Final Project Report

STROUBLES CREEK STREAM RESTORATION

A collaborative effort between the Virginia Department of Conservation and Recreation and Virginia Tech Biological Systems Engineering Department

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EXECUTIVE SUMMARY

Nationwide, numerous public agencies are expending considerable funds and effort to restore riparian forests and to control streambank erosion as a means of reducing sediment and nutrient loads, yet there is little quantitative evidence regarding the cost- and environmental-effectiveness of various stream restoration practices. This project restored 1.3 miles of Stroubles Creek and an unnamed tributary to reduce sediment and nutrient loading to the stream and to improve biological integrity. Upstream urbanization, stream channelization, and livestock access have resulted in significant streambank erosion, impairment of the benthic macroinvertebrate community, and violations of the bacteria standard. The Stroubles Creek TMDL Implementation Plan identified stream restoration on the Heth farm and the establishment of forested riparian buffers as two best management practices (BMPs) needed to reduce sediment loading. Based on the IP recommendations, the mainstem of Stroubles Creek was restored using the following three techniques: livestock exclusion, livestock exclusion with bank reshaping and replanting, and livestock exclusion with an inset floodplain. Along the unnamed tributary, cattle were excluded and a 35-ft. forested riparian buffer was planted. The restoration project was completed in May 2010. Just three months after project complettion, the channel has noticably narrowed, there is distinctly less fine sediment on the gravel bed and alternating gravel bars are forming. Long term project impacts will be assessed using pre- and post-project topographic surveys. Additionally, Virginia Tech students will continue to assess the biological integrity of the reach using benthic macroinvertebrate and fish surveys. It is estimated the project will produce an reduction of 242 tons/yr of sediment, 33 lbs/yr of phosphorus, and 190 lbs/yr of nitrogen. Faculty within the Biological Systems Engineering department at Virginia Tech are developing the project site into an outdoor laboratory; the site was the focus of four formal and numerous informal tours during the project period. Project success will be assessed based on vegetation success and channel stability. Project results will be communicated locally and nationally through site tours, a project web site, outreach materials, and scientific publications.

ACKNOWLEDGEMENTS

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PROJECT DESCRIPTION

Project Need

Stroubles Creek, a tributary of the New River, was listed on the 1998 303(d) list for a benthic impairment along a 4.98-mile segment (VAW-N22R_STE04A00) between the Virginia Tech Duck Pond and the downstream confluence with Wall Branch. A 2003 TMDL study identified sediment as the primary stressor, with additional contributions from organic matter and nutrients. Construction and streambank erosion were cited as major sources of sediment within the watershed. The Stroubles Creek Benthic TMDL was approved by EPA in January 2004 (VADEQ and VADCR, 2003) and the Implementation Plan (IP) was approved in 2006 (Yagow et al., 2006). This stream segment was also listed on the 2002 303(d) list for violations of the bacteria standard, but a TMDL has yet to be developed. Stroubles Creek is a tributary to the New River, an American Heritage River. Improved landuse management within the New River Watershed is crucial for the protection and preservation of this important national resource.

The 6,120-acre watershed corresponding to the impaired segment of upper Stroubles Creek is located in Montgomery County, Virginia and the headwaters include major portions of the Town of Blacksburg and the Virginia Tech campus. The main land use category in this watershed is urban/residential, comprising approximately 46% of the total area. Forest, pasture, and cropland acreage account for the remaining 28%, 21%, and 5% of the watershed area, respectively. Extensive streambank erosion in the downstream sections of Stroubles Creek has resulted from increased flows due to extensive urban development in the headwaters, stream channelization, and cattle access to the stream on the former Heth farm, which is currently owned by the Virginia Tech Foundation, a private, 501(c)(3) non-profit organization. The project watershed is 4,180 ac. with 17% commercial/institutional, 6% cropland, 6% forest, 23% pasture, and 48% residential. The reach of Stroubles Creek flowing through the Heth farm is a poorly formed gravel-bed riffle-pool stream with occasional bedrock exposures. The gravel bed is embedded due to high suspended sediment loads.

Of the 47,000 farms in Virginia in 2005, over half of those farms (25,000) were cattle operations with a total land area of over 1.2 million acres (USDA-NAS, 2006). Uncontrolled access to streams is common throughout Virginia to provide cattle drinking water and to allow the animals to cool off during warm weather. Research has shown that livestock access to streams causes soil compaction, erosion, and damage to riparian vegetation, resulting in changes in watershed hydrology, channel morphology, and water-quality impairments (Belsky et al., 1999). While extensive research has been conducted on the impacts of livestock exclusion on stream systems, the majority of this research was conducted in the western United States (USDI, 1994). Existing research on eastern streams is limited, but has shown that complete livestock exclusion reduces streambank erosion rates and improves water quality (Line et al., 2000; Agouridis et al., 2004).

Riparian forest restoration is a management option for improving stream ecosystems since woody riparian buffers filter pollutants from adjacent sources (Herson-Jones et al., 1995; Lowrance et al., 1995; King et al., 1997), and regulate hydrologic and nutrient fluxes, light and temperature regimes, physical habitat, and the food/energy base (Gregory et al., 1991; Sweeney et al., 2004). Data concerning streambank erosion as a pollution source and the benefits of stream restoration activities in reducing instream nutrients and sediment are scarce, leaving watershed managers with questions regarding the cost-effectiveness of streambank stabilization and riparian reforestation for sediment and nutrient reduction, as compared to other management practices.

Project Objectives

The overall project goal is to remove Stroubles Creek from the Clean Water Act list of impaired waters [303(d) report]. Specific project objectives include the following:

1. Improve aquatic habitat within Stroubles Creek, as indicated by a change in the Virginia Stream Condition Index score for the benthic macroinvertebrate community from the current average of 45.3 to >60 for two successive samples;
2. Reduce sediment loading from eroding streambanks of Stroubles Creek and an unnamed tributary by removing cattle access from a total of 1.3 miles and by conducting a Priority 4 restoration (reshape and revegetate banks) on 1,800 ft. (0.34 mi.) of stream and a Priority 2 restoration (natural channel design) on 2850 ft. (0.54 mi.);
3. Reduce bacteria loadings to the stream by removing cattle access to the stream and restoring forested riparian buffers, thereby, proactively addressing the bacteria impairment, as measured by continued DEQ monthly monitoring at two downstream stations;
4. Assess the effectiveness of three methods of stream rehabilitation: livestock exclusion; livestock exclusion with bank reshaping and replanting; and, livestock exclusion with natural channel design; and,
5. Develop an education and outreach program on stream function and restoration which highlights the project.

Overall Content

As indicated in the Implementation Plan (IP), restoration of the section of Stroubles Creek on the former Heth farm is critical to reducing sediment, nutrient, and bacterial loading to the stream and to improving instream biological integrity (Figure 1). This stream segment is currently impacted by both increased flows from urbanized areas of the watershed, previous channelization, and cattle access; average streambank erosion rates as high as 19 in/yr have been measured (Figure 2). This project restored over one mile of Stroubles Creek and an unnamed tributary and will be used long term to compare three standard methods of streambank stabilization/restoration: cattle exclusion, cattle exclusion with bank reshaping and stabilization, and cattle exclusion with natural channel design. Completion of this project provided riparian buffers along the majority of the impaired reach and has reduced streambank erosion on the former Heth farm, achieving two major objectives of the IP. The project will provide ultimately information on the cost-effectiveness of typical stream restoration methodologies. Considering over one billion dollars are spent annually in the US on stream restoration (Bernhardt et al., 2005), an economic and physical comparison of stream restoration practices will provide valuable information to help guide future projects. Additionally, this project complements ongoing work within the watershed to reduce stormwater flows from the Town of Blacksburg and Virginia Tech. Project results continue to be disseminated across the New River watershed, the Commonwealth, and the nation through an education/outreach program.

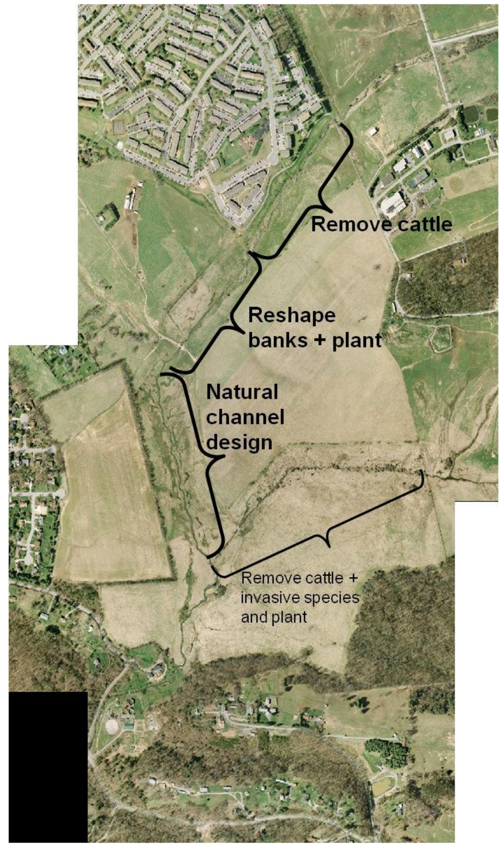

Figure 1. Layout of implemented restoration treatments along Stroubles Creek and an unnamed tributary on the former Heth Farm.

Methodology

As outlined in the 2006 Implementation Plan (Yagow et al., 2006), streambank erosion along a total of 1.3 miles of Stroubles Creek and an unnamed tributary (UT) within the impaired reach was reduced using three standard restoration techniques. The mainstem Stroubles Creek, upstream of the confluence with the UT, was divided into thirds, based on both distance and minor tributary and stormwater inflows (Figure 1).

Cattle were excluded from all stream reaches on the project site in July 2009; following cattle exclusion, the existing vegetation regrew rapidly (Figure 3). The upper third of both the UT and the mainstem of Stroubles Creek were both allowed to recover naturally, without further input (research treatment 1). This treatment represents the lowest level of input in a stream restoration project. While the vegetation has recovered following cattle exclusion, bank retreat continues to occurs as the channel adjusts to a stable geometry.

In the middle third of the mainstem, the next level of stream restoration was conducted (research treatment 2). To stabilize the streambanks and to ensure the establishment of native woody vegetation, unstable streambanks (those undergoing active geotechnical slope failure) were reshaped to a geotechnically stable angle (3:1) using a track hoe. Because only failing streambanks were graded, the 3:1 slope was used as guidance and the bank slope was ultimately adjusted in the field to tie the regraded slopes into existing stable banks. The toe of each excavated slope was stabilized with 12-in. diameter, 10-ft. long coir fiber logs. The logs were sewn together and staked to the toe of the bank. Coir Each regraded bank was raked, seeded, and mulched with straw. Coir fiber matting was placed on top of the straw, sewn to the coir fiber logs, and staked and stapled in place. The matt edges were buried to a depth of at least 4 in. The lower banks and inset floodplains were seeded with a wetland mixture. The upper banks were seeded with a mixture of annual and perennial rye grass. The bank faces were planted with 2-in. tubelings. The lower banks were planted with native wetland herbaceous species and the upper bank faces were planted with native shrubs (Appendix A). Invasive plant species, primarily multiflora rose and autumn olive, were removed by cutting at ground level following planting. Subsequent regrowth will be sprayed with a general herbicide that is safe for use in riparian areas. Figure 4 shows a streambank prior to and following restoration.

Figure 2. Streambank erosion along Stroubles Creek on the Heth farm.

The lower third of Stroubles Creek was restored based on natural channel design (Priority 2 restoration) and analytical techniques (sediment entrainment and bank stability calculations, and flood modeling; research treatment 3). In 2005 Dr. Wynn installed a stream gage adjacent to the concrete bridge on the site. Since that time, graduate students in the Biological Systems Engineering Department have been measuring stream discharge during storm events to develop a rating curve for the gage.

A reference reach along Stroubles Creek, upstream of the project site (Figure 5) was identified and surveyed to develop initial stream cross sections (Table B1). The restoration reach was classified as a C4 stream by the Rosgen (1994; 1996) classification. The sinuosity for Stroubles Creek (1.1; Table B1) was less than the value (1.2) specified by the classification system. This difference was attributed to the different physiographic soils. The classification scheme was developed in western United States and may

Figure 3. Upper section of Stroubles Creek on the Heth farm (research treatment 1) with cattle (a), taken from the streambank looking at the channel and following cattle exclusion (b), taken from the stream, just downstream of the bridge in (a).

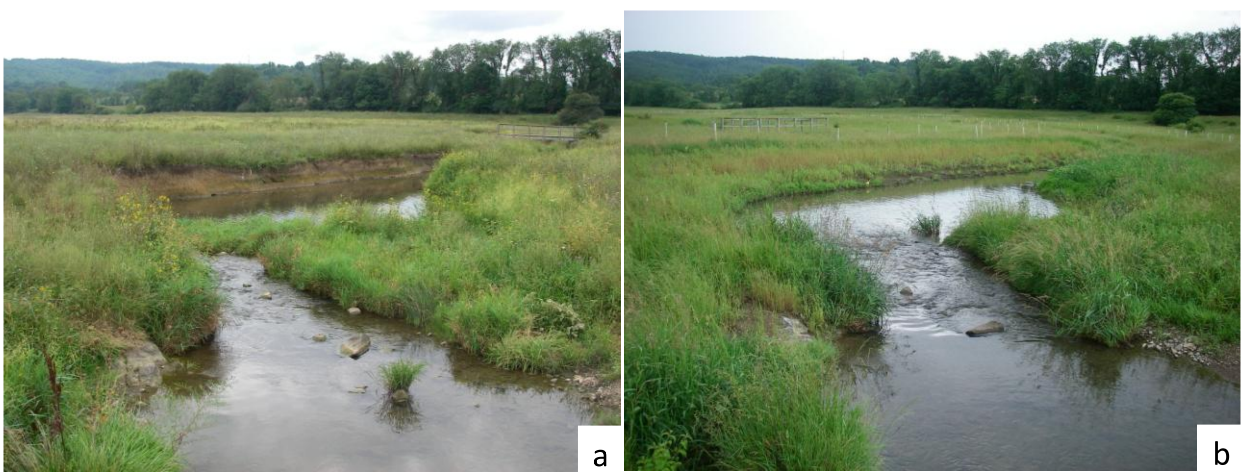

Figure 4. Middle section of Stroubles Creek on the Heth farm (research treatment 2) prior to restoration (a), and nine months following restoration.

not properly define eastern streams. The restoration reach may have been historically channelized to increase farmable area. All other values, entrenchment ratio (6.1), width/depth ratio (16.7), and slope (0.0079-0.36%; Table 2), fell within the classification ranges. For these reasons, the stream was classified as a C4 stream. However, because the reference reach was located close to the Duck Pond, these data were used only as a guide.

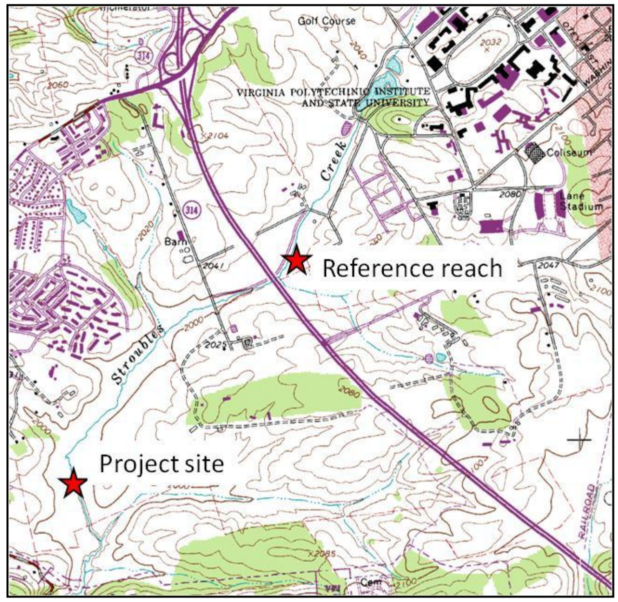

Figure 5. Reference reach location.

Using the reference reach data as an initial design, a two-stage channel was designed to create a lower bench that is inundated annually by flows of 200 cfs, and a high bench accessible every 2.5 years (300 cfs; Table 2). Design storm event discharge values were estimated using gaging station data gathered on a perennial stream in the Blue Ridge physiographic province and gaging data collected on site. Additional information was generated using the Virginia Tech/Penn State Urban Hydrology Model and regional curves (Keaton et al., 2005; Kibler et al., 2005; Table 2). Hyetographs were developed for each storm event (2, 5, 10, 25, 50 and 100-year) based on rainfall data for the 24-hour storm for Montgomery County, Virginia (DCR, 1999). Manning's n was calculated using stage-discharge curves at known cross sections and compared with tables from Chow (1959; 0.012). These data were then combined with cross sections at each riffle, estimated Manning's n for coir logs (0.014), and a 3:1 bank slope to determine the necessary geometry which could contain the bankfull discharge (200 cfs). An inset floodplain was then designed to contain an estimated 2.5-yr flood (300 cfs) given an estimated floodplain Manning's n, and 3:1 side slopes. The calculated geometries were then checked to ensure sand-sized particles would be moved at 200 cfs, to provide regular scouring of the gravel bed, and to minimize movement of 84th percentile grain size (21 mm) at 300 cfs, to maintain the riffles. The mobility of the different grain sizes was determined using Shield's diagram and a dimensionless critical shear stress of 0.045. Because no bedload transport data were available, only bed material entrainment was modeled.

Table 2. Flood recurrence interval estimations used for Stroubles Creek.

Recurrence Interval (yrs)	Regional Curves for Maryland, Virginia and West Virginia (cfs)	Log Pearson type III for Abrams Creek, Northern Virginia, USA (cfs)	VTPSUHM (cfs)	Regression Model (cfs; Discharge versus Drainage Area; Keaton et al., 2005)
Bankfull			225	170
1		71		
1.5		212		264
2	470	282	442	
5	808	388	890	
10	1179	424	1416	
25	1377	494	1699	
50	1578		1990	
100	1987		2595	

There are several methods used to sample bed material; however, the prevailing method is the Wolman (1954) pebble count. Using the Wolman method, a pebble count was conducted on a riffle to describe the grain-size distribution of surface bed material. A modified version of the Wolman method was used to determine a reach-wide median particle size (D_{50}) of 8.9 mm (Rosgen, 1998). Sediment size distributions are listed in Table 3.

The initial design cross-sections were adjusted to reduce shear stress on the banks and to increase flood accessibility along designed floodplains (NCSRI, 2002). Field observations of Stroubles Creek on the Heth Farm in Blacksburg, VA, revealed that bank retreat processes were taking place, many of which are caused by scour of the lower streambanks, which then lead to cantilever failure of the upper bank (Figure 2). The Bank Toe Erosion Model (BSTEM version 4.1) was used to better understand the factors that contributed to bank failure, and to test the effectiveness of restoration design. It is an Excel-based model that calculates bank factor of safety (FS) for new or existing banks (USDA-ARS, 2006). It can also be used to model hydraulic erosion caused by hydraulic shear stress. Thus, the effects of erosion protection on the bank and bank toe can be incorporated to show the effectiveness of such measures (USDA-ARS, 2006). The model was applied to riffle cross sections along the design reaches of Stroubles Creek to determine current bank stability and to estimate the potential effects of our restoration design.

Table 3. Stroubles Creek particle size distribution.

Diameter Class	Diameter (mm)
D16	4
D35	8
D50	11
D65	14
D84	21
D95	27
Rosgen D50	9
Rosgen D84	15

Streambank erodibility parameters were needed to estimate bank scour during storm events using the BSTEM model. The rate of erosion (E_r in cm/s) is related to the erodibility of the streambank (K_d in cm^3/N-s), shear stress of the water (τ in Pa) applied on the bank, and the maximum allowable shear stress the bank can withstand without erosion (τ_c in Pa; Eqn. 1).

$$E_r = K_d\,(\tau - \tau_c) \qquad (1)$$

Values for K_d and τ_c were determined using a method developed by Hanson and Cook (1997) and the multi-angle submerged jet test device. The device applies a jet of water to the bank, which creates a scour hole. Scour depths are measured at 5-min. intervals for 45 min. Average values for K_d and τ_c were 0.7 cm^3/N-s and 10.6 Pa, respectively. These values were incorporated into the BSTEM model to evaluate pre- and post-restoration bank stability.

A sensitivity analysis was conducted to evaluate the influence of multiple design parameters on the proposed stream cross sections. Bankfull discharge, particle size distribution, Manning's n, and the Shield's dimensionless critical shear stress were varied across an expected range and Monte Carlo simulation was conducted to evaluate the range of possible design channel geometries. Sensitivity analysis results indicated the range of possible "reasonable" channel geometries determined based on flow and sediment entrainment modeling varied over four orders of magnitude. This analysis is summarized in a journal article that will be submitted to the Journal of the American Water Resources Association (JAWRA) in 2010.

The final design cross sections were ultimately determined based on all of the design methodologies and existing site constraints (Appendix C). To minimize impact to Stroubles Creek and because the stream sinuosity on the project site was similar to the reference reach, we did not change the existing planform and baseflow channel width. Thus, the main dimensions were elevation and width of the inset floodplain. Elevation of the inset floodplain was determined primarily based on the bed material entrainment constraints discussed previously (mobilize sand annually and do not mobilize the D84 material at the 2.5-yr return period); this elevation corresponded to existing depositional surfaces on the site, confirming our design. Thus, the width of the inset floodplain was the most flexible aspect of the design. This width was set at each cross section based on site constraints. Extensive emergent floodplain wetlands exist along both mainstem Stroubles and the UT. The wetland hydrology is controlled by surface and subsurface hillslope runoff, a restricting subsurface soil layer which perches water on the floodplain, and a small levee along the channel. To minimize impact to these wetlands, the width of the inset floodplain bench was limited to a width that would not completely remove the levee and drain the floodplain wetlands. Once graded, the streambanks in research treatment 3 were stabilized and planted in the same manner as the treatment 2 reach. Figure 6 shows an example of research treatment 3 as constructed.

Figure 6. Students planting streambank with inset floodplain (research treatment 3). Students are standing on the inset bench.

In addition to stream channelization, floodplain wetland adjacent to Stroubles Creek were previously ditched and drained and several relic agricultural drainage ditches cut through the levee. To provide stable access to the stream for equipment and to reverse this prior wetland drainage, these ditches will be filled with soil plugs. Following construction, these plugs were stabilized with vegetation.

The original stream restoration design included the removal of a corrugated metal culvert and concrete crossing on the UT. Following the start of the restoration construction, the tenant at the Heth farm changed from the Wall Brothers dairy to the Virginia Tech farm operations. Because the university farms wanted access to hay fields in the southern part of the property, we agreed to leave the culvert and concrete crossing on the UT. Because the stream slope was not being altered by the culvert removal and because the eroding streambanks along the UT were stabilizing naturally, we did not regrade the UT streambanks and limited restoration to cattle exclusion, invasive species control, and establishment of a 35-ft wide woody riparian buffer in the lower two-thirds of the UT.

As part of research treatments 2 and 3, and restoration along the UT, native riparian buffers were established. A total of 7467 2" diameter herbaceous tubelings were planted (Appendix A). Native shrubs (1145 tubelings and 300 2-ft.) and trees (1531 tubelings and 115 4-ft.) were planted to achieve a 35-foot woody riparian buffer. The tubelings were planted by volunteers, while the larger trees and shrubs were planted by a contractor and included a tree shelter and a VisPore mat. Over 1200 hours of labor was volunteered by Virginia Tech faculty and students, as well as local citizens, to install erosion control measures and to plant vegetation. In addition to plants purchased with project funds, several donations of plant materials were made. RPM Ecosystems, LLC donated 80, 3-gallon experimental trees to compare to standard bareroot plantings (Appendix A). The roots of these trees were air-pruned to accelerate growth. While this experiment will not be scientifically defensible, it will provide some anecdotal knowledge regarding the success of RPM trees and traditional plantings under similar field conditions. Additionally, 2500 willow tubelings were donated by Wetland Studies and Solutions, Inc. in Gainesville, VA. Environmental Services and Consulting, LLC in Christiansburg, VA donated approximately 200 live stakes that were a mixture of silky dogwood, black willow, silky willow, elderberry, and nine bark. As of July 2010, there was 76% survival of trees and shrubs planted in with tree shelters. Because of the dense vegetation across the site, it was impossible to determine which individual plants were planted versus volunteers.

Monitoring Plan

The project area will be monitored for the first three years following construction to ensure the maintenance and success of the bank stabilization treatments and riparian buffer vegetation. Physical assessment of the stream restoration effort will include monitoring of permanent cross sections as well as the longitudinal profile of the channel.

A. Cross section monitoring will be conducted to determine the extent of lateral channel migration, changes in cross section geometry, and erosion/deposition dynamics. At least three permanent cross sections will be established in each research reach. Permanent cross sections will be identified by installing markers which consist of permanent iron rods (two per cross section) with orange plastic safety caps placed approximately 35 feet beyond the top of the left and right banks, but not beyond the limits of the established riparian buffer zone. Permanent iron rods will be field surveyed, and coordinates noted such that lost rods can be relocated and re-established. Cross section geometry will be measured and photographs will be taken at these stations at the same time of year during low flow conditions prior to construction and for each of the first three years following completion of construction.

B. Longitudinal profile monitoring will be conducted to determine and document geometric changes as well as depth/velocity regimes at different bed features. A field survey of the longitudinal profile of the thalweg will be completed prior to construction and each year for the first three years following completion of construction. Each profile will be compared to the pre-existing profile and subsequent post-construction profiles.

Riparian vegetation monitoring will be performed to ensure vegetative success. Vegetative success will be defined as 30% cover by non-invasive species after one full growing season, 60% cover after two full growing seasons, and 75% cover after three full growing seasons. This monitoring will include the establishment of permanent photographic stations along the stream, upon completion of construction. Photographs will be taken at these stations at the same time of year during the height of the growing season for each of the first three years following completion of construction. Additional remedial plantings, removal of invasive species and maintenance or upkeep of existing vegetation required to ensure vegetative success will be conducted as necessary.

Aquatic ecosystem integrity will be assessed using benthic macroinvertebrate and fish sampling. Faculty in the Biological Sciences department will use the project site as a field laboratory for the Freshwater Ecology course, thus providing both biological assessment of the project and educational opportunities for students. Additionally, the student branch of the American Fisheries Society has volunteered to sample the project site to assess the fish community.

Education and Outreach

The restoration project has and will continue to have impacts locally and nationally. Locally, this project educates the residents of Blacksburg and the New River watershed about water-quality issues in the Stroubles Creek watershed, as well as faculty and students on the Virginia Tech campus. The location of this project just downstream from the Virginia Tech campus and adjacent to the Huckleberry Trail (a rails-to-trails path) makes it highly visible to a broad audience. An outreach sign was designed and installed along the Huckleberry Trail at the upstream edge of the property (Appendix D). The sign is located along a section of trail that has high traffic volumes (Figure 7). Brochures describing the project and providing basic water quality information were also developed and are available at the outreach sign and for tour groups.

Figure 7. Project outreach sign (a) along Huckleberry Trail (b).

Virginia Tech and the Town of Blacksburg have a number of demonstration sites for water-quality practices, including riparian buffers, clustered development, and rain gardens. This project provides a valuable addition. Building this set of demonstration practices increases Virginia Tech's capacity for sharing watershed-management practices with other communities, residents, consulting engineers, and landowners living adjacent to streams through tours, workshops, news releases, volunteer riparian buffer plantings, and conferences. The project was featured in tours for the Virginia chapter of the Soil and Water Conservation Society (4/25/2009), the Virginia Tech Master Gardener's College (6/24/10), the NASA Inspire program (7/6/10) and the Center for Engineering Education Diversity (7/8/10).

This project was also used as a real world example of stream restoration techniques for the education of both undergraduate and graduate students at Virginia Tech. The project was featured in a junior-level hydrology course (BSE3305), a senior level watershed management course (ALS 4614) and a new course on stream restoration (BSE5984) co-taught by Drs. Hession and Wynn. Additionally, the Advanced Wetland Soils class (CSES 5864) developed wetland mitigation plans for the site as a semester project. Over 200 individuals volunteered at the restoration, learning first hand about nonpoint source pollution and water quality.

The project has national exposure through the Center for Watershed Studies and presentations at national conferences. This center comprises one of the leading academic groups involved in TMDL and watershed management research in the U.S. The main goal of the Center is to improve the scientific basis for, and methodologies used in, the development, implementation, and evaluation of TMDLs in watersheds impaired predominantly by NPS pollution. Faculty from the Center have established Stroubles Creek as an outdoor laboratory with a rain gage network, a stream gage, floodplain piezometers, three monitoring bridges, and a camera with a radio transmitter. The long-term goal is to have real time water quality data and images available on the web site for use in education and outreach (http://www.cws.bse.vt.edu/index.php/research/project/stroubles_creek_restoration). This site was also featured in a stream restoration workshop Drs. Hession and Wynn conducted as part of the 2008 American Ecological Engineering Society conference in June. The Stroubles design site was used as an example in the design charette and a tour of the site was given to the 25 workshop participants.

While not part of the actual stream restoration project, several synergistic activities have and will continue to occur. Dr. Erich Hester, a new faculty member in Civil and Environmental Engineering, installed piezometers in the bed of Stroubles Creek upstream of and within the restoration reach to examine changes in hyporheic flow due to the restoration project. The Biological Systems Engineering (BSE) department holds an undergraduate research program each summer, funded by the National Science Foundation (NSF-REU). Four NSF-REU students conducted research on the restoration reach during summer 2009 under the direction of Drs. Hession, Scott, and Wynn. Dr. Durelle Scott, a new faculty member in Biological Systems Engineering, conducted a tracer study of the reach to examine pollutant travel time in the pre-restoration condition. Additional studies will be conducted in the future to examine changes in hydraulic retention time within the reach following stream restoration. Similar research is being directed by Drs. Hession and Wynn, looking at the flow of groundwater through the floodplain on the restoration site. As part of this research, the floodplain sediments are being mapped to help better understand the site history and hydrology. Changes in site hydrology following stream restoration will be evaluated. These projects serve to increase our understanding of the impact of stream restoration on water and pollutant transport through floodplains and streams and to educate the next generation of water quality professionals.

Environmental Results

The overall project goal is improvement in the health of the benthic community in Stroubles Creek and the removal of Stroubles Creek from the Clean Water Act list of impaired waters [303(d) report]. The project provided riparian buffers along much of the impaired reach and is reducing streambank erosion on the Heth farm, achieving two major objectives of the IP. In addition to reducing fine sediment inputs to Stroubles Creek, the restoration project is encouraging the development of an improved physical structure of the stream channel. The stream has narrowed significantly, a common response to the elimination of livestock impacts. Coarse sediment deposition is occurring throughout the site, including the formation of alternating gravel bars (Figure 8). Prior to the restoration project, little coarse sediment was stored in the reach. Additionally, by removing cattle access to the stream, the project takes a proactive approach to reducing bacterial loading to the stream, which could serve as a basis for reclassifying the segment to a 4B category (impaired or threatened for one or more designated uses but does not require the development of a TMDL because other pollution control requirements are expected to result in attainment of the water quality standard by the next reporting period). By plugging the outlet of historic agricultural drainage ditches, prior wetland degradation was reversed, improving the quality and quantity of existing floodplain wetlands. While there were minor, short-term sediment impacts to the stream from construction, ultimately, the project significantly reduced sediment loading to the channel and enhanced aquatic resources by stabilizing the streambanks and establishing a native, woody riparian buffer.

Based on model simulations and erosion pin data used in the development of the Stroubles TMDL Implementation Plan (Yagow et al., 2006), the combination of streambank stabilization and riparian buffer pollutant removal from upland agricultural fields will result in an average sediment reduction of 51 lbs/ft-yr, or a total of 175 tons/yr. Since nitrogen and phosphorus were not assessed during the TMDL IP plan, the pollutant removal rates used in version 4.3 of the Chesapeake Bay model for stream restoration (0.0035 lbs/ft of phosphorus, and 0.02 lbs/ft of nitrogen) were assumed, resulting in estimated nutrient reductions of 24 lbs/yr of phosphorus, and 137 lbs/yr of nitrogen by this project. This analysis does not consider changes in sediment load due to storage within the restored channel or additional nutrient reductions resulting from improved stream nutrient processing. There is some evidence that restoring streams to reconnect them to their floodplain may enhance denitrification (Gooseff et al., 2004; Mayer et al., 2004).

Figure 8. Alternating gravel bars forming at the restoration site.

Because a bacterial TMDL has not been developed for Stroubles Creek, bacterial loading rates were not available. However, since research has shown that bacteria preferentially attach to sediment particles, reductions in sediment loading to the stream will likely produce concurrent reductions in bacteria loads (Henry, 2004). Removing cattle access to the stream also produces a direct reduction in bacterial loading.

By utilizing three different restoration methods, the relative success and cost of each technique can be evaluated. Because the property is owned by the Virginia Tech Foundation and is located just downstream of the main campus, it is easily accessible for university faculty, staff, and students for the foreseeable future. This project will continue to provide important data on whether active stream restoration is a cost-effective method of reducing nonpoint source pollution, as compared to natural revegetation and bank stabilization.

This project also has the potential to produce water-quality benefits across the Commonwealth. Water quality problems within the upper Stroubles Creek watershed are typical of many areas in the mid-Atlantic: increased stormwater runoff due to urbanization, channelization, and cattle access have created an unstable eroding stream channel in the lower watershed. By demonstrating and evaluating different stream restoration practices, cost-effective solutions to stream restoration can be developed within the New River watershed and across in the Commonwealth.

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Appendices

Appendix A. Plant list

Appendix B. Stroubles Creek stream restoration design data

Appendix C. Design plans

Appendix D. Outreach sign

Appendix A. Plant list

Table A1. Plant list

Quantity	Species	Common Name	Type	Description
50	ACER RUBRUM	Red Maple (bareroot)	Tree	4 ft.
10	ACER RUBRUM	Red Maple (RPM)	Tree	4 ft.
100	ACER SACCHARUM	Sugar Maple (bareroot)	Tree	4 ft.
100	ACER SACCHARUM (sugar)	Sugar Maple	Tree	tubeling
40	ALNUS SERRULATA	Hazel Alder (bareroot)	Shrub	2 ft.
258	ANDROPOGON GERARDII	Big Bluestem	Herbaceous	2" plug
93	ARONIA ARBUTIFOLIA	Chokeberry	Shrub	tubeling
514	ASCLEPIAS INCARNATA	Swamp Milkweed	Herbaceous	2" plug
258	ASTER NOVAE-ANGLIAE	New England Aster	Herbaceous	2" plug
258	ASTER NOVI-BELGII	New York Aster	Herbaceous	2" plug
50	BACCHARIS HALIMIFOLIA	Eastern Baccharis	Tree	tubeling
100	BETULA LENTA	Sweet Birch	Tree	tubeling
143	BETULA NIGRA	River Birch	Tree	tubeling
150	BETULA NIGRA	River Birch (bareroot)	Tree	4 ft.
10	BETULA NIGRA	River Birch (RPM)	Tree	4 ft.
240	BETULA POPULIFOLIA	Grey Birch	Tree	tubeling
515	CALAMAGROSTIS CANADENSIS	Bluejoint	Herbaceous	2" plug
258	CAREX INTUMESCENS	Greater Bladder Sedge	Herbaceous	2" plug
514	CAREX LACUSTRIS	Hairy Sedge	Herbaceous	2" plug
60	CEPHALANTHUS OCCIDENTALIS	Buttonbush (bareroot)	Shrub	2 ft.
141	CERCIS CANADENSIS	Eastern Redbud	Tree	tubeling
190	CLETHRA ALNIFOLIA	Coastal Sweetpepperbush	Shrub	tubeling
50	CORNUS RACEMOSA	Grey Dogwood	Shrub	tubeling
258	ELYMUS RIPARIUS	Riverbank Wildrye	Herbaceous	2" plug
772	EUPATORIUM PERFOLIATUM	Common Boneset	Herbaceous	2" plug
150	FRAXINUX PENNSYLVANICA	Green Ash (bareroot)	Tree	4 ft.
70	HAMAMELIS VIRGINIANA	Witch Hazel (bareroot)	Shrub	2 ft.
50	ILEX VERTICILLATA	Common Winterberry	Shrub	tubeling
50	ILEX GLABRA	Inkberry	Shrub	tubeling
515	IRIS VERSICOLOR	Harlequin Blueflag	Herbaceous	2" plug
32	ITEA VIRGINICA	Virginia Sweetspire	Shrub	tubeling
30	JUGLANS NIGRA	Black Walnut (bareroot)	Tree	4 ft.
10	JUGLANS NIGRA	Black Walnut (RPM)	Tree	4 ft.
514	JUNCUS EFFUSUS	Common Rush	Herbaceous	2" plug
258	LIATRIS SPICATA	Dense Blazing Star	Herbaceous	2" plug
50	LINDERA BENZOIN	Spicebush (bareroot)	Shrub	2 ft.
4	LIQUIDAMBAR STYRACIFLUA	Sweetgum	Tree	tubeling
100	LIRIODENDRON TULIPIFERA	Tuliptree	Tree	tubeling
150	LIRIODENDRON TULIPIFERA	Tuliptree (bareroot)	Tree	4 ft.
514	LOBELIA SIPHILITICA	Great Blue Lobelia	Herbaceous	2" plug
50	MYRICA CERIFERA	Wax Myrtle	Shrub	tubeling
258	PANICUM VIRGATUM	Swtichgrass	Herbaceous	2" plug
258	PENSTEMON DIGITALIS	Talus Slope Penstemon	Herbaceous	2" plug
50	PLATANUS OCCIDENTALIS	American Sycamore	Tree	tubeling
200	PLATANUS OCCIDENTALIS	Sycamore (bareroot)	Tree	4 ft.
14	PLATANUS OCCIDENTALIS	Sycamore (RPM)	Tree	4 ft.
100	QUERCUS BICOLOR	Swamp White Oak	Tree	tubeling
30	QUERCUS PALUSTRIS	Pin Oak (bareroot)	Tree	4 ft.

Table A1, cont. Plant list

Quantity	Species	Common Name	Type	Description
43	QUERCUS PALUSTRIS	Pin Oak	Tree	tubeling
75	QUERCUS PHELLOS	Willow Oak (bareroot)	Tree	4 ft.
13	QUERCUS PHELLOS	Willow Oak (RPM)	Tree	4 ft.
150	QUERCUS RUBRA	Northern Red Oak (bareroot)	Tree	4 ft.
10	QUERCUS RUBRA	Northern Red Oak (RPM)	Tree	4 ft.
141	RHUS COPALLINUM	Winged Sumac	Tree	tubeling
140	ROSA VIRGINIANA	Virginia Rose	Shrub	tubeling
258	RUDBECKIA LACINIATA	Cutleaf Coneflower	Shrub	2" plug
93	SALIX DISCOLOR	Pussy Willow	Tree	tubeling
20	SAMBUCUS CANADENSIS	Elderberry (bareroot)	Shrub	2 ft.
43	SAMBUCUS CANADENSIS	American Black Elderberry	Tree	tubeling
515	SCIRPUS CYPERINUS	Woolgrass	Herbaceous	2" plug
140	SPIRAEA LATIFOLIA	White meadowsweet	Shrub	tubeling
92	SPIRAEA TOMENTOSA	Steeplebush	Shrub	tubeling
515	VERBENA HASTATA	Swamp Verbena	Herbaceous	2" plug
515	VERNONIA NOVEBORACENSIS	Broadleaf Ironweed	Herbaceous	2" plug
60	VIBURNUM DENTATUM	Southern Arrowwood (bareroot)	Shrub	2 ft.
140	VIBURNUM DENTATUM	Southern Arrowwood	Tree	tubeling
43	VIBURNUM TRILOBUM	American Cranberrybush	Tree	tubeling

Appendix B. Stroubles Creek stream restoration design data

Table B1. Chanel dimensions of Stroubles Creek in relation to design specifications.

Stream Reach	Restoration Reach: Heth Farm	Reference Reach: Plantation Road	Regional Curves	Empirical Equation	Threshold Channel	Rosgen C4
Stream Channel Feature	Mean (3 Rifles)	Mean (2 Riffles)	Keaton et al., 2005	Hey and Thorne, 1986	Chang, 1988	
Mean Bankfull Width (ft)	30.8	31.2	26.9	43.0	50.2	
Mean Bankfull Depth (ft)	2.3	1.6	1.6	2.6	4.3	
Max Bankfull Depth (ft)	3.9	2.6	---	4.3	---	
Bankfull Area (ft^2)	145.2	214.1	176.4	---	---	
W:D	13.5	19.9	16.4	16.4	---	>12
Slope (S)	0.022	0.0049	---	0.0014	0.0053	<0.02
Channel Sinuosity	1.07	1.065	---	2.9	---	>1.2
Entrenchment Ratio	12.8	---	---	---	---	>2.2

Appendix C. Design plans

Appendix D. Outreach sign