Middle States Geographer, 2007, 40:96-105

QUANTIFYING WATER QUALITY IMPAIRMENTS AND DEVELOPING MANAGEMENT INITIATIVES FOR A PRIORITY STREAM SEGMENT OF THE WEST BRANCH OF THE ELIZABETH RIVER IN NEW JERSEY

John F. Dobosiewicz
Department of Geology & Meteorology/Institute of Urban Ecosystem Studies
Kean University
1000 Morris Avenue
Union, NJ 07083

ABSTRACT: *The West Branch of the Elizabeth River is an impaired stream in New Jersey Watershed Management Area 7, the Arthur Kill Metropolitan Watershed, and has been targeted by the New Jersey Department of Environmental Protection for water quality evaluation and a subsequent priority stream segment management initiative. Water quality in the West Branch of the Elizabeth River is poor, with severe impairment in most water quality indicators, primarily from non-point source pollution. The water quality parameters of concern include fecal coliform, nutrients, pH, and dissolved oxygen. These water quality impairments and the land use characteristics of the watershed are consistent with water quality impairment and land use in urban watersheds. Local scale spatial and temporal variability in water quality was determined from samples collected at six sites under base flow and storm flow conditions. Sites were selected to compartmentalize the priority segment and watershed into sub-segments that represent different land use and stream corridor impacts. ArcMap GIS ™ is used to analyze watershed characteristics for the entire priority stream segment and surrounding each site. A site-specific management initiative is developed for each site based on the results of the water quality sampling and the GIS analysis. Preliminary suggestions to reduce impairment at specific sites include the restoration of native species, buffering the stream corridor, evaluation of fertilizer use in residential areas and on nearby golf courses, geese management plans, storm drain marking, and education.*

Keywords: *Urban watersheds, Water quality, Non-point source pollution*

PROBLEM AND BACKGROUND

Watershed urbanization is a major threat to the physical, chemical and biological integrity of streams and lakes. Land use and impervious surface cover are important factors for assessing the watershed condition. Water quality in a stream is directly impacted by the land use and land cover characteristics of the stream's watershed (Tong and Chen, 2002) by impact to aquifer recharge and base flow to streams (Hasse and Lathrop, 2003) and impervious surface cover (Kaplan and Ayers, 2000). Land development and the removal of vegetation impacts the natural workings of the hydrological cycle, especially infiltration and storage, to potentially remove contaminants and reduce runoff. Ecologists have described the "urban stream syndrome" as stream conditions with elevated nutrients and contaminants, increased hydrologic flashiness, and altered biologic assemblages (Meyer et al., 2005). Since the implementation of the Clean Water Act, there has been greater control of point source pollution from discharge pipes, resulting in non-point source pollution from poor land and water use practices becoming the most significant threat to water quality. Non-point source assessment is inherently a geo-spatial problem, inclusive of spatial and temporal variability (Phillips, 1988). Surface runoff is an important source of non-point source of pollution (Tong and Chen, 2002) with concentrations of pollutants typically higher when rainfall occurs after a dry period, called the "first flush phenomena" in urban hydrology. Runoff in urban watersheds may be enriched with many different types of sources of non-point source pollution such as automobiles, outdoor storage piles, muddy construction sites, lawn fertilizers, septic fields, pet wastes, pesticide spills, and opportunistic fauna.

Previous studies have successfully modeled specific land use impacts on discrete water quality parameters (e.g. the Hydrologic Simulation Program-FORTRAN (Im et al., 2004). Strong causal relationships have been developed in some cases between a single landscape metric such as mining and discrete variables such as heavy metals (Xiao and Ji, 2007). Geographic Information Systems (GIS) can integrate modeling (e.g., AVGWLF GIS) to calculate nutrient loads at large spatial and temporal scales (100,000 acres and monthly, seasonally, annually) but not at small scale with temporal variability (Evans et al., 2002; Chang, 2004). While overall environmental quality of water within a watershed is directly related to the amount of impervious surface within the basin, this single variable approach does not necessarily address complexity within small spatial scales in a watershed to include factors such as wildlife, recreational land use, and wetland loading and release of contaminants. Models require detailed calibration which is generally lacking in everyday catchments (Johnes, 2007). Correlating multiple physiographic characteristics of watersheds to multiple water quality parameters is profoundly difficult to model in urban watersheds due to the many confounding and synergistic relationships. Biological health decreases with impervious, but impervious is still a flawed predictor of overall river health (Booth et al., 2004). Urbanization increases nutrient transport by artificially accentuating naturally occurring erosion processes (Brett et al., 2005) with concentrations of pollutants increasing during dry days due to lower discharge (Brezonik and Stadelmann, 2002). Nutrient loading is generally correlated to land use but the causal relationships are not completely understood (Poor and McDonnell, 2007) and confounded by alternating as source and sink in wet and dry years in natural or vegetative habitats and seasonally (Ahearna et al., 2005).

Urban stream restoration is complex and must include the local scale, both near stream human activities, including landowner in residential backyards, and regional watershed conditions (Booth et al., 2004). Stream habitats in New Jersey are threatened and water quality impaired primarily by the complexity of non-point pollution from varied land use management. Indicators of land use impact have been developed in New Jersey at the county level and indicate persistent conversion of natural habit to some developed land use in the context of suburban sprawl (Hasse and Lathrop, 2003). These indictors must be used cautiously, especially when applied to potential land use impacts to water quality, because while the highest changes have occurred in suburban and rural counties, predominantly urban counties are ranked very low but still experience loss. Land is still being converted from “open space” to development in predominantly urban areas in New Jersey and will potentially impact water quality. Successful land restoration to a more natural function designed to improve water quality (Peterson, 1999) depends on a geomorphic inventory and evaluation based on units (e.g., land use) that perform similar hydrologic function.

SITE STUDY

Most water quality parameters in the West Branch of the Elizabeth River located in Union County, New Jersey are impaired and targeted in a scope of work under 319(h) project guidelines in state fiscal year 2005 (New Jersey Department of Environmental Protection, 2007) (NJDEP). Impairments in mercury, phosphorus and total dissolved solids are also listed in the statewide integrated report submitted to the Environmental Protection Agency (EPA) (NJDEP, 2006). The water quality impairment and land use characteristics of the West Branch are consistent with water quality impairment and land use in Watershed Management Area (WMA) 7 – The Arthur Kill Metropolitan Watershed. Seventy eight percent of the land use in WMA 7 is classified as urban with the percent area impervious in the Elizabeth River/Arthur Kill Watershed ranging from 45% - 60% (Hatch, Mott, and MacDonald Inc., 2003a). The sub-watershed for the priority stream segment of the West Branch is located in Hydrologic Unit Code (HUC) 14 boundary number 02030104020020, described as the Elizabeth River CORP BDY to I-78, in WMA 7. The sub-watershed for the priority stream segment of the West Branch was delineated using ArcMap GIS™ based on a 10 m Digital Elevation Model provided the New Jersey Department of Environmental Protection (NJDEP) and corrected to fit the pre-existing edges of the HUC boundary. The land use is primarily urban using Anderson’s Classification (~90% urban, ~10% forest, wetlands, and water). The urban land use can be classified at the next level of the hierarchy to residential, recreational, industrial, commercial, and transportation. The West Branch of the Elizabeth River is a major tributary of the Elizabeth River within this HUC boundary. The sample design consists of six sites to representing the diversity in land use in urban watersheds, with sites situated between significant changes in land use.

Land use and cover in both the entire HUC watershed and the sub-watershed are similar, with the majority residential and significant percentages of recreational land, commercial services, industrial, and transportation, communications, utilities (Figure 1). High and medium density residential housing is believed to be the source of 60% of the pollutant loadings in WMA 7 (Hatch, Mott, and MacDonald Inc., 2003b). The West Branch traverses two large golf courses in the sub-watershed, one a public course owned by Union County, and the other private. Besides golf courses, a variety of land uses and covers exist along the stream corridor, including industry, residential, forests, and wetlands. Portions of the Elizabeth River as well as other rivers in WMA 7 have moderate to severe water quality impairments due to low dissolved oxygen, elevated total phosphorus and fecal coliform, and high total dissolved solids (Hatch, Mott, and MacDonald Inc., 2003b).

FIELD STUDY

The sampling design was to conduct half of the samples within three days of storm events with at least 6.35 mm (0.25 in) of precipitation between May and June 2006. Weather and time constraints limited the sampling to two samples that met the criteria. Water monitoring data must be sampled and tested carefully and using a strict chain of custody and over time frames that are representative of the parameters being evaluated in order to potentially drive informed policy (Duckson, 1984). All sampling handling, custody, data collection, sensitivity and accuracy of analytical methods, and detection limits were consistent with a Quality Assurance Project Plan approved by the NJDEP (Dobosiewicz, 2006) to ensure quality control, accuracy, and acceptable standards, including calibration and duplicates, precision (repeatability) and bias (persistent distortion). Samples were collected in plastic containers, tagged, stored in a cooler, and taken to an EPA certified analytical lab, for the analysis all parameters, except pH which was tested in-situ using a multi-probe sensor and a chemical test kit. The data reports generated by the laboratory included coliform bacteria counts, total phosphorus and nitrate concentration, dissolved oxygen, temperature, turbidity, and conductivity. Water quality and watershed characteristics were assessed at the six sites along the priority stream segment of the West Branch during various flow regimes, including post-storm assessments. Water quality was analyzed for eight samples at each site except for coliform bacteria which required only five samples based on sampling protocols from the NJDEP.

The selected sites compartmentalize the priority segment into sub-segments that represent a homogenous land use and are easily accessible from nearby roads. Land use includes residential, industrial, mixed use, forests, and wetlands in order to be able to develop a stream segment management plan that includes site-specific and multi-scale options for the various land uses characteristic of large urban watersheds. Sampling sites are spatially distributed to distinguish different second order land use characteristics (e.g., residential to commercial to industrial to forest/wetland types to recreational).

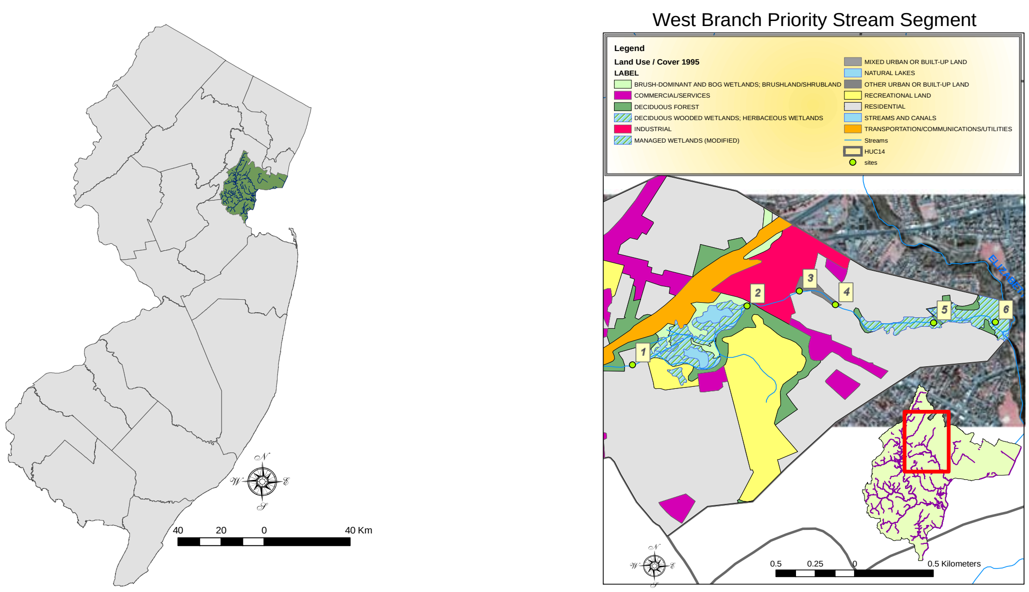

Figure 1. The location of the priority stream segment and relationship to various hydrologic units. NJ contains 20 WMAs. The priority stream segment is located in WMA 7 (upper right) and HUC 14 code 02030104020020 (bottom left).

Stream corridor characteristics also vary (Figure 1).

The coordinates of each site were recorded using a global positioning system with and accuracy of 3-5 meters using wide area augmentation system correction. Site 1 is located in a residential area with a 2-4 m stream buffer with a major transportation route and large public golf course upstream. Site 2 is located in a wooded area approximately 25 m downstream of a private golf course. Site 3 is located in a mixed urban land use with a combination of industrial, commercial, barren, and recreational land nearby. Site 4 is located in a park in a residential area with grass mowed up to the stream channel which is common along much of the stream in residential areas. Site 5 is located near an Ambient Biomonitoring Network (AMNET) monitoring site in a wooded area where the stream flows through a homogenous residential zone with more significant forest cover than Sites 3 and 4. Site 6 is located in a wooded wetland near the confluence of the West Branch with the Elizabeth River. Lawn mowing is common up to the stream channel.

RESULTS AND DISCUSSION

Many of the waterways in WMA 7 are classified as FW 2-Nontrout (FW2-NT), SE2 and SE3 within the Surface Water Quality Standards (N.J.A/C. 7:9B). Under these standards all streams within the state are required to maintain a level of water quality appropriate for designated use. The Elizabeth River and the West Branch are classified as FW-2-NT, indicating that they are primarily fresh water but not suitable for fishing. SE2 and SE3 designations are saline estuarine waters. The Elizabeth River and the West Branch are also classified as 3rd order streams, indicating that other streams contribute to the water quality and quantity. The water quality measurements in this study are comparable to those data existing from AMNET site #01393450 and a report from Hatch, Mott, and McDonald Inc. (2003a). Measures of central tendency indicate that the water quality parameters assessed in this study are impaired for three of the parameters when compared to the threshold criteria for FW2-NT streams and for general EPA standards for all streams (Table 1).

The data was plotted to give an overall representation of the spatial (Figure 2) and temporal (Figure 3) distribution of the stream's water quality, compare sites, and evaluate base flow and storm flow conditions. The geometric mean of fecal coliform count exceeds the EPA standards of 200 org/100 ml at all sites, ranging from a low of 353 at Site 2 to a high of 1,052 at Site 4. Approximately 56% of the fecal coliform tests (20 out of 36) exceeded 400 org/100 ml. The EPA threshold for exceeding 400 org/100 ml is 10%. While fecal coliform is a definitive impairment for the entire stream segment, it is more pronounced at Sites 1, 3 and 4. The highest individual values appear after storms with five sites exceeding 2,500 org/100 ml at least one time during the sampling interval. Canadian Geese, other animals and pet waste are observed in the study area. Septic tanks and combined sewers are not nearby. The mean values of total phosphorus concentration in all six sites typically exceed the criteria value (0.1 mg/l) most of the time. However, total phosphorus is more pronounced at Site 6. The major contributor of phosphorus is fertilizer used in residential and recreational area. Other sources include urban runoff containing chemicals from construction sites, and motor oil. High phosphorus levels are likely related to low dissolved oxygen in water by increasing plant growth, decomposition and degradation leading to eutrophification. This is evident at Site 2 where dissolved oxygen is low and phosphorus high (mean 0.4 mg/l). Site 6 does not exhibit this characteristic since dissolved oxygen is slightly higher than other sites and phosphorus high (mean 0.36 mg/l), indicating the role of wetlands in releasing phosphorus to the stream during dry conditions (not with 72 hours of rainfall). Nitrate/nitrite concentrations are within the standard range of 0.3-0.9 mg/l at most of the time. Only 17% of the total samples exceed the criteria value. Site 1 is significantly impaired in nitrate/nitrite concentration (mean nitrite/nitrate 2.3 mg/l). Site 1 is particularly

Table 1. Water Quality Comparisons to General EPA Standards and Criteria for Fresh Water 2-Nontrout Waters

Parameter (*impaired)	n	Mean	Criteria (EPA	FW2-NT
Fecal Coliform (org./100ml)	30	425*	200	200
Nitrate/Nitrite (mg/l)	48	0.27	10	0.3-0.9
Turbidity	48	3.5	40	40
Total Phosphorus (mg/l)	48	0.22*	0.1	0.1
Total Dissolved Solids (mg/l)	48	352.5	500	500
Dissolved Oxygen (mg/l)	48	2.1*	5.0	4.0
pH	48	6.61	6.5-8.5	6.5-8.5

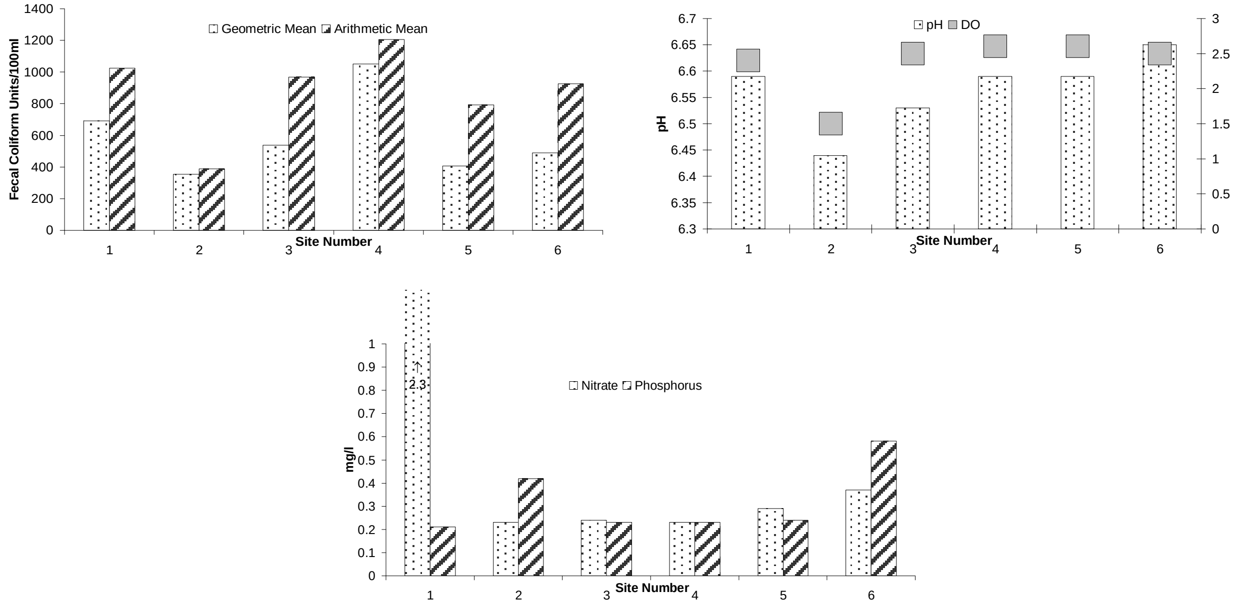

Figure 2. Selected water quality parameters for the six study sites.

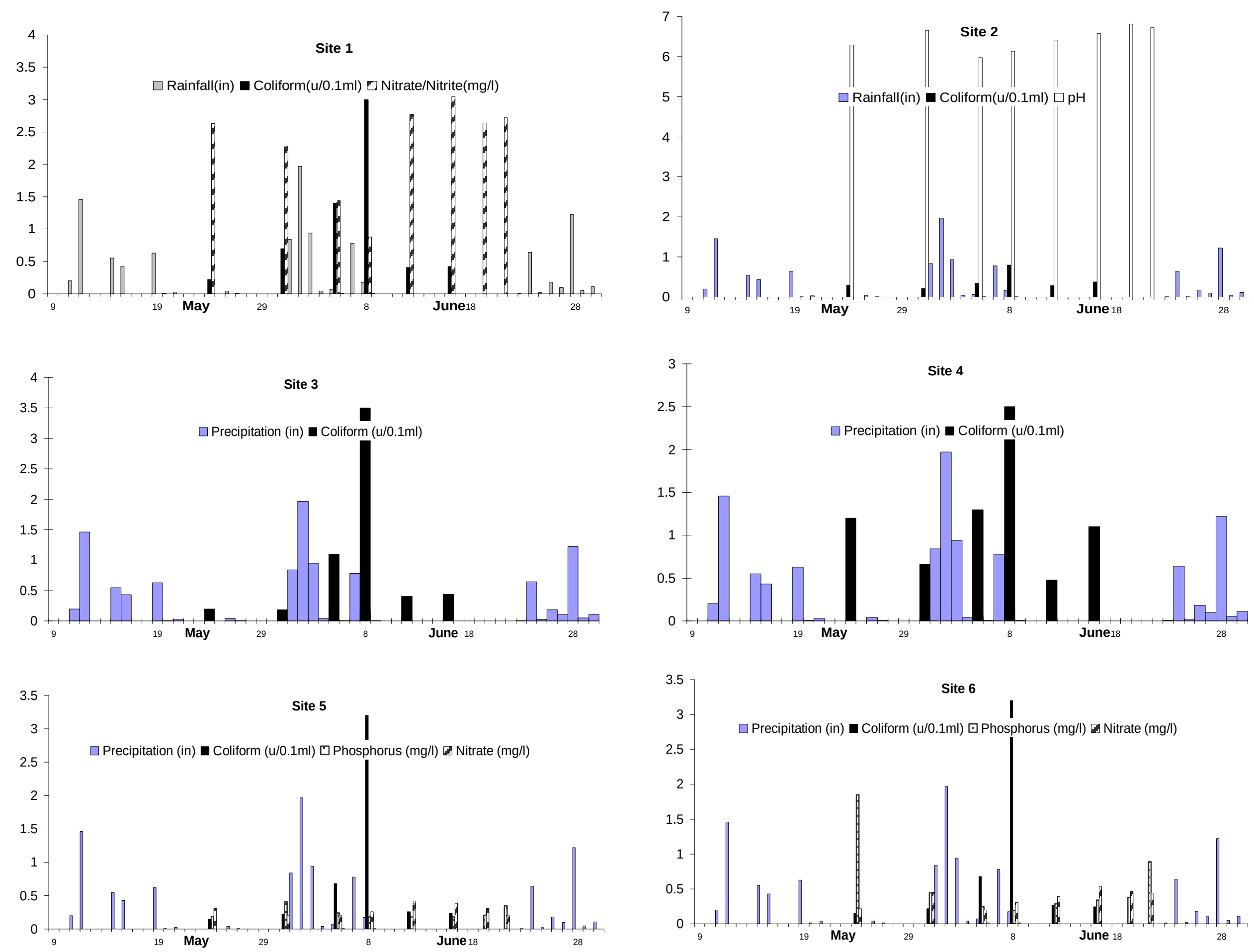

Figure 3. Temporal variability in select water quality parameters.

intriguing because of the extremely high value, an order of magnitude higher than any other site and the close proximity upstream of a major transportation route (Garden State Parkway, 12 lane wide toll road) and a public golf course. An increase in nitrogen concentration is evident from Site 3 downstream. The downstream increase beyond Site 3 is likely due to persistent runoff from residential properties. Dissolved oxygen is lower than the standard 5 mg/l at all six sites. Site 2 has lowest mean dissolved oxygen concentration of 1.4 mg/l and ranged from 2.1 to 0.8 while the mean at all other sites exceeding 24 mg/l. The water is generally considered eutrophic and this is common in streams with high nutrient loads. The pH values of the water at most of the sites are within the permissible range of 6.5 to 8.5. However, Site 2 shows a significant decrease in pH value than other sites as well as lower dissolved oxygen. Almost half of the samples drawn at Site 2 have a pH value of less than 6.5. Fertilizers may contain sulfate which makes water more acidic and produces a lower pH (Caitcheon et al., 1994). The management practices of the private golf course are suspected. Turbidity and total dissolved solids generally did not exceed the critical established limits of 40 NTU and 500 mg/l respectively and therefore are not considered in the discussion.

SITE SPECIFIC ANALYSIS AND RECOMMENDATIONS

Numerous structural and non-structural approaches to non-point source pollution mitigation and watershed restoration were considered and listed below. Most of these approaches are also listed in the Union Township, Union, NJ Storm Water Management Plan (Bucco and Henderson, 2005). Structural approaches include stream corridor buffer and vegetative filter strips, bioretention systems, disconnecting impervious areas, and soil stabilization. Non-structural and combined approaches include geese and nutrient management, street sweeping, storm drain markings, pet waste and residential yard practices, rain gardens, and native species restoration. The graphs demonstrate the high loading of substances following storms and highlight the parameters of concern at each site (Figure 3). Upstream influences are evident across Sites 3-5 where residential land use is consistent.

Site 1. The West Branch of the Elizabeth River emerges from beneath the Garden State Parkway, a 12 lane major roadway. Residential housing exists across the street from the stream. The stream corridor is mowed to the bank, resulting in sparse native vegetation. Pet feces were observed. Dozens of Canadian Geese were observed in the water and are also prevalent on a public golf course upstream of the site. Nitrate/nitrate values were an order of magnitude higher at this site than at all the other sites. Elevated levels of fecal coliform and nitrate/nitrite indicate that golf course and Garden State Parkway have impacted water quality at this site. The recommendation is to mitigate water quality impacts through geese and nutrient management practices in upstream land use. The impairments are exacerbated by poor management of the stream corridor and buffer zone. The specific management plan for the near stream corridor includes the restoration of native species and restrictive mowing of the stream corridor, and the development of a pet waste and storm drain marking program through educational outreach. Bioretention systems and/or vegetation strips are not necessary because there is not a significant impervious surface leading to the stream.

Site 2. The West Branch of the Elizabeth River traverses through a wetland in a braided drainage pattern and begins its journey under a four lane roadway. Tributaries within a private golf course supply water to the West Branch. The site has significant wooded vegetation. Fecal coliform is lowest at this site suggesting that the private golf course, while not documenting one, actively pursues a geese management plan. However, pH is significantly lower at this site. Numerous small businesses exist along the roadway including automobile repair shops. Test for organics were not performed although qualitative description of the water indicated the presence of oil. The recommendation is to mitigate water quality impacts through a fertilizer management plan to reduce pH, most likely from excessive sulfates. The golf course should be encouraged to pursue more environmental friendly practices to allow for more the possible restoration of native species and restrictive mowing near the tributaries. An educational campaign along the roadway is possible through the distribution of information on storm drains and water quality.

Site 3. The West Branch of the Elizabeth River traverses a shopping area with a large impervious surface and detention basin. The stream corridor near the site has a grassy area that is maintained but not mowed to a level that would provide recreational use. An unimproved lot exists nearby and the land use nearby is classified as industrial. Fecal coliform and other parameters were high but considerably unremarkable considering the land use indicating that the detention basin is likely to be mitigating water quality impacts. The residential housing that abuts the stream on the southern bank is of concern because trash and lawn clippings are commonly dumped in this area. The recommendation is to mitigate water quality impacts along the stream corridor through the restoration of native species and educational outreach to the residents on non-point source pollution.

Site 4. The West Branch of the Elizabeth River continues through mixed urban land use into a recreational area at Site 4, only about 0.25 kilometers from Site 3. As in the case of Site 3, residential housing abuts the stream on the southern bank. Since this site is in open view, litter is not as much of a concern as in the case of Site 3 which is more secluded. The stream corridor is mowed to the bank on both sides, resulting in sparse vegetation. Canadian Geese were observed in the water at this site. The elevated levels of fecal coliform would indicate that the geese are of primary concern here. Generally, pet feces were not observed nearby. The recommendation is to mitigate water quality impacts at this site primarily at the stream corridor level. The specific management plans include the restoration of native species and restrictive mowing of the stream corridor, and educational outreach to the residents on non-point source pollution. Bioretention systems and/or vegetation strips do not appear necessary as there is not a large disconnected impervious surface leading to the stream.

Site 5. The West Branch of the Elizabeth River traverses the residential area with limited access to the stream corridor for about 0.5 km between Sites 4 and 5. Significant vegetation exists between the residential housing and the stream corridor. Site 5 is near the Vauxhall Road Bridge and the site of the AMNET biological monitoring site. As in the case with all sites, fecal coliform exceeds acceptable criteria but of more concern is the increase in nutrient concentrations (Nitrate/nitrite and total phosphorus). This is consistent with the downstream loading of nutrients seen when a homogenous land use (i.e., residential) is impacting a stream consistently (frequent fertilization and landscaping). Canadian Geese were not observed in the water at this site or on the nearby open spaces. The suggestion therefore is to mitigate water quality impacts at this site are both at the watershed level. The specific management plans residential yard care practices and educational outreach. The storm drains on Vauxhall Road are imprinted with a clean water message creating an ideal opportunity to engage the public on the importance of understanding their watershed.

Site 6. The West Branch of the Elizabeth River traverses a wooded wetland between Site 5 and 6, near the confluence of the Elizabeth River. As in the case with all sites, fecal coliform exceeds acceptable criteria but of more concern is the increase in nutrient concentrations (Nitrate/nitrite and total phosphorus). This is not only consistent with the downstream loading of nutrients seen when a homogenous land use (i.e., residential) is impacting a stream consistently (frequent fertilization and landscaping) but is also an indicator that the wetland could be serving as a source of additional loading. Dozens of Canadian Geese were observed in the water at this site and on nearby open spaces that abuts the main channel of the Elizabeth River. The recommendation is to mitigate water quality impacts at this site are at the sub-watershed level through land use management. The specific management plans residential yard care practices and educational outreach. This site can provide a significant research opportunity for evaluating the importance of wetlands as both a potential sink and source of nutrient (i.e., phosphorus).

CONCLUSIONS

The result demonstrates that dominant land uses leave biogeochemical fingerprints on surface water quality. As nutrients and other materials are transported downstream, they may be retained or transformed by physical, chemical and biological processes. Studying spatial scale variability, drainage network connectivity and downstream trends are important to assess the effect of urbanization on streams. Moreover, the hydrology of the watershed is influenced by man-made networks such as roads, ditches, and underground drainage systems. Typically in a densely urbanized area high level of nutrients can arise from a variety of potential sources including treatment plant discharge, septic tank seepage, combined sewer overflows, sanitary sewer overflows, surface water runoff of fertilizers and animal waste products. Neither combined nor sanitary sewer outflows are not found in the study area therefore surface water runoff from land use adjacent to the stream degrades water quality. Fertilizers used in both residential and recreational area pose harmful effects on quality of the water. Reduction in riparian vegetation by urbanization degrades the terrestrial and aquatic habitat and increases nutrient loading. Feedbacks include increased surface runoff from impervious areas erodes the stream banks which ultimately deteriorate riparian habitat quality. The benefit of riparian corridors and wetlands to water quality is not well appreciated even as economic assets (Lant and Tobin, 1989). High fecal coliform count at Sites 1, 2, 4, and 6 may be due to the geese wastes and these sites require measures to restrict the geese dwelling. Maintaining or planting dense woody vegetation around the perimeter of a pond or wetland is the most effective means of deterring geese from taking over and contaminating local lakes and ponds. Union County, NJ has a permit for removing 2,700 geese annually but recent years have typically removed a few hundred. Minimizing the amount of land that is mowed will limit the preferred habitat for geese. Best management practices such as the proper timing of application of fertilizer and pesticides, irrigation without excessive runoff, manage rough areas to benefit wildlife, create buffer strips to filter runoff, and create clear pool and gravel substrate riffle zones in streams, significantly reduce nutrients and increase biodiversity in streams within and near golf courses (Mankin, 2000).

Watershed management has been most successful at small scales and in relatively simple systems, however while urban watersheds may be of small physical and spatial scale they are often complicated built and human altered systems (Carluer and DeMarsily, 2004) with considerable temporal and spatial variability in water quality (Whitlock et al., 2002). Successful research collaborations between stakeholders and human agencies (Johnson et al., 2001; Wilderman, 2003; Wilderman et al., 2003) with applications of GIS technology and practical suggestions at local scales can reduce non point source pollution in a complex urban watershed. Human agencies must be engaged in the process of understanding the geophysical dynamics of hydrologic systems like watersheds (Phillips, 2004). GIS integration into water resource decision-making can yield more analysis and less deliberation (Nyerges et al., 2006). This research provides specific achievable recommendations to improve water quality based on detailed and relevant information explored utilizing GIS, for multiple stakeholders, including state agencies, a local university and community organizations.

ACKNOWLEDGEMENTS

The field work for this project was supported by priority stream segment funding from the Division of Watershed Management at the NJDEP. The Elizabeth River/Arthur Kill Watershed Association and Future City, Inc. in Elizabeth, NJ provided field and logistical support with special thanks to Sanchita Basu-Mallick.

REFERENCES

Ahearn, D., Sheibley, R., Dahlgren, R., Anderson, M., Johnson, J., and Tate, K. 2005. Land Use and Land Cover Influence on Water Quality in the Last Free-flowing River Draining the Western Sierra Nevada, California. *Journal of Hydrology* 313:234-247.

Booth, D., Karr, J., Shauman, S., Konrad, C., Morley, S., Larson, M., and Burges, S. 2004. Reviving Urban Streams: Land Use, Hydrology, Biology, and Human Behavior. *Journal of the American Water Resources Association*, pp. 1351-1364.

Brett, M., Mueller, S. and Arhonditsis, G. 2005. A Daily Time Series Analysis of Stream Water Phosphorus Concentrations along an Urban to Forest Gradient. *Journal of Environment Management* 35(1):56-71.

Brezonik, P. and Stadelmann, T. 2002. Analysis and Predictive Models of Stormwater Runoff Volumes, Loads, and Pollutant Concentrations from Watersheds in the Twin Cities Metropolitan Area, Minnesota, USA. *Water Research* 36:1743-1757.

Bucco, R. and Henderson, K. 2005. Municipal Stormwater Management Plan, Township of Union, Union County, New Jersey. March 2005.

Carluer, N. and De Marsily, G. 2004. Assessment and Modeling of the Influence of Man-made Networks on the Hydrology of a Small Watershed: Implications for Fast Flow Components, Water Quality, and Landscape Management. *Journal of Hydrology* 285:76-95.

Caitcheon, G., Donnelly, T., Wallbrink, P., and Murray, A. 1994. Sources of Phosphorus and Sediment in the Catchment of Chaffey Reservoir, New South Wales. Technical Memorandum 94/16, CSIRO Division of Water Resources.

Chang, H. 2004. Water Quality Impacts of Climate and Land Use Changes is Southeastern Pennsylvania. *The Professional Geographer* 56(2):240-257.

Dobosiewicz, J. 2006. Quality Assurance Project Plan for the West Branch of the Elizabeth River. New Jersey Department of Environmental Protection, Division of Watershed Management. Trenton, New Jersey.

Duckson, D. 1984. Water-Quality Monitoring and Specious Data: The Example of Georges Creek, Maryland. *The Professional Geographer* 36(4):473-478.

Evans, B., Lehning, D., Corradini, K., Petersen, G., Nizeyimana, E., Hamlett, J., Robillard, P., and Day, R. 2002. A Comprehensive GIS Based Modeling Approach for Predicting Nutrient Loads in Watersheds. *Journal of Spatial Hydrology* 2(2):1-18.

Hasse, J. and Lathrop, R. 2003. Land Resource Impactors of Urban Sprawl. *Applied Geography* 23:159-175.

Hatch, Mott, and MacDonald Inc. 2003a. A Technical Report for the Characterization and Assessment of Watershed Management Area 7. Revised January 2003.

Hatch, Mott, and MacDonald Inc. 2003b. The Metropolitan Watershed WMA 7 – Surface Water Quality, Pollutant Loadings and Critical Resources Assessment. August 6, 2003. Assessment of Watershed Management Area 7. Revised January 2003.

Im, S., Brannan, K., Mostaghimi, S., and Cho, J. 2004. Simulating Fecal Coliform Bacteria Loading from an Urbanizing Watershed. *Journal of Environmental Science & Health*, Part A – Toxic/Hazardous Substances & Environmental Engineering 39(3):663- 679.

Johnes, P. 2007. Uncertainties in Annual Riverine Phosphorus Load Estimation: Impact of Load Estimation Methodology, Sampling Frequency, Baseflow Index and Catchment Population Density. *Journal of Hydrology* 332(1-2):241-258.

Johnson, N., Ravnborg, H., Westerman, O., and Probst, K. 2001. User Participation in Watershed Management and Research. *Water Policy* (3):507-520.

Tong, S. and Chen, W. 2002. Modeling the Relationship between Land Use and Surface Water. *Journal of Environmental Management* 66(4):377-393.

Kaplan, M. and Ayers, M. 2000. Impervious Surface Cover: Concepts and Thresholds. Basis and Background in Support of the Water Quality and Watershed Management Rules. NJ Department of Environmental Protection. Trenton, NJ.

Lant, C., and Tobin, G. 1989. The Economic Value of Riparian Corridors in the Cornbelt Floodplains: A Research Framework. *The Professional Geographer* 41(3):337-349.

Mankin, K. 2000. An Integrated Approach for Modeling and Managing Golf Course Water Quality and Ecosystem Diversity. *Ecological Modeling* (133):259-267.

Meyer, J., Paul, M., and Taulbee, W. 2005. Stream Ecosystem Function in Urbanizing Landscapes. *Journal of North American Benthological Society* 24(3):602-612.

NJDEP. 2006. New Jersey Integrated Water Quality Monitoring and Assessment Report 2006. NJ Department of Environmental Protection Water Monitoring and Standards, Trenton, NJ.

NJDEP. 2007. Available at: www.state.nj.us/dep/watershedmgt/DOCS/WMA7sow.pdf

Nyerges, T., Jankowski, P., Tuthill, D., and Ramsey, K. 2006. Collaborative Water Resource Decision Support: Results of a Field Experiment. *Annals of the Association of American Geographers* 96(4):699-725.

Petersen, M. 1999. A Natural Approach to Watershed Planning, Restoration and Management. *Water Science Technology* 39(12):347-352.

Poor, C. and McDonnell, J. 2007. The Effects of Land Use on Stream Nitrate Dynamics. *Journal of Hydrology* 332(1-2):54-68.

Phillips, J. 1988. Nonpoint Source Pollution and Spatial Aspects of Risk Assessment. *Annals of the Association of American Geographers* 78(4):611-623.

Phillips, J. 2004. Laws, Contingencies, Irreversible Divergence, and Physical Geography. *The Professional Geographer* 56(1):37-43.

Whitlock, J., Jones, D., and Harwood, V. 2002. Identification of the Sources of Fecal Coliforms in an Urban Watershed Using Antibiotic Resistance Analysis. *Water Research* 36(17):4273-4282.

Wilderman, C. 2003. College-Community Partnerships: Who Benefits? *The Volunteer Monitor* 15(1):5.

Wilderman, C., Barron, A., and Imgrund, L. 2003. The ALLARM Program: Growth, Change, and Lessons Learned. *The Volunteer Monitor* 15(1):1,3-4.

Xiao, H. and Ji, W. 2007. Relating Landscape Characteristics to Non-point Source Pollution in Mine Waste-located Watersheds Using Geospatial Techniques. *Journal of Environmental Management* 82(1):111-119.