient Water Quality Criteria Recommendations. Information Supporting the Development of State and Tribal Nutrient Criteria Rivers and Streams in Nutrient Ecoregion XIV. United States Environmental Protection Agency, Office of Water, Washington, D.C.

USEPA (2000b) National Water Quality Inventory. Office of Water, U.S. Environmental Protection Agency.

USEPA (2002) Fact Sheet: Ecoregional Nutrient Criteria. United States Environmental Protection Agency, Offic eof Water, Washington, D.C.

USEPA (2005) National Management Measures to Control Nonpoint Source Pollution from Urban Areas. United States Environmental Protection Agency, Office of Water, Washington, D.C.

Wall G. R., Riva-Murray K., and Phillips P. J. (1998) Water Quality in the Hudson River Basin, New York and Adjacent States, 1992-1995. In: U.S. Department of the Interior, U. (Ed.). USGS.