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Evaluation of Receiving Water Improvements from Stream Restoration (Accotink Creek, Fairfax City, VA)

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Evaluation of Receiving Water Improvements from Stream Restoration (Accotink Creek, Fairfax City, VA)

By

Ariamalar Selvakumar
Thomas P. O'Connor

Urban Watershed Management Branch
Water Supply and Water Resources Division
National Risk Management Research Laboratory
Edison, NJ 08837

Scott Struck
Former Federal Post-doc with U.S. EPA
(Currently with Tetra Tech, Golden, CO 80401)

NATIONAL RISK MANAGEMENT RESEARCH LABORATORY
OFFICE OF RESEARCH AND DEVELOPMENT
U.S. ENVIRONMENTAL PROTECTION AGENCY
CINCINNATI, OH 45268

Notice

Abstract

Installation of best management practices (BMPs) in watersheds or streams is widely used as a means of reducing, eliminating, or controlling the input of human-based physical, chemical, or hydrologic stressors to those systems. Although BMPs may be effective in managing a particular stressor, installation of stream bank and channel restoration alone may not fully restore nor fully protect the biological condition of the receiving waterbody since multiple stressors are known to affect aquatic biota.

The National Risk Management Research Laboratory (NRMRL), part of U.S. Environmental Protection Agency's (U.S. EPA) Office of Research and Development (ORD) evaluated the effectiveness of stream bank and channel restoration as a means of improving in-stream water quality and biological habitat in Accotink Creek, Fairfax City, Virginia using discrete sampling and continuous monitoring techniques before and after stream restoration. Continuous water quality monitoring showed that temperature of the creek changed with season and wet weather flow events with the highest temperature observed in summer (e.g., July). Specific conductivity was higher in winter due to street salting while pH stayed close to neutral year around. There were no statistically significant differences in other chemical constituents and bacteriological indicator organisms before and after restoration as well as upstream and downstream of the restoration. Macroinvertebrate indices such as Virginia Stream Condition Index (VASCI) and Hilsenhoff Biotic Index (HBI) and Emphemeroptera, Plecoptera, Trichoptera (EPT) taxa showed a general improvement in biological quality between pre- and post-restoration. The differences were statistically significant for VASCI, HBI, and EPT taxa. However, they were all below the impairment level, indicating poor water quality conditions. The United States Geological Survey (USGS) also performed continuous monitoring and discrete sampling under an Interagency Agreement (IAG No. DW-14-922064010) to U.S. EPA. Their monitoring and predictive equations showed a stronger relationship between turbidity and suspended sediment concentration than turbidity and *E. coli*. There was no change in the results derived from the predictive equations before and after restoration, likely because improved conditions have yet to be realized or stream restoration did not reduce sediment transport. A pebble count analysis also suggested that very little has changed in the restoration reach.

These results indicate that stream restoration alone may have little effect on improving the conditions of in-stream water quality and biological habitat. It should be recognized that improvement may not be reflected in a two year post-restoration period and that additional monitoring is needed. Also, reduction of stormwater runoff volumes and associated pollutants of concern should be addressed in the watershed through source control and stormwater retrofits to achieve desired biological outcomes.

Foreword

The U.S. Environmental Protection Agency (EPA) is charged by Congress with protecting the Nation's land, air, and water resources. Under a mandate of national environmental laws, the Agency strives to formulate and implement actions leading to a compatible balance between human activities and the ability of natural systems to support and nurture life. To meet this mandate, EPA's research program is providing data and technical support for solving environmental problems today and building a science knowledge base necessary to manage our ecological resources wisely, understand how pollutants affect our health, and prevent or reduce environmental risks in the future.

The National Risk Management Research Laboratory (NRMRL) is the Agency's center for investigation of technological and management approaches for preventing and reducing risks from pollution that threaten human health and the environment. The focus of the Laboratory's research program is on methods and their cost-effectiveness for prevention and control of pollution to air, land, water, and subsurface resources; protection of water quality in public water systems; remediation of contaminated sites, sediments and ground water; prevention and control of indoor air pollution; and restoration of ecosystems. NRMRL collaborates with both public and private sector partners to foster technologies that reduce the cost of compliance and to anticipate emerging problems. NRMRL's research provides solutions to environmental problems by: developing and promoting technologies that protect and improve the environment; advancing scientific and engineering information to support regulatory and policy decisions; and providing the technical support and information transfer to ensure implementation of environmental regulations and strategies at the national, state, and community levels.

This publication has been produced as part of the Laboratory's strategic long-term research plan. It is published and made available by EPA's Office of Research and Development to assist the user community and to link researchers with their clients.

Sally C. Gutierrez, Director
National Risk Management Research Laboratory

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Acronyms and Abbreviations

ANOVA	Analysis of Variance
APHA	American Public Health Association
BMP	Best Management Practice
COD	Chemical Oxygen Demand
CFU	Coliform Forming Unit
CWA	Clean Water Act
CWP	Center for Watershed Protection
DNA	Deoxyribonucleic Acid
DPWES	Department of Public Works and Environmental Service
EC	*E. coli*
EN	Enterococci
EPA	U.S. Environmental Protection Agency
EPT	Emphemeroptera, Plecoptera, Trichoptera
FC	Fecal Coliforms
HBI	Hilsenhoff Biotic Index
IAG	Interagency Agreement
LogTurb	Log of Turbidity
MS4	Municipal Separate Storm Sewer System
MSL	Mean Sea Level
NPDES	National Pollutant Discharge Elimination System
NRMRL	National Risk Management Research Laboratory
NTU	Nephelometric Turbidity Unit
ORD	Office of Research and Development
SOP	Standard Operating Procedures
SS	Suspended Solids
SSC	Suspended Sediment Concentration
TKN	Total Kjeldahl Nitrogen
TMDL	Total Maximum Daily Loads
U.S. EPA	U.S. Environmental Protection Agency
USGS	United States Geological Survey
UWMB	Urban Watershed Management Branch
UWRF	Urban Watershed Research Facility
VADEQ	Virginia Department of Environmental Quality
VASCI	Virginia Stream Condition Index
WT	Water Temperature
YSI	Yellow Springs Instruments

Acknowledgements

An undertaking of this type requires the dedication and cooperation of many individuals. The technical direction and coordination for this project was provided by the technical project team of the Urban Watershed Management Branch. Many members of the Branch assisted in making this product available to the public. Anthony Tafuri and Michael Borst performed reviews of this report. Carolyn Esposito reviewed the quality assurance project plan and this report.

Jim Keating of U.S. EPA's Office of Water, Ron Landy of U.S. EPA Region 3, and Wayne Green of Green Management Ltd. peer reviewed this report. Paula Estornell, Charlie App, Ann Carkoff from U.S. EPA Region 3 gave support throughout the project. Greg Pond of U.S. EPA Region 3's Wheeling Laboratory conducted the macroinvertebrate analysis and reviewed the section pertaining to macroinvertebrates. Jeanne Classen of Virginia Department of Environmental Quality assisted with continuous operation of field equipment. Christian Jones of George Mason University and his graduate student, Iyad Aburdeineh, assisted with wet weather sampling. Adrian Fremont, Engineer for the City of Fairfax was instrumental in finding the location and helped us in many other ways. Ken Hyer of USGS performed continuous monitoring and discrete sampling under an Interagency Agreement (IAG No. DW-14-922064010) to U.S. EPA.

Most monitoring, sampling and laboratory analysis was performed by personnel from PARS Environmental, Inc., the operating contractor of the Urban Watershed Research Facility (UWRF) under U.S. EPA contract number EP-C-04-064. Most notably, Christa Casciolini, Michael Cerrato, John Lapinski, Yogesh Parikh, and Clarence Smith should be recognized for their contribution to the completion of the sampling and analyses.

Executive Summary

Increased urbanization results in a larger percentage of connected impervious areas and can contribute large quantities of stormwater runoff and significant quantities of debris (litter and floatables) and pollutants (oils, microorganisms, sediments, nutrients, organic matter, and heavy metals) to receiving waters. Land-use practices directly impact urban streams. Stream flows in urbanized watersheds increase during wet weather events as a function of impervious area and can result in degradation of the natural stream channel morphology affecting the physical, chemical, and biological integrity of the stream. Stream bank erosion, which also increases with increased stream flow, can lead to bank instability, property loss, infrastructure damage, and increased sediment loading to the stream. Increased sediment loads may lead to water quality degradation downstream and have negative impacts on fish, benthic invertebrates, and other aquatic life. To improve water quality in urban and suburban areas, watershed managers often incorporate best management practices (BMPs) to reduce the quantity of runoff and to minimize pollutants and other stressors contained in stormwater runoff.

This study addresses the effectiveness of stream bank and channel restoration techniques on improving benthic macroinvertebrate indices and in-stream water quality within an urban watershed. The project monitored the effects of restoring 1,800 linear ft (550 m) of degraded stream channel in the North Fork of Accotink Creek in the City of Fairfax, Virginia. Restoration, which was completed in June 2006, included planting native plant materials along the stream and installation of bioengineering structures to stabilize the stream channel and bank. These actions were intended to restore the stream channel to a stable condition, thereby reducing stream bank erosion and sediment loads in the stream. Monitoring was performed before and after the restoration by both U.S. Environmental Protection Agency (U.S. EPA) and United States Geological Survey (USGS).

Chapter 1 provides an introduction and justification of the project. Chapter 2 describes the project background and site location. Chapters 3 and 4 detail water quality monitoring, sampling and analysis conducted by U.S. EPA and USGS, respectively. Chapter 3 also summarizes the results of macroinvertebrates sampling conducted by U.S. EPA. Finally, Chapter 5 provides the conclusions drawn from this project.

Chapter 1 Introduction

Background

Since the inception of the Clean Water Act (CWA) in 1972, the United States has made great efforts in restoring and preserving the physical, chemical, and biological integrity of nation's waters. However, nearly half of the nation's assessed surface waters remain incapable of maintaining water quality adequate for supporting one or more designated uses, i.e., recreational swimming or drinking water supply (U.S. EPA, 2007). One of the top causes of river and stream impairment is sediment or siltation. The National Water Quality Inventory 2000 Report (U.S. EPA, 2002a) estimated that about 30% of identified cases of water quality impairment are attributable to stormwater runoff. Since its formation, the U.S. EPA has established several regulatory programs to address the various point and non-point sources; however, the laws the Agency implements have led to less regulatory emphasis on non-point source pollution. In 1987, CWA was amended to establish National Pollutant Discharge Elimination System (NPDES) stormwater discharge requirements. To implement these requirements, the U.S. EPA published the "Phase I" stormwater permit program on November 16, 1990 to address certain stormwater discharge categories associated with 10 categories of industrial activity, construction and development activities disturbing more than five acres, and medium and large municipal separate storm sewer systems (MS4s) with populations greater than 100,000. In December 8, 1999, the U.S. EPA promulgated "Phase II" stormwater regulations expanding the list to include small MS4s located in "urbanized areas" as defined by the Bureau of Census, and those small MS4s located outside of a urban area that are designated by NPDES permitting authorities with populations fewer than 100,000 and construction sites disturbing more than one acre and less than five acres of land (U.S. EPA, 2000).

Land development and urbanization impact receiving streams by adversely altering watershed hydrology in several ways. The conversion of natural forested or grassland areas to impervious surfaces results in an increased volume of surface runoff because less water is able to infiltrate into the ground, i.e., more water enters the receiving water by surface runoff than via groundwater pathways. Examples of impervious surfaces in an urban area include roadway surfaces, parking lots, and roof tops. Surface runoff is also directed to the stream channel more quickly than water that infiltrates the soil. The routing to the receiving stream is expedited by curbs, gutters, and stormwater pipes, which convey water rapidly from impervious surfaces to the stream. Consequently, stream flows in urbanized watersheds increase in magnitude during wet weather flows as a function of impervious area (Schueler, 1995).

Natural streams follow predictable meandering patterns, which dissipates energy and minimize scouring of the streambed and banks. Increased stream flows during wet weather impact the natural stream channel morphology, which affects the physical, chemical, and biological integrity of the stream (Natural Resources Conservation Service, 1998). The increased flows alter the stream channels by widening the cross-sectional area between stream banks and down-cutting of the stream bed. This, in turn, triggers a cycle of streambank erosion and habitat degradation (Schueler, 1994). Streambank erosion can lead to bank instability and increased sediment loading to the stream. The increased sediment load may cause channel instability and water quality degradation and have negative impacts on fish, benthic invertebrates, and other aquatic life in the stream. Channel instability leads to the loss of in-stream habitat structures, such as the loss of pool and riffle sequences. Klein (1979) noted that macroinvertebrate diversity dropped sharply in Maryland urban streams as a result of an increase in imperviousness in the catchment areas of streams. Sensitive aquatic insects such as stoneflies, mayflies, and caddisflies are replaced by species tolerant to pollution and hydrologic stress such as chironomids, tubificid worms, amphipods, and snails. In addition to the physical damage done to the streams, stormwater runoff may bring many types of pollutants which have the potential to significantly impact the biological community. Table 1-1 lists major pollutants in stormwater runoff and their effects on streams.

Table 1-1. Major pollutants (stressors) in stormwater runoff and their effects on streams

Stressor	Potential Sources	Environmental Effect
Sediment	Construction sites, winter road sand, in-stream erosion, unvegetated lots (bare soils)	Increases turbidity, disturbs aquatic and benthic habitat, embeds substrate
Nutrients (Nitrogen and Phosphorus)	Landscaping practices (application of fertilizers), animal wastes, leaks from sanitary sewers and septic systems, air deposition	Stimulates algae growth, depletes dissolved oxygen, accelerates eutrophication
Organic Matter	Leaks from sanitary sewers and septic systems, garbage, yard waste	Depletes dissolved oxygen, impacts life in the surface waters
Bacteria	Leaking sanitary systems, garbage, pet waste, homeless populations, animals	Affects recreational uses and aquatic life, imposes health risks
Oil and Grease	Vehicle traffic, maintenance and fueling activities, leaks and spills, runoff from areas with industrial land use	Creates slicks and disrupts water/air exchanges, stresses stream biota
Heavy Metals	Automobiles, paints, preservatives, motor oil	Toxic to some aquatic life, accumulates in aquatic animals
Temperature	Runoff from hot impervious surfaces, water stored in shallow unshaded ponds and impoundments, removal of natural vegetation (tree canopy), industrial discharges	Impacts water body’s ability to support certain fish and aquatic organisms, reduces capacity for dissolved oxygen

The use of effective best management practices (BMPs), such as stream restoration is one way to mitigate these impacts of urbanization and increased impervious cover. Stream restoration projects are popular in the United States as a result of public awareness concerning the connection between stream health and community health. Many projects aim to protect infrastructure or to improve aesthetics. Communities spend millions of dollars annually on watershed restoration and stream habitat improvement, yet little is known about the effects of stream restoration as post-restoration evaluation and monitoring are not that common. Even if they are monitored, they are not monitored for a long time (i.e., longer than 1-year). This may be due to lack of funding or other reasons. Laeser and Stanley (2004) have noted no detectable changes in nutrient concentrations in association with streambank improvement programs. It is important to conduct post-restoration evaluation to understand the effects of restoration, which will lead to better planning of restoration projects.

Bohn and Kershner (2002) pointed out that aquatic habitat restoration must be implemented at a watershed scale to be effective. Unless larger scale watershed issues are addressed in restoration planning, the current practice of direct structural modification of channels at the site level is unlikely to reverse aquatic population densities. Many habitats result from a change in environment; attempts to fix them at a particular point in space or time fail to recognize that stream channels are dynamic and that high quality habitats are a product of this dynamism (Beechie *et al*., 1996).

In the past decade, hundreds of millions of dollars have been invested in the implementation of BMPs in watersheds or streams as a means of reducing, eliminating, or otherwise controlling the input of human-based physical, chemical, or hydrological stressors to these systems. In Virginia alone, over $60 million have been spent on agricultural BMP implementation activities from 2000 to 2006 with the explicit goal of improving water quality (Virginia Department of Conservation and Recreation, 2007). Earlier research conducted by the U.S. EPA and the data in the International BMP Database (www.bmpdatabase.org) have demonstrated that BMPs can be effective at the pilot-scale and the field-scale (Strecker *et al*., 2002; Struck *et al*., 2006). However, less information is available to document the effectiveness of these BMPs at the subwatershed to watershed scale, which is precisely the scale at which water quality compliance and water quality improvements are typically judged. Because of the costs associated with the implementation of these BMPs, federal, state, and local agencies are asking:

- Are the implementation activities working?
- How long will it take for the BMPs to work?
- Are there more time-efficient, cost-effective methods for detecting these improvements?

Answers are needed to these questions to support the development of watershed implementation plans, to motivate stakeholders to implement BMPs, and to ensure the vitality of the cost-share programs that have supplemented the cost of implementing these BMPs.

Unfortunately, few studies have been able to provide rigorous evidence of improvements in water quality following implementation activities. This inability to detect statistically significant improvement in water quality conditions occurs for several reasons.

First, numerous individual samples are often needed every year to provide sufficient data, depending on parameters, with which to statistically determine trends in water quality parameters. The cost associated with the collection of these samples is significant and often limits monitoring after BMP implementation.

Second, environmental factors cause extensive variability (noise) in concentrations of monitored parameters and confound attempts to quantify improvements (signal) that are related to BMP activities. Flow is the single greatest of these confounding environmental factors because even small changes in flow typically are associated with measurable changes in nutrient, sediment and bacterial concentrations. Additional confounding variables include rainfall rate, rainfall amount, and seasonality.

Lastly, lag times between implementation of BMPs and corresponding improvement in water quality may be considerable, depending on the sensitivity of the parameter, scale of management compared to runoff area, and the current and future condition of the watershed (current level of degradation and future changes to the watershed). For example, when using a biological indicator such as fish populations, 10 years or more of monitoring is often required to detect a response to restoration because of the large inter-annual variability in abundance of juvenile and adult salmonids (Bisson *et al*., 1992; Reeves *et al*., 1997). Roni *et al.* (2002) asserted that biological response to various restoration techniques is the ultimate measure of restoration effectiveness, but drawing conclusions about the biological effectiveness of various techniques has been difficult and has hampered efforts to provide scientific guidance on restoration activities.

Objectives

The objective of this project was to investigate the effectiveness of BMPs, specifically, stream restoration techniques, to improve biological and in-stream water quality in an impaired stream in an urban watershed. This objective was achieved by continuous monitoring of water quality and by collecting physical, chemical, and biological data in the receiving stream before and after stream restoration.

This project tested the following three hypotheses at the 90% level of confidence:

Hypothesis #1: The quality of the water, as measured by physical, chemical, and biological parameters, in the stream before and after stream restoration will be different.

Hypothesis #2: The type and number of macroinvertebrate community in the stream before and after stream restoration will be different.

Hypothesis #3: The physical habitat parameters in the stream before and after stream restoration will be different.

Accotink Creek in Fairfax City, Virginia was selected as the project site mainly because the City of Fairfax was proceeding with restoration of 1,800 linear ft (550 m) of degraded stream channel in the North Fork of Accotink Creek from Lee Highway to Old Lee Highway. In-stream samples were collected and analyzed for physical, chemical, and biological (macroinvertebrates, bacterial indicators) parameters before and after restoration to document the changes in-stream quality as a result of the restoration.

Project Partners

This project was a joint effort between U.S. EPA ORD and U.S. EPA Region 3. Additional cooperators were the Center for Watershed Protection (CWP) under a cooperative agreement with U.S. EPA Region 3 and the USGS under an interagency agreement with U.S. EPA ORD.

Chapter 2 Project Description

Site Location and Background

The Accotink Creek watershed covers about 3,400 acres (5.3 square miles) of drainage area within the Fairfax City limits. There are about 22,000 people living in the city. The majority of the soils in the city is well-drained with moderately coarse-texture and moderate infiltration rates. Percentage of imperviousness is about 35% (DPWES, 2001). Elevation in the city watershed ranged from 425 ft (130 m) above mean sea level (MSL) at its highest point to 285 ft (87 m) above MSL at the point Accotink Creek flows out of the city. Recent land development and redevelopment projects have included provisions for stormwater management practices that effectively slow and distribute high stormwater flows over a period of time, thereby reducing erosion in the streams (The Louis Berger Group, 2005).

The Accotink Creek headwater watershed has uncontrolled urban runoff that has resulted in the deepening and widening of the creek's channel, sediment removal from the stream reach and deposition downstream, and streambank instability. The Creek and its tributaries within the city are important natural features that provide recreational and aesthetic values that enhance the quality of life in the city. The headwaters of Accotink Creek originate within the City of Fairfax and flow southeast through Fairfax County to its confluence with Potomac River at Gunston Cove, which flows into the Chesapeake Bay.

According to Virginia Water Quality Standards, "all state waters are designated for the following uses: recreational uses; the propagation and growth of a balanced indigenous population of aquatic life, including game fish, which might be reasonably expected to inhabit them; wildlife; and the production of edible and marketable natural sources (e.g., fish and shellfish)." Many of the fish and other aquatic life, which are important for the Creek's viability, began to disappear when the open areas were developed and paved (Fairfax, 2005). Overall stream health measured by the physical, biological, and habitat assessment is fair to poor in the majority of the city, erosion potential remains at a very high level, sedimentation is a problem, and down-cutting streams threaten city utilities and surrounding property.

High runoff volume from impervious surfaces is the primary cause of stream degradation in the Accotink Creek watershed. The amount of stormwater runoff generated under existing conditions is almost double the runoff that would be generated under 100% forested conditions (The Louis Berger Group, 2005). The Fairfax County Stream Protection Strategy Baseline Study conducted by Department of Public Works and Environmental Services (DPWES) concluded that the benthic macroinvertebrate community health in the Accotink Creek were poor; habitat conditions were very poor; and fish taxa richness is low (DPWES, 2001).

Point sources do not appear to be an important factor in water quality impairment in the Accotink Creek watershed. The Creek was listed as impaired on Virginia's 1998 303(d) Total Maximum Daily Load (TMDL) priority list due to violation of the State's water quality standard for fecal coliform (VADEQ, 1998). As part of the TMDL study, the U.S. Geological Survey (USGS) Virginia District conducted DNA fingerprinting, called ribotyping, on fecal coliform samples from Accotink Creek (downstream of the restoration reach). The dominant bacterial sources were found to be geese (24%), humans (20%), and dogs (13%). Other sources identified included ducks, cats, raccoons, sea gulls, cattle, and deer (USGS, 2003).

Impacts of stormwater runoff are common in highly urbanized areas. Changes in land use in the City of Fairfax, which has grown and developed over the years, affected the stream conditions in many parts of the city. The city is characterized by commercial and, high- and low-density residential development that accounts for greater than 60% of land use. Consequently, the city proactively developed a Watershed Management Plan when faced with major water quantity and quality problems (The Louis Berger Group, 2005). One cause of poor water quality and stream degradation, as reported by the plan, was elevated volumes of uncontrolled stormwater runoff due to directly connected impervious surfaces.

More than 75% of the overall stream health condition assessments (calculated using the physical, habitat, and biological conditions) performed for the management plan indicated a fair to poor result. Along with other BMPs, the management plan called for streambank restoration as an important facet to improve stream conditions. Fairfax chose to focus on areas which stood to gain the most benefit from the use of BMPs and have attempted to coordinate improvements with an overall watershed strategy by utilizing regional and holistic approaches where possible.

Restoration of the stream channel of Accotink Creek was necessary to reduce loss of property, restore public safety, protect infrastructure, stop the destruction of downstream habitat, and improve aquatic life in Accotink Creek. The city determined that stream restoration was the most cost effective way to minimize channel erosion (Personal Communication with Adrian Fremont, City Engineer, City of Fairfax, 2006). Since 1994, the city has been conducting systematic stream restoration in the Accotink Creek watershed. More than three miles of stream, just over half of the city's total stream miles, have been restored or stabilized to date. In the spring of 2002, the city completed stream restoration improvements on the North Fork of Accotink Creek from Stafford Drive to Lee Highway.

The subject of this monitoring project was a more recent stream restoration of a segment of 1,800 linear ft (550 m) of the North Fork of Accotink Creek from Lee Highway to Old Lee Highway in the City of Fairfax, Fairfax County, Virginia (Figure 2-1). The stream restoration

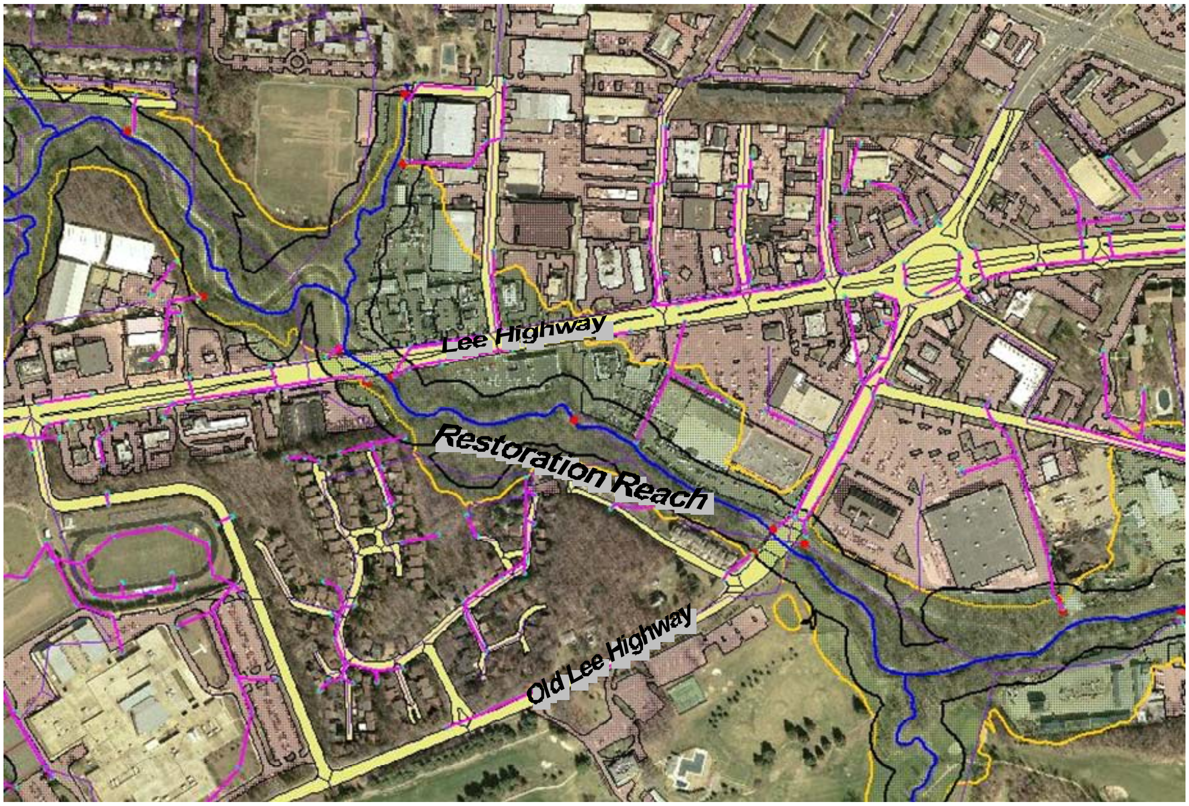

Figure 2-1. Accotink Creek areal map showing major highways and 100yr flood plain

included placing bioengineering structures (coir fiber logs, erosion control fabrics, and live willow stakes) to prevent erosion and establish deeper rooted vegetation to stabilize the bank. Rocks were individually placed to divert stream flow from the edge of the channel to the center of the stream. Rock veins were constructed to reduce slope and form step pools to slow water velocity. Dense planting and seeding of native vegetation along the stream was done to protect exposed soils from erosion and sedimentation during heavy rainfall and high flows completed the channel restoration (Figure 2-2). These actions were intended to restore the stream channel to a stable condition and reduce streambank erosion thereby reducing sediment loads in the stream. The construction started in March of 2006 and was completed in June of 2006.

Sampling and Monitoring

The U.S. EPA and USGS carried out continuous monitoring and discrete water quality monitoring and sampling beginning in December 2005 following standard sampling protocols. At the designated locations, electronic water quality and quantity monitoring equipment was installed to monitor pH, temperature, turbidity, conductivity, water depth, and water velocity continuously. In addition, discrete samples were collected during storm events, with the objective of attempting to obtain samples at least twice per season. Additionally, dry weather samples were collected. These samples were analyzed for physical and chemical [i.e., pH, dissolved oxygen, turbidity, conductivity, temperature, suspended solids (SS), suspended

Figure 2-2. Three photos of stream restoration

sediment concentrations (SSC), particle size distribution, and nutrients], and bacteriological (i.e., fecal coliform, enterococci, and *E. coli*) parameters. The results of both U.S. EPA and USGS monitoring and sampling and analysis are described in detail in Chapters 3 and 4, respectively.

Physical habitat monitoring and biological sampling (including macroinvertebrate sampling) were conducted three times before restoration to establish the pre-existing condition. Biological sampling was conducted five times following restoration. U.S. EPA Region 3's Wheeling Laboratory in West Virginia performed the macroinvertebrate identification, classification, and enumeration.

Chapter 3 U.S. EPA Sampling and Monitoring

Sampling and Monitoring

Continuous Water Quality Monitoring

Standard water quality parameters (pH, conductivity, temperature, turbidity) were measured both upstream and downstream of the restoration from December 2005 to March 2008. This water quality monitoring enabled the quantification of physical and chemical changes in the receiving water. Four continuous water quality monitoring stations were deployed (Figure 3-1) – three by U.S. EPA (WQ1 to WQ3) and one by USGS (WQ4). Water quality monitoring was conducted continuously except during the restoration period. Area-velocity flow meters combined with other monitoring probes (American Sigma, Loveland, CO) installed at two selected locations recorded average flow depth, velocity, water temperature, conductivity, and pH at 15-min intervals (Figure 3-1; Sampling Stations WQ2 and WQ3). Depth was measured using differential pressure (bubbler) or pressure transducers. Twin 1 MHz piezoelectric crystals were used to measure Doppler-based velocity. Internal electronics combined the measured values using the stream cross-section and computed an associated flow rate. In addition, a YSI (Yellow Springs Instruments, Yellow Springs, OH) probe placed at the upstream border of the restoration reach was used to measure water temperature, specific conductivity, turbidity, and pH also at 15-min intervals (Figure 3-1; Monitoring Station WQ1). All field instrumentations were battery powered. The instruments were connected to data logging and telemetry equipment that transferred all data to the U.S. EPA office in Edison, NJ. Following the initial deployment, approximately monthly maintenance visits were performed on the continuous water quality monitoring equipment to clean and check the calibration of the sensors. In-field recalibration was performed during these monthly maintenance visits, as necessary. The sampling and monitoring locations are shown in Figure 3-1.

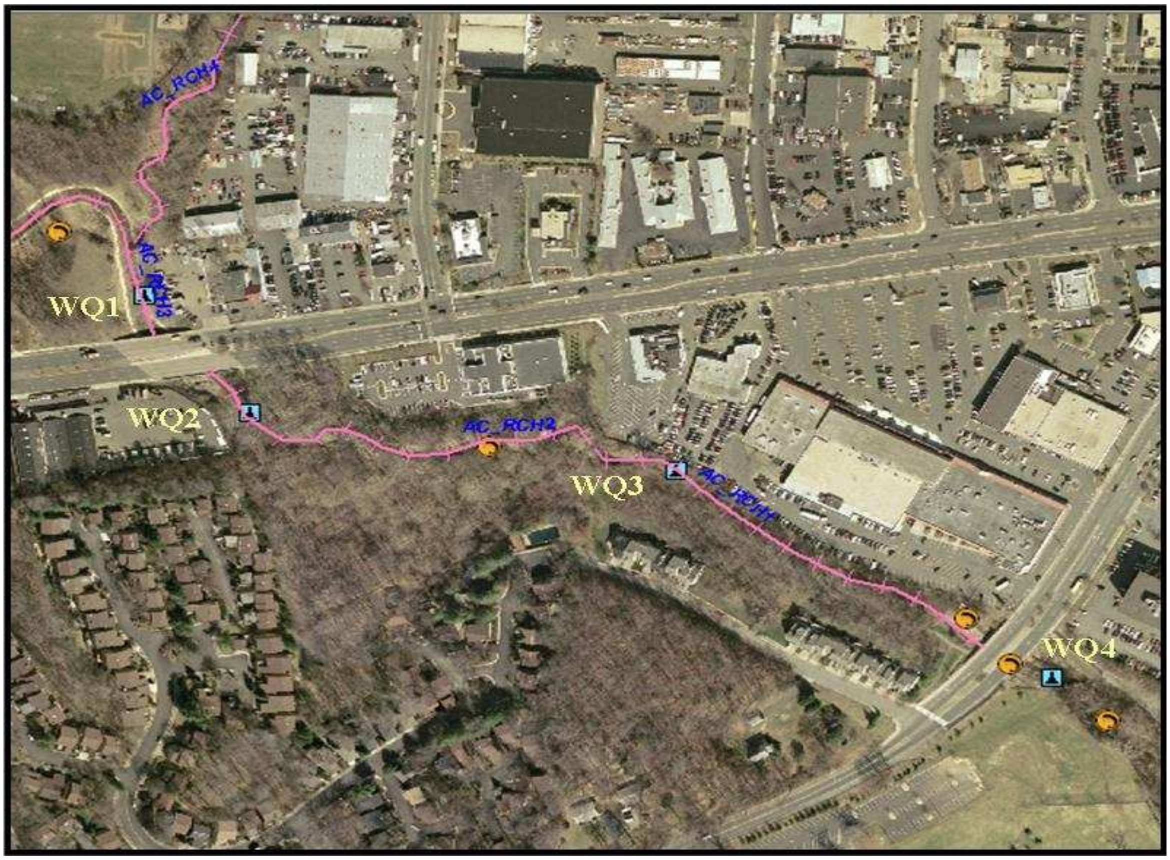

Figure 3-1. Water quality sampling and continuous monitoring stations (indicated by blue marker)

Discrete Water Quality Sampling

Both dry and storm event discrete samples were collected following standard U.S. EPA protocols from the middle of the water column in approximately the center of the stream flow.
Dry weather conditions were defined as time that was proceeded by at least 72 hours of no or only trace amounts of precipitation as per NPDES protocol (U.S. EPA, 1992).

Discrete samples were collected in duplicate, at WQ2 and WQ4, to represent water quality above and below the restored area, respectively. Samples were collected in pre-cleaned, sterile two-liter bottles by lowering the bottles from the bridge during significant wet weather events or by hand grab during dry weather or lesser wet weather events. Samples were either shipped by courier or brought back to the laboratory for analysis at the UWRF in Edison, New Jersey.

The samples were analyzed for SS, chemical oxygen demand (COD), nutrients (total phosphate (TPO_4^{3-}), orthophosphate (OPO_4^{3-}), total Kjeldahl nitrogen (TKN), ammonia (NH_3), nitrate (NO_3^-), and nitrite (NO_2^-)) and bacteriological indicator organisms (fecal coliform, enterococci, and *E. coli*). The samples were analyzed following Standard Methods (APHA *et al.*, 1998). All the analysis was conducted in triplicate.

For indicator organisms, samples were sequentially diluted with sterile buffered water using three dilution factors based on previous analyses of similar samples. Dilution factors were estimated to obtain the method recommended colony count on at least one dilution set. Sequential dilutions usually used at least 10 mL aliquots and always used at least 5 mL. All results were volume-normalized to give concentrations in colony forming units (CFU) per 100 mL. Each analytical batch included laboratory blanks and positive controls. Blanks were run before and after each analytical set. Verification was performed on 10 colonies for each organism following Standard Methods (APHA *et al.*, 1998). After incubation, the plates were manually enumerated.

Macroinvertebrate Sampling

Biological integrity above, within, and below the restored area before and after restoration were evaluated using benthic macroinvertebrate data. Water quality monitoring programs use macroinvertebrates as indicators of water quality. For example, Collins *et al.* (2008) reported that invertebrate community index (ICI) developed by Bennett *et al.* (2004), which comprised of 10 metrics based on the structure, function, and condition of the taxa collected, is capable of predicting the biological integrity of the urban streams in Choctawhatchee and Pea River watersheds in Alabama. Benthic macroinvertebrates are a major component of healthy stream systems and are an important link in any aquatic food web, forming the core diet of many fish. Macroinvertebrates play an important role in the nutrient processing and organic energy cycling in lotic environments. Most of the organic matter that enters a stream is ingested and excreted by macroinvertebrates many times along the length of a stream. Benthic macroinvertebrates, as the name implies, are insects generally visible to the naked eye (though identification typically requires a dissecting microscope (10 x magnification)) that often inhabit areas of streams, especially under rocks and near the sediment water interface, for at least part of their life cycle. They can include larval forms of many common insects such as mayflies, caddisflies, damselflies, and craneflies; or crustaceans like crayfish and scuds. They make good indicators of watershed integrity because they:

- live in the water for all or most of their life,
- inhabit areas suitable for their survival,
- are relatively easy to collect,
- differ in their tolerance to amount and types of pollution,
- are relatively easy to identify in a laboratory,
- have limited mobility (in the larval forms),
- are among the first organisms to recruit disturbed areas, and
- are indicators of environmental condition.

Individual macroinvertebrate kick-net samples covering 2 m^2 of each riffle were collected using modifications of the established protocols of the U.S. EPA's Rapid Bioassessment protocol for Use in Wadeable Streams and Rivers (Barbour *et al*., 1999) which the Virginia Department of Environmental Quality (VDEQ) employs for bioassessments. An area of 0.5 m x 0.5 m (0.25 meter square) upstream of the net was sampled using the 0.5 m-wide kick-net. Using the toe or heel of the boot, the upper layer of cobble or gravel was dislodged and the underlying bed was scraped. Larger substrate particles were picked up and rubbed by hand to remove attached organisms prior to kicking and allowing the detached macroinvertebrates to float downstream into the net. A total of 8 kick-net collections were composited into one sample for a total of 2 m^2 within each riffle during dry weather flow conditions. All organisms caught in the net were transferred to a two liter sampling container. Samples were preserved with 70% ethanol before sending to EPA Region 3's Wheeling Laboratory for analysis. Five locations, selected for macroinvertebrate sampling, are shown in Figure 3-2. Site C (just above the bridge) had to be moved about 50 ft (15.2 m) below the bridge after restoration due to the relocation of the riffle following the restoration. The sixth location, not shown, was in the previously restored (2003) upstream riparian park. Macroinvertebrate collections were initiated at the downstream location and proceeded upstream. Samples were collected in riffle and run habitats. Macroinvertebrates retained on a No. 35 mesh dip net (500 µm) were randomly subsampled to 110±20 organisms and identified using macroinvertebrate identification keys of Merritt and Cummins (1996), Pennak (1989), Peckarsky *et al.* (1990), and Thorp and Covich (1991). After identification and enumeration of macroinvertebrates, the Virginia Stream Condition Index (VASCI), total taxa, total taxa family, EPT (Emphemeroptera, Plecoptera, and Trichoptera) taxa, EPT family, Hilsenhoff biotic index (HBI), percent of scrapers, and percent of most dominant taxon were calculated.

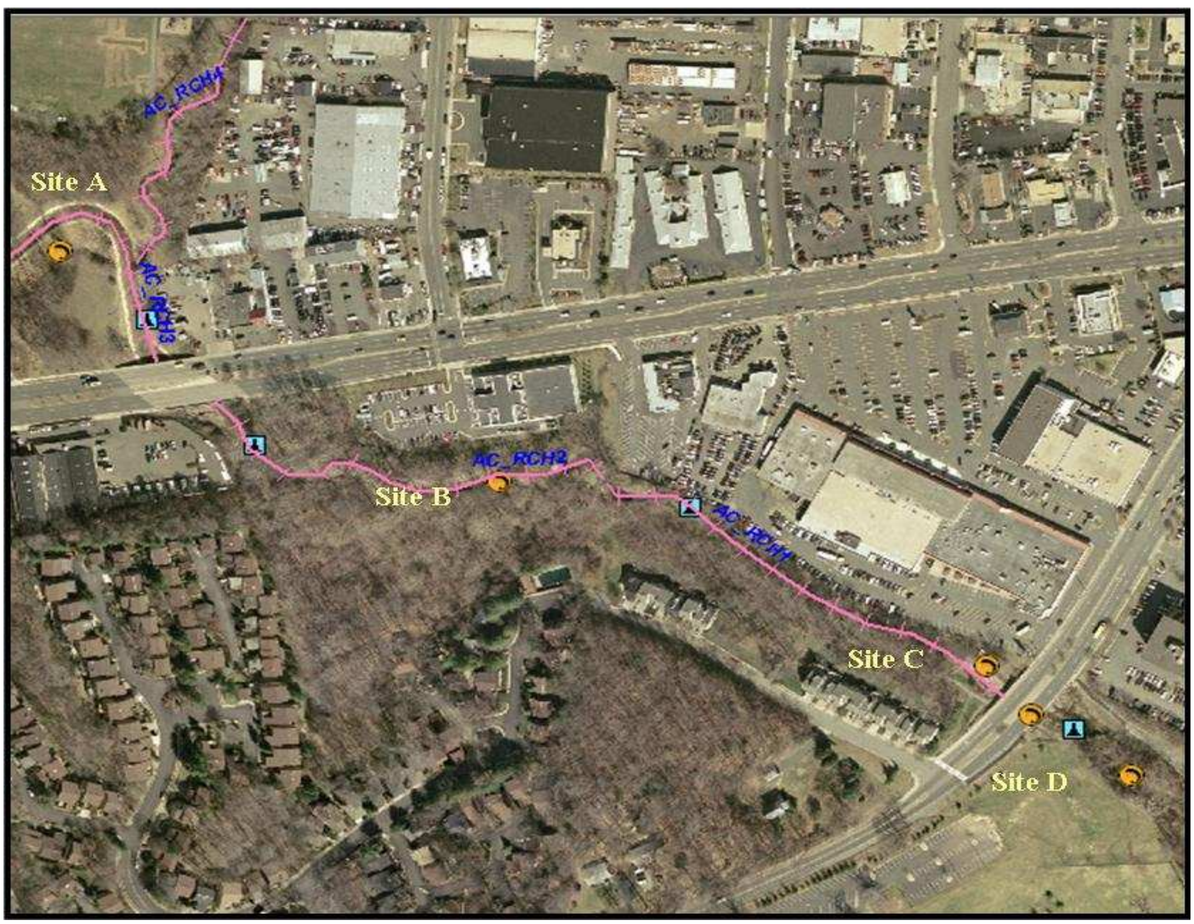

Figure 3-2. U.S. EPA's macroinvertebrate sampling locations (indicated by orange marker)

Although HBI (Hilsenhoff, 1987) was originally developed to assess low dissolved oxygen caused by organic loading, a purpose for which it works best, the HBI is also considered to be sensitive to the effects of impoundment, thermal pollution, and some types of chemical pollution (Hilsenhoff, 1998; Hooper, 1993). This index has also been used to detect nutrient enrichment, high sediment loads, and thermal impacts. In addition, since originally developed, this index has been modified to accommodate comparisons of samples collected throughout the year. The HBI ranges from 0-10 with 10 being the worst and 0 being the best; there is no defined impairment threshold value. Samples with HBI values of 0-2 are considered clean, 2-4 are slightly enriched, 4-7 are enriched, and 7-10 are polluted (Hilsenhoff, 1988).

The VASCI is a multi-metric biological index developed using recent advances in bioassessment methods and is calibrated from Virginia data for use in the assessment of Virginia's nontidal, upland streams. This index was used to compare with regional and local reference datasets. The VASCI ranges from 0-100 (100 is the best possible), with 60 being the impairment threshold in VA. VASCI and HBI are inversely related with respect to water quality.

EPT family richness is also commonly used to assess water and habitat quality and is defined as <2=poor water quality; 2-5=fair; 6-10=good; and >10=excellent quality.

Results

Continuous Water Quality Monitoring

Daily averages of the continuous monitoring 15-minute data collected for pH, conductivity, turbidity, temperature, and depth recorded by YSI are shown in Figures 3-3 through 3-5. The gap in the data from June 2006 to August 2006 was due to the equipment being damaged after a large storm event, which came right after the restoration was completed. Three inches of rainfall fell in 2 hours on June 9th. During the period of June 23-26, 2006, there was major flooding in the area. On June 25, 2006, in Fairfax County, VA, two stream flow gages recorded peaks near the 50-year recurrence interval and one stream flow gage recorded a peak near the 100-year recurrence interval.

As expected, pH stayed close to neutral ranging between 6.5 and 8. Temperature changed seasonally, but also had an event-related effect, where the daily average temperature decreased with increasing depth due to increased flow during wet weather events and likely due to the difference in temperature between rain water and stream water. Turbidity and conductivity appear to be event-related with spikes occurring during wet weather events. The conductivity also was seasonally dependent as it peaked during winter, likely due to runoff from salt during snow melt. Salting is a regular snow and ice management practice in the City of Fairfax.

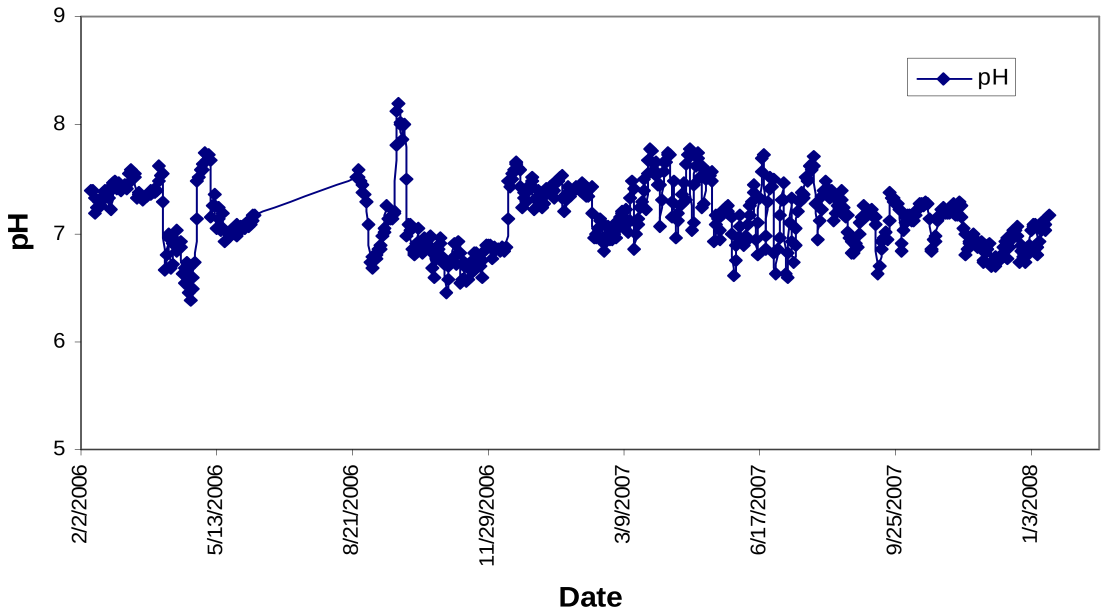

Figure 3-3. Continuous water quality monitoring at Site WQ1 for pH

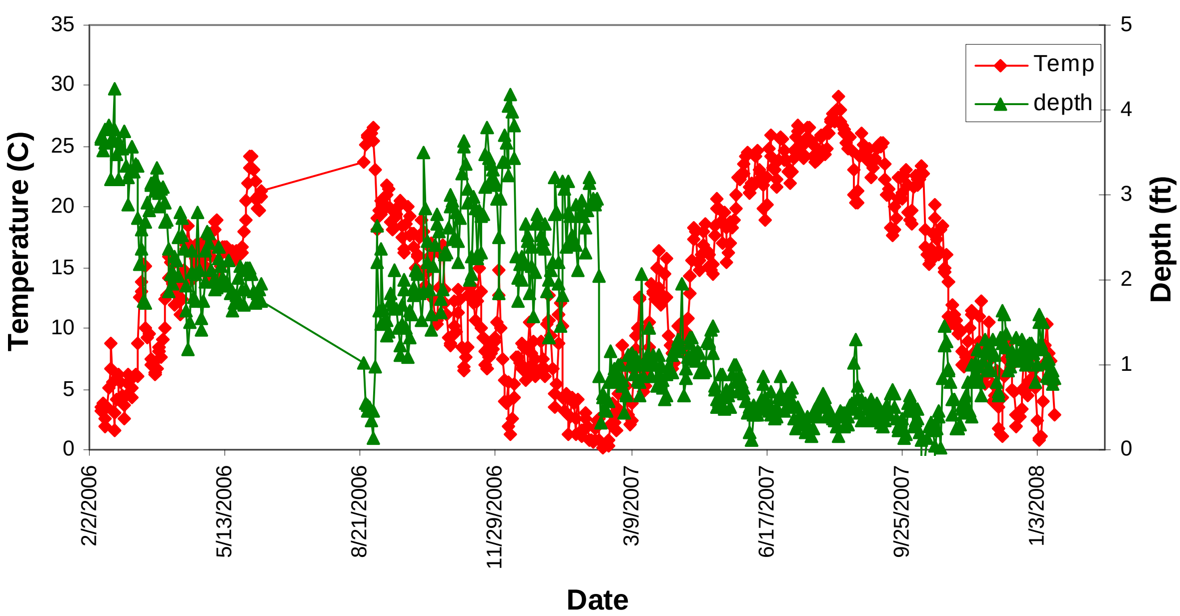

Figure 3-4. Continuous water quality monitoring at Site WQ1 for temperature and depth

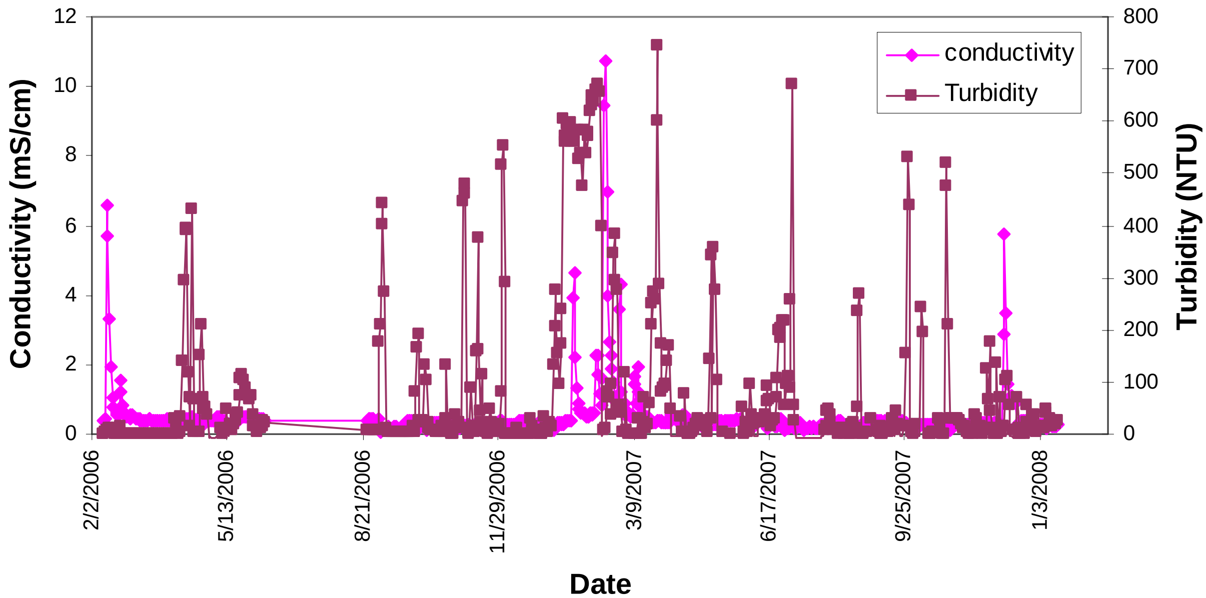

Figure 3-5. Continuous water quality monitoring at Site WQ1 for conductivity and turbidity

Continuous monitoring data for pH, conductivity, temperature, level, and velocity recorded by the area-velocity flow meters for WQ2 and WQ3 are shown in Figures 3-6 through 3-11. Again, it can be seen that the conductivity was higher in February due to events involving street salting. Temperature of the creek water changed with the season and the wet weather flow events. The highest temperatures were observed in July. pH ranged between 5 and 10. Flow data are not very reliable as can be seen in the figures. The flow rates were calculated by the American Sigma unit based on the flow level (a pressure transducer or bubbler), a velocity measuring device (sonar) and a specified area. Negative or vey low velocity values were recorded by the velocity probe. Open channel conditions in the field are not ideal conditions for this type of velocity measurement. Increasing flow can lead to turbulent conditions, and eddies can trigger the velocity sensor to record negative values, resulting in negative flow calculations. The level sensor was calibrated in the field, and the velocity sensor was factory calibrated. The in-situ flow values presented are not considered calibrated flow values in the sense that standard stream gauges which typically use weirs or flumes. They are presented for demonstrative purposes only to show changes in the flow regime in the stream being monitored.

At monitoring station WQ3, the base flow level changed from approximately 85 cm to 28 cm as the location changed slightly after restoration placing the probe in shallower water.

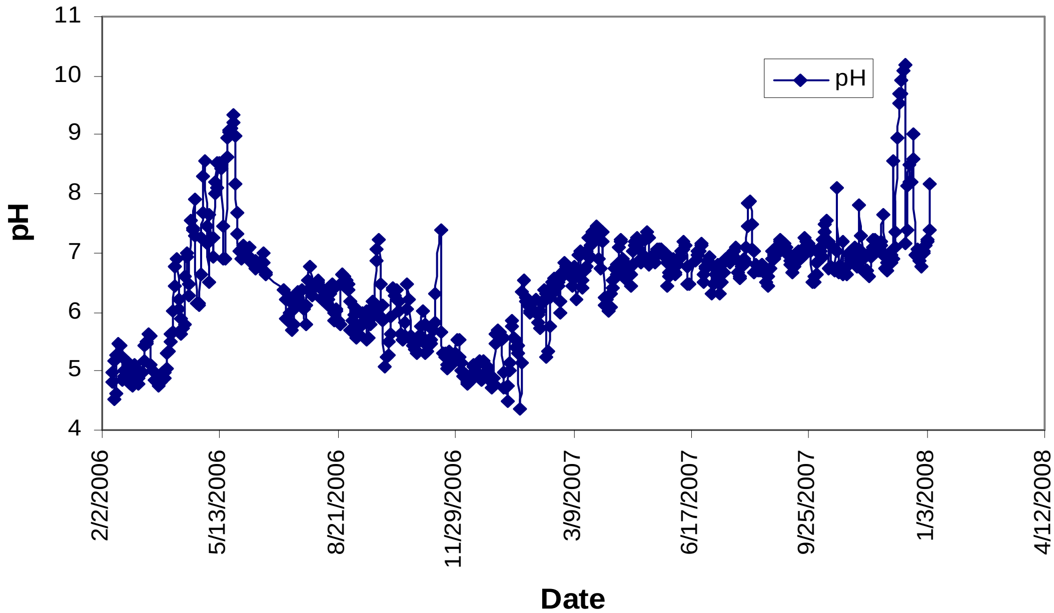

Figure 3-6. Continuous water quality monitoring at Site WQ2 for pH

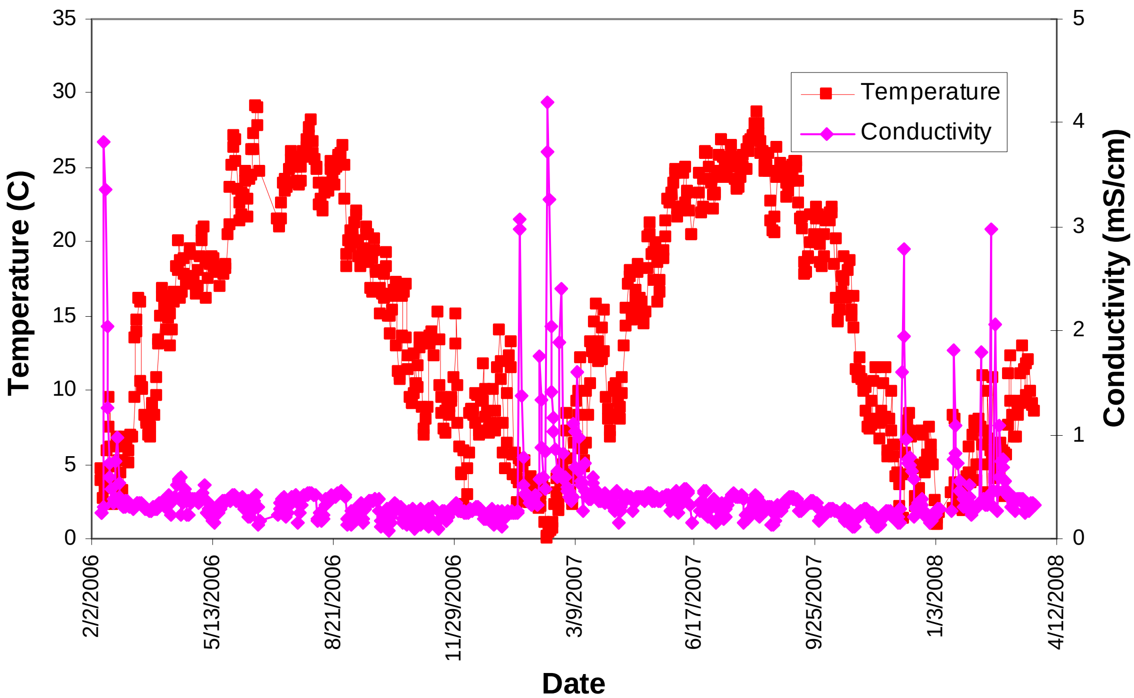

Figure 3-7. Continuous water quality monitoring at Site WQ2 for temperature and conductivity

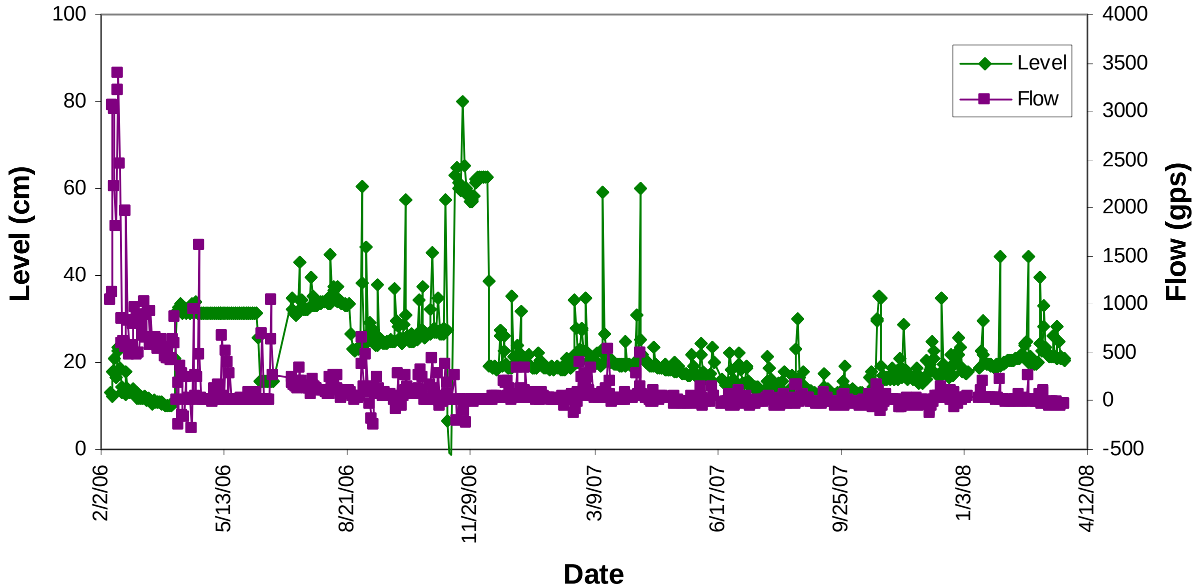

Figure 3-8. Continuous water quality monitoring at Site WQ2 for level and estimated flow

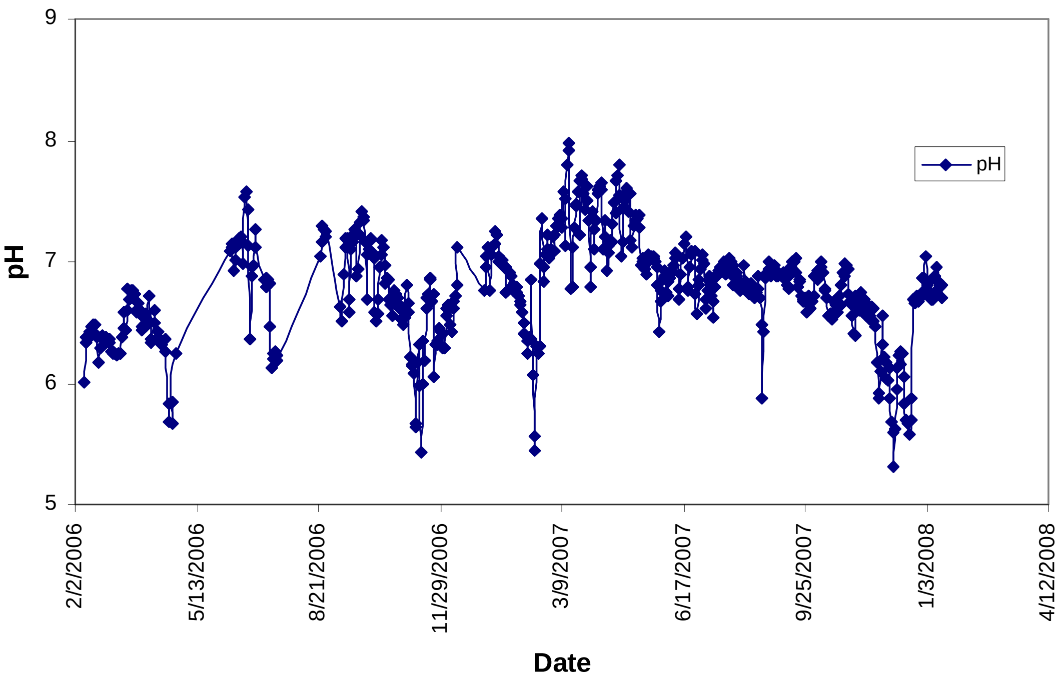

Figure 3-9. Continuous water quality monitoring at Site WQ3 for pH

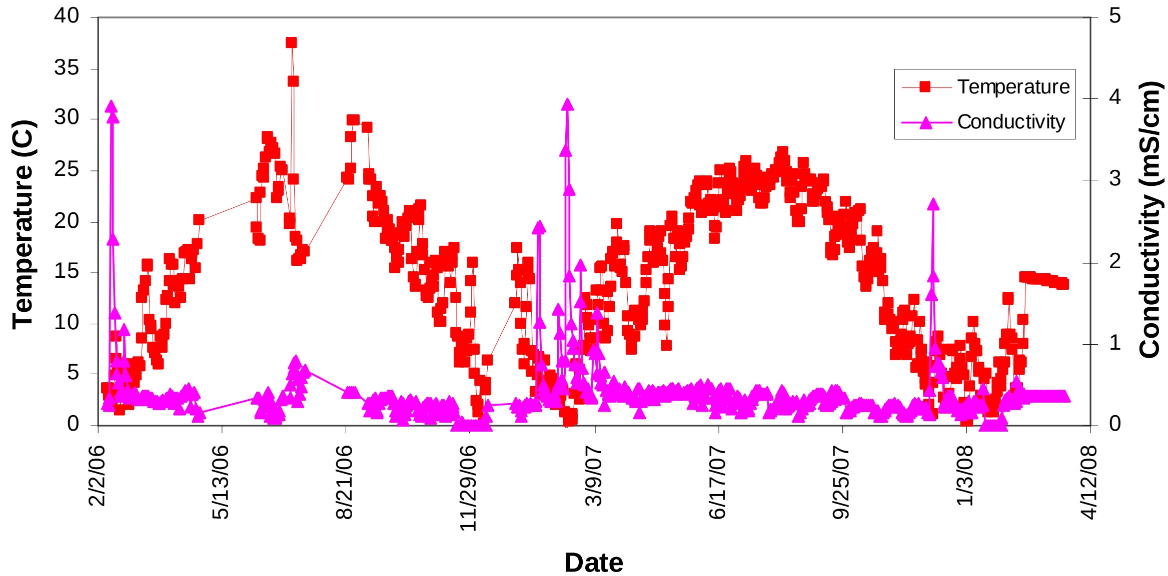

Figure 3-10. Continuous water quality monitoring at Site WQ3 for temperature and conductivity

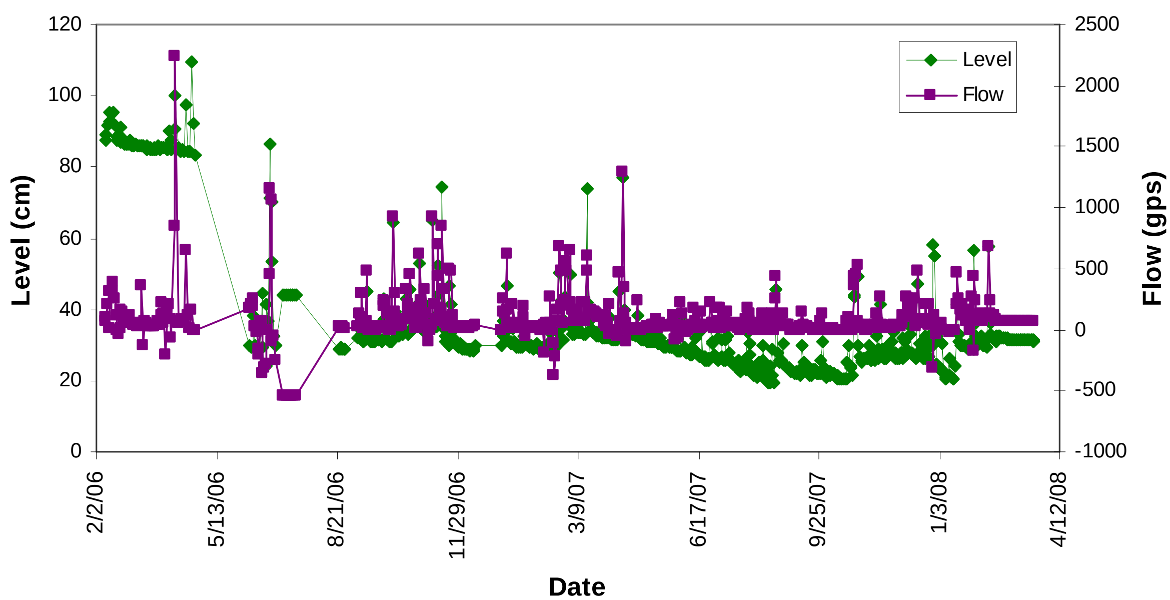

Figure 3-11. Continuous water quality monitoring at Site WQ3 for level and estimated flow

Relationship between the level and the rainfall recorded by the nearby station is plotted in Figure 3-12. It can be seen that the level increased with rainfall and has a direct relationship as expected. For example, on June 25, 2006, the rainfall was about 3.07 in. and the level jumped from 36.46 cm on June 24, 2006 to 86.35 cm on June 25, 2006.

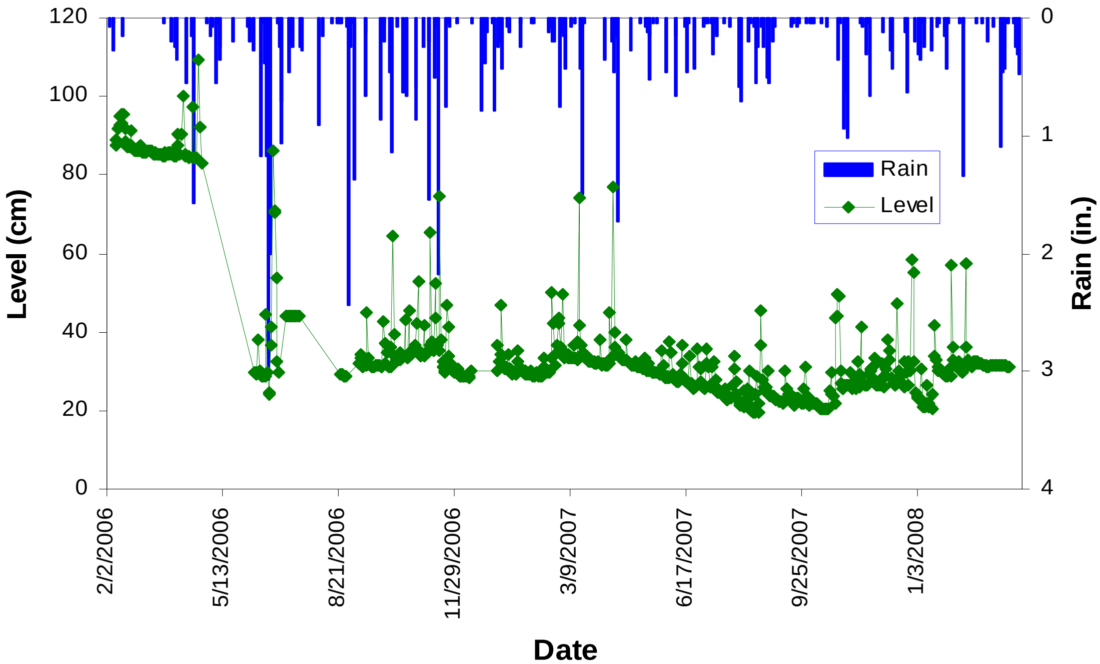

Figure 3-12. Relationship between level and rain at Site WQ3

Discrete Water Quality Sampling

Results of the discrete samples collected before and after restoration in both upstream (Lee Highway) and downstream (Old Lee Highway) locations and analyzed for physical and chemical constituents are shown in Table 3-1. Seven wet weather (two before restoration and five after restoration) and seven dry weather (two before restoration and five after restoration) sampling events were conducted with the full suite of analytes. Data in Table 3-1 indicate that wet weather concentrations of TPO_4^{3-}, NH_3, TKN, SS, and COD were higher than the dry weather concentrations typically. SS concentrations ranged between 0.20 – 20 mg/L and 89 – 291 mg/L respectively for dry and wet weather samples. COD concentrations ranged between 0.4 – 15 mg/L and 11 – 73 mg/L for dry and wet weather samples, respectively.

Concentrations of wet weather SS increased significantly after restoration. This may be because restoration work disturbed the stream channel and liberated sediments. Also, it takes time to stabilize the stream banks as plants require time to grow before being effective. Concentrations of SS ranged between 3 – 13 mg/L and 97 – 291 mg/L for before and after restoration, respectively at the downstream location. Concentrations of COD did not change and ranged between 12 – 67 mg/L. TPO_4^{3-}, NH_3, and TKN concentrations increased slightly after restoration. Concentrations ranged between 0.07 – 0.35 mg/L, 0.5 – 1.3 mg/L, and <0.01 – 0.29 mg/L for TPO_4^{3-}, TKN, and NH_3, respectively after restoration. However, these changes are not

Table 3-1. Results of water quality analysis (physical and chemical constituents)

	Date	Flow Condition	Concentrations in mg/L									
			Upstream (Lee Highway)					Downstream (Old Lee Highway)				
			SS	COD	TPO_4^{3-}	TKN	NH_3	SS	COD	TPO_4^{3-}	TKN	NH_3
Pre –Restoration	3/1/06	Dry	0.67	0.37 (0.44)	0.03 (<0.01)	0.07 (<0.01)	0.03 (<0.01)	2.00	1.88 (0.34)	0.02 (<0.01)	0.09 (0.01)	0.03 (<0.01)
	4/5/06	Wet	6.67	14.92 (0.39)	0.02 (<0.01)	0.40 (0.02)	0.08 (<0.01)	3.33	19.44 (2.31)	0.03 (<0.01)	0.39 (0.02)	0.11 (<0.01)
	5/2/06	Dry	1.40	7.61 (0.34)	0.04 (0.06)	0.20 (0.02)	0.01 (<0.01)	25.07 (1.04)	10.33 (1.11)	0.04 (<0.01)	0.54 (0.05)	0.10 (<0.01)
	5/9/06	Wet	26.67	61.66 (0.88)	0.35 (0.04)	0.58 (0.04)	0.19 (<0.01)	13.25 (0.35)	68.01 (2.04)	0.13 (<0.01)	0.44 (0.02)	0.07 (0.01)
Post –Restoration	6/20/06	Wet	4.40 (0.28)	28.86 (1.21)	0.06 (<0.01)	0.61 (0.01)	0.06 (<0.01)	6.30	22.25 (0.88)	0.07 (0.01)	0.65 (0.01)	0.06 (<0.01)
	9/21/06	Dry	0.40	15.24 (0.92)	0.06 (<0.01)	0.32 (0.03)	0.08 (<0.01)	0.22	28.45 (0.35)	<0.01 (<0.01)	0.37 (0.01)	0.03 (0.01)
	10/13/06	Wet	89.10 (1.84)	11.08 (0.67)	0.28 (<0.01)	0.49 (0.02)	<0.01 (<0.01)	96.80	12.48 (0.85)	0.32 (0.01)	0.50 (0.03)	0.01 (<0.01)
	11/16/06	Wet	252.10 (10.04)	72.52 (0.94)	0.24 (<0.01)	0.83 (0.04)	<0.01 (<0.01)	290.60	67.08 (2.31)	0.22 (<0.01)	0.95 (0.05)	<0.01 (<0.01)
	12/14/06	Dry	0.20	7.69 (1.27)	0.04 (<0.01)	0.18 (0.01)	<0.01 (<0.01)	1.20	6.03 (0.57)	0.04 (0.01)	0.21 (0.02)	0.01 (0.02)
	4/4/07	Dry	30.32	30.11 (1.21)	0.03 (0.02)	1.35 (0.02)	0.73 (<0.01)	19.60 (2.26)	20.35 (2.42)	0.04 (0.02)	1.28 (0.01)	0.76 (0.02)
	4/15/07	Wet	127.50	21.96 (1.60)	0.13 (0.01)	0.99 (0.07)	0.29 (<0.01)	120.20 (0.85)	27.03 (1.40)	0.12 (0.01)	0.63 (0.02)	0.29 (0.01)
	7/11/07	Wet	171.30 (0.99)	23.27 (2.38)	0.29 (0.06)	1.35 (0.05)	0.14 (<0.01)	204.40	29.24 (1.02)	0.35 (0.02)	1.30 (0.07)	0.14 (0.01)
	9/18/07	Dry	2.40 (1.41)	3.36 (1.08)	0.04 (<0.01)	1.14 (0.06)	ND	ND	3.81 (1.21)	0.03 (<0.01)	0.51 (0.07)	ND
	1/16/08	Dry	0.30 (0.14)	1.05 (1.14)	0.03 (<0.01)	0.64 (0.02)	0.03 (<0.01)	ND	1.81 (0.56)	0.02 (0.02)	0.49 (0.04)	0.04 (<0.01)

Note: Restoration was completed on June 6, 2006
Brackets indicate standard deviation

great enough to associate with restoration activities. The One-way ANOVA statistical analysis indicates that there is no statistically significant difference between before and after restoration and as well as upstream and downstream of the restoration except for wet weather SS. These concentrations are well below Virginia Water Quality Standards (State Water Control Board, 2007). Concentrations of SS, COD, TPO_4^{3-}, NH_3, and TKN in wet weather samples before and after restoration in both upstream and downstream locations are shown in Figures 3-13 and 3-14.

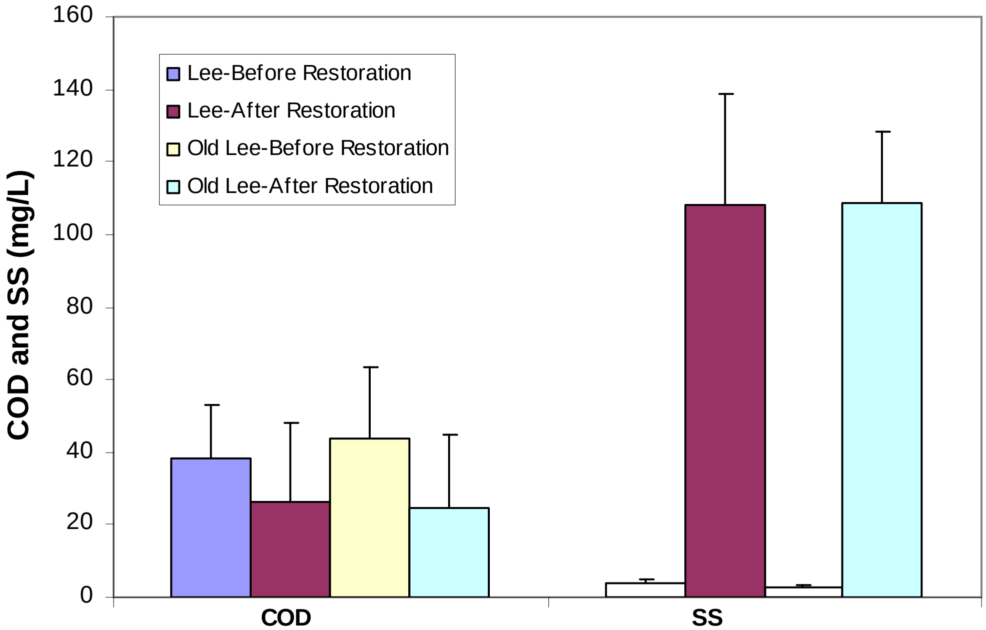

Figure 3-13. Average of wet weather concentrations of COD and SS before and after restoration

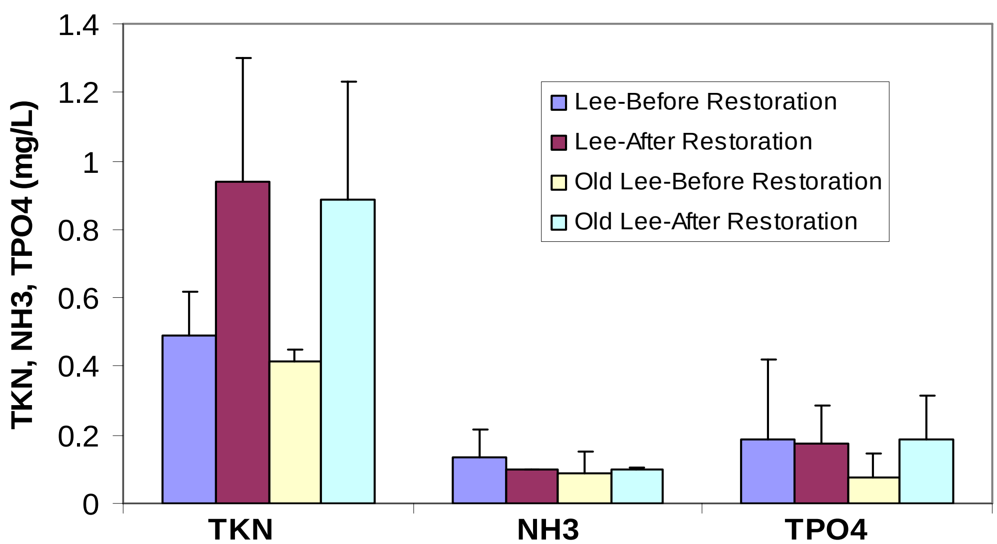

Figure 3-14. Average of wet weather concentrations of TKN, NH_3, and TPO_4^{3-} before and after restoration

Results of the discrete samples collected before and after restoration in both upstream (Lee Highway) and downstream (Old Lee Highway) locations and analyzed for bacteriological constituents are shown in Table 3-2. Data in Table 3-2 indicate that wet weather concentrations of fecal coliform, enterococci, and *E. coli* are much larger than the dry weather conditions as expected. Except for the November 6, 2006 wet weather sampling event, both upstream and downstream samples had concentrations in the same order of magnitude. Concentrations of all three indicator organisms in the November 6, 2006 samples were much higher in the downstream samples compared to upstream samples. The November 2006 sampling event may be anomalous. Concentrations of organisms vary with seasons and summer concentrations were significantly higher compared to other seasons as expected. The One-way ANOVA statistical analysis indicates that there is no statistically significant difference between before and after restoration as well as upstream and downstream of the restoration. Concentrations of fecal coliform, enterococci, and *E. coli* in wet weather samples before and after restoration in both upstream and downstream locations are shown in Figure 3-15.

Table 3-2. Results of water quality analysis (indicator organisms)

	Date	**Flow Condition**	**Concentrations in CFU/100 mL**					
			Upstream (Lee Highway)			**Downstream (Old Lee Highway)**		
			FC	**EN**	**EC**	**FC**	**EN**	**EC**
Pre-Restoration	3/1/06	Dry	31±9	7±3	23±7	74±46	20±10	31±12
	4/5/06	Wet	1867±719	119±39	365±55	1865±212	214±94	520±204
	5/2/06	Dry	160±36	66±26	101±30	224±85	338±84	179±42
	5/9/06	Wet	77000±6557	4900±608	7733±252	74333±6028	7100±361	3533±551
Post –Restoration	6/20/06	Wet	33667±6807	1163±162	8700±1082	26667±5033	1665±398	11167±2021
	9/21/06	Dry	643±133	70±13	436±76	285±157	78±1	302±12
	10/13/06	Wet	3887±271	3933±457	11267±1106	7033±252	6333±551	13667±666
	11/16/06	Wet	777±25	3453±334	30±26	143500±12021	6600±600	99000±8485
	4/4/07	Wet	5117±776	6183±2646	3900±1905	4567±208	2883±1089	2600±385
	4/15/07	Wet	5033±513	ND	2300±361	6167±351	ND	2700±458
	7/11/07	Wet	67500±4950	148±53	18000±4000	52333±10693	163±90	9267±513
	9/18/07	Dry	1000±586	15±5	104±23	233±48	19±8	93±11
	1/16/08	Dry	72±71	ND	200±141	37±28	ND	250±71

These physical, chemical, and bacteriological data suggest that local restoration in and around streams may not be sufficient enough to see significant measurable effects on the water quality of the stream.

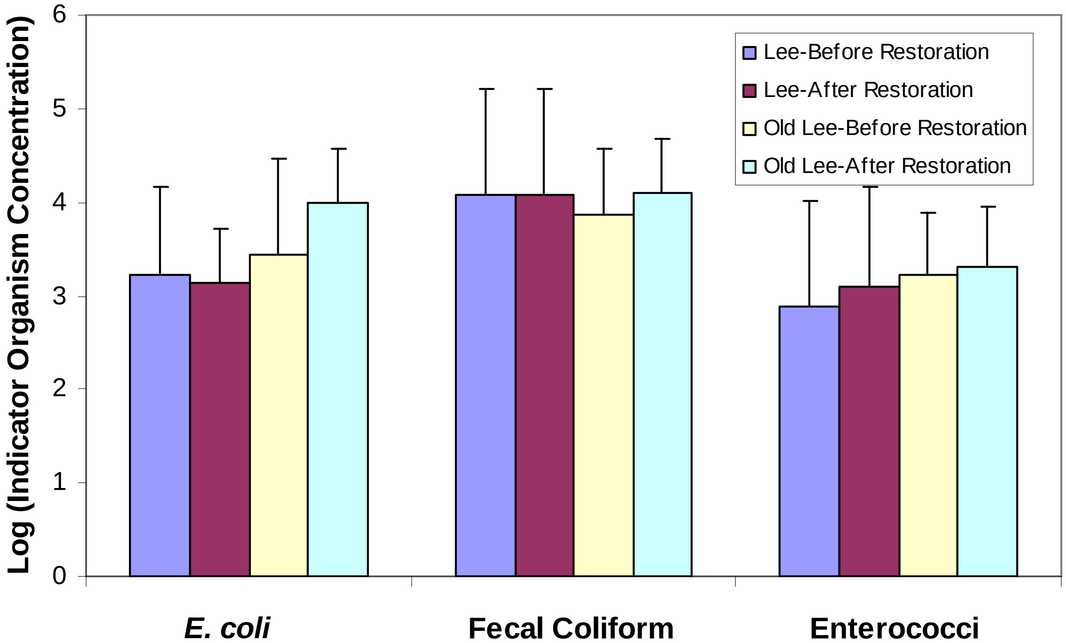

Figure 3-15. Summary of indicator organism concentrations before and after restoration

Macroinvertebrate Sampling

The results for VASCI and HBI indices, number of EPT taxa families, and number of total taxa families for all sampling events are summarized in Table 3-3. Total number of taxa families between sampling locations ranged between 3 and 10 and typically had more than 5 families represented. EPT taxa families ranged between 0 and 3 between sampling locations and typically are 1 and 2 indicating poor water and habitat quality. All of the sites, including the control sites, received VASCI scores less than 60, the impairment threshold in Virginia, indicating impaired macroinvertebrate conditions. The scores of the HBI index for all the sites are within the "enriched" category (4-7) as defined by Hilsenhoff (1988) which indicates that most species identified are moderately tolerant to polluted water with high organic content or excessive nutrient.

Seasonal variation in-stream biota makes it difficult to compare data over time unless comparisons are made only with data from a single season. Three and five sampling events were conducted before and after restoration, respectively. Longer duration of pre-restoration sampling was not possible as the city had the project design, funding, and implementation plan in place. Comparison of data within a season was only possible for the fall season. The fall season data were collected in 2005 (2 events) before restoration and 2006 (2 events) and 2007 (2 events), which were collected after the restoration. Paired *t*-test, which examines the changes that occur before and after a treatment to determine whether or not the treatment had any effect, indicated the changes that occurred are not great enough to exclude the possibility that the difference are due to chance for both indices in all locations ($P>0.05$).

Table 3-3. Results of macroinvertebrate data

Pre- and Post-Restoration	Date	Species	Site A (~120 m North of Lee Hwy) Upstream	Site B (~100 m South of Lee Hwy) Restoration Area	Site C (~10 m North of Old Lee Hwy) Restoration Area	Site D (~200 m South of Old Lee Hwy) Downstream	Site RUP (~50 m West of Bridge at River Road) Upstream
Pre- Restoration	11/03-04/2005	VASCI	21.2	29.1	24.3	25.9	
		HBI	6.86	5.87	5.94	6.06	
		# of EPT Taxa Families	1	2	1	1	
		# of Total Taxa Families	5	6	5	5	
	12/07-08/2005	VASCI	21.5	25.1	30.7	25.6	28.5
		HBI	5.91	6.17	6.03	6.13	5.95
		# of EPT Taxa Families	1	1	1	1	1
		# of Total Taxa Families	5	5	9	6	6
	3/13-14/2006	VASCI	25.2	23.9	26.3	27.2	24.2
		HBI	6.03	6.82	6.03	6.59	6.13
		# of EPT Taxa Families	2	1	1	1	1
		# of Total Taxa Families	5	5	6	6	8
Post- Restoration	9/21/2006	VASCI	36.8	28.2	33.5	32.2	38.6
		HBI	6.02	5.9	5.75	5.71	5.28
		# of EPT Taxa Families	3	2	2	2	3
		# of Total Taxa Families	5	4	7	6	4
	11/15/2006	VASCI	29.6	26.6	28.4	24.8	33.3
		HBI	5.35	6.09	6.03	5.98	5.79
		# of EPT Taxa Families	2	1	2	1	2
		# of Total Taxa Families	6	5	7	5	10
	5/9/2007	VASCI	27.9	22.8	12.3	22.2	26
		HBI	6.09	6.59	6.02	6.79	6.08
		# of EPT Taxa Families	3	1	0	2	2
		# of Total Taxa Families	7	5	3	5	6
	9/18-19/07	VASCI	32	30.5	22.5	31.7	32.2
		HBI	5.9	5.93	6	5.86	5.84
		# of EPT Taxa Families	3	2	2	2	2
		# of Total Taxa Families	6	7	8	7	7
	11/14-15/07	VASCI	27.1	28.5	30.4	29.2	28.8
		HBI	6.47	6.02	6.13	5.97	6.16
		# of EPT Taxa Families	1	1	1	1	1
		# of Total Taxa Families	6	7	8	6	9

Table 3-4 summarizes the average values for the parameters before and after restoration. Benthic invertebrate data collected to date indicate areas within the restoration reach have VASCI scores that are not significantly different than before the restoration. Controls show substantial variability before and after restoration. The VASCI score at control site A was much smaller than expected in the pre-restoration sampling event. This may be due to seasonal variability and related to the velocities experienced in this stream that remain unchanged with this management strategy. Upstream control site VASCI scores following restoration were intended to provide an attainable goal for sites B and C within the current restoration reach. Both sites B and C in the restored section were moved owing to the fact that the restoration altered the riffle locations that the original riffle did not exist in the same location. The HBI average was 6.05 in the restored area, 6.06 downstream, and 5.89 upstream sites after restoration. All were ranked as enriched per Hilsenhoff (1988) and there was no significant difference between indices.

Macroinvertebrate data completed for VASCI, HBI, and EPT taxa families showed a slight improvement trend in conditions between pre- and post- restoration for all sites up to two years after the restoration (Table 3-4). Paired t-test indicated a statistically significant change in VASCI (P=0.014) and HBI indices (P=0.012) and total number of EPT Taxa families (P=0.017) between before and after restoration as the change occurred was greater than would be expected by chance.

Table 3-4. Average macroinvertebrate indices and EPT taxa families before and after restoration

	Site RUP*		**Site A**		**Site B**		**Site C**		**Site D**	
	Pre	**Post**	**Pre**	**Post**	**Pre**	**Post**	**Pre**	**Post**	**Pre**	**Post**
VASCI	26.4 (3.0)	31.8 (4.8)	22.6 (2.2)	30.7 (3.9)	26.0 (2.7)	27.3 (2.9)	27.1 (3.3)	28.7 (4.6)	26.2 (0.9)	28.0 (4.4)
HBI	6.04 (0.13)	5.83 (0.35)	6.27 (0.52)	5.96 (0.41)	6.29 (0.49)	6.11 (0.28)	6.17 (0.32)	5.99 (0.14)	6.26 (0.29)	6.06 (0.42)
EPT Taxa Families	1.00 (0.0)	2.00 (0.71)	1.33 (0.58)	2.40 (0.89)	1.33 (0.58)	1.40 (0.55)	1.00 (0.0)	1.40 (0.89)	1.00 (0.0)	1.60 (0.55)
	Upstream Controls				Restoration Reach				Downstream Affects	

*RUP: Restored Upstream Park
Parentheses indicate standard deviation

An important factor influencing the slow recovery of benthic invertebrates in this system may be the substantial increase in wet weather flow velocities. The stream restoration likely created more habitats through the added pool-riffle structure incorporated in the restoration, but little or no volume control management was done in the watershed to attenuate wet weather flow volumes during this phase of watershed enhancement. Volume control to reduce flow velocities (e.g., stream bed scouring) from directly connected impervious areas and continuation of invertebrate collection sensitive to timing may improve recorded macroinvertebrate conditions in the restored reach. Moreover, macroinvertebrate communities may be limited by water quality since many of the taxa collected were considered tolerant of adverse chemical conditions. The results for VASCI and HBI indices are shown in Figures 3-16 and 3-17, respectively. Differences in invertebrate indices are shown in Figures 3-18 and 3-19.

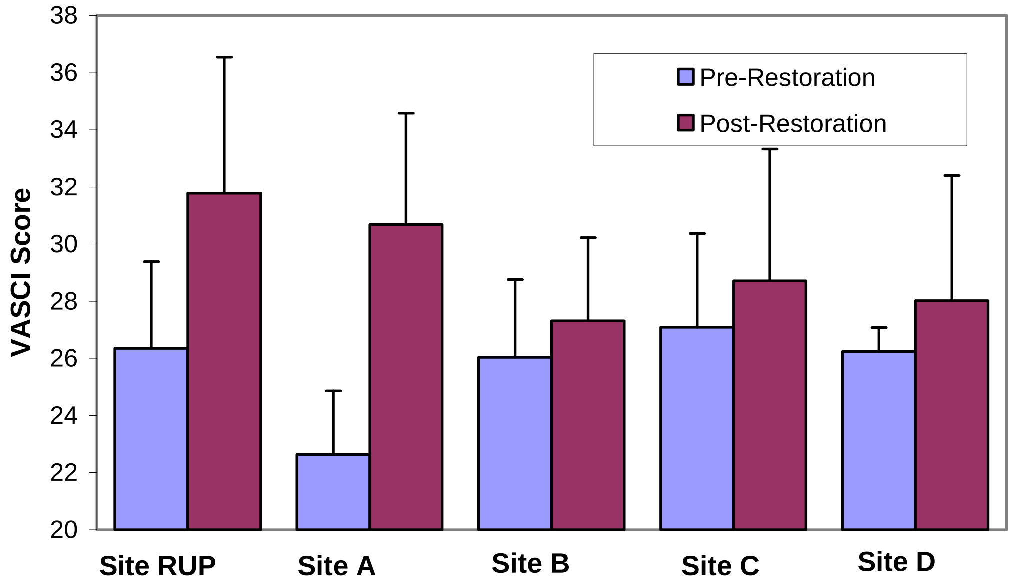

Figure 3-16. Virginia Stream Condition Index (VASCI) scores for before and after the Accotink Creek stream restoration

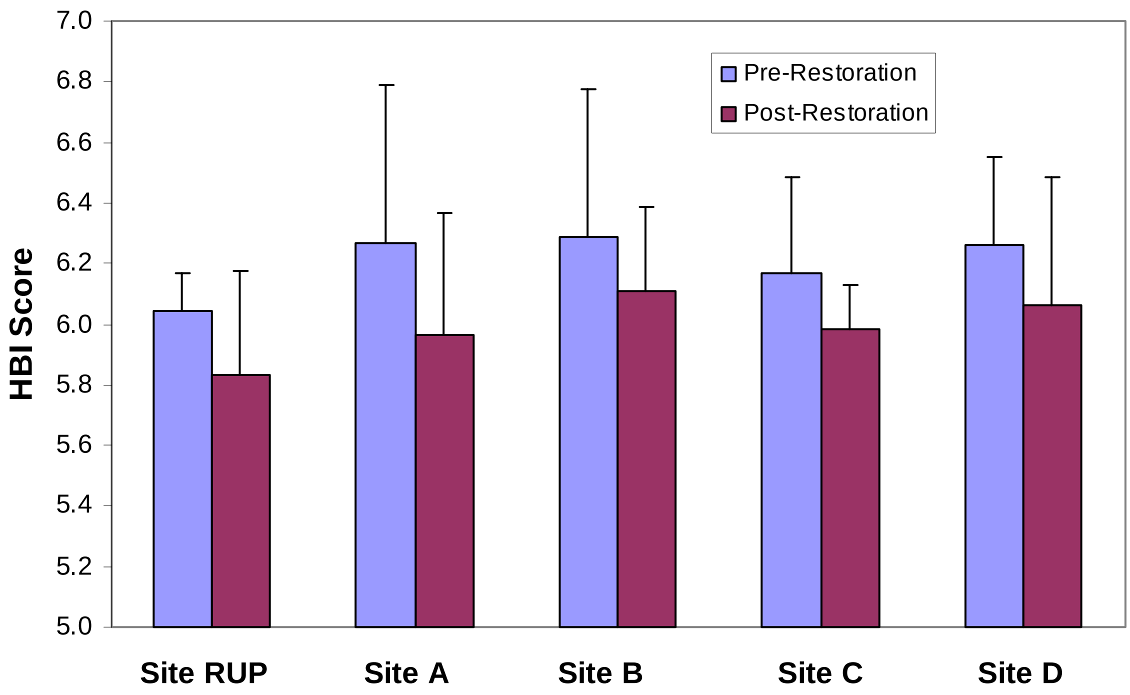

Figure 3-17. Hilsenhoff Biotic Index (HBI) scores for before and after the Accotink Creek stream restoration

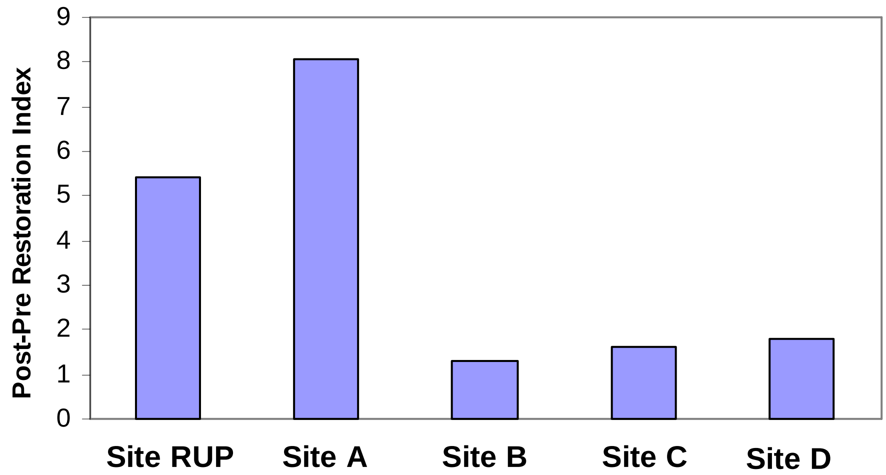

Figure 3-18. Differences in VASCI between post and pre-restoration

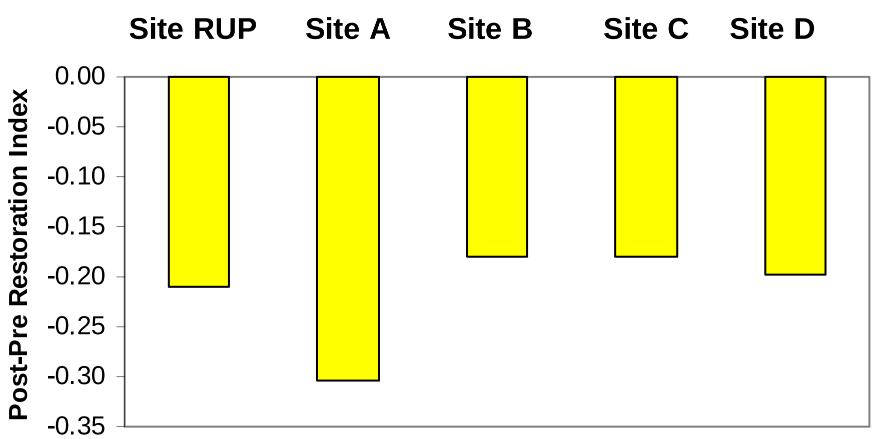

Figure 3-19. Differences in HBI between post and pre-restoration

Table 3-5 summarizes the type and number of dominant species for all sampling events. Except for March 2006, all the sites had a similar total number of macroinvertebrates (i.e., taxa) and there was no statistically significant difference in total macroinvertebrate relative abundance over all the sampling dates. There was also no significant difference in the total number of macroinvertebrates between the upstream, downstream, and restored sites. The upstream, downstream, and restored areas have similar percent dominance values. The most dominant taxa at these sites were Chironomidae, Hydropsychidae, Naididae, and Lumbriculidae representing 87% of the upstream site samples, 93% of the restored area samples, and 92% of the downstream samples composed of these four families. All other families were relatively rare, with most composing less than 1% of represented taxa (i.e., 1-2 taxa).

While there were no differences in the total number of families, there were more Chironomidae than Hydropsychidae at all sites before restoration. This was reversed after the restoration as

Table 3-5. Total number of macroinvertebrates

Pre- and Post-Restoration	Date	Species	Site A (~120 m North of Lee Hwy) Upstream	Site B (~100 m South of Lee Hwy) Restoration Area	Site C (~10 m North of Old Lee Hwy) Restoration Area	Site D (~200 m South of Old Lee Hwy) Downstream	Site RUP (~50 m West of Bridge at River Road) Upstream
Pre- Restoration	11/03-04/2005	Chironomidae	79	45	72	40	
		Hydropsychidae	31	59	33	77	
		Naididae					
		Lumbriculidae	3	1		1	
	12/07-08/2005	Chironomidae	98	55	65	67	76
		Hydropsychidae	6	14	29	30	32
		Naididae		1	2	3	
		Lumbriculidae	3	9	1	4	4
	03/13-14/2006	Chironomidae	27	8	72	23	69
		Hydropsychidae	1	1	3	1	9
		Naididae	10	2	22	10	
		Lumbriculidae	12	5	5	4	
Post- Restoration	09/21/2006	Chironomidae	30	7	15	13	31
		Hydropsychidae	52	102	80	106	46
		Naididae	1				
		Lumbriculidae	1		1	1	
	11/15/2006	Chironomidae	25	15	4	7	16
		Hydropsychidae	67	93	90	106	71
		Naididae	7	1	4	1	
		Lumbriculidae	4	1	1	1	3
	05/9/2007	Chironomidae	100	80	104	68	90
		Hydropsychidae	1			2	
		Naididae	19	42		52	9
		Lumbriculidae	2	2	1	1	
	09/18-19/07	Chironomidae	30	42	132	50	30
		Hydropsychidae	87	126	9	80	91
		Naididae					
		Lumbriculidae		2	2	2	1
	11/14-15/07	Chironomidae	6	24	25	46	45
		Hydropsychidae	60	93	22	58	70
		Naididae		1			
		Lumbriculidae	35	3	3	10	12

there were more Hydropsychidae than Chironomidae except for the 5/19/2007 sampling event. It is plausible that restoration created more stable substrates which are required for attachment by net-spinning Hydropsychids. Many Chironomidae are silt and sand tolerant and early colonizers following streambed scouring. The May 2007 sampling event may be anomalous, or other water quality factors may be responsible for higher Chironomidae on this sampling occasion.

Overall, the poor VASCI scores and relatively high HBI indicate that water quality may be limiting macroinvertebrate recovery following restoration activities. The dominant taxa found in Accotink Creek (pre- and post restoration) suggest a variety of pollutants (e.g., nutrients, metals, other trace toxicants) could be responsible for structuring the observed communities. Moreover, additional monitoring is needed to detect changes in macroinvertebrate communities over time. Improvement may not be realized in two years post-restoration, a finding common to many stream restoration projects (Personal communication with Wheeling biologist Gregory Pond, 2008).

Stream Channel Cross Sections

Stream channel cross sectional measurements were taken using a folding ruler and a flexible tape measure stretched perpendicular to the direction of stream flow. Measurements were taken from bank to bank at 0.5 ft (0.15 m) increments close to the banks and at 1 ft (0.3 m) interval else where at four different locations (one upstream, one downstream, and two in restored area). Figures 3-20 and 3-21 show the channel profiles at two different locations. In the upstream location, the bottom contours did not change much after restoration. In the restored area, the depth profile showed deeper and more sharply defined bottom contour after restoration compared to before restoration. Bottom depth changed from approximately 7 ft (2.13 m) to 11 ft (3.35 m). Substrate was mostly gravel and cobble comprising 90-95% of the streambed of the creek in the restored area, whereas gravel and cobble comprised 77-84% of the streambed upstream of the restoration.

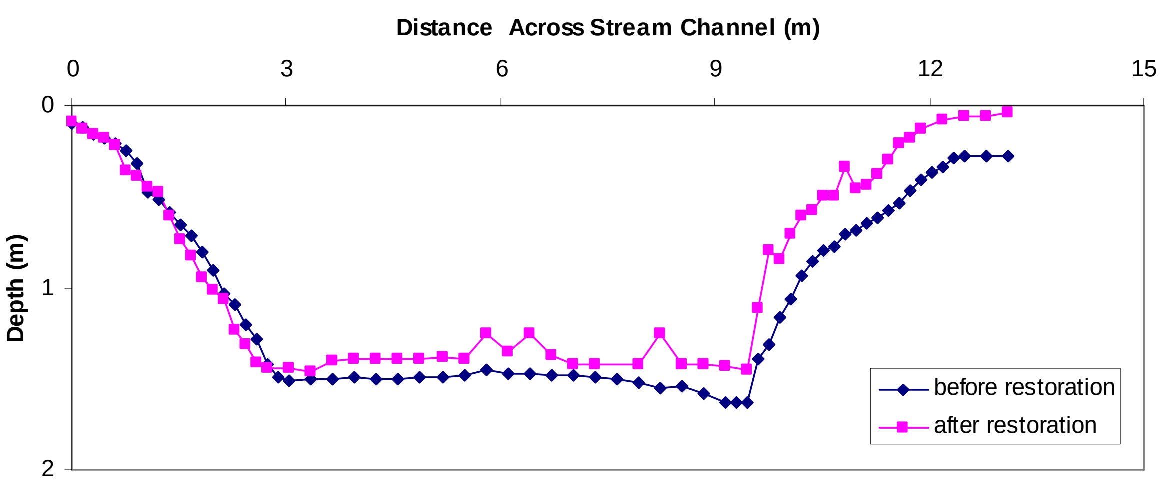

Figure 3-20. Representative depth profiles before and after restoration at an upstream location

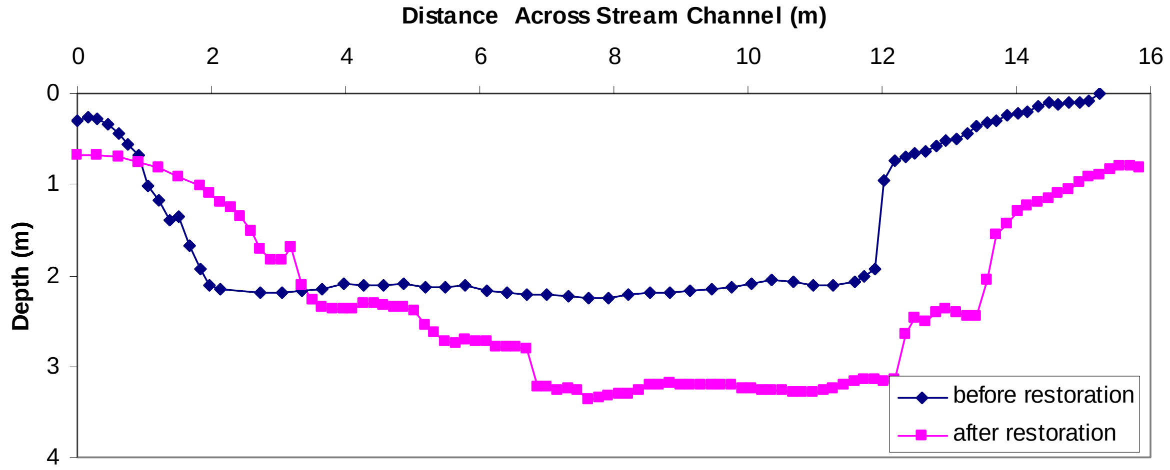

Figure 3-21. Representative depth profiles before and after restoration at a restored location

Pebble Count

The pebble count was conducted 2 times before restoration (November 3, 2005 and March 1, 2006) and once after restoration (October 3, 2006). The pebble count was conducted at 5 different riffle locations (Ranger Road – upstream of restoration; Site A – Upstream of Old Lee Highway – upstream of restoration; Site B – Below Lee Highway at Harley Dealer – restoration reach; Site C – upstream of Old Lee Highway – restoration reach; and Site D – downstream of Old Lee Highway – downstream of restoration) to evaluate streambed particle-size distributions. Counts were performed in a manner similar to that described by Wolman (1954); minor modifications to the methods were needed to accommodate site characteristics. The pebble count technique developed by Wolman in 1954 has long been used to document the surface particle size distribution of coarse riverbed material. Because Accotink Creek is a relatively narrow stream, an entire stream riffle with multiple transects were needed for the pebble count to be more representative, rather than just an individual transect within a riffle. On average, the sampled riffles were about 25 ft (7.62 m) long and approximately 18 ft (5.5 m) wide. Pebbles were selected for size determination from within the wetted perimeter of the stream, and were chosen for size determination using the first-blind-touch approach. Particle size was determined using a pebble count template (which provided a standard classification system). Particles that were smaller than 2 mm were compared to a sand gauge card to determine size. A total of 100 pebbles were selected from within each riffle section. By classifying particles using the template and sand card, the particles could be grouped into sieve size classes according to the Wentworth scale. Following size classification, the data were plotted to summarize the relative size classes identified in each riffle.

The pebble count data are summarized below in Table 3-6 and Figures 3-22 through 3-26, and these data indicate that as of this study period, very little has changed in this stream reach. A more quantitative statistical analysis is limited by the number of samples collected at each site. By evaluating the pebble count data at each site with time, there is a slight increase in the post-restoration (October 2006) sampling at both the most upstream and downstream cross sections.

However, the most upstream site (at Ranger Road) is a control that is above the restoration, it cannot be concluded that the slight increase in particle size at the most downstream site is caused by the restoration. The other three intermediate sites demonstrate very little changes in the size distributions over time. This lack of change in the stream bed size classes is most likely due to the restoration not changing the rate of water courses down the stream.

Table 3-6. Results of pebble counts

Date	Pebble Count Data	Site A - Above Lee Hwy (Above Restoration)	Site B - Below Lee Hwy (Within Restoration)	Site C - Above Old Lee Hwy (Within Restoration)	Site D - below Old Lee Hwy (Below Restoration)	Site 5 - Ranger Road (Above Restoration)
11/03/2005 Pre-Restoration	% Silt/Clay % Sand % Gravel % Cobble Particle Size (mm)	3 13 84 0 7.9±3.9	0 11 76 13 19.1±3	0 9 61 30 34.0±2.5	2 4 90 4 19.9±2.0	
3/1/2006 Pre-Restoration	% Silt/Clay % Sand % Gravel % Cobble Particle Size (mm)	3 20 76 1 6.3±4.5	0 5 87 8 20.5±2.6	0 9 60 31 29.5±3.0	2 33 65 0 4.3±8.0	2 14 68 16 8.2±6.1
10/03/2006 Post-Restoration	% Silt/Clay % Sand % Gravel % Cobble Particle Size (mm)	1 17 79 3 8.0±4.5	0 5 82 13 24.2±2.4	0 2 77 18 32.2±2.4	4 4 76 16 29.2±2.2	0 21 73 6 24.8±2.8

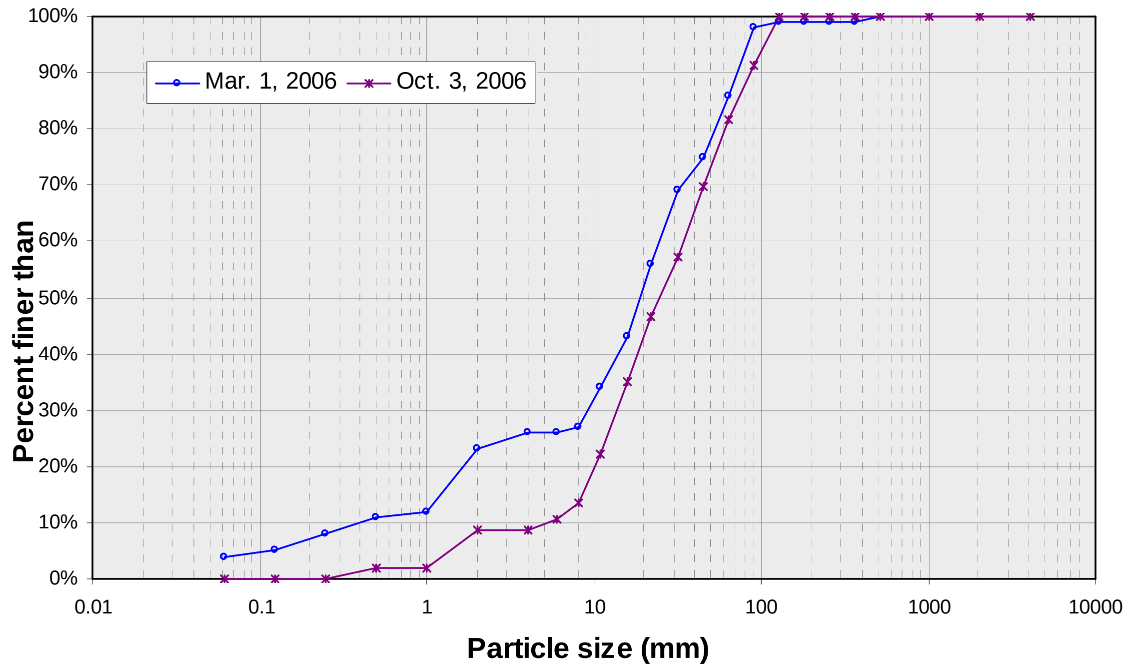

Figure 3-22. Pebble count results at Site 5 – Ranger Road (upstream of restoration)

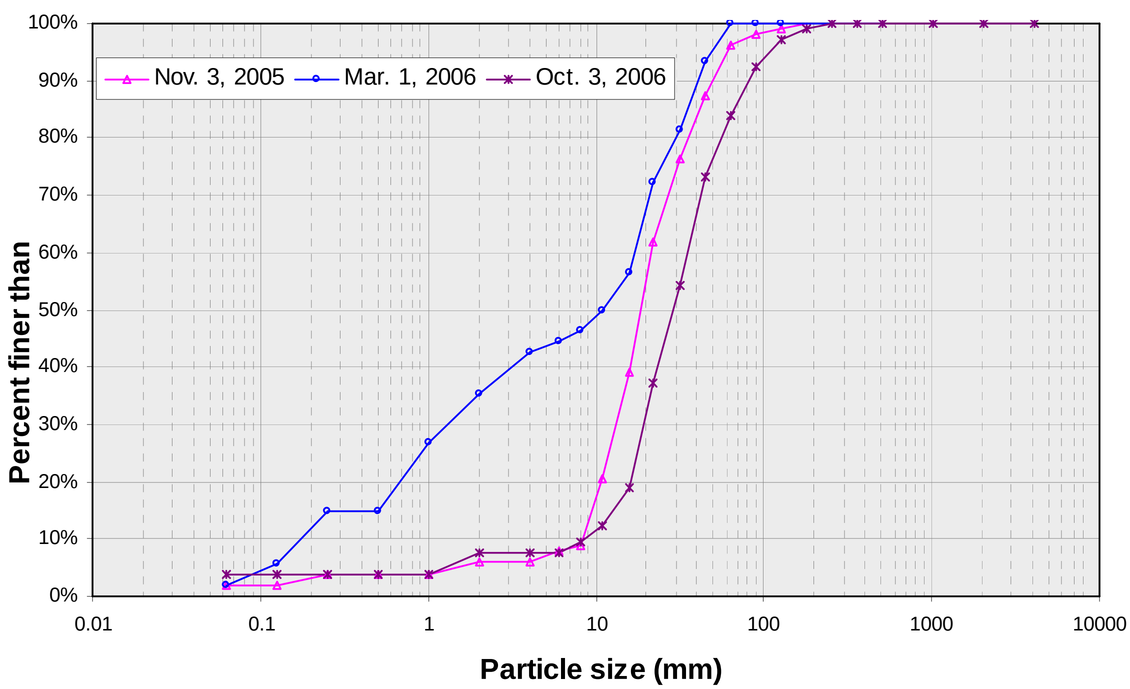

Figure 3-23. Pebble count results at Site D – downstream of Old Lee Highway (downstream of restoration)

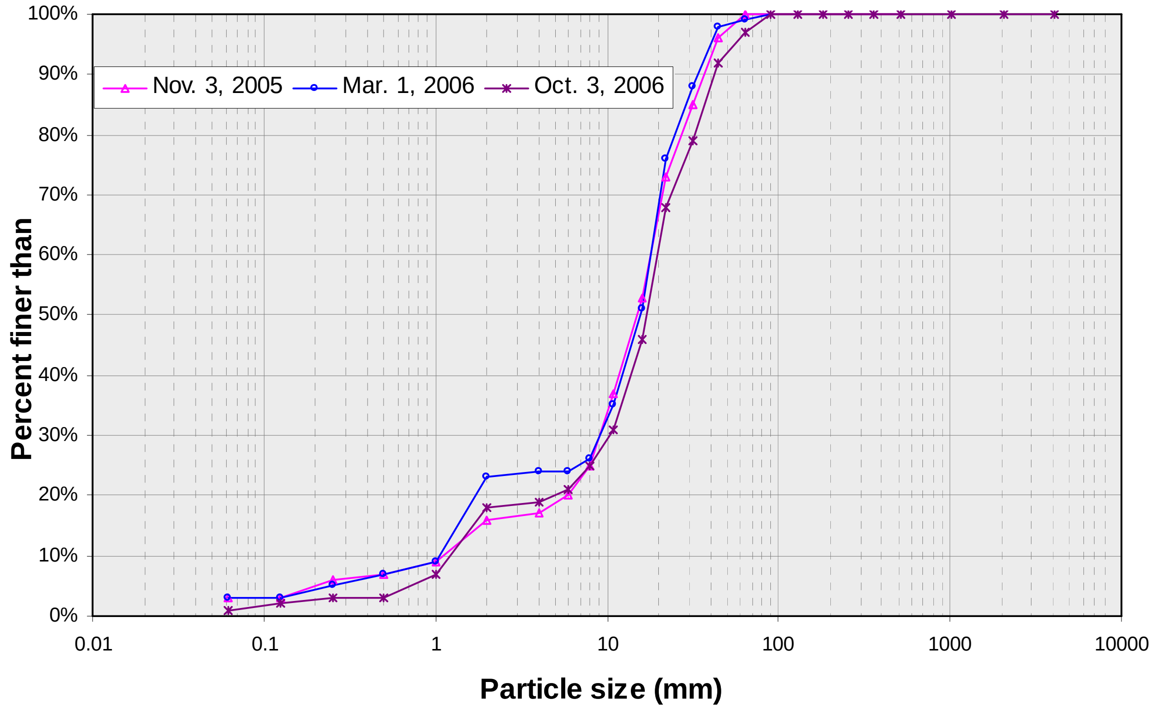

Figure 3-24. Pebble count results at Site A – upstream of Lee Highway (upstream of restoration)

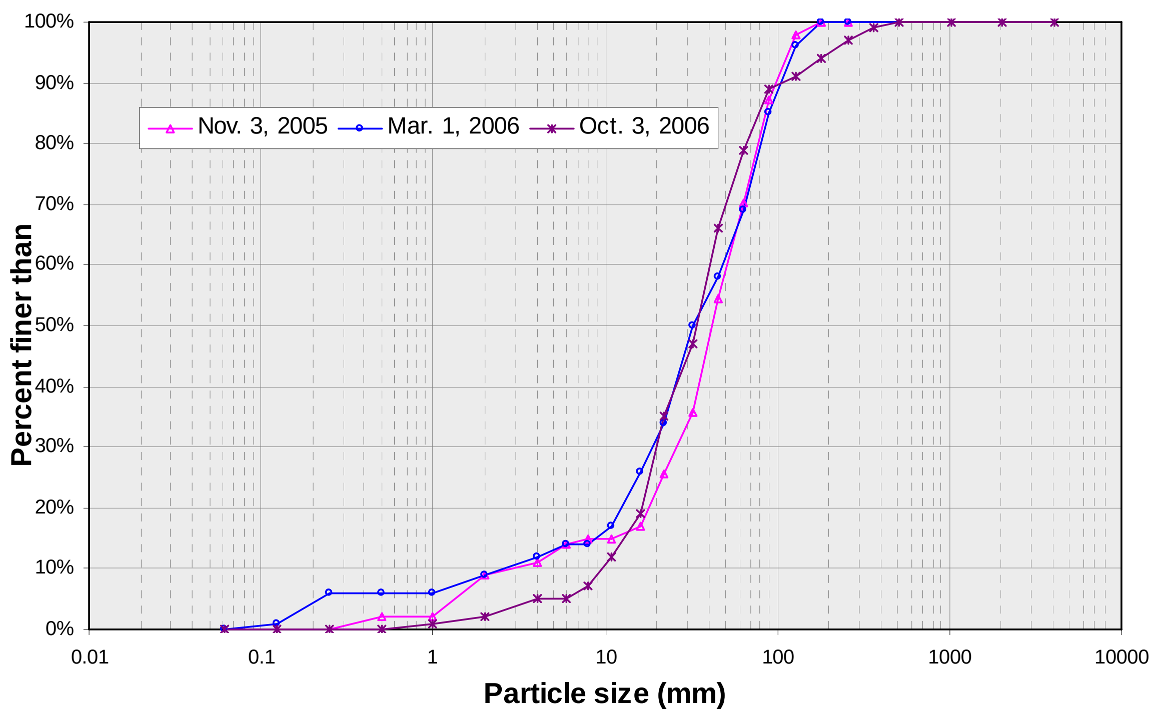

Figure 3-25. Pebble count results at Site C – upstream of Old Lee Highway (restoration reach)

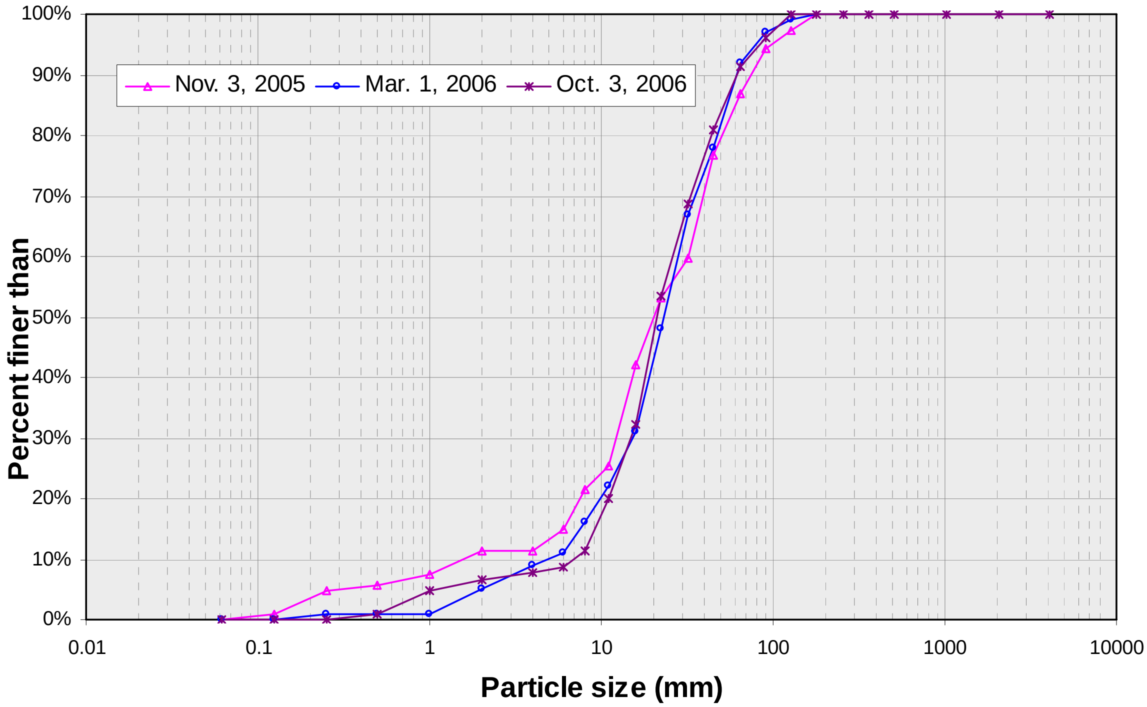

Figure 3-26. Pebble count results at Site B – below Lee Highway at Harley Dealer (restoration reach)

Chapter 4 USGS Sampling and Monitoring

Background

The USGS conducted continuous water quality monitoring and collected grab samples from December 2005 to August 2007 under an interagency agreement (IAG No. DW-14-922064010) with U.S. EPA ORD. A YSI sensor was used to monitor turbidity, specific conductance, pH, and water temperature. The sensor, an YSI extended deployment sonde, was installed just downstream of the restoration area hanging from the bridge at Old Lee Highway. In general, continuously monitored data can provide detailed records of water quality (Figure 4-1), and allow scientists and watershed managers to better understand their systems. As part of the IAG, the USGS also collected approximately 21 water quality samples over a wide range of flow conditions and analyzed them for *E. coli* and suspended sediment concentrations and performed pebble counts (results were presented in Chapter 3) at designated sites before and after the restoration.

Relationships often exist between the water quality parameters that can be measured with sensors and other contaminants of interest; these relationships make the technology even more powerful. For example: turbidity values typically correlate well with both suspended sediment and bacteria concentrations. When discrete water quality samples are collected manually during both low flow and storm flow periods, in conjunction with the continuously monitored data, regression equations can be developed to relate a target water quality constituent in the discrete samples (e.g., suspended sediment or bacteria concentration) to the water quality parameters that are monitored continuously (e.g., turbidity). This regression equation can then be used to estimate continuous concentrations of the target water quality constituent. This approach is completely analogous to the standard methods for developing continuous discharge records, in which stream stage (water level) is recorded continuously and a regression equation (a rating curve) is developed to relate continuous stage and discrete discharge measurements. Instead of developing a stage-discharge relationship to calculate continuous discharge, this approach is used to develop such models as turbidity-bacteria correlations to calculate continuous bacteria concentrations. Figure 4-2 shows the relationship between turbidity and fecal coliform from a previous study further downstream.

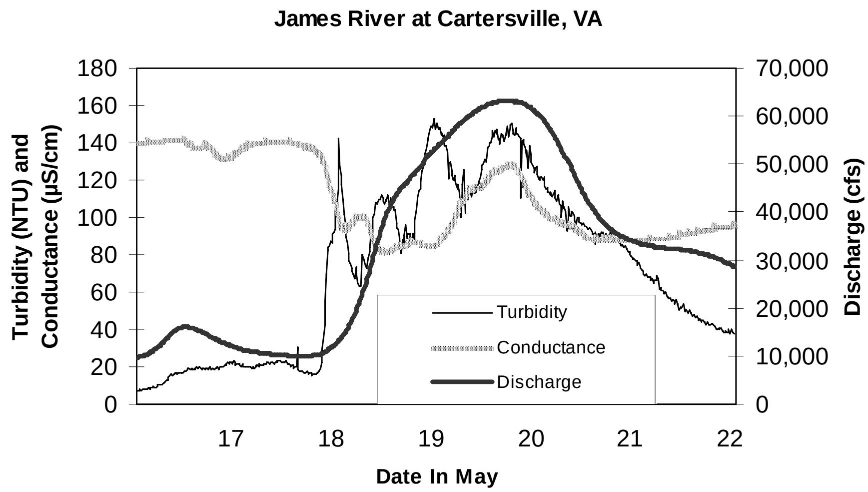

Figure 4-1. Example of continuous water quality data determined by sensor technology (http://va.water.usgs.gov/ContinuousWaterQuality.pdf)

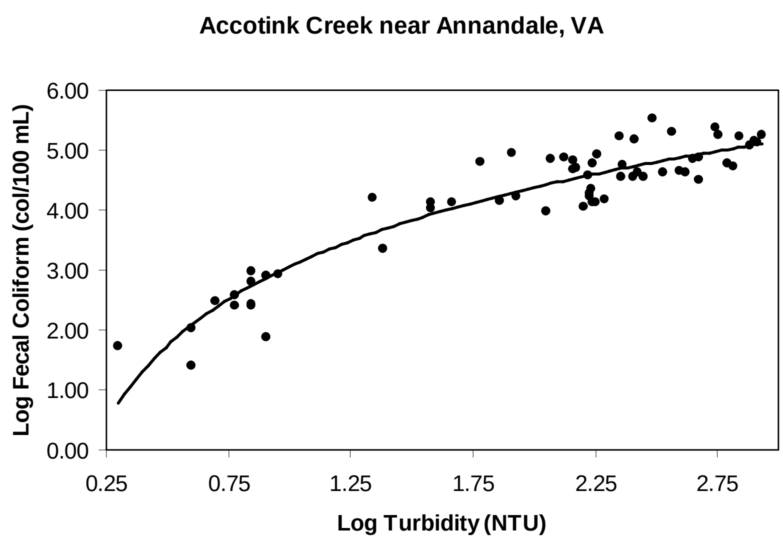

Figure 4-2. Example of correlation between turbidity and fecal coliform concentration

One novel application of this continuous water quality monitoring and development of regression equations is for the detection of change in water quality that is related to BMP implementation activities. Detection of measurable improvements in water quality can be achieved through numerous univariate and multivariate statistical analyses of these data. These analyses can include an evaluation of changes in the developed regression equations, the regression residuals, and the overall distribution of continuously estimated constituents. The direct benefits of this approach are that the data analysis is largely independent of confounding environmental factors, the continuous data provide a better dataset with which to efficiently detect environmental change, and over the long term this approach should be less costly than traditional monitoring plans.

Continuous Water Quality Monitoring

All continuous water quality monitoring operations in the USGS are performed according to the USGS standard methods for the operation of this equipment. Published USGS standard operating procedures (SOP) (Wagner *et al*., 2000) were followed during this study, therefore, only a summary of these procedures are outlined below and an internet link to the full SOP is provided in the references section.

The continuous water quality monitor (YSI Model 6920 multi-parameter monitor) was deployed at the Old Lee Highway Bridge on December 14, 2005 and configured to measure water temperature, turbidity, specific conductance, and pH at 15-minute intervals. The instrument was connected to data logging and telemetry equipment that transferred all data to the USGS office in Richmond, VA, where the data were displayed on the internet for access by all interested individuals during the time of monitoring. Following initial deployment, monthly maintenance visits were performed on the monitoring equipment to clean and check the calibration of the sensors. In-field recalibration was performed during these maintenance visits as necessary following the equipment tolerances as specified by the monitor manufacturer and the SOPs (Wagner *et al*., 2000).

Following the monthly maintenance visit, the maintenance data were used to determine whether the monitoring equipment was subject to bio-fouling or calibration drift. If either of these conditions was observed to be outside the SOP tolerances, the continuous water quality record may be shifted to correct these data. At the conclusion of each water year, the data were reviewed for accuracy, all shifts were checked, the quality of the data were rated (as excellent, good, fair, or poor), a station analysis for the water year was prepared, and the finalized data were published in the Annual Virginia Water Science Center Data Report. By following the SOPs outlined by Wagner *et al.* (2000), these continuous data were of known quality and were able to be compared to any other continuous water quality data that also were collected following these guidelines.

Continuous water quality monitoring continued during most of stream restoration construction in the Accotink Creek above Old Lee Highway through until early May 2006, when the contractors needed the monitor removed so that they could clear sediment from underneath the bridge and do minor restoration downstream of Old Lee Highway. The monitor was re-deployed on June 1, 2006, after the stream restoration around the Old Lee Highway Bridge was completed. The restored stream channel around the Bridge caused considerable monitoring difficulty following the June 1, 2006 re-deployment, because it was difficult to keep probes of the unit submerged. The restored channel was considerably wider and shallower than it had originally been and the creek drawdowns with the growing season. Following several storm events, a slightly deeper channel had developed, allowing the water quality monitor to be fully submerged.

Discrete Water Quality Sampling

During the 19-month monitoring period, approximately 21 discrete water quality samples were collected and analyzed by the USGS from the bridge at Old Lee Highway over a wide range of flow conditions, with special effort paid to the collection of water quality samples during storm flow conditions. Approximately 13 samples were collected before restoration and 8 samples were collected after restoration. These discrete water quality samples were collected and analyzed following standard USGS protocols (USGS, 1998). Samples for analysis of suspended sediment concentration (SSC) and *E. coli* were collected as grab samples from the approximate center of stream flow, under varying hydrological conditions. Samples for analysis of SSC were collected in clean, pre-weighed glass bottles, while samples for the analysis of *E. coli* were collected in clean, sterilized glass bottles. For all samples collected, SSC and percent of the sediments finer than sand size were determined. For as many of these samples as possible, *E. coli* concentrations also were determined; the decision on which samples to analyze for *E. coli* were based on their ability to process these samples within the prescribed 6-hour holding times. Sediment samples were shipped to the USGS Eastern Region (Kentucky) Sediment Laboratory for analysis following approved sediment analysis techniques (Sholar and Shreve, 1998; ASTM, 2007). Bacterial samples were processed using standard membrane filtration techniques (USGS, 1998; U.S. EPA, 2002b). As described in the USGS manuals for water quality sampling and analysis, approximately 10% of the samples were made up of quality control samples, such as blanks and duplicate samples.

Results

Continuous Water Quality Monitoring

A sample of continuous monitoring data for pH, conductivity, turbidity, and water temperature recorded by the YSI Model 6920 multi-parameter monitor is shown in Figure 4-3. It can be seen that the conductivity was higher in February due to snow and freezing events requiring street salting. The temperature of the creek water changed with the season and the wet weather flow events. The highest temperatures were observed in July and August. pH stayed close to neutral. Similar results were observed with U.S. EPA monitoring equipment.

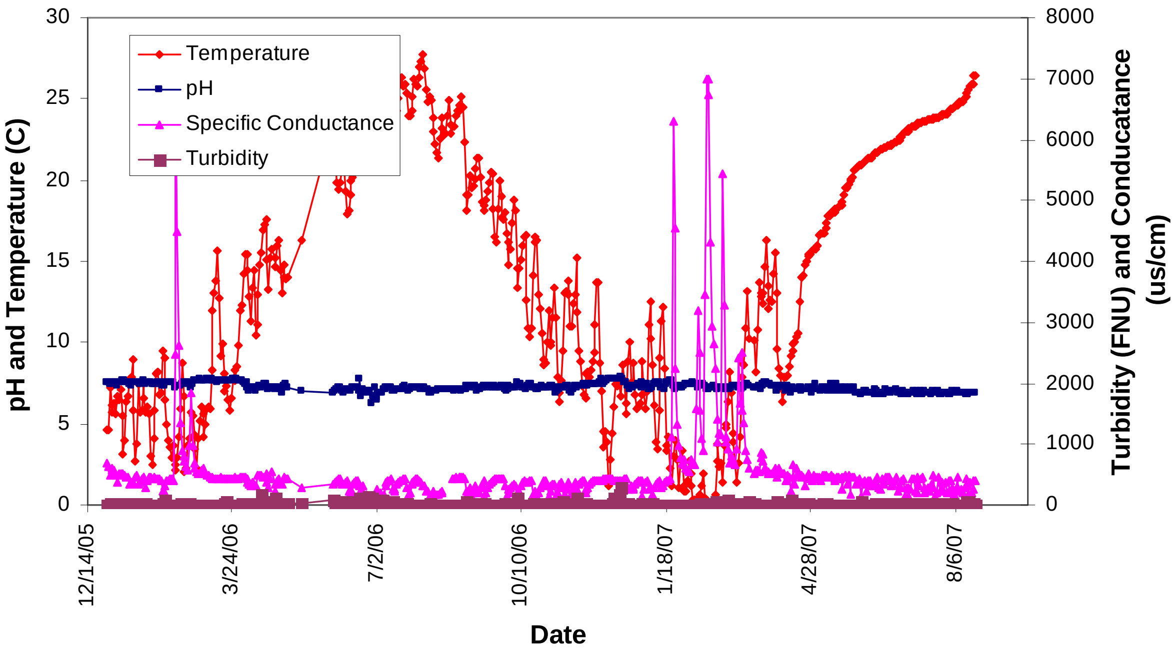

Figure 4-3. Continuous water quality monitoring by USGS at Old Lee Highway

Discrete Water Quality Sampling

The water quality samples were collected from January 2006 and the final water quality samples were collected during March 2007. Altogether 21 grab samples (13 samples before and 8 samples after restoration) were collected. The data analysis is summarized below. Statistically significant regression equations were developed for *E. coli* and suspended sediments, and the equations are presented below. A stronger relationship appears to exist between turbidity and suspended sediment than for turbidity and *E. coli*.

$$Log(E.coli) = 0.7129(LogTurb) + 0.0610(WT) + 1.4433 \qquad (R^2 = 0.73)$$

$$Log(SSC) = 0.7543(LogTurb) + 0.4705(LogTurb \times V1) + 0.5708(LogTurb \times V2) - 0.5228(V1) - 0.8617(V2) + 0.2511 \qquad (R^2 = 0.96)$$

Where:

LogTurb = Log of Turbidity
WT = Water Temperature (^{o}C)
SSC = Suspended Sediment Concentration (mg/L)
V1 = Categorical variable #1 representing stage
V2 = Categorical variable #2 representing stage
The categorical variables were used to represent three different stage conditions as:
V1,V2 = 0,0 = Baseflow conditions
V1,V2 = 1,0 = Rising limb of the hydrograph or peak flow
V1,V2 = 0,1 = Falling limb of the storm hydrograph

The stage information was determined from the metadata that were recorded on field sheets during the collection of stream samples. An interaction term between turbidity and the categorical flow variables was found to be significant and justified on the basis of residual plots. Predictive equations (with 1:1 lines) and residual plots are presented below for both *E. coli* and SSC in Figures 4-4 through 4-7.

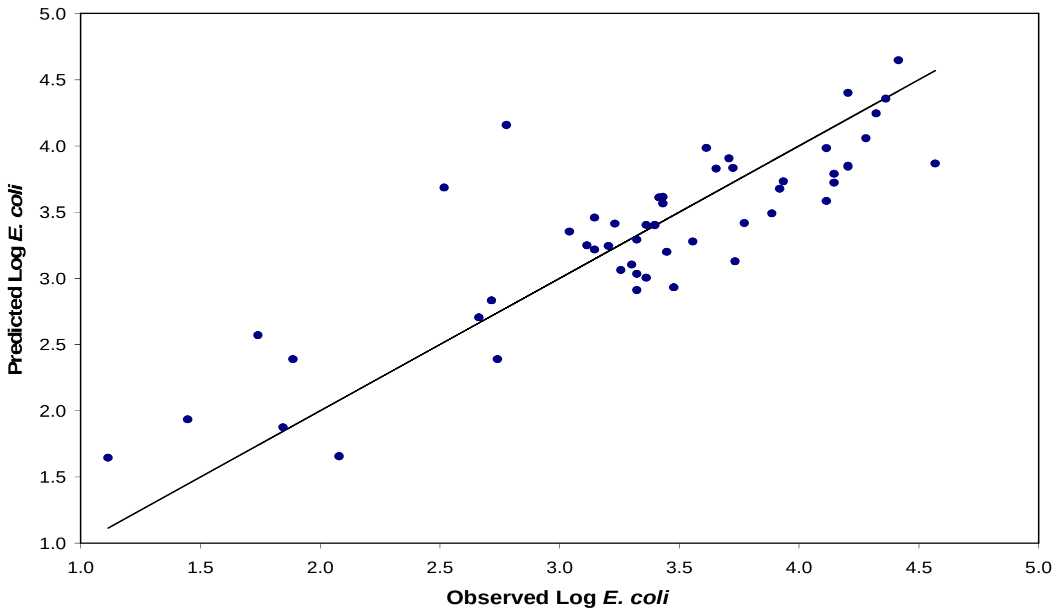

Figure 4-4. Graph of predicted vs. observed for *E. coli*

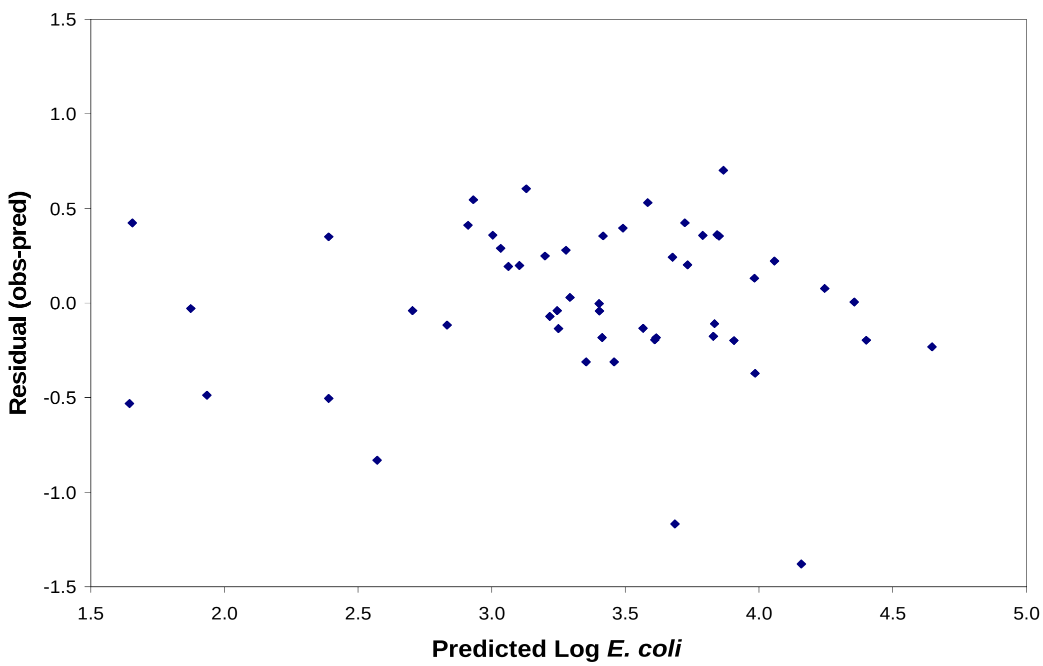

Figure 4-5. Graph of observed *E. coli* vs. residual

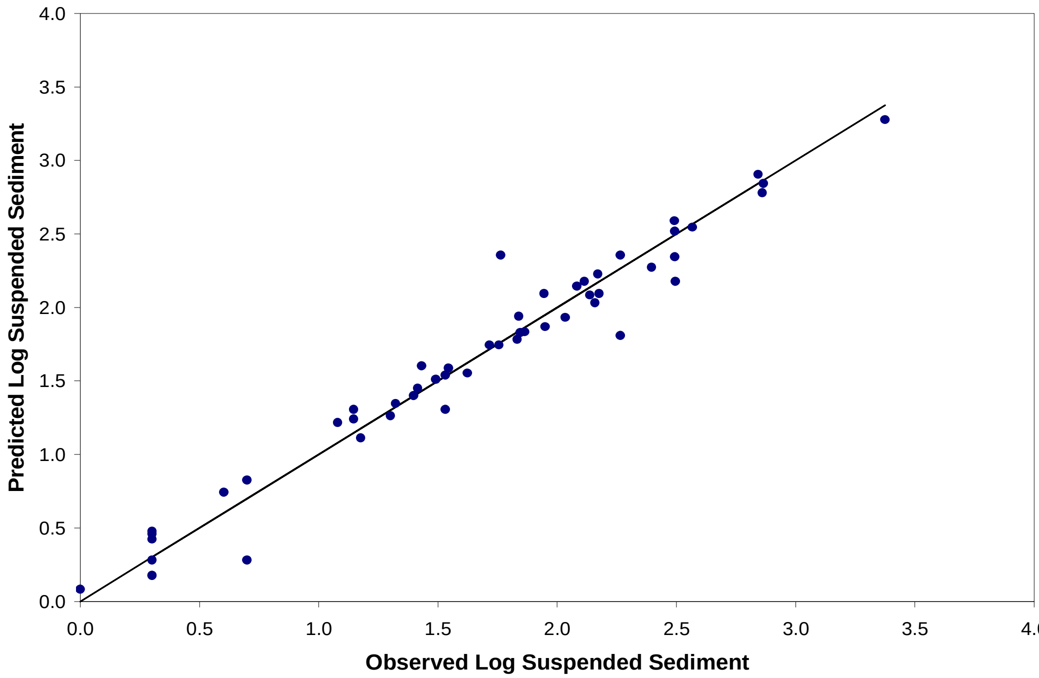

Figure 4-6. Graph of predicted vs. observed for suspended sediment

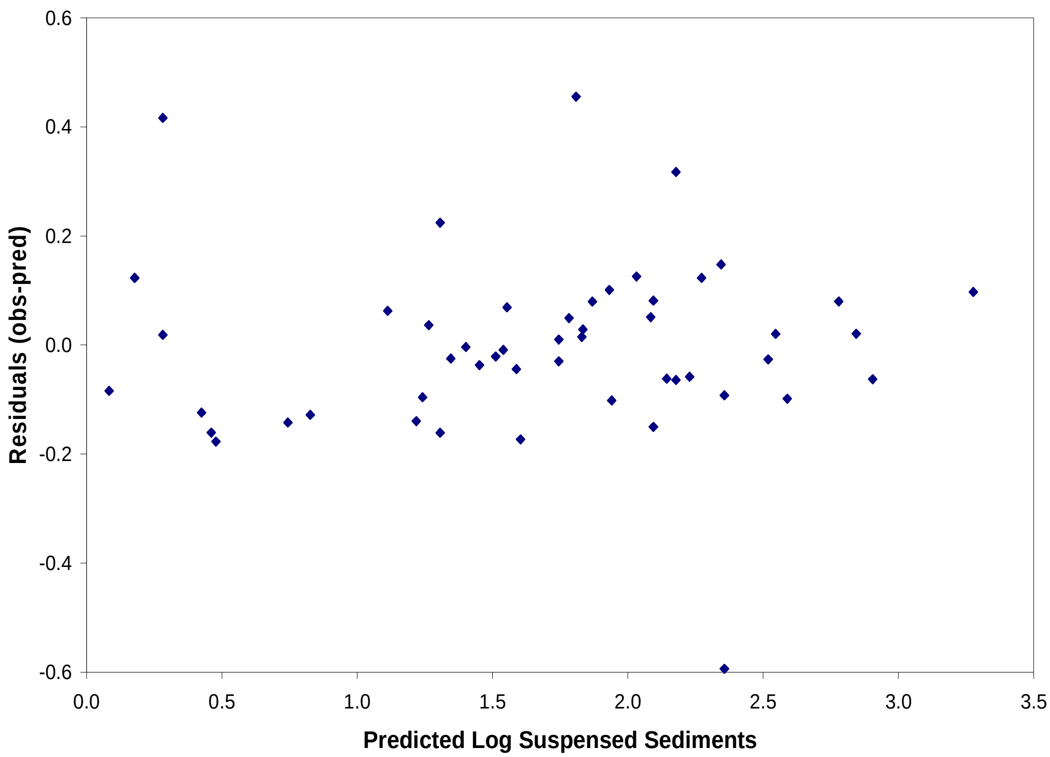

Figure 4-7. Graph of observed suspended sediments vs. residual

Figure 4-8 is a plot of a simplified SSC equation prior to the addition of the stage interaction terms (the equation is $LogSSC = 0.9823(LogTurb) + 0.1052$). Before the addition of the stage terms, there is a consistent over-prediction of SSC on the falling limb, and an under-prediction on the rising limb and peak samples.

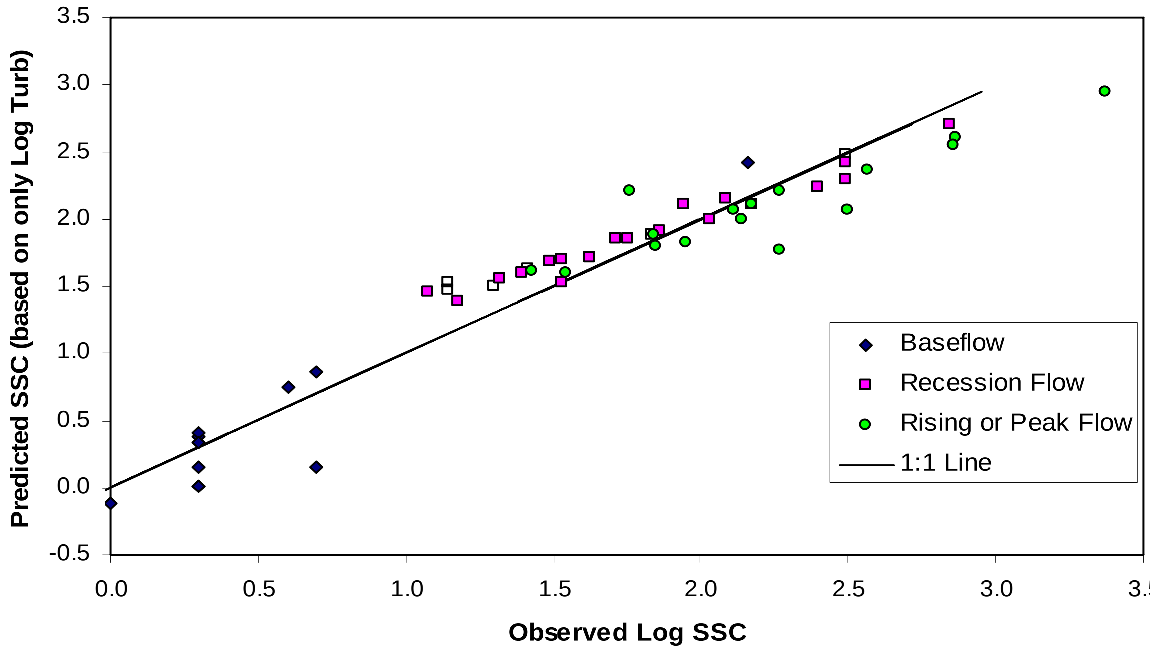

Figure 4-8. Graph of observed SSC vs. predicted SSC (based on Turbidity Only)

After developing predictive equations for *E. coli* and SSC, the effect of the restoration activities on the predictive relationships was evaluated through the use of a categorical variable representing pre-restoration and post-restoration samples. For both *E. coli* and SSC, the categorical variable for the restoration activities was not statistically significant, indicating that no detectable change has occurred in the predictive equations before and after the restoration. This lack of a detectable change in the sediment or bacterial transport is also evident in plots of the data before and after restoration (see Figures 4-9 and 4-10 for SSC and *E. coli*, respectively). The lack of change may be because of insufficient data or inadequate length of data collection or that the restoration activity did not impact a sufficiently substantial portion of the watershed to reduce sediment transport.

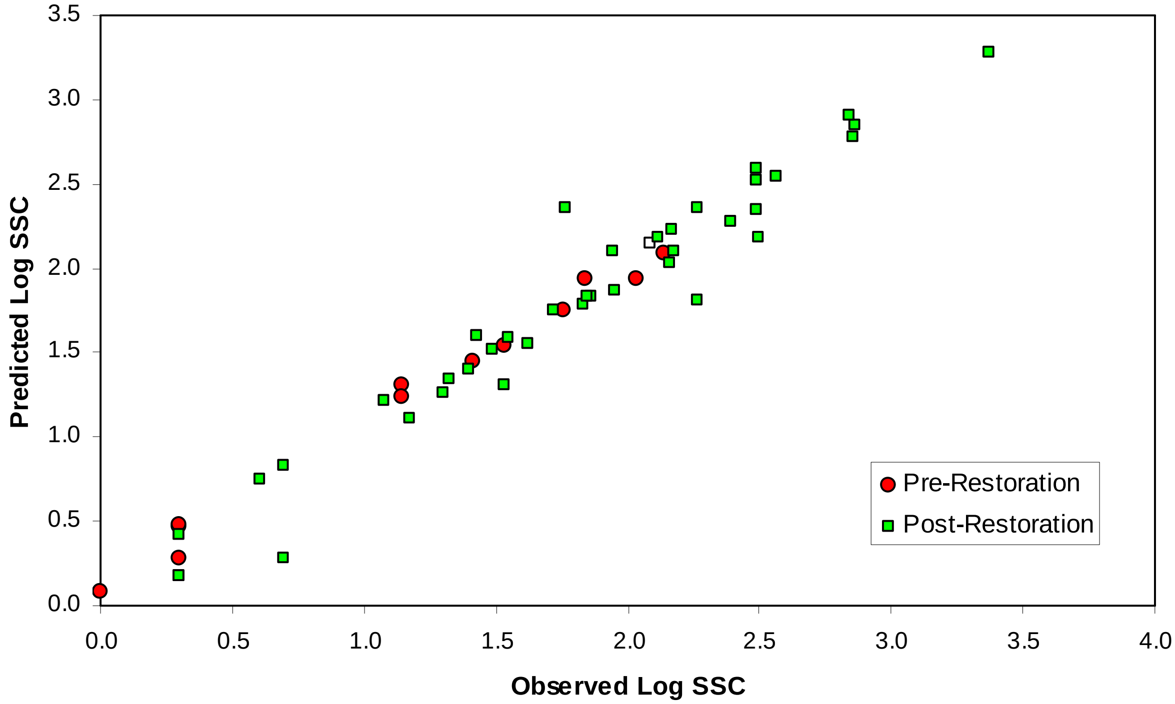

Figure 4-9. Graph of SSC showing pre- and post-restoration samples

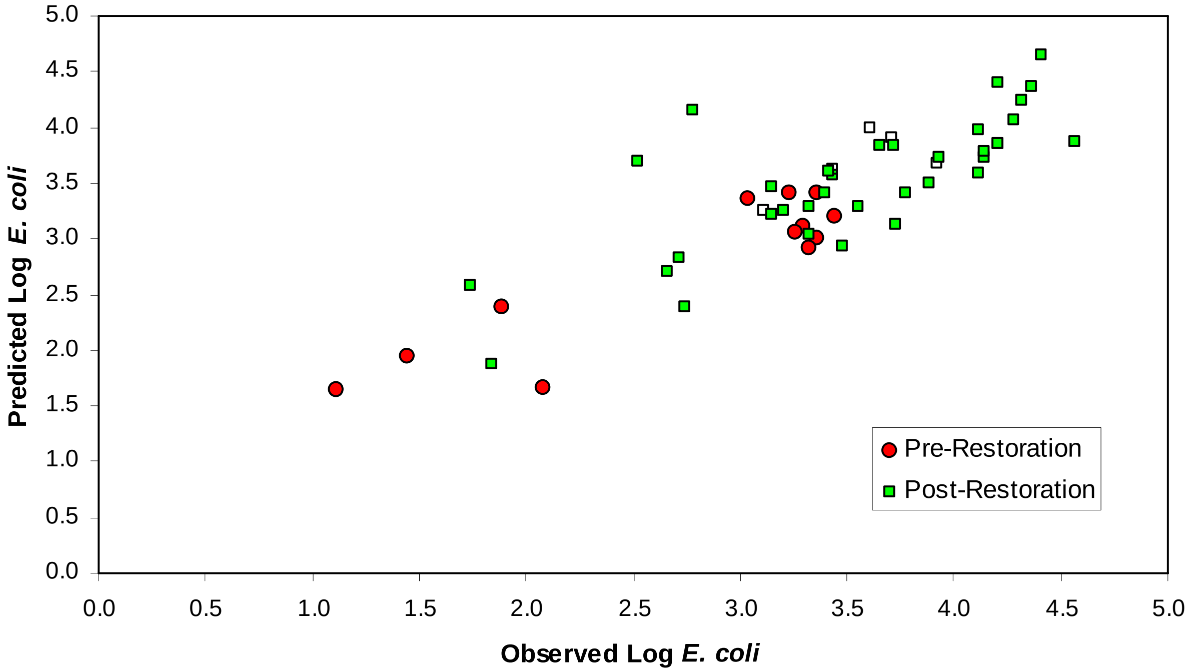

Figure 4-10. Graph of *E. coli* showing pre- and post-restoration samples

Utility of the Continuous Data for the Prediction of SSC and Bacteria Concentrations

The better equation for predicting SSC involved the determination of a relative flow condition (rising stage, falling stage, or baseflow conditions); however, a simpler predictive equation exists that does not require this determination (the simpler equation includes only SSC and turbidity). Continuous estimates of *E. coli* and SSC are useful for several applications which are described below.

One application of predictive equations for estimating continuous SSC and *E. coli* concentrations is that the records could be used to evaluate the frequency with which concentrations of either constituent exceeds a particular level. For example, a continuous record of estimated *E. coli* concentrations can be analyzed to estimate how often a given bacterial water quality standard might be exceeded.

Additionally, the continuous estimations of SSC and *E. coli* could be combined with a continuous record of stream flow to produce loading estimates of these constituents for the stream (load can be computed as the product of a concentrations term and a flow term). As there was no stream gage at the Old Lee Highway site, the load computations cannot be performed with the current data.

Another application of these continuous data is in the calibration and verification of watershed models for SSC and *E. coli*. Continuous records of estimated SSC and *E. coli* could provide more robust data sets with which to evaluate models.

Patterns in Turbidity Concentrations Before, During, and After Restoration

Another application of the continuous turbidity data is in the evaluation of the turbidity patterns before, during, and following the stream restoration. The detail provided by 15-minute interval data can be used to provide a robust image of the distribution of turbidity values that occurred at and around the monitoring site. Figure 4-11 below presents the distribution of turbidity values that were observed before restoration, during restoration, and after restoration. The dates used for the different restoration periods are:

-pre-restoration: December 14, 2005 – April 2, 2006
-during restoration: April 3, 2006 – May 31, 2006
-post-restoration: June 1, 2006 – August 28, 2007

In this figure, the turbidity value corresponding to the 50% on the y-axis represents the median turbidity value observed for a given period. These plots can be described as S-curves. Unusually low turbidity values are on the lower left corner of the plot and unusually high turbidity values are in the upper right corner of the plot.

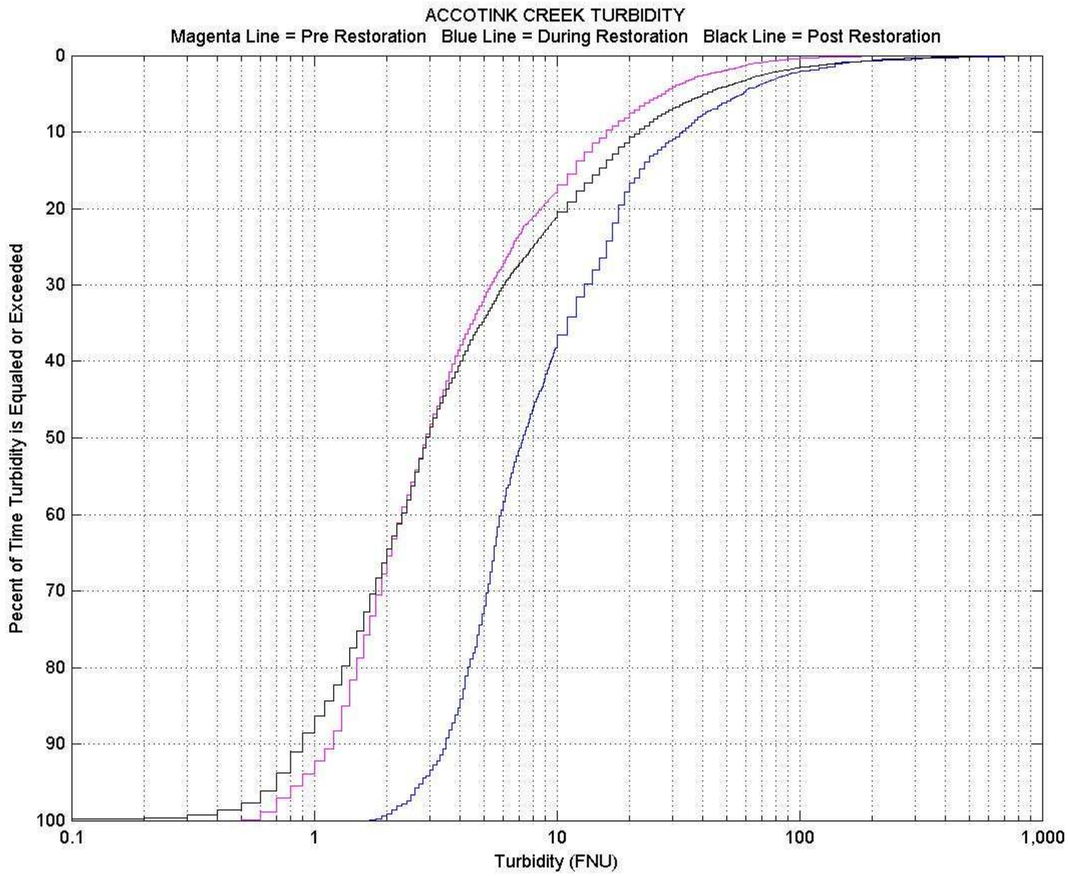

Figure 4-11. Distribution of Accotink Creek turbidity values before, during, and after restoration

An interesting pattern is observed in these turbidity distribution lines, in that the distributions of pre- and post-restoration data are similar, while the during-restoration data set indicates an increase in turbidity concentrations at all frequencies. This increase in turbidity concentrations during the restoration period is completely consistent with the in-stream patterns that were observed by field crews during the restoration period; turbidity values were frequently elevated (relative to the pre-restoration period), as the restoration work disturbed the stream channel and liberated sediments. While this pattern of increased turbidity levels during the restoration effort isn't a surprise it is interesting to observe that over the short term, the restoration appeared to result in increased turbidity levels.

Perhaps more significant than the increase in turbidity observed during the restoration work is the similarity of the distributions of turbidity values observed in the pre- and post-restoration periods. The median concentrations observed during these two monitoring periods are essentially identical, and the overall shape of the distribution curves is almost identical. This seems to indicate, that overall, the restoration did not appear to result in major changes to the in-stream turbidity levels. This observation is important because the same conclusion was reached in the analysis of the discrete water-quality samples; the restoration activities had not had an impact on sediment transport within Accotink Creek. Reaching the same conclusion regarding the effects of the restoration effort in Accotink Creek using these two different monitoring approaches lends additional support to this particular conclusion for the study.

In the analysis of these distribution curves, it is important to acknowledge that the distribution plots cannot take into account that the turbidity data were collected during time periods of differing length, and over differing hydrological conditions. These differing lengths and hydrological conditions could play a role in causing apparent differences in the distribution of turbidity values, which makes it that much more interesting that the pre-restoration and post-restoration turbidity data look so similar.

Chapter 5 Conclusions

Data collected from Accotink Creek in Fairfax City, Virginia before and after stream bank and channel restoration of 1800 linear ft (550 m) of degraded stream channel indicates the stream restoration alone has little effect on improving the conditions of in-stream water quality, stream bed, and biological habitat within a two year period of time.

Continuous water quality monitoring data showed that temperature of the creek water changed with season and wet weather flow events as expected. Temperature decreased with increasing level (i.e., increasing flow) because rain water temperature may be less than creek water temperature. The highest temperature was observed in July. This indicates that the stream temperature responds to atmospheric temperature. The rainfall temperature (particularly associated with cold fronts) appeared to dominate and was not as affected by surface temperature of impervious areas as one might expect. The other source for this cooling affect can be routing of runoff through the sewer where the runoff cools to the surrounding temperature of the buried pipe. The pH stayed close to neutral and ranged between 5 and 10. The pH was not affected by flow or wet weather events. Turbidity and conductivity appear to be event related with spikes occurring during wet weather events. Conductivity was higher in winter due to street salting during frozen precipitation events. Otherwise, conductivity decreased with wet weather flow and recovered quickly afterwards within 6 hours.

Analysis of discrete samples for chemical constituents such as SSC, SS, COD, total phosphate, total nitrogen, and ammonia and indicator organisms such as fecal coliform, enterococci, and *E. coli* indicated that wet weather concentrations were typically higher than dry weather concentrations. However, there was neither statistically significant difference in concentrations between before and after restoration, nor between upstream and downstream of the restoration. Concentrations of organisms vary with seasons and summer concentrations were significantly higher compared to other seasons.

Macroinvertebrate data such as for VASCI, HBI, and EPT taxa showed a general improvement in conditions between pre- and post- restoration for all sites. The differences are statistically significant for VASCI and HBI indices and EPT taxa. However, all sites are still below the impairment level, indicating poor water quality conditions. Further because of the large standard deviation of the invertebrate index score values, there was no statistical significant difference between the upstream control sites and the sites within the restoration reach for the VASCI and HBI indices. This is further complicated by the inherent temporal variation in macroinvertebrates studies which makes it difficult to determine the effectiveness of restoration with the short sampling periods such as the ones used in this study. The system which includes previously restored areas may not have achieved equilibrium, and might take a longer sampling period to result in greater differences in index scores.

Except for one sampling event before restoration, all the sites had similar total numbers of macroinvertebrates and there was no statistically significant difference in total macroinvertebrate abundance over the sampling dates. Most of the species identified were moderately tolerant to polluted water. There was also no significant difference in the total number of macroinvertebrates between the upstream, downstream, and restored sites. The upstream, downstream, and restored areas have similar percent dominance values. The most dominant species at these sites were Chironomidae, Hydropsychidae, Naididae, and Lumbriculidae, comprising 87% of the upstream site samples, 93% of the restored area samples, and 92% of the downstream samples. All other families were relatively rare, most composing of less than 1-2 species.

Macroinvertebrates composition changed after restoration, but did not decrease in abundance. There were more Chironomidae in all sites than Hydropsychidae before restoration. After the restoration, it was reversed; i.e., there were more Hydropsychidae than Chironomidae. These differences are probably due to the disturbance in the restored area caused by the restoration.

The regression equations developed by the USGS to relate a target water quality constituent in the discrete samples (i.e., SSC or *E. coli*) to the water quality parameters that are monitored continuously (i.e., turbidity) using discrete water quality samples collected manually during both low flow and storm flow periods, in conjunction with the continuously monitored data showed a stronger relationship between turbidity and suspended sediment than for turbidity and *E. coli.* The same conclusion was reached with the U.S. EPA data, but the relationship was much weaker. No detectable change occurred in the results of the predictive equations before and after restoration. Also, the median turbidity concentrations observed during the before and after monitoring periods were essentially identical, and the overall shape of the distribution curves was almost identical. The lack of change is either because data have not been collected over a long enough monitoring period, or the restoration activity did not impact a sufficiently substantial portion of the watershed to reduce sediment transport. This latter conclusion is supported by the pebble count data, which indicated that very little has changed in the restored reach.

Summary

One of the three hypotheses tested (Hypothesis #2) in this project was satisfied. The differences are statistically significant for VASCI and HBI indexes and EPT taxa between before and after restoration at 90% level of confidence. However, all sites are still below the impairment level, indicating poor water quality conditions in comparison to Virginia reference streams. Stream restoration was successful in stabilizing stream banks, preventing bank sloughing and further incision. This was important to the infrastructure in the stream restoration area and property owners of Fairfax City. If one of the goals of stream restoration is to restore habitat and biological communities, stabilizing banks alone may not enough to bring back species that depend on good water quality. Reduction of stormwater runoff volumes and associated pollutants of concern must be addressed through pollution source control and stormwater retrofits to achieve improved biological outcomes (e.g., detention ponds, swales, downspout disconnection program, oil grit separators, etc.). Beechie *et al.* (1996) pointed out that traditional approaches to aquatic habitat restoration concentrating on repairing or enhancing specific habitat conditions rather than restoring the landscape processes that form and sustain high quality aquatic habitats is not effective. Laeser and Stanley (2004) concluded that local restoration in and around streams are insufficient for improving the water quality of the stream as there were no changes in nutrient concentrations in association with restoration activities. Many habitats are a result of change; attempts to fix them at a particular point in space or time fail to recognize that stream channels are dynamic and that high quality habitats are a product of this dynamism. Unless larger scale watershed issues are addressed in restoration planning, the current practice of direct structural modification of channels at the site level is unlikely to reverse aquatic population declines (Bohn and Kershner, 2002).

It should be noted that the current restoration was limited by the confined area of the stream section; however, the previous restoration efforts were able to reconnect the stream flood plain and therefore were able to provide some storage in the flood plain. This project would indicate that neither the current or previous restoration measures were enough and that further volume and flow controls are necessary for the runoff further up in the watershed, before it reaches the stream channel and the modified flood plain to achieve greater habitat restoration.

Restoring healthy ecosystems that have been impacted over the years by human mismanagement is not an easy task. Restoration requires understanding of factors that caused deterioration of the ecosystem. Stream restoration alone rather than addressing the whole watershed may yield no net improvement in the health of aquatic systems. However, stream restoration was successful in protecting infrastructure and adjacent properties.

Recommendations for Further Action

The study results indicate that the stream restoration did not improve the water quality of this particular or previously restored reaches. The indications are that the hydrology has not significantly changed, though the restoration has lessened further degradation to the stream banks in critical areas. Longer term monitoring may yet prove that streambank erosion is not the source of continued sediment transport and that the sediment measured in the control and restored reaches in this study are from inherent sources upstream.

Restoration by design transitioned the stream to a step pool function to accommodate current flows, while the natural state before watershed development may have been a pool riffle structure. Because of this change, there may be a shift in the biota type as the ecosystem is in a continued state of change based on upstream watershed activities that result in the need for continued adaptation or replacement of tolerant stream biota.

A fish assemblage study should be performed and Rapid Bioassessment Survey and habitat assessment should have been performed before restoration (U.S. EPA, 1999). This can still be done in areas that need to be restored for comparative purposes.

Few run off volume water quantity controls have been implemented prior to, during or even after restoration activities. A recommendation to improve water quality involves the institution of wet weather flow controls, upstream in the watershed. Stormwater BMPs, strategically placed throughout the watershed could reduce and delay discharge to the stream. This coupled with the existing restoration, may ultimately lead to improved habitat and water quality conditions. A failure to incorporate stormwater BMPs and controls will result in continued high and flashy flows to the Accotink creek. These continuing conditions will wear on the existing restoration, and ultimately will once again begin to alter the stream channels in ways that will further degrade the system or even negate the effects of the restoration.

As improvement may not be realized in the two years post-restoration, continued monitoring, and particularly of macroinvertebrates may be warranted, as indications are that the indices are potentially still trending to improve. Also, indices for the macroinvertebrates are based on scores obtained from pristine conditions and these may be unachievable in these disturbed urban systems. To date there is no index score or attainability level that has been mapped out or charted for affected urban streams. The Accotink Creek and other restored streams like it may be approaching the highest macroinvertebrate scores for the type of watershed that now shapes the creek. Developing relevant index scores for urban and suburban areas may require a larger study (i.e., at regional and national level) to index and catalog results.

Chapter 6 References

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