EFFECTS OF STREAM RESTORATION ON IN-STREAM WATER QUALITY IN AN URBAN WATERSHED

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ABSTRACT

The purpose of this on-going project is to provide information to Municipal Separate Storm Sewer System (MS4s) operators and states on the performance of selected best management practices (BMPs), specifically, stream restoration techniques, on improving biological and in-stream water quality within an urban watershed. Accotink Creek in Fairfax City, Virginia was selected as the study location. This project involves monitoring before and after restoration of 1,800 linear feet of degraded stream channel in the North Fork of Accotink Creek from Lee Highway to Old Lee Highway in the City of Fairfax, Virginia. Restoration, which was completed in June 2006, included installation of native plant materials along the stream and 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. In-stream samples were collected and analyzed for physical, chemical, and biological (macroinvertebrates, bacterial indicators) parameters to document the changes in stream quality as a result of the restoration. The preliminary results of the sampling and monitoring are summarized in the paper.

KEY WORDS

Stream Restoration, Continuous Monitoring, Urban Stormwater runoff, Water Quality, Best Management Practices.

INTRODUCTION

Since the inception of the Clean Water Act (CWA) in 1972, the U. S. Environmental Protection Agency (U.S. EPA) has made great efforts in restoring and preserving the physical, chemical, and biological integrity of the nation's waters. However, nearly half of the nation's assessed surface water resources remain incapable of supporting basic aquatic values or maintaining water quality adequate for recreational swimming or drinking water supply. In the National Water Quality Inventory 2000 Report, states estimated that approximately 30% of identified cases of water quality impairment are attributable to stormwater runoff (U.S. EPA, 2002). Over the last few decades, the U.S. EPA established several regulatory programs to address the various point and non-point sources. However, less emphasis was placed on non-point source (NPS) pollution, which includes runoff from urban and agricultural areas.

Land development and urbanization processes impact receiving streams by adversely altering watershed hydrology in several ways. The conversion of natural forested lands to impervious surfaces associated with land development results in an increased volume of surface runoff because less water is able to infiltrate into the ground. This leads to more water entering the stream by surface runoff rather than groundwater pathways. Surface runoff is also routed to the stream channel more quickly than water that is infiltrated, or is intercepted by plants and trees. This 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 as a function of impervious area (Schueler, 1995).

Natural streams follow meandering patterns, which dissipates energy and minimizes scouring of the streambed and banks. Increased stream flows impact the natural stream channel morphology, which affects the physical, chemical, and biological integrity of the stream (Natural Resources Conservation Service, 1998). Stream channels respond to increased stream flows by increasing their cross-sectional area through widening of the stream banks and down-cutting of the stream bed. This, in turn, triggers a cycle of stream bank erosion and habitat degradation (Schueler, 1994). Stream bank erosion can lead to bank instability and increased sediment loading downstream. This increased sediment load may cause water quality degradation, negatively impacting fish, benthic invertebrates, and other aquatic life in the stream. Channel instability and the loss of instream habitat structures, such as the loss of pool and riffle sequences, also results from increased stream flows leading to degraded habitat for aquatic life. Klein (1979) noted that macroinvertebrate diversity drops sharply in urban streams in Maryland as a result of increased imperviousness. In addition to the physical damage done to the streams, stormwater runoff may bring many forms of pollution which can have a significant impact on the biological community. Sensitive aquatic insect species, such as stoneflies, mayflies, and caddisflies are replaced by species, such as chironomids, tubificid worms, amphipods, and snails that are more tolerant of pollution and hydrologic stress. One way to mitigate these stream impacts to the greatest extent possible is to use effective stormwater best management practices (BMPs).

OBJECTIVE

The overall objective of this project is to investigate the effectiveness of best management practices (BMPs), specifically, stream restoration techniques, on improving biological and in-stream water quality in an impaired stream of an urban watershed. This objective will be achieved by collecting physical, chemical, and biological data and monitoring improvement in water quality and biological conditions in the receiving stream before and after stream restoration.

STUDY LOCATION

The Accotink Creek in Fairfax, Virginia was selected as the study location. Accotink Creek and its tributaries within the City of Fairfax are important natural resources 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 the Potomac River at Gunston Cove, which then flows into the Chesapeake Bay. As a tributary to the Potomac and Chesapeake Bays, Accotink Creek has very strict sediment criteria. All state waters are designated for recreational uses and therefore must meet these water quality standards. 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.

Accotink Creek has been subject to uncontrolled runoff that deepened the creek's channel, widened the stream, deposited sediment on important aquatic habitat, and caused erosion which exposed sanitary sewer lines. High volume of runoff from impervious surfaces is the primary cause of stream degradation in the Accotink Creek watershed. Many of the fish and other aquatic life, which are important for the Creek's viability, began to disappear in recent years (http://www.fairfaxva.gov/environment/streams.asp, 10/25/2005). Overall, the stream health, calculated using 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 threatens City utilities and surrounding property. 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 the Department of Public Works and Environmental Services (DPWES) concluded that the benthic macroinvertebrate community health in the Accotink Creek was poor; habitat conditions were very poor; and fish taxa richness was low (DPWES, 2001).

Accotink 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 ribotyping (DNA fingerprinting) on fecal coliform samples from Accotink Creek. The dominant bacterial sources were geese (24%), humans (20%), and dogs (13%). Other sources identified included ducks, cats, raccoons, sea gulls, cattle, and deer (USGS, 2003).

Stormwater runoff impacts are common in urbanized areas. The City of Fairfax which has grown and developed over the years and their land-use changes have 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 uses. Much of the development in Fairfax was prior to the issuance of stormwater management regulations, which lead to a significant amount of uncontrolled stormwater entering the City's stream channels. Many of the streams are not able to handle the existing storm flows. Consequently, the City of Fairfax proactively developed a watershed management plan when faced with major water quantity and quality problems (The Louis Berger Group, 2005). Over 75% of the overall stream health condition assessments performed for the management plan indicated a fair to poor result. One cause of poor water quality and stream degradation identified by the management plan was elevated volumes of uncontrolled stormwater runoff due to directly connected impervious surfaces. Recent land development 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).

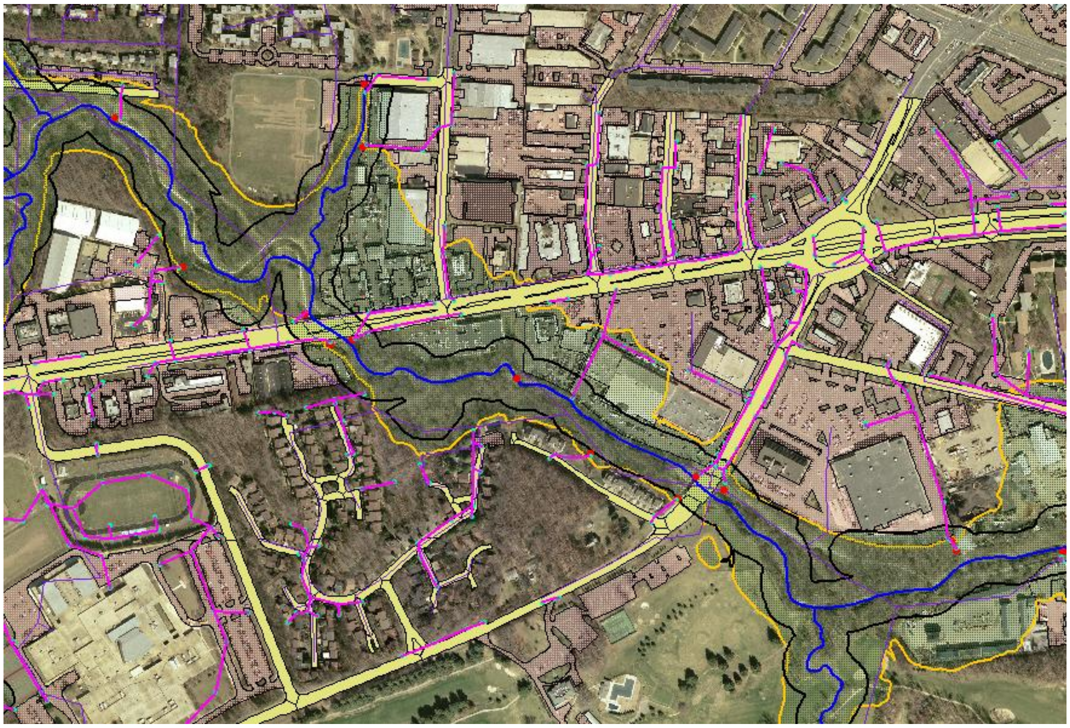
Along with other BMPs, the management plan called for streambank restoration as an important method of improving water quantity and quality. Fairfax chose to focus on areas which stood to gain the most benefit from the use of BMPs and have attempted to coordinate improvements with their overall watershed strategy by utilizing regional and holistic approaches where possible.

The Accotink watershed covers approximately 3,400 acres (5.3 mi^2) of drainage area within the Fairfax City limits. The majority of the soils in the City is well-drained and moderately coarse textured, with moderate infiltration rates; percent imperviousness is about 35% (DPWES, 2001). Elevation in the City of Fairfax watershed ranged from 425 ft above mean sea level (MSL) at its highest point to 285 ft above MSL at the point Accotink Creek flows out of the City.

Restoring Accotink Creek was necessary to reduce loss of property, restore public safety, stop the destruction of downstream habitat, and restore aquatic life native to Fairfax. 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 current project consisted of stream restoration of a segment of 1,800 lft of the North Fork of Accotink from Lee Highway to Old Lee Highway in City of Fairfax, Fairfax County, Virginia (Figure 1). The actual construction started in April of 2006 and was completed in June of 2006.

Stream restoration used coconut-fiber matting on sloped areas where willow (*Salix nigra*) stakes were planted. Imbricated rock boulders were placed in highly eroding areas to stabilize stream banks and eliminate undercutting. Root wads of felled trees during channel reconstruction were used in some portions of the stream bank both to divert flow and add natural habitat to the stream reach. This use of natural materials was cost-effective, because trees, which would otherwise need disposal, were used as a construction material in place of costly purchased materials. Rock veins were individually placed to divert stream flow from the edge of the channel to the center of the stream. In some locations, rock veins reduced stream slope, promoted pool formation, and added aquatic habitat and structure. These actions were intended to restore the stream channel to a stable condition and reduce stream bank erosion, thereby reducing sediment loads in the stream.

Figure 1 - GIS coverage of Accotink Creek showing the stream restoration (light green), riparian corridor (outlined in black), parking lots (stippled-red), roads (yellow), stormwater lines (pink) inlets (cyan) and outlets (red), 100-year flood plain (orange) and sewer lines (purple).



FIELD MONITORING

This project is a joint effort between U. S. EPA Office of Research and Development (ORD) and U. S. EPA Region 3. Current additional cooperators are the Center for Watershed Protection (CWP), Virginia Department of Environmental Quality (VADEQ), Northern Virginia Regional Council (NVRC), and the United States Geological Survey (USGS). The project's field monitoring will enable significant physical, biological, and water quality improvement in the receiving water to be quantified.

Electronic water monitoring and sampling equipment were installed to monitor pH, temperature, conductivity, dissolved oxygen, water depth, and water velocity continuously. In addition, discrete samples were collected during storm events at least twice per season both upstream and downstream locations. Additionally, dry weather samples were collected. These samples were analyzed for physical (i.e., pH, dissolved oxygen, turbidity, conductivity, temperature, total suspended solids (TSS), suspended sediment concentrations (SSC), particle size distribution, etc.), chemical (i.e., nutrients), and biological (i.e., fecal coliform, fecal streptococci, and *E. coli*) parameters.

Physical habitat monitoring and biological sampling, which includes macroinvertebrate sampling, were conducted three times before restoration to establish the pre-existing condition.

Biological sampling will be conducted quarterly for at least two years following restoration. Macroinvertebrate analysis is being performed by U.S. EPA Region 3's Wheeling Laboratory.

In addition, the USGS conducts continuous water-quality monitoring using sensors to record turbidity, specific conductance, pH, and water temperature downstream of the stream restoration area. The USGS is also collecting approximately 28 water-quality samples over a wide range of flow conditions and analyzing for *E. coli* and suspended sediment concentrations. These continuously monitored data provide detailed records of water quality, and allow the community to better understand the trends and variability in the system.

RESULTS

Water Quality Sampling and Monitoring

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. Depth was measured using differential pressure (bubbler) or pressure transducers. Twin 1 MHz piezoelectric crystals were used to measure Doppler-based velocity. Internal electronics combine the measured values using the stream cross-section to compute an associated flow rate. In addition, Yellow Springs Instruments (YSI) probes placed at the beginning and end of the restoration reach were used to measure water temperature, specific conductivity, turbidity, dissolved oxygen, and pH also at 15-min intervals.

A sample of continuous monitoring data for pH, conductivity, temperature, velocity, and level recorded by the flow meter is shown in Figure 2. It can be seen that the conductivity was higher in February due to snow and freezing events requiring street salting. Temperature of the creek water changed with the season and the wet weather flow events. The highest temperatures were observed in July.

Results of the discrete samples collected before and after restoration in both up-stream (Lee Highway) and down-stream (Old Lee Highway) locations are shown in Table 1. There are five wet weather and three dry weather sampling events in which the full suite of analytes was recorded. At this time, the sampling size of water quality data is insufficient to determine the effects of restoration, but some general trends can be reported. Data indicate wet weather concentrations of total phosphate, total nitrogen, ammonia, and COD were higher than the dry-weather concentrations typically. Total phosphate (TPO_4) and nitrogen (TKN) concentrations increased after restoration, while ammonia (NH_3) concentrations decreased after restoration, however these results can not be separated from possible seasonal variations until further monitoring can be completed. There is little overall change in COD concentrations; however, event to event variations were dramatic.

Figure 2 - An example of continuous monitoring data.

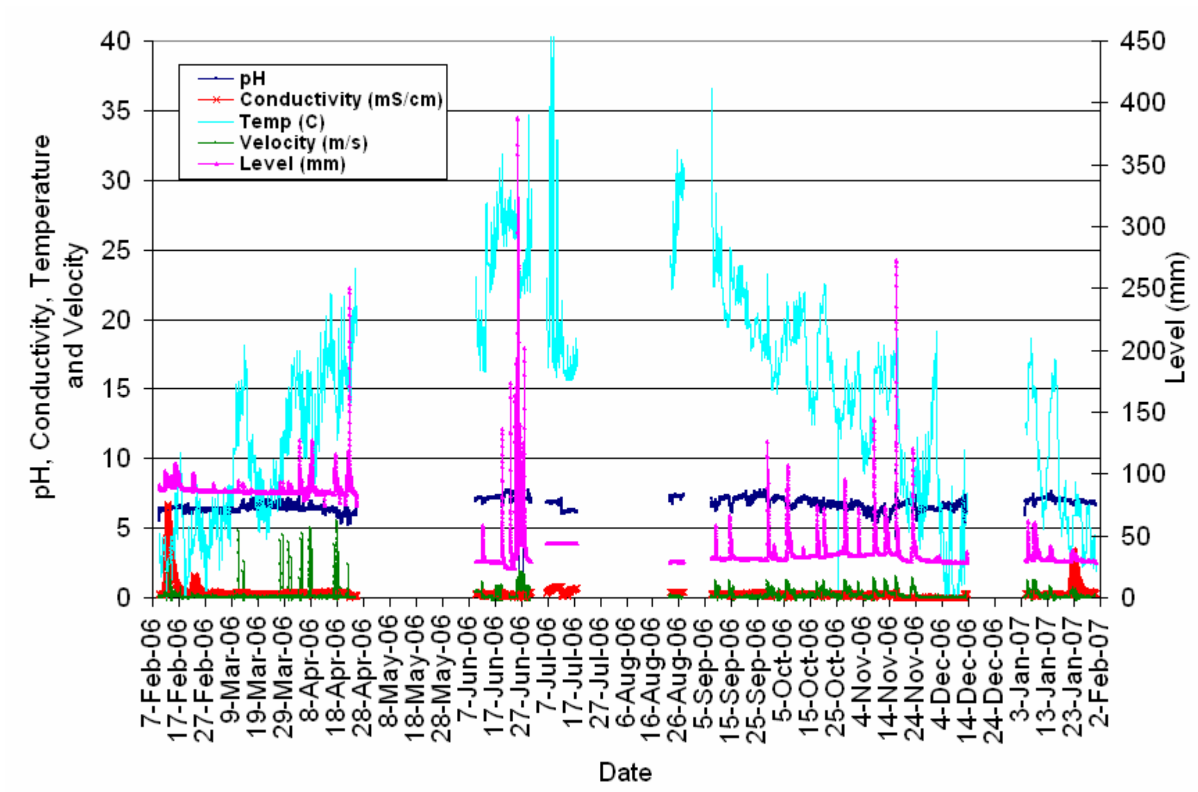


Table 1 - Results of Water Quality Analysis

	Date	Flow Condition	Upstream (Lee Highway)				Downstream (Old Lee Highway)			
			COD	TPO_4	TKN	NH_3	COD	TPO_4	TKN	NH_3
Pre -Restoration	3/1/06	Dry	0.16 (0.56)	0.03 (<0.01)	0.07 (<0.01)	0.03 (<0.01)	1.88 (0.34)	0.02 (<0.01)	0.09 (0.01)	0.03 (<0.01)
	4/5/06	Wet	14.926 (0.39)	0.02 (<0.01)	0.40 (0.02)	0.08 (<0.01)	19.44 (2.31)	0.03 (<0.01)	0.39 (0.02)	0.11 (<0.01)
	5/2/06	Dry	7.61 (0.34)	0.04 (0.06)	0.20 (0.02)	0.01 (<0.01)	10.33 (1.11)	0.04 (<0.01)	0.54 (0.05)	0.10 (<0.01)
	5/9/06	Wet	61.66 (0.88)	0.35 (0.04)	0.58 (0.04)	0.19 (<0.01)	68.01 (2.04)	0.13 (<0.01)	0.44 (0.02)	0.07 (0.01)
Post -Restoration	6/20/06	Wet	28.86 (1.21)	0.06 (<0.01)	0.61 (0.01)	0.06 (<0.01)	22.25 (0.88)	0.07 (0.01)	0.65 (0.01)	0.06 (<0.01)
	9/21/06	Dry	15.24 (0.92)	0.06 (<0.01)	0.32 (0.03)	0.08 (<0.01)	28.45 (0.35)	<0.01 (<0.01)	0.37 (0.01)	0.03 (0.01)
	10/13/06	Wet	11.08 (0.67)	0.28 (<0.01)	0.49 (0.02)	<0.01 (<0.01)	12.48 (0.85)	0.32 (0.01)	0.50 (0.03)	0.01 (<0.01)
	11/16/06	Wet	72.52 (0.94)	0.24 (<0.01)	0.83 (0.04)	<0.01 (<0.01)	67.08 (2.31)	0.22 (<0.01)	0.95 (0.05)	<0.01 (<0.01)

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

The USGS conducted continuous water-quality monitoring using turbidity, specific conductance, pH, and water temperature sensors at the downstream terminus of the stream restoration area at the bridge at Old Lee Highway. The instrument is connected to data logging and telemetry equipment that transfers all data and is available on the internet. Following the initial deployment, approximately monthly maintenance visits have been and will be performed on the continuous water quality monitor to clean the equipment and check the calibrations of the sensors following the equipment tolerances as specified by the monitor manufacturer and those outlined by Wagner and others (2000). The USGS also collected approximately 13 water-quality samples over a wide range of flow conditions that were analyzed for *E. coli* and suspended sediment concentrations (SSC).

The utility of continuous water quality monitoring may demonstrate that the above described method of data collection will prove to be an innovative, cost-effective tool for detecting in-stream water quality improvements that incorporate the effects of BMP implementation. Relationships often exist between the water quality parameters that can be measured with sensors and other contaminants of interest. For example, turbidity values typically correlate well with both suspended sediment and bacteria concentrations. The regression analysis can be used to estimate continuous concentrations of target water quality constituents analogous to the standard methods for developing continuous discharge records. Plots were developed for turbidity vs. SSC and *E. coli* (Figures 3 and 4, respectively). A correlation appears to exist between turbidity and SSC (R^2 = 0.90). Similarly, a correlation is apparent between turbidity and *E. coli*, but is not as strong as with suspended sediment (R^2 = 0.58).

Figure 3 - Correlation between turbidity and suspended sediment concentrations.

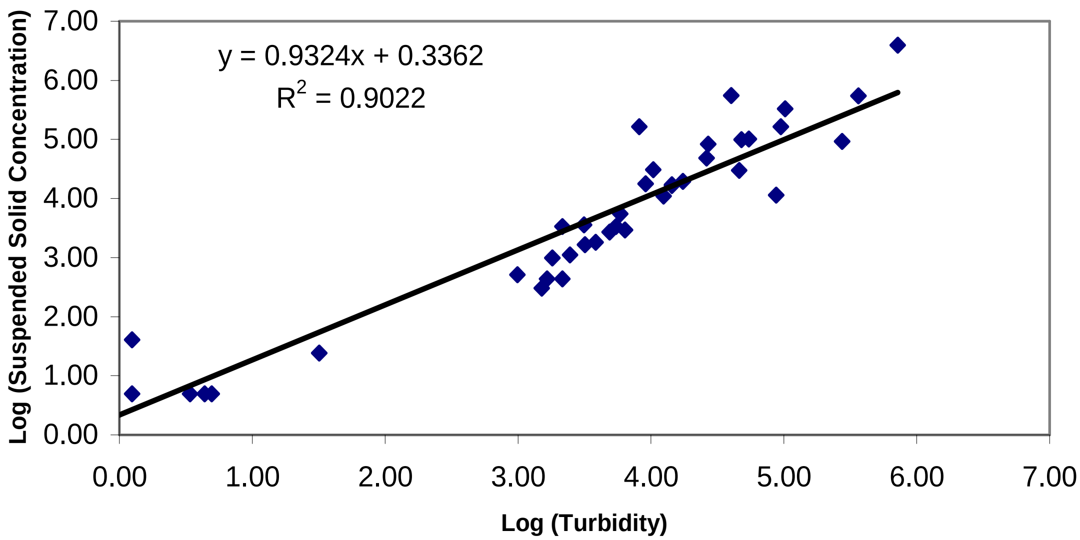
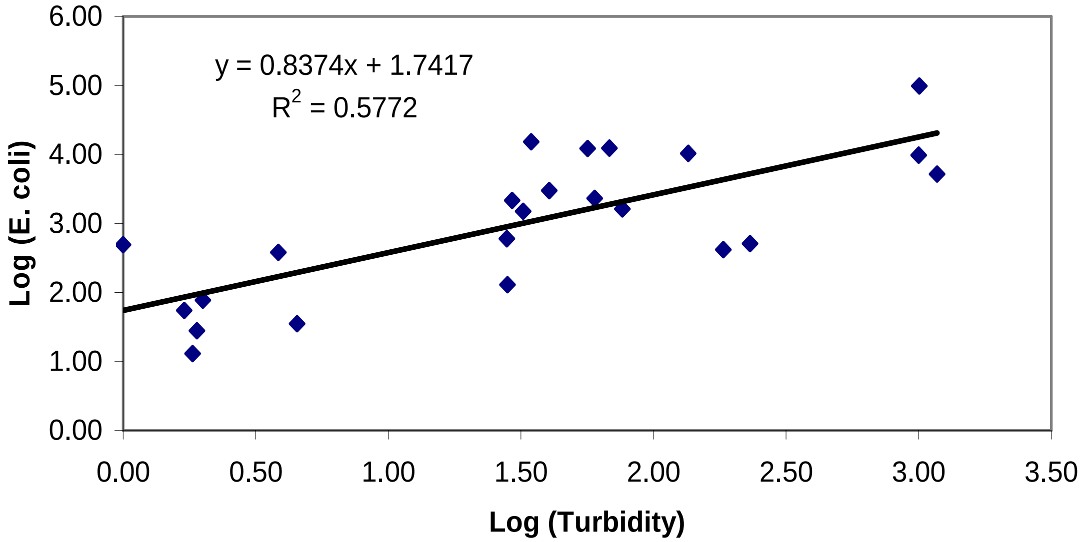


Figure 4 - Correlation between turbidity and *E. coli* concentrations.



Macroinvertebrate Sampling

Aquatic invertebrates live in the bottom parts of water coarses. They are also called benthic macroinvertebrates, or benthos (bottom animals without a backbone) and make good indicators of watershed health because they live in the water for all or most of their life, stay in areas suitable for their survival, are easy to collect, differ in their tolerance to amount and types of pollution, are easy to identify in a laboratory, often live for more than one year, have limited mobility, and are integrators of environmental conditions. They are usually found in the bottom areas of streams and under rocks for at least part of their life cycle. They include larval forms of many common insects such as Dragonflies, Damselflies and Craneflies, and crustaceans such as crayfish and scuds.

Biological integrity above, within, and below the restoration area before and after restoration were evaluated using benthic macroinvertebrate analyses. An area of 0.5 m x 0.5 m (0.25 m^2) 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 scraped. Larger substrate particles were picked up and rubbed by hand to remove attached organisms prior to kicking. Eight collections were completed in riffles of each selected stream location. The eight kick-net samples of a single location were composited into one sample for a total sample area of 2 m^2. Samples were preserved with 70% ethanol before sending to EPA Region 3's Wheeling Laboratory for analysis.

Samples were identified to the genus level in most cases. Taxa richness and invertebrate biotic indices such as the Virginia Stream Condition Index (VASCI), Hilsenhoff Biotic Index (HBI), and matrices of (dis)similarity indices were applied to determine sample and site differences. The results for VASCI and HBI are shown in Figure 5 and Table 2.

Figure 5 - Virginia Family Index Scores for before and after the Accotink Creek stream restoration showing (a) all samples, and (b) samples collected in the fall of 2005 and 2006.

a. **b.**

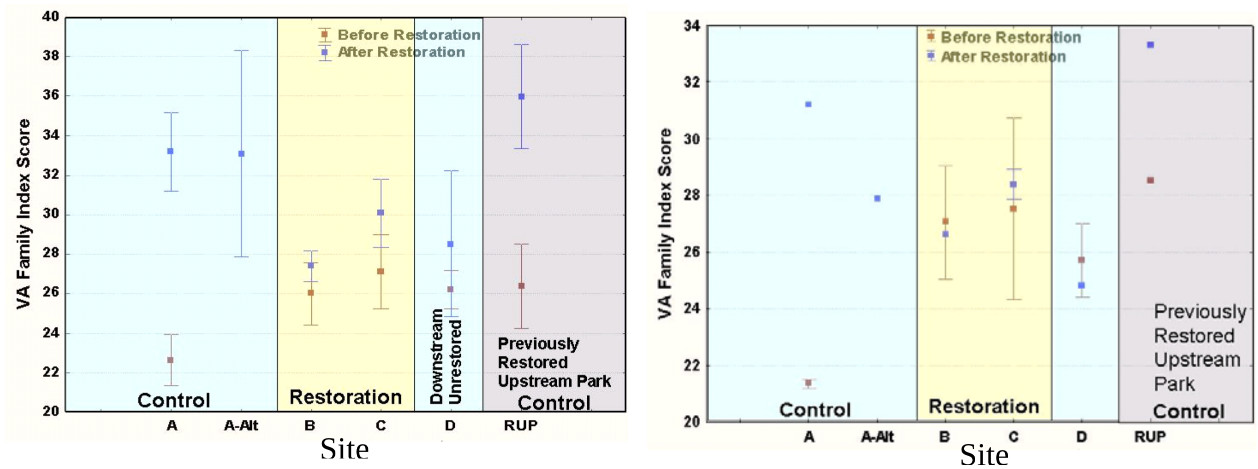


Table 2 - Results of Macroinvertebrate Analysis

Pre-, during, Post-Restoration	Date	Species	Site A (~120 m North of Lee Hwy) Upstream	Site B (~200 m South of Lee Hwy) Restoration Area	Site C (~300 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	VA SCI	21.2	29.1	24.3	25.9	
		HBI	5.91	5.87	5.94	6.06	
Pre-Restoration	12/07-08/2005	VA SCI	21.5	25.1	30.7	25.6	28.5
		HBI	6.03	6.17	6.03	6.13	5.95
Pre-Resoration	3/13-14/2006	VA SCI	25.2	23.9	26.3	27.2	24.2
		HBI	6.86	6.82	6.53	6.59	6.13
Post-Resoration	9/21/06	VA SCI	36.8	28.2	33.5	32.2	38.6
		HBI	5.38	5.90	5.75	5.71	5.28
Post-Resoration	11/15/06	VA SCI	29.6	26.6	28.4	24.8	33.3
		HBI	6.00	6.09	6.03	5.98	5.79

Note: VA SCI – Virginia Stream Condition Index
HBI - Hilsenhoff Biotic Index

Benthic invertebrate data collected to date indicate areas within the restoration have VASCI scores lower than controls after the restoration. The VASCI score at control site A was much lower than expected in the pre-restoration sampling event. Control site VASCI scores following restoration can provide an attainable goal for sites B and C within the current restoration reach. Parity between all sites of VASCI scores above 36 during the same season of the year would indicate a successful restoration for benthic macroinvertebrate habitat.

CONCLUSIONS

Preliminary data indicate that there is a good relationship between turbidity and suspended sediment concentrations (R^2 = 0.90) and a reasonable relationship between turbidity and *E. coli* concentrations (R^2 = 0.58). It is hoped that by continuously monitoring Accotink Creek and developing correlative relationships, the overall water quality trends before and after stream restoration in this impaired urban stream can be assessed. The technique of using continuously collected data may improve the understanding of trends in stream water quality. Similarly, this technique may reduce the variability that typically exists with collecting stormwater and in-stream discrete samples alone. Better assessment techniques may also inform watershed managers of the lag between stream restoration and corresponding changes in water quality. Both continuous and grab sample monitoring of physical, chemical, and biological parameters can provide information to the community on whether implementation of BMP activities will truly achieve improved water quality. With additional continuous and discrete monitoring in Accotink Creek, more predictive relationships may be made between these two monitoring types and may be ultimately linked to biological indicators. Also, longer term monitoring can allow the assessment of other planned upland enhancements on water quality and quantity in the Accotink Creek watershed.

Disclaimer: Any opinions expressed in this paper are those of the author(s) and do not, necessarily, reflect the official positions and policies of the U.S. EPA. Any mention of products or trade names does not constitute recommendation for use by the U.S. EPA.

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