Channel Restoration and Riparian Reforestation Along Wilson Creek: A Demonstration Site

Section 319(h) Nonpoint Source Project Final Report

Submitted by:
Bernheim Arboretum and Research Forest

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Overall coordination of the project was the responsibility of Margaret Shea, Director of Natural Areas, Bernheim Arboretum and Research Forest.

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Executive Summary

The overall objective of the project was to demonstrate techniques to improve water quality in streams draining human-altered lands in central Kentucky. A demonstration site was created in Bernheim Forest within an approximately 16 acre area along Wilson Creek just upstream from its confluence with Harrison Fork. This project has returned Wilson Creek, which was channelized to facilitate farming of the bottomland, to its original meandering bed. The riparian area adjacent to Wilson Creek, once a tall fescue hay field, was revegetated with native woody and herbaceous species that are typical of riparian communities from this region of the state. Wilson Creek, a tributary of the Rolling Fork in the Salt River watershed, is classified as a High Quality Water (Kentucky Division of Water, Nonpoint Source Section, 1998).

Channelization of Wilson Creek and destruction of the adjacent riparian forest resulted in physical impairment of the stream and increased nutrient loading into the stream. The primary physical impairment of the stream was incision and widening. A wider, deeper channel results in lower groundwater levels and reduced frequency of flooding into the floodplain. The decreased connectivity between the stream and the floodplain results in reduced wetland habitat, and reduced resident time of sediment and nutrients. Incision of the stream also results in increased bank erosion and decreased channel bar stability. Thus, stream channelization increased sediment input into the stream by increasing bank erosion and simultaneously reduced the capacity of the stream to retain sediment and nutrients by disconnecting it with the floodplain.

By redirecting a currently channelized stream into its previous drainage, this project has: 1) reconnected the stream to its floodplain causing an increase in floodplain flooding; 2) raised groundwater levels that support and create adjacent wetlands; 3) created floodplain ponds; and 4) reestablished a primarily gravel streambed substrate. As part of the overall objectives, revegetation activities have improved water quality by increasing nutrient uptake by plants and microbes and by increasing physical filtration of suspended sediments.

The Wilson Creek demonstration site was the center of a series of educational programs offered throughout the five years of this project and beyond. Programs were offered for private landowners, college students, and professionals interested in stream protection and restoration. Initially, student programs were designed for students in grades 4-6 and their teachers. Programs focus on the importance of water quality, the value of stream systems, and the use of riparian buffers and stream channel restoration in improving water quality. A brochure is available promoting riparian corridors and discussing results of this project. Information is also posted at www.bernheim.org.

Introduction and Background

Goals for this project encompassed improving water quality in Wilson Creek including relocation of the streambed and revegetation of the riparian zones. Additionally the project serves to demonstrate techniques to improve water quality in streams draining human-altered lands in central Kentucky. One of the primary goals of this project was to establish ongoing educational programming for college level students, teachers, land management professionals, landowners and students in grades K-12.

The degradation of stream systems has been widespread throughout the United States. Only 2% of the streams within the contiguous U.S. are reported to have escaped significant modification (Benke, 1990). In Kentucky, more than 89,430 miles of rivers and streams cross the state (Kentucky Division of Water, 1996). Almost all of Kentucky's large streams have been impounded or channelized for navigation or flood control (United States Army Corps of Engineers, 1993). Human disturbances have also impacted Kentucky's smaller streams, altering the physical, chemical and biological make-up of the systems.

Loss of vegetation adjacent to streams is a major cause of declining quality of streams. The fertile soil adjacent to streams is a valuable agricultural resource; therefore, farmers often clear the land to the edge of the stream, or leave only a narrow buffer of trees. The absence of deeply rooted riparian vegetation results in increased movement of soil and agricultural chemicals into stream water.

Stream channelization, designed to drain periodically-flooded land and increase the area available for agriculture, has a negative impact on the water quality of streams. The meanders of a natural stream act to control the rates of flow and the natural patterns of erosion and deposition. An artificially straight channel increases the rates of flow, increases erosion of soil from the banks and reduces the amount of sediment deposited along the stream.

Wilson Creek is classified as a High Quality Water by the Kentucky Division of Water (Division of Water, Nonpoint Source Section, 1998). Biological surveys of the stream indicate that healthy populations of algae, macroinvertebrates and fish are present in Wilson Creek (Hannan et al, 1984). Water quality studies completed in 1983 and 1984 indicated that most harmful constituents were below state water quality requirements (Hannan et al, 1984). Never-the-less, long term water quality data indicate that Wilson Creek's water quality is adversely affected by agricultural activity (Jan Stevenson, personal communication, 1999). Wilson Creek has elevated levels of dissolved inorganic nitrogen and phosphorus in comparison to Overalls Creek and Harts Run, two tributaries of Wilson Creek with no agricultural activity. Although 89% of the 26,041 acre Wilson Creek watershed is forested (Hannan et al, 1984), land conversion is concentrated along the riparian corridors where it has the greatest impact on water quality.

Prior to this project, the floodplain adjacent to Wilson Creek was maintained in mowed fescue fields. Portions of Wilson Creek were channelized to facilitate farming of the bottomlands. Alterations of the stream and the adjacent bottomlands had a significant impact on the morphology and function of the stream. Channelization of the stream and the resultant increased force of the flow resulted in channel deepening and widening through bank erosion. This increased erosion resulted in a bedrock stream bed that was deeply incised. These changes in the stream geomorphology altered the types of habitat present in the stream. The bedrock stream bed limits the depth of pools in the stream. The stability of the stream substrate was reduced because of the lack of floodplain relief during flood events; therefore riffles were associated with bedrock or unstable gravel deposits. Channelization of the stream also resulted in a reduction in groundwater levels in the floodplain alluvium.

These changes in the geomorphology of Wilson Creek resulted in decreased water quality and nutrient buffering capacity. Bank erosion and destabilization of valley wall colluvium increased sediment loads to the stream. The depth of the hyporheic zone was reduced to a thin, unstable deposit that was actively transported during flood events. Many studies of nutrient retention in streams have focused on communities that live on the surfaces of the stream bottom. Recent studies, however, have documented the importance of stream water storage zones within streambed sediments that are as large or larger than the flowing water in some streams (Mulholland et al., 1997). These zones allow temporary storage of stream water via slow rates of exchange with surface water and play an important role in controlling stream water chemistry (Findlay, 1995). For example, bacterial transformations of nitrogen, phosphorus and carbon can be much more important in these subsurface zones than in the surface water (Hendricks and White, 1991).

Materials and Methods

Project Area

Wilson Creek is a 55.9 km long, 4th order tributary of the Rolling Fork of the Salt River that drains portions of Bullitt and Nelson counties, Kentucky and is within the Knobs-Norman Upland (71c) ecoregion (Woods et al., 2002) (Figure 1). The Wilson Creek watershed encompasses an area of 105 km^2. Land use in the watershed is primarily forested (79.5%), with agriculture (16.2%), urban (0.9%) and other landuses (4%) making up the landscape (USGS, 2000).

A 2,670-ft reach of Wilson Creek and its adjacent valley bottom within Bernheim Arboretum and Research Forest were restored in 2003 to a 3,147-ft-long sinuous stream with a low-level forested floodplain and several adjacent wetland areas. Details on the assessment, design and construction of the restored stream channel can be found in Appendix D. Bernheim's role in the channel reconstruction was to provide assistance with the operation of heavy equipment such as dozers and backhoes under the direction of researchers from the University of Louisville who were responsible for the channel design and its implementation.

Following the relocation of the stream channel, Bernheim was primarily involved with site revegetation along with researchers from the University of Kentucky. In addition, researchers from Virginia Commonwealth University assessed the effects of channel restoration on stream hydrology and nutrient retention (Appendix E).

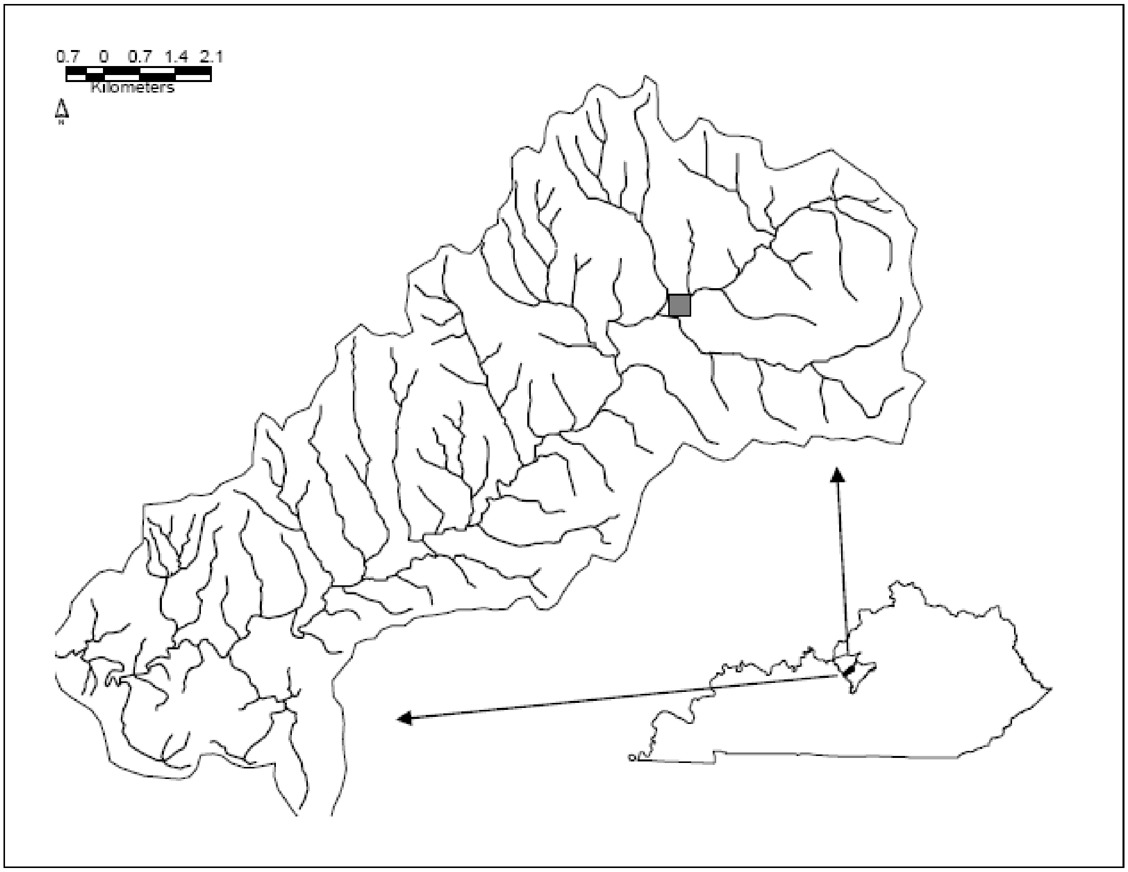

Figure 1. Wilson Creek Watershed, Nelson/Bullitt Counties, Kentucky, USA. Shaded region represents project location.

Two studies were conducted on the effects of channel restoration on the biological aspects of the stream community. Researchers from the Kentucky Division of Water (Department of Environmental Protection) assessed the biological response to channel restoration and riparian reforestation in the project area (Appendix F) and in a parallel study, researchers from the University of Louisville concentrated on the effects on the fish and aquatic macroinvertebrate fauna of the relocated stream (Appendix G).

Since Bernheim was involved with the site's revegetation and the educational programs associated with the site, those details are included in the body of this report.

Revegetation

Revegetation of the relocated stream corridor followed the Kentucky Natural Resource Conservation Service (NRCS) guidelines to improve water quality and protect against soil erosion using riparian forest buffers (NRCS, 1995). Every effort was made to establish a riparian corridor typical of the native waterways of this region.

The riparian corridor was divided into two zones paralleling the stream channel. The inner zone, extending 5 meters on either side of the stream, was stocked with shrubs and trees adapted to occasional flooding and frequent disturbance (Table 1).

Table1: Woody Species Planted (Floodplain)

Common Name	**Latin Name**	**Form**	**Total #**
River Cane	*Arundinaria gigantea*	bamboo	300
Buttonbush*	*Cephalanthus occidentalis*	shrub	550
Silky Dogwood	*Cornus amomum*	shrub	800
Persimon	*Diospyros virginiana*	tree	1500
White Ash	*Fraxinus americana*	tree	500
Green Ash	*Fraxinus pennsylvanica*	tree	1200
Blue Ash	*Fraxinus quadrangulata*	tree	400
Black Walnut	*Juglans nigra*	tree	350
Spicebush*	*Lindera benzoin*	shrub	1400
Sycamore	*Plantanus occidentalis*	tree	1900
Swamp White Oak	*Quercus bicolor*	tree	400
Bur Oak*	*Quercus macrocarpa*	tree	500
Swamp Chestnut Oak	*Quercus michauxii*	tree	400
Pin Oak	*Quercus palustris*	tree	400
Coralberry	*Symphoricarpos orbiculatus*	shrub	1400

- Trees planted on 6 x 6 ft spacing
- Shrubs interspersed with trees

* Potted plants grown in Bernheim nursery

Live Stakes (Floodplain)

Common Name	**Latin Name**	**Form**	**Total #**
Sandbar Willow	*Salix exigua*	shrub	100
Black Willow	*Salix nigra*	tree	400

- Harvested locally and planted in late January; 2-3 ft X).75 - 1.25“ diameter

Native giant cane (*Arundinaria gigantea*), a historic feature of central Kentucky river bottoms (Campbell, 1985) that is presently found in small patches in Bernheim floodplain communities, has been established as a canebrake in the inner zone. American sycamore (*Plantanus occidentalis*), boxelder (*Acer negundo*), black willow (*Salix nigra*), dogwood (*Comus* sp.), alder (*Alnus serrulata*) and northern spicebush (*Lindera benzoin*) - all common in Bernheim riparian zones were spaced along the stream and outside edges of the canebrake. A second zone extending 10 meters beyond the inner stream bank zone was planted with a variety of trees and shrubs accustomed to occasional flooding and saturated soils. Herbaceous wetland communities (sedge and bulrush meadows) have been established to slow and store floodwaters (Table 2).

Table 2: Wetland Plugs

Common Name	**Latin Name**	**Total #**
Bristly Sedge	*Carex comosa*	190
Bristly Catail Sedge	*Carex frankii*	190
Porcupine Sedge	*Carex hystericina*	190
Bottlebrush Sedge	*Carex lurida*	76
Lance-fruited Oval Sedge	*Carex scoparia*	190
Awl-fruited Sedge	*Carex tribuloides*	190
Blunt Spike Rush	*Eleocharis obtusa*	76
Great Spike Rush	*Eleocharis palustris major*	152
Common Boneset	*Eupatorium perfoliatum*	190
Fowl Manna Grass	*Glyceria striata*	190
Sneezeweed	*Helenium autumnale*	190
Rose Mallow	*Hibiscus laevis*	190
Dark Green Rush	*Scirpus atrovirens*	190
Wool Grass	*Scirpus cyperinus*	190
Chairmaker's Rush	*Scipus pungens*	190

- Spaced 16” on center in seasonal, depressional wetlands and floodplain access areas

The remaining floodplain was planted as a hardwood bottomland forest typical of central Kentucky. A native, mixed-species herbaceous layer was established prior to tree planting. Establishment of natives required removal of the non-native pasture grass tall fescue (*Festuca arundinacea*). Non-native species removal used a combination of fire and chemical control designed to rapidly form dense native communities and minimize soil erosion. Native grass and forb species adapted to moist and constantly wet soils was seeded using a no-till drill and hand-seeders.

Areas above the floodplain were vegetated with grasses and forbs typical of native grasslands of this area (Table3).

Table3: Upland Seed Planted

Common Name	Latin Name	Form	% of Total
Big Bluestem	*Andropogon gerardii*	grass	7.3
New England Aster	*Aster novae-angliae*	forb	3.3
Tickseed	*Bidens polylepis*	forb	4.0
Side Oats Gramma	*Bouteloua curtipendula*	grass	1.2
Tall Coreopsis	*Coreopsis tripteris*	forb	2.7
Purple Prairie Clover	*Dalea purpurea*	forb	4.1
Purple Coneflower	*Echinaceae purpurea*	forb	12.2
Downy Sunflower	*Helianthus mollis*	forb	5.5
Rough Blazingstar	*Liatris aspera*	forb	6.1
Wild Bergamot	*Monarda fistuosa*	forb	1.0
Wild Quinine	*Parthenium integrifolium*	forb	12.2
Slender Mountain Mint	*Pycnanthemum tenufolium*	forb	1.1
Yellow Coneflower	*Ratibida pinnata*	forb	18.2
Black-eyed Susan	*Rudbeckia hirta*	forb	1.2
Little Bluestem	*Schizachyrium scoparium*	grass	1.8
Rosinweed	*Silphium trifoliatum*	forb	1.2
Gray Goldenrod	*Solidago nemoralis*	forb	4.9
Indian Grass	*Sorghastrum nutans*	grass	12.2

- - 82 lbs seed over 7.5 acres. Seeding rate 10.9 lbs/acre
  - Mixture was 23% grass and 77% forbs
-

Revegetation efforts began at the Wilson Creek stream restoration in September of 2003 after a majority of construction on channel and floodplain had been completed. At this stage, Bernheim staff began installation of erosion control measures to conserve soil on the newly constructed stream banks. Over the next 1½ months, fabric was laid as riffle and pool construction was completed. In all, Bernheim staff covered >3,500 linear feet of riffle bank and >2,000 linear feet of pool bank.

Riffles were covered using a combination of Anti-Wash Geojute™ (4' X 225' rolls) and 10 oz. burlap fabric (6' X 300' rolls). A burlap wrap was constructed to stabilize the toe of the stream bank. The burlap was constructed to be functionally similar to a coir log which can be placed along the toe of restored stream banks for stabilization (Figure 2). It was thought the relatively tight weave of the burlap fabric would hold soil better than the jute mesh, which has a much greater proportion of open space (≈ 60% open space). Burlap was rolled perpendicular to the stream channel along the toe of the bank and secured using six inch sod staples. Next, the burlap was filled with soil using a skid loader. After excess soil, clods, rocks, and other debris were hand raked from the burlap, cover crop and native seed was sown into the soil. The fabric was folded along the long axis to form a "soil log" along the stream bank. The soil wrap was then tied into a section jute mesh using wooden stakes every four to five feet. The jute, which was placed over straw and seed, was then secured using sod staples placed every few feet on center. The coverage of fabric along riffles varied from six to seven feet wide, depending on the overlap between the burlap and jute mesh.

Figure 2: Newly constructed riffle in stream restoration before introduction of flow to the channel. Anti-Wash Geojute™, burlap wrap, and stream channel are pictured from left to right

A similar burlap/soil wrap was constructed in the outside bends of pools. For pools, 15 ft strips (5 feet wide) of burlap were cut before going to the job site. Burlap strips were laid perpendicular to the stream; each strip overlapped the adjacent strip by several inches. Soil was then dumped onto the burlap using a skid loader. The soil depth decreased from a maximum height of eight to ten inches near the water's edge to one to two inches at the opposite end to promote a smooth transition from burlap on the bank to uncovered soil in the floodplain. Cover crop (Table 4) and native seed was sown into the soil (Table 5). Burlap strips were then folded along the short axis back over the soil and secured using wooden stakes. Fabric width in pools averaged between 10 and 12 feet.

Table 4: Cover Crop Planted

Common Name	**Latin Name**	**Seeding Rate (lbs/acre)**
Sorghum	*Sorghum bicolor*	60
German Millet	*Setaria italica*	40
Buckwheat	*Fagopyrum sagittatum*	40
Annual Rye Grass	*Lolium perenne*	40
Rye	*Secale cereale*	90

Cereal rye and a variety of native species were sown throughout the floodplain in mid-October. The rye is very cold tolerant and was meant to provide cover over the winter months and subsequent spring. As the rye died off the following spring, the native seed would germinate and begin growing (many native plants need a period of cold, moist stratification before germination). In this idealized scenario, soil should not have been exposed for long periods of time and erosion potential should have been low.

Table 5: Floodplain Seed Sown in 2003

Common Name	**Latin Name**	**Form**	**% of Total**
Water Plantain	*Alisima subcordatum*	forb	0.8
Common Milkweed	*Asclepias syracia*	forb	0.7
Begger's Ticks	*Bidens polyeps*	forb	2.5
Canada Brome	*Bromus pubescens*	grass	1.3
American Bellflower	*Campanula americana*	forb	0.1
Bristly Catail Sedge	*Carex frankii*	sedge	16.3
Sedge	*Carex granularis*	sedge	1.4
Shallow Sedge	*Carex lurida*	sedge	6.6
Hop Sedge	*Carex lupulina*	sedge	0.3
River Oats	*Chasmanthium latifolium*	grass	1.7
Riverbank Wildrye	*Elymus riparius*	grass	8.5
Downy Wildrye	*Elymus villosus*	grass	0.8
Virginia Wildrye	*Elymus virginicus*	grass	0.2
Joe-Pye Weed	*Eupatorium maculatum*	forb	0.4
Fowl Manna Grass	*Glyceria striata*	grass	1.4
Rush	*Juncus* sp.	rush	3.7
Rush	*Juncus brachycarpus*	rush	0.1
Common Rush	*Juncus effusus*	rush	<0.01
Western Panic Grass	*Panicum acuminatum*	grass	0.5
Switchgrass	*Panicum virginica*	grass	0.3
Foxglove Beardtongue	*Penstemon digitalis*	forb	1.3
Leafcup	*Polymnia canadensis*	forb	8.9
Browneyed Susan	*Rudbeckia triloba*	forb	16.5
Dark Green Bulrush	*Scirpus atrivirens*	sedge	10.8
Woolgrass	*Scirpus cyperinus*	sedge	2.7
Yellow Wingstem	*Verbesina alternafolia*	forb	6.5
White Wingstem	*Verbesina virginica*	forb	5.5

-92 lbs seed over 5.5 acres. Seeding rate was 16.5 lbs/acre
- Mixture was 41% forb, 16% grass, 4% rush, 38% sedge

Education Activities

An important goal of this project was to promote an understanding of sources of nonpoint source pollution and the benefit of management techniques that promote healthy riparian systems. The demonstration site was intended to be a focal point for educational programs designed for multiple audiences:

- Landowners
- College students
- Professionals involved in water management
- Teachers
- School students (Grades 4-12)
- Youth groups (scouts and others)
- Other non-profits

All programs were designed with the specific needs of the audience in mind.

Programs for K-12 Students

Programs for K-12 students focused at grades 3-6 since those grade levels currently participate in Bernheim programs at the highest level. As much programming as possible took place at the restoration site. A school program called “Kentucky’s Water Wealth” focused on non-point pollution was developed for larger groups that were not able to visit the stream site. This program is currently Bernheim’s most requested group program and we will continue to offer the program as least through the 2006-2007 school year. The program presents information to students through hands-on activities and group participation geared toward the specific objectives and guidelines of the Kentucky Education Reform Act. Students are introduced to the value of water as a natural resource, specific information about Kentucky’s water resources, threats to water quality and strategies for protecting water. The program focuses primarily on non-point sources of water pollution. Through separate hands-on activity stations students are introduced to stream plant communities, riparian forests, the microscopic stream community, and how healthy natural communities can protect water quality.

Teacher Training

Teacher Training was also a focus of the project. Bernheim provided in-depth training for 72 teachers throughout the course of the project. Additionally, Bernheim entered into an agreement with Bullitt County Public Schools in 2006 to provide two teacher training programs a year for 2006 through 2008 in return for use of a Stream Demonstration table that is being shared between Bernheim and Bullitt County Fiscal Court as their part of the EPA Grant. This cooperative agreement insures an additional level of teacher training in the future. Teachers in Bullitt and Nelson counties were a focus of the first teacher training efforts. Bernheim then worked with other organizations to offer teacher training through Summer Teacher Institutes. Many of the teachers trained through these programs are now bringing their students to the school programs about water.

Workshops for College Students

Workshops for college students were coordinated through the University of Kentucky and the University of Louisville. UK and U of L notified nearby universities about the workshop and solicited their participation. Participants in the workshops were graduate and upper-level undergraduate students. The stream restoration project served as the basis for a 1-month teaching module for students participating in BIOL 410 Applied Ecology at University of Louisville. This course is offered each spring semester as a writing-intensive introduction to environmental problem solving. Activities included introductory lectures on stream ecology, a field trip to Bernheim (observe the restoration process and collect water quality samples), laboratory analyses of dissolved nutrient concentrations and a scientific-style paper comparing water quality in the restored stream with nearby streams. This module was linked to other activities including a watershed simulation project and an algal bioassay experiment to foster an appreciation of the effects of land-use practices on nutrient loading to aquatic ecosystems.

Workshops for Private Landowners

The private landowner workshops were advertised through mailings to landowners along Wilson Creek, notices in the Bernheim Newsletter, notices in publications of the Floyd's Fork Environmental Association, notices in local newspapers, and notices in publications of the Salt River Watershed Watch. Agencies and organizations with an interest in stream restoration and protection were mailed notices regarding the workshops for professionals. Agencies that were notified of the workshops included Daniel Boone National Forest, TVA, Mammoth Cave National Park, Big South Fork National Recreation Area, Kentucky State Nature Preserves Commission, The Nature Conservancy, Kentucky Department of Transportation, Fort Knox, Kentucky State Parks, Kentucky Department of Fish and Wildlife, U.S. Army Corps of Engineers, and Kentucky Department of Forestry. All agencies were encouraged to inform other professionals about the workshops. The Kentucky Division of Water was informed of all workshop schedules in advance so that they could direct any other interested parties to the workshops.

Mobile Water Lab

As part of the EPA grant educational efforts Bernheim developed an interpretive package related to the objectives of the Wilson Creek Stream Restoration project designed for use with Bernheim’s mobile labs. The interpretive package is designed to be used with the mobile labs when they travel to schools, festivals and other off-site locations as well as with programs offered on-site. The modular interpretive displays were designed to be used in whole or in part depending on the focus of the program or event. This design allows Bernheim to present information about non-point water pollution, water ecology, stream restoration, and other related subjects to large audiences effectively. Photographs of the lab in different kinds of on-site use including school groups and events are included on a CD in Appendix I.

Stream Table

In cooperation with Bullitt County’s educational efforts on non-point water pollution through the Bullitt County Public Schools, Bernheim assisted in the purchase of a stream table manufactured by *TeachWater*. Bernheim shared the initial purchase cost of the stream table with Bullitt County Fiscal Court through a Memorandum of Agreement and houses the stream table at Bernheim in support of water education efforts for students in K-12 and for hands-on demonstrations with the general public. Additionally, Bernheim offers periodic teacher training programs related to the Wilson Creek Stream Restoration project that includes training on the use of the stream table in support of classroom studies. Teachers that have completed the training can pick up the stream table for use in their schools. The majority of stream table use is on-site at Bernheim in conjunction with school programs, special events and informal public programs.

Educational Brochure and Exhibits

An educational brochure (Appendix I) was developed outlining the stages of development of the Wilson Creek demonstration site using both photos and text. These brochures were sent to landowners along Wilson Creek and were made available to the general public in the Bernheim Visitor Center.

Educational panels and flash animation information were exhibited in the Bernheim Visitor Center that featured the stream site restoration efforts (Appendix I – on CD). In that manner Bernheim could inform the public about the project. Public programs were also offered periodically so that the public could have guided visits to the stream site.

A final draft of all existing materials and drafts of printed materials (agendas, announcements, fliers, pamphlets, newsletters, news articles, etc.), video scripts and other products was submitted to the Division of Water for review and approval prior to final product development and/or distribution.

Results and Discussion

Revegetation

During the first winter following construction of the Wilson Creek Stream restoration, the watershed received abnormally high levels of precipitation. The wet winter resulted in numerous out-of-bank events (>12), which caused significant erosion of stream banks and floodplain soil and the probable loss of native seed sown on site.

A second factor contributing to erosion on site was the relatively low banks of the restored section of Wilson Creek. Subsequently, even with normal levels of precipitation, out-of-bank events would have occurred more frequently than in many stream restoration projects. Increased floodplain access (beyond that of many “restored” streams) was a primary goal of this stream restoration project and bank height was consistent with what University of Louisville researchers believed existed before wholesale human manipulation of riparian corridors. This in and of itself did not cause erosion, but projects utilizing the floodplain to the extent that the Wilson Creek project did are inherently at higher risk of erosion during the period before vegetation is firmly established.

The lack of established vegetation on-site at the end of the 2003 growing season also exacerbated soil loss. Floodplain soils were disked after construction to provide a seedbed conducive to growth, but a large out-of-bank event occurred less than two weeks after seeding the cover crop/natives resulting in loss of seed and soil. Even if the first out-of-bank flow had not occurred, seeding, which took place in mid to late October, was too late to achieve adequate herbaceous cover before the coming winter. Seeding was pushed back to that late date because of extensive construction delays that occurred earlier in the year. These delays were primarily the result of unusually high rainfall during the summer months.

With the beginning of the 2004 growing season very little herbaceous vegetation existed on the project site. Scouring and top soil losses that occurred during the winter months produced a situation that was not conducive establishment of herbaceous vegetation. However, initial survival of tree, shrub, and river cane planting was quite high (>90%). Exposed, scoured subsoil prone to rapid drying was the primary substrate in the floodplain. Sorghum was sown throughout the site at ≈ 60lbs./ac during early June as a warm season cover crop. The relatively high seeding rate was due to lack of proper seedbed present on site. Seedbed preparation (disking, harrowing) was hindered due to the recent plantings of over 10,000 bare root tree seedlings on site. The sorghum, along with native and nonnative volunteers, and seeded species began to fill in as the season progressed. Unfortunately, vegetation establishment did not occur rapidly enough to prevent bank degradation and floodplain erosion.

Repairs - 2004

Repair of stream banks and replacement of floodplain soils began in late July, 2004. Based on erosion observed the previous winter, Bernheim staff used Anti-Wash Geojute™ to cover large swaths (total fabric >110,000 ft^2) of the floodplain instead of only a thin strip (total fabric ≈ 12,000 ft^2) along riffles. After bringing the floodplain to grade, areas were seeded with several cover crop species and numerous native floodplain species (Table 10). Straw was placed over the seed, and the area was covered with fabric. Fabric was primarily secured using wooden stakes (18”x1”x 2”) with a hole drilled several inches from the top. As the wooden stakes were driven into the ground along the fabric edges, a nail, three to four inches long, was placed in the hole.

Table 10: Floodplain Seed Sown in 2004

Common Name	Latin Name	Form	% of Total
Marigold spp.	*Bidens* spp.	forb	2.8
Bottlebrush Sedge	*Carex lurida*	sedge	1.5
Brown Fox Sedge	*Carex vulpinoidea*	sedge	3.0
Riverbank Wild Rye	*Elymus riparius*	grass	67.4
Joe-Pye Weed	*Eupatorium maculatum*	forb	2.1
Sneezeweed	*Helenium autumnale*	forb	2.1
Switch Grass	*Panicum virgatum*	grass	11.2
Wild Golden Glow	*Rudbeckia laciniata*	forb	2.8
Sweet Black-eyed Susan	*Rudbeckia subtomentosa*	forb	1.8
Dark Green Rush	*Scirpus atrovirens*	sedge	1.9
Wool Grass	*Scirpus cyperinus*	sedge	1.9
Ironweed	*Vernonia altissima*	forb	1.4

- unlike 2003 seeding, in 2004 used pure live seed. Seeded at 10 lbs/acre

When the stake was driven in the nail firmly held the fabric in place. Sod staples were still used, but their primary function was to hold seed and straw in place during an out-of-bank flow. When these flows do occur, water can move underneath the fabric washing seed and soil away. Sod staples effectively prevent this from occurring, but do not effectively secure the fabric.

Additionally, the burlap soil wrap was abandoned due to its ineffectiveness; vegetation did not penetrate the burlap well, especially after the scouring produced in an out-of-bank flow. Instead we placed large pieces of sod (4' X 8') along the toe of the stream bank (Figure 3). These pieces of sod were eight to 10 inches thick and provided an instant mass of soil, roots, and foliage in the most vulnerable areas of stream bank . The sod layer provided a much greater level of protection (sod is eight feet wide in every riffle) and appears to be very stable in comparison to the methods of 2003.

Figure 3 Sod mats adjacent to stream directly following installation. Erosion mesh is tied into the sod and covers much of the floodplain

Additional Plantings in 2005

In April an additional 500 sycamores and 500 swamp white oaks were planted along the riffle areas of the stream. Also, 1140 wetland plugs representing 76 plugs of the same 15 species were added to the prior years' plantings (Figure 4).

Figure 4 Rushes and sedges have become established by 2004

In 2005 the native upland grassland plantings were filling in well and no additional cover crop was needed Figure 5). Late summer some repair was also made to the imbedded logs that had been washed out of the stream bank during heavy rain.

Figure 5 By June of 2005 upland species were becoming fully established and no further cover crops were needed.

Education Activities

When the program was first envisioned Bernheim expected to be able to take large numbers of school students to the restoration site for intensive sets of programs offered periodically. As the project matured we found that most schools were unable to attend that type of program and that transportation issues would limit our ability to get busses of people to the site. Additionally there was some concern on the impact of 100's of students on a newly planted site. Soil compaction and vegetative damage was certain to occur. The MOA was therefore amended so that more programs for large groups could be done at the Education Center at Bernheim. Smaller groups continued to visit the restoration site for programs.

Table 11 shows the number of people the educational goals initially set by the project sought to reach. Although widely announced, numbers of college level students, landowners and professionals fell below the levels of the goals stated in the grant. However, Bernheim will continue to offer programs for K-12 students, landowners and professionals well beyond the period of this grant. Bernheim also offers programs concerning the restoration site on regular basis through their public programs. Also, professors at the University of Louisville have been and will continue to use the site for their classes on an ongoing basis.

A listing of programs offered and attended can be found in Appendix I.

Table 11 Stated goals and actual attendence achieved by educational programs offered.

Audience	Goal	Actual
Student Groups (K-12) (*)	**1440**	**1517**
Teachers	**60**	**59**
College Level	**250**	**164**
Landowner	**150**	**84**
Professional	**150**	**169**
Additional audiences served:		
Adult visiting groups	**none**	**137**
Conferences	**none**	**266**
Off-site Presentations	**none**	**369**
Visitor Center Education Efforts	**none**	**4000+**
Mobile Lab Education Efforts	**none**	**3000+**
Wilson Creek Brochure	**none**	**1500**
Wilson Creek Brochure (2nd order)	**none**	**1500**
Bernheim Web Site	**none**	**unknown**

In addition to programming, one of Bernheim's mobile labs has been outfitted with nonpoint pollution educational components. The lab consists of visual aids, books, microscopes to look at living stream macroinvertebrates, and literature. This lab is used onsite at Bernheim but also has the capability of being moved to the streamsite, the Zoo, schools or anywhere there is opportunity to put it on display.

A brochure (Appendix I) dedicated to the streamsite restoration also travels with the mobile lab and is made available in the Bernheim Visitor Center for public distribution. Bernheim's website has information on the revegetation of the streamsite restoration area and will be updated with changes in the streamsite as they occur. This way new data can quickly become available to the public.

Conclusions

Strong Education and Natural Areas programs make Bernheim Forest an ideal location for a stream restoration demonstration site. The long-standing commitment of Bernheim to natural resource conservation insures a dedication to managing the demonstration site and actively promoting use of the demonstration site for research and education long past the five year span of the proposal.

The goal of this project was to demonstrate techniques to improve water quality in streams draining human-altered lands in central Kentucky. We have achieved this goal by creating a demonstration riparian buffer and stream restoration along Wilson Creek. By redirecting a currently channelized stream into its previous drainage, this project has increased the nutrient absorption and sediment capture by increasing the resident time of water moving through the system. Non-disruptive, whole-stream experiments were conducted to measure hydraulic characteristics, ecosystem metabolism and nutrient retention in Wilson Creek before and after channel restoration. Channel restoration has increased the proportion of water that passes through sub-surface storage zones. Greater water-sediment interaction results in higher retention of dissolved nutrients (nitrogen and phosphorus) and a diminishment of downstream fluxes.

As part of the overall objectives, revegetation activities are improving water quality by increasing nutrient uptake by plants and microbes and by increasing physical filtration of suspended sediments (Appendix E). Corridor vegetation is providing organic inputs to drive aquatic food webs, building physical structure to ameliorate in-stream abiotic conditions and producing coarse woody debris to enhance habitat for aquatic invertebrates. Thus, revegetation efforts influence the immediate and longer-term restoration project goals.

A photographic record of the development of the vegetation in the different areas of the riparian zone was kept over a period of several years. These photos can be viewed in the form of a slide presentation labeled "Vegetation Photo Monitoring of Wilson Creek" on the CD in Appendix H. An additional CD labeled "Vegetation Photo Monitoring" containing raw photograph files of the project is also located in Appendix H..

Assessment of the restored channel suggests that the restoration has been successful. Four years after its construction, the restored reach of Wilson Creek continues to demonstrate a dynamically stable planform and profile. The channel retains an alluvial pool-riffle morphology, with bedrock exposure only in pools and at the transition to the supply reach. Floodplain depressions, gravel riffles, log vanes, and shorter, deeper, more widely distributed pools provide diverse wetland and channel habitat.

In periods of low flow, the groundwater-fed pools remain at least partially filled, harboring fish and other aquatic organisms that require surface water. The continued evolution of channel and floodplain morphology will determine the sustainability of the restored habitat. Thus, a more extended period of monitoring will be required to definitely evaluate the results of the restoration and the implications of the methods it employed.

The rapid restoration of both invertebrate and fish communities show that the enhancement of habitat in streams through techniques such as natural channel design can be effective in enhancing the ecological integrity and function of even high quality waters.

The demonstration site also serves as an example for restoration of modified stream sections in Kentucky with similar geologic conditions - gravel substrate overlying bedrock. Stream restoration projects that are currently underway in Kentucky involve streams in the far western end of the state that have deep alluvial streambeds. The Wilson Creek demonstration site fills a gap in information regarding restoration of streams with gravel and bedrock streambeds.

The demonstration site is also designed to facilitate education programs for students, teachers, landowners and professionals interested in riparian and stream restoration. The stream and riparian restoration site serves as a resource for programs relating to water quality and the function of riparian ecosystems in maintaining water quality. Experience gained during the restoration activities provides a case study for other landowners and professionals with similar water quality objectives. Bernheim is committed to working towards improving water quality within the Wilson Creek watershed and is working with private landowners within the watershed to promote Best Management Practices (BMPs). The development of a demonstration site along Wilson Creek is an important focal point for future work to maintain high water quality within the watershed.

There is an existing strong connection between Bernheim and local schools who are eagerly participating in educational programs at the site. Bernheim continues to develop a strong connection with other agencies throughout Kentucky that are involved in the protection and restoration of stream systems, including The Nature Conservancy and The Kentucky State Nature Preserves Commission. Bernheim has strong relationships with local universities including, University of Louisville, University of Kentucky, Bellarmine College, Northern Kentucky University, and Western Kentucky University. Bernheim is actively working to continue to build additional relationships with universities in

Kentucky and nearby states. The demonstration site provides an excellent opportunity for continued demonstration of stream restoration technology and evaluation.

Lessons Learned

The following recommendations arise from what we experienced in establishing new vegetation during the course of this project:

- **Wait One Growing Season:** The ultimate challenge is establishing vegetation thereby stabilizing topsoil on a frequently, heavily disturbed site. In the case of the Wilson Creek site the first large, out-of-bank flow occurred less than two weeks after cover crop and native seed was sown. Because this disturbance occurred before vegetation establishment, seed and proper seedbed (for establishing future seed) was lost. The scenario could be avoided on stream restoration projects by waiting one growing season before introducing flow into the restored channel. This would involve building the restored channel and all its attributes, but leaving the connection between the existing and restored channel unbreached thereby giving vegetation an entire year before it could potentially be exposed to flood flow. When construction equipment reentered the site the following year to introduce flow, only a small percentage of the project area would have to be disturbed to connect the existing and restored channels.
- **Cover the floodplain:** Erosion control fabric should be used in restoration projects where the channel slope is high enough (>0.005, comment by Art Parola, University of Louisville) to cause floodplain erosion. This fabric acts as insurance to hold seed and soil in place during out-of-bank flow and accelerates plant growth during dry periods by retaining soil moisture. Using a layer of straw under the fabric also retains moisture and promotes seed growth.

- **Timing:** Revegetation efforts must begin earlier than mid-October to establish vegetation sufficient for protection during the first winter. This was known in 2003, but construction delays continually pushed the completion date back. The effect of the late completion date on vegetation establishment could have been minimized if better phasing methods were incorporated into the construction process. For instance, the project site should have been divided into sections. Then, entire sections could have been completed before moving on to the next area. This would have guaranteed many areas would have been seeded well before mid-October even with the occurrence of construction delays.

- **Utilize a variety of cover/native species:** Using a wide assortment of cover/native species adapted to a wide range of conditions is a good way to hedge your bets against issues that can inhibit vegetation growth. Uncertain hydrology in the restored site, inclement weather (drought, deluge), and insect predation don’t have to spoil revegetation efforts.

- **Don’t rely solely on native species:** Stream restoration projects with a high degree of floodplain access are inherently erosion prone. Revegetation efforts on theses sites must use species capable of rapid growth (See cover crop section of attached species list). Since many native species require dormancy periods of varying lengths, annual non-natives species that provide immediate cover are useful, if not integral, to restoration process. Invasive species should be avoided, but use of non-native cover crops does not have to interfere with the end goal of native dominated ecosystems. The principle concern should be preventing erosion.

- **Exotics management:** Restoration sites in the early stage of succession will certainly have a large non-native component. Consideration of the target plant community should play a vital role when planning for invasive plant management. The goal of the Wilson Creek restoration is a bottomland hardwood forest; a shaded community. Because of the end goal, spending money to control shade intolerant species is not necessarily an efficient use of resources. Species like *Microstegium vimineum*, which are shade tolerant and whose seeds are water dispersed should be of primary concern.

In addition to lessons learned during the revegetation process, perhaps the most important lesson learned on a project of this scope is that collaborations with persons whose expertise in specific aspects of stream restoration is absolutely essential to a successful project. Stream assessment, geomorphological design and construction of a new stream channel were all beyond the expertise of anyone on the Bernheim staff. Although the subsequent revegetation was within our capabilities, without the input of outside experts, species chosen and revegetation design might not have been as successful as they were. Nutrient studies and aquatic monitoring of the site were also accomplished by scientists expert in those fields and added a means for assessing the successful faunal and algal recolonization and nutrient flow through the study site.

Another important lesson learned was that change in personnel during the project does create hardship in maintaining continuity during a project of this duration. New personnel brought into a project must be brought up to speed in order to function efficiently and that is sometimes difficult to achieve.

Due to the success of the Wilson Creek stream restoration project, monies may be leveraged through the Kentucky Department of Fish and Wildlife Resources to undertake another stream restoration on nearby Harrison Fork shortly before its confluence with Wilson Creek a very short distance below the current project site.

The University of Louisville provided a CD showing photo documentation of the channel restoration activities located in Appendix H.

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Appendix A

Application Outputs

Milestone Summary
Budget Details

MILESTONE SCHEDULE		
	Expected Beginning Date	Actual Completion Date
1.Execute MOA with Division of Water		07/00
2. QA/QC Plan approval		07/01
3. *Baseline channel monitoring	09/00	02/03
4.*Water quality monitoring	09/00	12/04
5. Volunteer workdays - seed and cutting collection	09/00	03/02
6. BMP Plan approval		06/03
7. Channel construction	06/01	11/03
8. * Photomonitoring of restoration process	06/01	05/06
9. Initial water diversion		11/03
10. Revegetation of riparian corridor	10/01	04/05
11. Channel maintenance		06/05
12. Teacher's workshops	09/02	07/04
13. Student workshops	10/02	09/06
14. Technical workshops	10/02	09/04

15. *Evaluation of educational activities	10/02	09/05
16. Final diversion of water into restored stream	09/02	11/03
17. * Vegetation monitoring	10/02	09/04
18. *Post restoration channel monitoring	12/02	08/07
19. Submit brochure to Division of Water for approval		09/06
20. Develop brochure describing restoration process		09/06
21. Annual Report each September	09/01	09/05
22. Final and Close-Out Reports submitted to DOW		10/07
*** Measures of success**		

Detailed Budget

Budget Categories	Section 319(h)	Non-Federal Match	Total	Final Expenditures
Personnel	$189,780	$168,444	$358,224	$ 107,975.13
Supplies	22,325		22,325	0
Equipment	956	40,600	41,556	$ 8,178.57
Travel	10,750		10,750	0
Contractual	39,920	2,000	41,920	$ 21,313.13
Operating Costs	72,574	28,168	100,742	$ 45,822.28
Other				**0**
Total	$336,305	$239,212	$575,517	**$ 183,289.11**
	58 %	42 %	100%	

Bernheim Arboretum and Research Forest was reimbursed $103,102.58 . All dollars were spent; there were no excess project funds to reallocate. This project did generate overmatch provided by Bernheim Arboretum and Research Forest. This overmatch was not posted to the grant.

Equipment Summary

No equipment purchased under this grant has a current per-unit fair market value exceeding $5,000.

Equipment purchased with EPA 319 Monies

Date	Item	Amount	Notes
12/10/2004	MS 361 Stihl Chain Saw	$ 431.96	Replacement for Bernheim saw damaged in work on stream site
01/12/2005	Trencher Upgrade	$ 386.93	Bernheim
03/14/2005	Iomega External Harddrive	$ 139.60	University of Louisville
03/14/2005	Viking 256M Module	$ 70.71	University of Louisville
03/17/2005	Fire Safe 2 OCUFT	$ 400.43	University of Louisville
05/12/2005	Sony USB Storage Flashdrive	$ 59.67	University of Louisville
07/07/2005	HOBO Water Level Logger	$ 607.00	University of Louisville
08/24/2005	External Hardrive	$ 149.99	University of Louisville
08/30/2005	4 Stereomicroscopes	$ 520.00	Bernheim Educational Programs
09/26/2005	Velcro Board	$ 85.80	Bernheim Educational Programs
10/04/2005	GPS Mobile Mapper CE	$2,500.00	University of Louisville
03/28/2006	Streamtable (shared purchase with Bullitt Co.)	$ 720.00	Bernheim Educational Programs

Special Grant Conditions

There were no conditions placed on this project by USEPA.

Appendix B

QAPP for Water Monitoring

Project Title:

CHANNEL RESTORATION AND RIPARIAN REFORESTATION ALONG WILSON CREEK: A DEMONSTRATION SITE.

QUALITY ASSURANCE AND QUALITY CONTROL PLAN

Primary Contact:

Margaret Shea
Bernheim Arboretum and Research Forest
P.O. Box 130
Clermont, Kentucky 40110
Phone: 502-955-8512
Fax: 502-955-4039
e-mail: mshea@bernheim.win.net

QA/QC PLAN FOR MONITORING

1. **Title Section**

A. Full project name as stated in the WORKPLAN.

CHANNEL RESTORATION AND RIPARIAN REFORESTATION ALONG WILSON CREEK: A DEMONSTRATION SITE.

B. QA/QC Plan preparers

Dr. Paul Bukaveckas, Water Quality Monitoring QA/QC Officer, Associate Professor, Department of Biology, University of Louisville, Louisville, KY 40292.

Dr. Arthur Parola, Associate Professor, Civil and Environmental Engineering, University of Louisville, Louisville, Kentucky 40292

Dr. Charles Rhoades, Assistant Professor, Department of Forestry, University of Kentucky, Lexington, Kentucky 40506

Ms. Margaret Shea, Project Officer, Natural Areas Director, Bernheim Arboretum and Research Forest, P.O. Box 130, Clermont, KY, 40110.

C. Date of Plan

May 21, 1999

D. Type of nonpoint source problem

Agriculture, Hydrologic/Habitat Modification

2. **Project Organization and Responsibility**

A. Key people in charge of major monitoring activities

Ms. Margaret Shea, Project Officer, Natural Areas Director, Bernheim Arboretum and Research Forest, P.O. Box 130, Clermont, KY, 40110.

Dr. Paul Bukaveckas, Water Quality Monitoring QA/QC Officer, Associate Professor, Department of Biology, University of Louisville, Louisville, KY 40292.

Dr. Arthur Parola, Hydrologic Characterization and Site Restoration Planning, Associate Professor, Civil and Environmental Engineering, University of Louisville, Louisville, Kentucky 40292

Dr. Charles Rhoades, Native Plant Restoration and Assessment, Assistant Professor, Department of Forestry, University of Kentucky, Lexington, Kentucky 40506

Ronald Cicerello, Fish and Mussel Assessment, Aquatic Biologist, Kentucky State Nature Preserves Commission, 801 Schenkel Lane, Frankfort, Kentucky 40601

Greg Pond, Kentucky Division of Water, Frankfort Office Park, 14 Reilly Road, Frankfort, Kentucky 40601

B. Laboratories that will be used

University of Louisville Water Resources Analytical Laboratory

C. Other agencies involved with monitoring

Kentucky State Nature Preserves Commission will be assisting with biological monitoring of fish and mussel populations within Wilson Creek.

3. Watershed Information

A. Stream name

Wilson Creek

B. Major river basin

Salt River

C. Waterbody number

506901

D. USGS Hydrologic Unit number

05140103

E. Stream Order

Fourth

F. County

Bullitt and Nelson counties

G. USGS quadrangles

Samuels and Cravens

H. Milepoints of the stream that will be covered by project

Mile 16.0 through mile 16.6

4. Monitoring Objectives

The objective of monitoring will be to determine the effectiveness of riparian and stream channel restoration in improving the water quality and nutrient buffering capacity of Wilson Creek.

Monitoring stream chemistry, fluvial geomorphology and biotic communities (fish, mussels, and aquatic insects) before and after restoration will allow us to assess improvements in water quality and habitat usage arising from channel restoration. We will also conduct non-disruptive, whole-stream experiments to measure hydraulic characteristics, ecosystem metabolism and nutrient retention before and after channel restoration. We predict that channel restoration will increase the proportion of water that passes through sub-surface (hyporheic) storage zones. Greater water-sediment interaction will result in higher retention of dissolved nutrients (nitrogen and phosphorus) and a diminishment of downstream fluxes. Vegetation monitoring will assess the initial establish success of native plantings in riparian corridors and bottomlands, as well as establishment of coarse woody debris within aquatic and riparian zones.

5. Study Area Description

A. General description of the location of the project area.

The project area is Wilson Creek and associated bottoms from the confluence of Dunn Hollow into Wilson Creek, to the Harrison Fork Road crossing. This 0.6 mile section of Wilson Creek forms the boundary between Nelson and Bullitt counties. The study site is approximately 2.1 miles southwest of Henpeck, Kentucky and approximately 10 miles southeast of Shepherdsville, Kentucky. Harrison Fork Road bounds the south end of the study area. Geographic coordinates are 85º 36’ 10” long. 37º 52’ 20” lat.

B. Description of the physical environment of the project area.

Wilson Creek is within the Interior Low Plateau Ecoregion, and within the Knobs of the Outer Bluegrass Region of Kentucky. The geology of the study site consists of Ordovician dolomite within the existing streambed and Quaternary alluvium underlying the floodplain (Peterson, 1968). Soils that have been mapped within the study site are: Nolin silt loam, frequently flooded; Sensabaugh gravelly loam, occasionally flooded; Woolper silty clay loam, 2 to 6 percent slopes; and Woolper silty clay loam, 6 to 12 percent slopes (Whitaker and Waters, 1986). The elevation of the stream at the study site is 500’ with the adjacent hills reaching 800’ to 882’ elevation.

C. Description of the local hydrologic regime.

Wilson Creek is 16 miles in length and has a watershed of 26,041 acres. The study area includes a 0.6 mile stretch of the stream and encompasses 16 acres. Wilson Creek is a tributary of the Rolling Fork in the Salt River watershed. The creek is considered to be a High Quality Water by the KY Division of Water. Water quality data collected by Dr. Jan Stevenson (University of Louisville) during the early 1990’s showed that the site was being impacted by elevated nutrient loading. Concentrations of dissolved nitrogen and phosphorus were substantially higher in Wilson Creek than those measured in nearby reference streams (Overalls Creek and Harts Run) draining primarily forested watersheds. Both Overalls Creek and Harts Run are tributaries of Wilson Creek. Overalls Creek is approximately 2.9 miles long with a watershed of approximately 1,700 acres. Harts Run is approximately 2.7 miles long with a watershed of approximately 1,700 acres.

The data shown in the table below summarize nutrient concentrations in upper Wilson Creek and three nearby reference streams (based on monthly sampling in 1992). The results suggest elevated concentrations of nitrate, total nitrogen, soluble reactive phosphorus and total phosphorus in upper Wilson Creek consistent with anthropogenic effects from agricultural activities. For nitrate, peak concentrations were ca. 900 mg/L at upper Wilson Creek (Dec-Feb) but did not exceed 150 mg/L at any of the reference sites. These data have not been subjected to statistical analyses. As water quality data often do not meet assumptions associated with standard statistical tests, a non-parametric test (e.g., seasonal Kendall tau) or randomization approach could be used on these data and those arising from the proposed study (see below). These data have not been published.

	NO3 ug/L	NH3 ug/L	TN ug/L	SRP ug/L	TP ug/L	Si mg/L	CL mg/L
Upper Wilson	**307**	**33**	**546**	**11**	**22**	**7.10**	**4.63**
Harrison Fork	**34**	**17**	**163**	**6**	**13**	**8.75**	**3.11**
Overalls	**40**	**22**	**148**	**4**	**7**	**10.14**	**1.11**
Harts Run	**31**	**18**	**132**	**5**	**8**	**10.74**	**1.11**

D. Description of relevant land-use activities

The Wilson Creek watershed is predominantly forested (89%) with the exception of the bottom-land riparian areas which have been converted to agriculture (approximately 10% of the watershed area). Within the study area, the Wilson Creek stream channel has been substantially altered by past human activities. To facilitate agricultural use of the low, flat riparian area, farmers relocated the stream from its meandering corridor in the center of the riparian/floodplain zone to the extreme edge of the floodplain (proximal to a steep hillside). The bottomland within the study area is currently dominated by Fescue and is mowed annually. This site was previously in agricultural use.

Two tributaries of Wilson Creek, mentioned earlier as reference streams for water quality, are Overalls Creek and Harts Run. Overalls Creek is contained entirely within Bernheim’s natural area. The watershed is primarily forested, with the exception of approximately 15 acres of old fields that are currently mowed annually. Harts Run is primarily within Bernheim’s natural area with the exception of 183 acres in private ownership. Within Bernheim’s boundary there are 50 acres of old fields that are currently mowed annually. The 183 acres in private ownership is forested and timber is harvested periodically.

E. Site Map

See map of proposed study area.

6. Monitoring Program/Technical Design

A. Monitoring approaches and strategies to be used.

Physicochemical Sampling

Samples for water quality analyses will be collected on a rain event basis to ensure that the samples are representative of the bulk of the water leaving the catchment. Routine monitoring of stream water quality will entail monthly sampling on a rain event basis. A volume of rain exceeding one inch within 48 hours will trigger sample collection. Rainfall data are available from a nearby meteorological station maintained by Bernheim Arboretum and Research Forest. Our previous experience using this design (Jefferson County Memorial Forest) yielded 10-14 sample sets corresponding to 40-60 % of total annual stream discharge. No attempt will be made to determine whether samples were taken on the rising or falling hydrograph but stream stage will be measured for each sampling event.

Discharge will be measured in association with all stream water samples collected as part of this project. We will be installing a weir at a location just above the section of the channel undergoing restoration. This will allow us to estimate the amount of flow based on periodic measurements of stream stage. We do not plan to install automated stream gauging equipment as this is beyond the scope of our project. Drip experiments using a conservative tracer will be used to estimate groundwater inputs along the length of the current and restored channels. Analyses will include dissolved and particulate fractions of nitrogen and phosphorus as well as standard water quality parameters (temperature, pH, dissolved oxygen, suspended solids). We anticipate that approximately 300 streamwater samples will be collected and analyzed during the 5-year study. We will use randomization analyses to assess the statistical significance of changes in water quality associated with stream/riparian restoration. We are specifically interested in the effects of restoration on stream nitrate retention but will also test other parameters of interest (e.g., phosphorus, total suspended solids). Paired samples will be collected upstream and downstream of the restoration site (upper Wilson Creek) and from a nearby reference stream. Differences between paired samples pre- and post- restoration will be compared to assess changes in solute retention. The mean difference for pre- and post- restoration periods will be compared against a distribution of mean differences generated from randomizing paired samples through time to determine the likelihood of obtaining the observed difference by chance. This analyses will be used to test the null hypothesis that no significant change in solute concentrations occurred following stream restoration. Randomization of difference distributions does not require that the underlying data are normally distributed or other assumptions associated with fixed distribution statistics (t-, F- tests).

In-stream experiments will be conducted at Wilson Creek in its current channel (prior to restoration) and in the restored channel. We will simultaneously inject a conservative tracer (NaBr) and a dynamic solute (NaNO3) and track their fate downstream. These solutes are added to the stream at a steady rate (using a metering pump) at a location 5-10 m above the upper sampling location to allow mixing within the stream channel. Solutes are added for a 10-day period and monitored (upper and lower sampling sites) during the injection and for 10 days after. Tracer data are used to quantify infiltration and storage of stream water into sub-surface zones. Downstream changes in nitrogen concentrations (as a ratio to the conservative tracer) are used to determine uptake and retention. Methodology and data analyses follows those described by the Mulholland et al. (1997) and Valett et al. (1996).

Routine (monthly) monitoring of stream chemistry will be conducted on an event basis and will not require automated sampling devices. Experiments designed to measure in-stream nitrate retention require frequent sampling (15 min intervals for 6-8 hr) and will entail use of two recently purchased ISCO (Model 6712) portable automated samplers (battery powered). Samples will be retrieved at the end of each 1-day experiment and analyzed for nitrate and chloride. The samplers are also interfaced with a YSI probe for continuous monitoring of temperature and conductance during the experiment. The samplers will be located at the top (upstream) and bottom of the stream reach designated for restoration.

Biological Monitoring Methods

Fish will be sampled by seining and mussels will be sampled with a timed count. The Kentucky version of the Biotic Integrity Methodology will be used to analyze the fish samples (Kentucky Division of Water 1993).

Sampling for aquatic insects will be done in accordance with KDOW sampling protocols (SOP manual in preparation). Essentially, the technique is a multi-habitat sample that targets productive habitats found within the stream reach (e.g., riffle, under-cut banks, root mats, boulders, soft sediment, and leaf packs). Semi-quantitative riffle samples (a composite of 4--0.25 m2 samples taken from thalweg area) will be kept separate for analysis.

Vegetation Monitoring Methods

Permanent vegetation plots will be established for monitoring of tree, shrub and herbaceous strata. The sample design will consist of 1 X 1 meter herbaceous vegetation plots nested within 10 X 2 meter shrub and 10 X 10 meter tree plots (Elzinga et al, 1998). The vegetation sampling plots will be located randomly throughout the study area. Annual sampling will document survivorship and height and diameter growth of planted species. Frequency and cover of planted and colonizing native and non-native herbaceous vegetation and recruitment of tree and shrub seedlings will be measured in 1-m^2 quadrats. As riparian forests develop, monitoring will include estimation of coarse woody debris and fine litter inputs and accumulation within the stream channel.

Fluvial Geomorphic Monitoring Methods

Three types of fluvial geomorphic data will be collected: 1) existing channel and watershed assessment, 2) reference reach characterization, and 3) proposed site data collection. In addition, information on the history of the basin and the stream site will be collected. A brief description of the type of data that will be collected is provided below:

1) Existing channel and watershed assessment

- Channel and watershed assessment
- Stream bed characterization

- Geotechnical characterization and stability of streambanks including vegetation effects
- Flow characterization
- Streambed stability assessment
- Flood flow assessment
- Stream profile and planform assessment (bend, pool and riffle characteristics)
- Valley characteristics
- Range of pool and riffle cross-sectional shape
- Watershed sediment and flow characterization
- Downstream hydraulic control characterization
- Groundwater elevation at select locations

2) Reference Reach Assessment

- Stream bed characterization
- Geotechnical characterization and stability of streambanks including vegetation effects
- Flow characterization
- Streambed stability assessment
- Flood flow assessment
- Stream profile and planform assessment (bend, pool and riffle characteristics)
- Valley characteristics
- Range of pool, riffle, glide and run cross-sectional characteristics
- Watershed sediment and flow characterization
- Downstream hydraulic control characterization

3) Proposed Relocation Site Survey

- Valley floodplain soils and substratum – detailed sedimentation logs
- Valley slope and topography
- Watershed sediment and flow characterization
- Downstream hydraulic control characterization

The geomorphic data will be collected as described in Rosgen (1996) and Thorne (1998).

B. Monitoring station locations.

The five monitoring station locations are indicated on the map of the study site. Locations of these sites are as follows are: Site 1 85° 36' 30" long. 37° 52' 40" lat.; Site 2 85° 35' 50" long. 37° 52' 20" lat.; Site 3 85° 36' 15" long. 37° 52' 15" lat.; Site 4 85° 36' 20" long. 37° 52' 40" lat.; and Site 5 85° 37' 50" long. 37° 52' 00" lat.

Water quality monitoring will be conducted at 4 sites: 2 located on Wilsons Creek (up- and down-stream of the restored channel) and 2 located at nearby reference streams (Harts Run and Overalls Creek) (See map of study site, locations 1, 3, 4, and 5). This design will allow us to distinguish the effects of the restoration from natural interannual variability.

Fish, mussel and aquatic insect sampling will be completed at three locations: upstream from, downstream from and within the study area (See map of study site, locations 1, 2, and 3). The upstream sample locations will provide reference information to distinguish the effects of the restoration from natural interannual variability.

Vegetation monitoring plots will be located randomly within the study area. The restored stream reach will be partitioned into 100-m wide segments oriented perpendicular to the stream corridor. Within each segment, one sample transect running perpendicular to the stream corridor from the low flow width (streambank) upslope for 30 m. Sample transects will be located randomly within each stream segment.

Fluvial geomorphic monitoring will be located within the current Wilson Creek channel, within reference reaches of Wilson Creek and Overalls Creek, and within the proposed location of the restored stream.

C. Sampling frequency and duration.

Water quality monitoring will be conducted at 4 sites: 2 located on Wilsons Creek (up- and down- stream of the restored channel) and 2 located at nearby reference streams (Harts Run and Overalls Creek). This design will allow us to distinguish the effects of the restoration from natural interannual variability. Samples will be collected 12-15 times per year on a rain event basis to ensure that they represent the bulk of the water leaving the catchment. Analyses will include dissolved and particulate fractions of nitrogen and phosphorus as well as standard water quality parameters (pH, dissolved oxygen, suspended solids). We anticipate that approximately 300 streamwater samples will be collected and analyzed during the 5-year study.

Fish, mussel, and aquatic insects will be sampled in 2001 (pre-restoration), 2003 (early post-restoration), and 2005 (post-restoration). Sampling will occur in May and June

Vegetation monitoring will occur annually throughout the course of the project, once the plantings have occurred. Sampling will occur throughout the growing season.

D. Types of data to be tested.

Physicochemical Data to be collected:

Parameter	**Analysis (**Standard Methods (19th Ed., 1995))
*Ammonia	4500-NH3 G (automated phenate method)
Chloride	4500-Cl C (mercuric nitrate method)
Nitrate	4500-NO3 F (automated cadmium reduction)
Soluble Reactive Phosphorus	4500-P F (automated ascorbic acid reduction)

Preservation and recommended holding times

Parameter	Preservative	Holding Time	**Container**
Ammonia	none	7 days (dark, ice)	acid-washed 500 ml polyethylene bottles
Chloride	none	28 days (dark, ice)	acid-washed 500 ml polyethylene bottles
Nitrate	none	48 hr (dark, ice)	acid-washed 500 ml polyethylene bottles
Phosphorus	none	1-3 days (dark, ice)	acid-washed 500 ml polyethylene bottles

7. Chain of Custody Procedures

The Chain of Custody form (Appendix 1) will be used for all samples taken during this program and used for all tracking and QA/QC purposes. Forms include entries, to be filled by the sampler, of sample number, date and time, station description, method, type, size, type of preservation, and analysis requested. The sampler will carry the samples and records to the lab staff member designated to receive the samples. At all transactions, both the relinquishing and receiving parties will sign the Chain of Custody form.

8. Quality Control Procedures

A. Container and equipment decontamination:

All grab samples and samples extracted by the automatic samplers will be initially collected in 500 ml polyethylene bottles. All bottles and caps will be acid washed and triple rinsed (with Nanopure DI water). Caps will be placed on bottles and readied for field use. Any field measurements of pH, and specific conductance will be made with a portion of the sample not sent to the lab. Each probe will be rinsed in distilled/deionized water prior to placement in the next sample. The University of Louisville's Environmental Analyses Laboratory is currently undergoing the process of obtaining certification from the KY Division of Water. We expect to complete this process by July 31, 2001 and will provide a copy of our Standard Operating and Quality Assurance/Quality Control procedures at that time. During the interim, specific information can be provided by the lab manager, Dr. Jeff Jack (UofL).

For biological samples, all nets and sieves will be thoroughly rinsed between samples with filtered water to avoid cross-sample contamination. All holding vials and bottles will be factory cleaned to assure no sample contamination.

B. Equipment calibration:

All equipment will be calibrated in the lab prior to each day's use in accordance to manufacturers directions. Standard solutions will be brought to the field and instruments re-calibrated after each hour of use. A calibration form will accompany each probe and the sampler will enter all activities relative to sampling and calibration. Similar procedures will be followed for laboratory equipment, with calibration and logbooks being maintained for each instrument.

C. Sample contamination prevention:

Upon opening the automatic sampler, the technician will cap all sample bottles with acid-washed and labeled caps. The sample bottles will be taken to the lab for analyses.

D. Quality Control:

Field duplicates will be performed after each ten samples in order to determine instrument drift. One of each 20 samples will be split and sent to the lab as a blind duplicate, and one of each 20 samples will be split and spiked with a known concentration of an analyzed parameter and sent to the lab as a blind spike. The lab will be responsible for carrying out its QA/QC program as pertaining to lab and equipment blanks. Randomly-selected macroinvertebrate samples from each sampling period will be sent to outside authorities for taxonomic confirmation (macroinvertebrates: Dr. Gunther Schuster, Eastern KY University). Voucher species along with reference details and authorities consulted will be maintained in the laboratory.

E. Acceptable levels of variance for duplicate results.

In general, unacceptable variance in within-site samples will be defined as data points which differ more than one standard error of the mean from mean data values for that sample location. See “G” below for response to unacceptable data variance.

F. Laboratory references:-

See Tables in Data Types section for methods used and their EPA equivalents

G. Steps to address unacceptable results.

If unacceptable results are obtained, the following procedure will be followed. A report must be made within 24 hours to the Project QA/QC officer (Dr. Paul Bukaveckas) detailing: (1) data type, collection data, responsible person(s), (2) reasons for suspecting compromised data quality, and (3) possible reasons (if known) for compromised data quality.

Dr. Bukaveckas may then, in consultation with the appropriate member(s) of the project team:

- Order the samples retaken, instruments re-calibrated or some such action as he deems appropriate to correct the errors AND to obtain new data if possible to replace the compromised data.
- Call a meeting of the appropriate members of the project group to reconsider sampling methods or design to avoid errors in the future.
- Advise the project director to withhold payment of project funds to individuals and organizations whose data are compromised until they demonstrate they have rectified the situation and are providing data of good and uniform quality to the project.

Dr. Bukaveckas may also choose to delegate this responsibility to one of the associate QA/QC officers on this project (e.g. Dr. Parola for hydrology) if the associate QA/QC officer is deemed competent by the Project Director to accomplish the task.

9. Data Management and Data Reporting Standards

Data from the water quality will be housed at University of Louisville in the Department of Forestry. Dr. Paul Bukaveckas will oversee data analysis and quality control.

Data from hydrological and geomorphological monitoring will be housed at the University of Louisville in the Department of Civil Engineering. Dr. Arthur Parola will oversee data analysis and quality control.

Data from vegetation monitoring will be housed at the University of Kentucky in the Department of Forestry. Dr. Charles Rhoades will oversee data analysis and quality control.

Data from fish and mussel sampling within the study area will be housed at The Kentucky State Nature Preserves Commission office, 801 Schenkel Lane, Frankfort, Kentucky 40601. Ron Cicerello will oversee data analysis and quality control.

Data from aquatic insect sampling will be house at the Division of Water, Frankfort Office Park, 14 Reilly Road, Frankfort, Kentucky 40601

10. QA/QC References

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Appendix C

BMP

Wilson Creek Stream Restoration Project
Flood Plane Impact Study
Summary Report

Channel Restoration And Riparian Reforestation Along Wilson Creek: A Demonstration Site Revegetation

Wilson Creek Stream Restoration Project
Flood Plane Impact Study
Summary Report

Conducted for

Bernheim Arboretum and Research Forest
Margaret Shea
Clermont, Kentucky

Conducted by

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May 14, 2003

Introduction

Wilson Creek upstream of the Harrison Fork County road ford is being modified as an EPA 319(h) stream restoration demonstration project. The upstream restoration includes changes in the stream location, modification of channel cross-sections and profile characteristics, and reduction in floodplain elevation. In the vicinity and downstream of the county road ford, floodplain elevations will be lowered to increase flow in floodplains during overbank events and to reduce stress on the ford and nearby streambanks.

A hydraulic model study was conducted to determine the impact of the proposed restoration on flood flow water surface elevations. The one-dimensional water surface profile model HEC-RAS version 3.01 (Brunner, 2002) was used to evaluate the existing and proposed conditions. This report is a brief summary of the results of the study.

Project Extent and Location.

The project is located in Nelson County immediately west of the Bullitt county border. The total length of the proposed restoration channel is 3102 ft and located upstream of the Harrison Fork road ford. Floodplain excavation will extend downstream approximately 420 ft from the ford. The Harrison Fork Road ford is located at latitude of 85 degrees 36 minutes west and longitude of 37 degrees 52 minutes north.

Model Input

Model input for the existing and proposed conditions was based on 1 ft contour mapping of the project reaches (See included map sheet 1 and 2) and cross section surveys downstream of the project reaches. Channel and floodplain roughness was obtained from (Brunner, 2001) and modified based on site observation. Flood flows were computed using the USGS Regional Curve method for Kentucky Streams (Choquette,1987 and USGS, 1993) as indicated in Table 1.

Table 1. Watershed Area and 100 Year Event Flow Estimates.

Reach	Watershed Area (Sq. Mi.)	Estimated 100 Year-Event Flow (CFS)
Upstream of Dunn Hollow tributary	5.13	2080
Downstream of Dunn Hollow Tributary	5.53	2230
Downstream of Harrison Fork Confluence	9.38	3760

Cross section locations were selected to represent changes in channel and floodplain characteristics and the complex geometry of the proposed restored channel. Cross sections in the proposed model were positioned in approximately the same valley locations as the proposed model for ease in comparing water surface elevations; however, the transect represented by each cross section varied between models in some cross sections to allow for alignment of anticipated flow directions perpendicular to the cross sections. Interpolated cross sections were necessary in the existing model to represent supercritical flow through bedrock bottom reach. The interpolated cross sections were unnecessary in the relocated proposed channel.

Two stream confluences were modeled: an unnamed tributary that drains Dunn Hollow and Harrison Fork. Since the drainage area of Dunn Hollow is less than 10 percent of the combined watershed area below its confluence with Wilson Creek, a simple flow adjustment was made at the cross section immediately downstream of the confluence. The energy method presented in Brunner, 2001 was used to model the Harrison Fork and Wilson confluence because the watersheds are of similar size.

Model Results

Detailed HEC-RAS output reports for the existing and proposed condition models are provided in appendix A. Water surface profiles, energy grade lines, and critical depth information are provided graphically in Figures 1 and 2 for the existing and proposed conditions, respectively. These figures illustrate the characteristics of the existing and proposed stream profile for the 100 year event with respect to distance along the main channel.

Existing Conditions Model

Figure 1 shows the contraction and backwater effect of the existing high berm located parallel to Wilson Creek (see Existing Flood Study Plan Sheet 1 of 1). The most severe contraction caused by the berm was modeled in cross sections 4 through 7 although the ineffective areas of this berm extends well beyond these cross sections. The contraction effect of existing dredge spoil piles and the high berm extends downstream to cross section 2. Contracted high flow in the region of the ford causes bank erosion and bed erosion that requires maintenance of the ford.

The existing condition models show that supercritical flow and a hydraulic jump in the region of cross section 37 through 41. Interpolated cross sections were used to show details of the rapidly changing water surface profile in the region of the drop. The model provides an error message that it could not balance energy at the transition from subcritical to supercritical flow. Conditions at the transition were computed to be near critical. Although the model is incapable of balancing energy through the critical depth point, the model assumes critical depth (and energy) for flow in a reasonable location (cross section 40).

Proposed Conditions

Despite the complex geometry of the proposed restoration channel, the water surface and energy profile is more consistent than for the existing, relatively straight channel (compare Figures 1 and 2). Flood plain excavation, strategic removal of berms and relocation and grading of the channel bed have resulted in the relatively consistent dissipation of flood flow energy as illustrated in Figure 2.

Near the ford (cross sections 3 through 7), excavation of berm and floodplain material reduced contraction effects by allowing increased flood flow access to the floodplain and have reduced channel velocities that cause erosion of the streambanks and bed and destroy the ford during major flow events.

100 Year Event Water Surface Profile Comparison

Existing and proposed conditions invert elevations and computed water surface elevations are provided in Table 2 and shown as a graph in Figure 3. Main channel distances between cross sections are different because of the increase in channel length in the proposed model. For comparison of water surface elevations at approximately the same valley locations, Figure 3 shows elevations for parameters of the existing and proposed condition with respect to cross section number.

Table 2 provides also the difference in water surface elevations between the existing and proposed conditions. Figure 4 illustrates the variation of water surface elevation with respect to cross section number.

Downstream of Project and Area of Ford - downstream of the project reach, represented by cross section 1 there is no impact because subcritical backwater impacts are not propagates downstream in a one-dimensional energy model. At cross section 2, a slight rise in computed water surface was observed because of the reduction in flow velocity caused by the increased flood plain flow and flow area in the proposed model. The impact of the increased floodplain flow area of the proposed model is observed at and upstream of the ford with decreased flood elevations and reduced channel velocity between cross section 3 and 4 and significantly decreased flood flow elevations upstream to cross section 11.

Computed water surface elevations increased under the proposed model conditions in the central portion of the project area. This increase in flood elevation was designed to increase interaction of the floodplain with the channel for ecological benefits. There are no improved roads or structures in this area. At the upstream end of the project the channel invert and water surface are essentially identical for the existing and proposed conditions. The rapid return from about two feet of surcharge in the proposed model to virtually no surcharge occurred in the region where a bedrock drop occurs in the existing conditions model. Because this fall does not exist in the proposed model, flow energy is dissipated more uniformly in the proposed model than in the existing mode.

Conclusions

This study shows that water surface elevations will not be changed significantly (less than 1 ft) outside of the project limits. Within the project limits, floodplain elevations were reduced except in reaches were increases were designed to provide ecological benefits.

References

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Table 2. Modeled Channel Invert and Computed Water Surface Elevation Comparison of Existing and Proposed Conditions for 100 Year Flood Event.

Cross Section Number	Existing Channel Invert Elevation (ft)	Existing WSE (ft)	Proposed Invert Elevation (ft]	Proposed WSE (ft)	Invert Difference (ft)	WSE Difference (ft)
1	489.52	497.19	489.52	497.19	0.00	0.00
2	489.56	497.23	489.56	497.56	0.00	0.33
3	490.35	498.13	490.35	498.15	0.00	0.02
3.3	491.62	498.56	491 .62	498.22	0.00	-0.34
3.6	491.36	498.60	491.36	498.24	0.00	-0.36
4	491.49	498.43	491.49	498.26	0.00	-0.17
5	492.06	498.51	492.00	498.24	-0.06	-0.27
3	492.27	498.73	492.37	498.07	0.10	-0.66
7	492.30	499.16	492.90	498.78	0.60	-0.38
8	492.69	499.79	493.00	498.82	0.31	-0.97
9	492.69	500.05	493.00	499.21	0.31	-0.84
10	493.05	500.21	494.00	499.66	0.95	-0.55
11	493.42	500.26	494.00	500.18	0.58	-0.08
12	493.52	500.30	494.00	500.35	0.48	0.05
13	494.02	500.60	494.90	500.66	0.88	0.06
14	494.20	500.73	495.00	500.75	0.80	0.02
15	494.25	500.79	495.00	500.81	0.75	0.02
16	494.81	501.01	495.75	500.76	0.94	-0.25
17	494.88	501 .23	496.00	501.46	1.12	0.23
18	494.74	501 .78	496.00	501.93	1.26	0.15
19	495.26	502.19	497.00	502.68	1.74	0.49
20	495.35	502.19	497.00	503.04	1.65	0.85
21	495.56	502.21	497.00	503.39	1.44	1.18
22	497.52	502.68	498.30	503.66	0.78	0.98

23	496.67	502.95	498.30	504.17	1.63	1.22
24	496.43	503.02	498.30	504.30	1.87	1.28
25	496.49	503.15	499.00	504.65	2.51	1.50
26	496.59	503.48	499.00	504.84	2.41	1.36
27	496.65	503.63	499.00	504.99	2.35	1.36
28	497.25	504.22	499.82	505.44	2.57	1.22
29	498.20	504.27	498.12	505.79	-0.08	1.52
30	497.62	504.31	499.94	505.71	2.32	1.40
31	498.02	504.66	501 .00	506.56	2.98	1.90
32	498.26	505.00	501.00	506.74	2.74	1.74
33	498.38	505.19	501.00	506.88	2.62	1.69
34	500.15	506.00	503.00	507.77	2.85	1.77
35	500.60	506.51	500.61	507.90	0.01	1.39
36	499.52	506.64	503.00	507.94	3.48	1.30
37	501 .57	507.44	503.89	508.89	2.32	1.45
38	501.58	507.40	503.96	509.05	2.38	1.65
39	501.93	507.17	503.93	509.09	2.00	1.92
40	504.47	509.35	504.16	509.64	-0.31	0.29
41	504.35	509.96	504.30	509.93	-0.05	-0.03
42	503.36	510.13	503.36	510.08	0.00	-0.05
43	504.92	510.35	504.92	510.32	0.00	-0.03
44	505.15	511.47	505.15	51 1 .47	0.00	0.00
45	506.40	511.97	506.40	51 1 .97	0.00	0.00

Project Title:

CHANNEL RESTORATION AND RIPARIAN REFORESTATION ALONG WILSON CREEK: A DEMONSTRATION SITE.

BMP IMPLEMENTATION PLAN
for
SITE REVEGETATION

Primary Contact:

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Lead Agency:

Bernheim Arboretum and Research Forest

Part I. Sediment Control Measures

Construction activities have been planned to minimize erosion within the newly constructed stream channel and sediment export during or following construction activities. Exposed construction surfaces will be protected with erosion control fabric and a cover crop and silt fencing will minimize surface runoff. Construction activities are scheduled for central Kentucky’s driest season (late summer) to reduce erosion risks. Following channel construction, stream discharge will be diverted gradually into the new channel to reduce erosion.

Sediment Retention Pond

Prior to construction, a small be dug on the downstream end of the field. This area will act as a settling pond for suspended sediment carried along the constructed channel during and immediately after construction.

Silt Fences

To reduce sheet erosion, silt fence will be installed along portions of the new stream construction that are adjacent to the current channel. The ends of the fence will be turned uphill to increase ponding and sediment storage. Silt fence will consist of 3’ x 100’ woven fabric sections stapled to 1 ¼” x 1 ¼” X 4’ hardwood stakes. Post spacing shall not exceed 6’. The bottom of the silt fence will be placed into a trench and covered with dirt a minimum of 6” deep. At least 18” of overlap will be provided between fence segments. The silt fences will be installed as channel construction progresses and will remain on the site for one year following completion of the stream channel. To maintain the integrity of the silt fences, sediment shall be cleaned from behind the fence when it reaches 50% of the fence height (about 18”).

Erosion Control Fabric

Erosion control fabric will be secured on all newly constructed bankslopes below the bankful elevation. Fabric will be anchored with 6” long galvanized staples at upper, mid and toeslope positions. Where necessary, 2 tiers of fabric may be installed. Dense plantings of willow stakes, interspersed with rooted tree stumps (i.e. transplanted, coppiced, mature trees), will be installed along outside bends to increase bank stabilization and canopy cover near permanent stream pools (see the following section for additional information on revegetation of the site).

Part II. Revegetation of the Stream Corridor

Riparian Corridor Design

Revegetation along the restored Wilson Creek channel will occur in 3 separate zones (Table 1) within the valley floodplain and the banks within the active channel. An 8-acre riparian forest corridor, extending 50’ from the new channel will be planted shortly after channel construction. In addition to riparian forest, the restoration site will include wet meadow, canebrake, and bottomland forest plant community types native to the area.

Zone 1 will extend fifteen feet from bankfull elevation at the edge of the stream channel. This near-streambank zone will be planted with rapidly growing native tree and shrub species common to reference riparian streambank communities of Wilson Creek and neighboring drainages (Dattillo, 2003; Table 2). Trees and shrubs will be planted at 4’ by 4’ spacing. The close spacing is intended to promote rapid canopy closure and to compensate for seedling mortality. The herbaceous layer will consist of two native grass species, a half-dozen native graminoids (*Carex* spp. *and Scirpus* spp.), and about 20 native forbs (Table 3). All herbaceous seed was collected from riparian areas and floodplain forest within five miles of the restoration site and processed (dried, cleaned, mixed) at Bernheim Research Forest and Arboretum. The mixture of herbaceous species will be seeded at about 10 lb/acre (20 lbs. total in Zone 1) with an approximate 50:50 mix of graminoids and forbs.

The exposed bankslopes below the bankful elevation will be protected with jute erosion control fabric and an annual grass cover planting (annual rye). Willow stakes and native cane will be planted to enhance bank stablization and sediment retention near the outside and inside (point bars) of stream bends (included within zone 1 calculations).

The second band (**Zone 2**), extends the riparian forest an additional 35’ from the streambank. Tree and shrub species will be planted at 6 x 6 ft spacing in this 5.6 acre area. This zone will include overstory and shrub riparian species typically found on somewhat drier sites, relative to zone 1 conditions (i.e. bur oak, persimmon; Table 4). Herbaceous species and planting rate (10 lb/ac) will be similar to those planted in Zone 1 (Table 3).

Remainder of the valley bottom in the Wilson Creek restoration area (**Zone 3**), approximately 8 acres, will initially be planted in a mix of herbaceous prairie species (>54 species; Table 5). As the hydrology of the site stabilizes, portions of this bottomland area will be considered for development of a wet meadow community and further extension of the forested area. Permanent native upland herbaceous communities may be maintained to facilitate observation of the restored stream channel and riparian corridor.

Table 1. Wilson Creek riparian revegetation zones and tree spacing guidelines.

Zone	Vegetation	Width (ft. from each bank)	Acres	Tree spacing	Density (trees/ac)	Total Trees
1	Trees/Shrubs	15’	2.4	4’ x 4’	2,722	7,000
2	Trees/Shrubs	35’	5.6	6’ x 6’	1,210	7,000
3	Herbaceous		8.0			

Table 2. Tree and Shrub species for near-streambank revegetation (Zone 1).

Scientific Name	Common Name	Projected Stock
Salix nigra	Black willow	2,000
Juglans nigra	Black walnut	1,200
Platanus occidentalis	American	1,000
Fraxinus pennsylvanica var.	Green ash	1,000
Quercus bicolor	Swamp white	1,000
Quercus palustris	Pin oak	500
Aesculus glabra	Buckeye	400
Cephalanthus occidentalis	Buttonbush	1,500
Arundinaria gigantea	Cane	500

Table 3. Herbaceous species for near-streambank and riparian buffer striprevegetation (Zone 1 and 2).

Scientific Name	Common Name
Chasmamthium latifolium	River oats
Hystrix patula	Bottle brush grass
Carex granularis	Sedge
Carex lurida	Shallow sedge
Carex squarrosa	Squarrose sedge
Carex vulpinoidea	Fox sedge
Scirpus atrovirens	Scirpus
Scirpus cyperinus	woolgrass
Allisma subcordatum	Water-plantain
Asclepias incarnata	Swamp milkweed
Bidens polylepis	Awnless beggar-ticks
Bohemeria cylindrica	False nettle
Campanula americana	Tall bellflower
Echinodorus berteroi	Tall bur-head
Eupatoriadelphus	Hollow Joe Pye weed
Eupatorium perfoliatum	Boneset
Fimbrystylis sp.	Fimbrystlis
Helenium autumale	Sneeze weed
Hibiscus laevis	Halberd-leaf rosemallow
Liatris aspera	Lacerate blazing star
Lobelia cardinalis	Cardinal flower
Lobelia siphilitica	Blue lobelia
Ludwigia alternifolia	Bushy seedbox
Penstemon digitalis	Foxglove beard tongue
Polymnia canadensis	Leafcup
Pycanthemum tenuifolium	Slender mountain mint
Ratibida pinnata	Yellow-headed
Rudbeckia lanciniata	Cut-leaf coneflower
Rudbeckia triloba	Thin-leaved coneflower

Table 4. Tree and Shrub species for riparian buffer strip revegetation (Zone 2).

Scientific Name	Common Name	Projected Stock
Juglans nigra	Black walnut	2,000
Salix nigra	Black willow	2,000
Diospyros	Persimmon	900
Quercus palustris	Pin oak	500
Aesculus glabra	Buckeye	400
Quercus	Bur oak	150
Lindera benzoin	Spicebush	330

Table 5. Herbaceous species for floodplain revegetation (Zone 3).

Latin Name	Common Name
Agave virginica	False aloe
Andropogon gerardii	Big bluestem
Andropogon scoparius	Little bluestem
Bouteloua curtipendula	Side oats grama
Panicum virgatum	Prairie switch grass
Sorghastrum nutans	Indian grass
Asclepius tuberosa	Butterfly weed
Aster novae-angliae	New England aster
Blephilia ciliata	Wood mint
Cassia fasciculata	Partridge pea
Coreopsis palmata	Prairie coreopsis
Coreopsis tripteris	Tall coreopsis
Echinacea pallida	Pale purple coneflower
Eryngium yuccifolium	Rattlesnake master
Eupatorium rugosum	Boneset
Eupatorium serotinum	Late boneset
Guara parviflora	Guara
Helianthus hirsutus	Rough-leaved
Helianthus mollis	Downy sunflower
Hypericum	St. John’s wort
Lespedeza capitata	Round head bush
Liatris aspera	Rough blazing star
Monarda fistulosa	Prairie bergamot
Petalostemum	Purple prairie clover
Physostegia virginiana	False dragonhead
Prunella vulgaris	Heal-all
Pycnanthemum	Mountain mint

Ratibita pinnata	Yellow coneflower
Rudbeckia hirta	Black eyed susan
Rudbeckia fulgida	Orange coneflower
Sabatia angularis	Rose pink
Silphium laciniatum	Compass plant
Silphium integrifolium	Rosinweed
Silphium perfoliatum	Cup plant

Site Preparation and Plantation Establishment

Immediately following channel construction, the invasive non-native grass, tall fescue (*Festuca arundinacea*), will be eradicated with a broadcast herbicide spray (2% glyphosate). Herbaceous seed will then broadcast seeded into zones 1 and 2. To insure rapid soil coverage, an annual grass cover crop (annual rye) will be added to the native seed mix. Herbaceous seed will be drill seeded into zone 3, since we are using a wet prairie mix in this zone and drill seeding is more effective for these seeds. Shrub and tree seedlings will be planted into zones 1 and 2, following planting of the herbaceous species. Where possible, a mechanical tree planter will be used; in other locations staff and volunteers will plant the woody stems using dibble bars.

Monitoring and Follow Up

Vegetation will be monitored annually in the late growing season to evaluate both growth and survivorship of woody and herbaceous species. Native woody or herbaceous species replanting will be conducted annually as the stream channel and site hydrology stabilizes. Non-native species will be controlled frequently until native vegetation becomes well established.

List of BMP technologies to be installed

1. **Stream restoration**: Returning meanders to channelized section of stream, lowering floodplain level to allow for flooding, placement of gravels and boulders in channel for soil stabilization and fish and macroinvertebrate habitat.
2. **Revegetation of stream corridor**: Replanting native vegetation along stream edge and floodplain area.
3. **Erosion Control Measures**:

    a. Silt Collection Pond at downstream end of construction work.
    b. Silt fences on erosion-prone portions of construction work.
    c. Planting of cover crop over sections of completed construction.
    d. Erosion Control Fabric along the bank edges.

Technology Selection Process (estimated cost, relative efficiency, maintenance)

Silt Fences	$2.00 ft	4 areas, 100’ each, 400’	$800
Cover Crop	$1/# 30 #/acre	18 acres	$500 seed; $100 straw
Erosion Control Fabric	$52/roll (4’ X 225’)	6000’	$1387 1 tier; $2773 2 tiers.
Stream Restoration	$6.66 per linear foot	$20,000 in equipment rental for 3,000’	(Some equipment and all operators supplied by Bernheim)
Revegetation	All grown in Bernheim and KY Forestry nurseries.		

Location of BMPs

1. **Stream restoration:** see attached map
2. **Revegetation of stream corridor:** Zone 1 planting will extend from the bankfull level of the creek to 15’ on both sides of the creek. Zone 2 planting will extend from zone 1 out an additional 35’ on each side of the creek. The remainder of the field will be planted in Zone 3 material. Density and species mixes for the zones are outlined on the previous pages
3. **Erosion Control Measures**

    a. Silt Collection Pond: Will be located at downstream end of the new construction just upstream from where the new channel will reconnect to the existing channel.
    b. Silt Fences: Will be location at all points where construction approaches the current channel.
    c. Planting of cover crop: Cover crops will be used over the entire construction area to reduce erosion.
    d. Erosion Control Fabric: Will be used only along the edge of the newly constructed stream in conjunction with planting of both woody and herbaceous native species.

Means of Notifying DOW prior to BMP locations

Bernheim will contact DOW prior to any changes in the above mentioned locations of BMPs.

Financial Plan

Because Bernheim is supplying all the native seed and plant material for the restoration project, adequate funding will be available through the grant to allow for the purchase of all BMPs.

Maintenance Agreement

Bernheim will agree to maintain the stream restoration project in perpetuity.

The BMP Implementation Plan shall include a restoration design which specifies or documents the procedure that will be used to develop the restoration design, describes the extent of the design, relates the restored area to the extent of disturbance, identifies how transitions upstream and downstream from the restoration area will be planned, and describes any channel changes and changes in flooding potential.

The BMP Implementation Plan shall include a post-restoration assessment which evaluates the success (stability, duration, etc.) of the restoration techniques. The post-restoration assessment should provide a means for periodic and long term evaluation of the restoration sites,

Appendix D

Geomorphic Assessment and Stream Restoration Design of Wilson Creek

by

Arthur Parola *el al*

(University of Louisville)

Geomorphic Assessment and Stream Restoration Design of Wilson Creek

Submitted:	September 10, 2007
Submitted to:	Kentucky Division of Water Frankfort, Kentucky
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INTRODUCTION

A 2670-ft reach of Wilson Creek and its adjacent valley bottom within Bernheim Arboretum and Research Forest were restored in 2003 to a 3147-ft-long sinuous stream with a low-level forested floodplain and several adjacent wetland areas. Prior to restoration, this section of Wilson Creek was considered by the Kentucky Division of Water to be one of the least impacted streams in the region, and they therefore had used it as a biological reference. A well-established riparian zone and good canopy cover afforded Wilson Creek the appearance of a healthy system, but the channel had, in fact, been radically altered. Like many Kentucky streams, Wilson Creek had been channelized and relocated to its floodplain margin. The channel was confined to the east valley hill slope by well-vegetated dredge spoil piles. It had incised down to bedrock and was entrenched and confined, and aquatic habitat had degraded. The channel supported very few deep pools, and the substrate was primarily bedrock or a thin gravel veneer over bedrock. The stream's transformation from an alluvial regime to one dominated by bedrock had brought about changes in several other important stream and wetland habitat features: reduced bed topographic variation, a decrease in groundwater level that adversely affected its hyporheic zones, and reduced frequency of floodplain inundation.

Examination of stream valleys in the region revealed that the modifications to the Wilson Creek valley are typical for central Kentucky. Thus, a restoration of a section of this third-order stream could serve to investigate and demonstrate methods for restoring streams and their valley corridors having similar geologic and climatic conditions. The restoration design was based on a combination of analytical techniques, site observations, and empirical morphological relationships.

Important restoration design components were the elevation of the floodplain, the proximity of valley groundwater levels and aquifer thickness, pool complexity, and the creation of gravel riffles and substrate over the bedrock. Establishment of native riparian zones and wetlands would also be important in providing sustainable, diverse habitat.

GEOMORPHIC ASSESSMENT

Watershed and reach-scale assessments were conducted to determine the specific causes of existing channel degradation and to evaluate the characteristics and quantity of sediment supplied to the restoration reach. Other streams in the region were examined to evaluate the similarity of Wilson Creek to them and to locate channel reaches that could serve as references for the restored channel characteristics.

Background Data

Watershed Characteristics

USGS 7.5-minute topographic maps and geologic quadrangle mapping available from KGS were examined to assess the watershed-scale characteristics of Wilson Creek. Based on a delineation of the watershed using the USGS topographic map, the watershed area is 4.76 mi^2 at the upstream end of the restoration, 5.2 mi^2 downstream of the Dunn Hollow tributary confluence, and 5.3 mi^2 at the downstream end of the restoration. Aerial photographs from 1938 and 1998 were used to broadly determine current land-use and to examine and consider the change in watershed characteristics between those periods. Table 1 shows a slight increase in forested watershed area and a significant increase in the urban land use. The change in urban land use, although significant, is concentrated in the most upstream point of the basin.

Table 1 Land-use Data

	Percent of Total Area		
Land Use	**1938**	**1998**	**Change**
Agriculture	22.7	12.8	–9.9
Water	0	0.3	0.3
Urban	0	8.1	8.1
Forest	77.3	78.8	1.5

Watershed Geology

The sediment supply from the Wilson Creek basin is derived from a heavily dissected plateau that drains the Knobs and a small section of the Outer Bluegrass physiographic region of central Kentucky. Mississippian epoch shale and siltstone form the highest elevation ridges and upper slopes. Devonian and Silurian epoch interbedded shale, limestone, and dolomite are present along the hill slopes. Ordovician epoch interbedded dolomite, limestones, shale, and mudstone are present at the base of the hill slopes and in the valley bottom in the headwater areas. Quaternary alluvium overlays Ordovician epoch shale over most of the wide valley bottoms of the watershed, including reach being restored. Sediment derived from this lithology and supplied to the restoration reach are composed of limestone, dolomite, siltstone, chert, and shale fragments.

Geomorphic Assessment of the Restoration Reach

Visual Assessment of the Channel

The channel regions examined during the visual assessment were delineated as three distinct reaches: the downstream reach, the restoration reach, and the supply reach. The downstream reach extended from the Wilson Creek and Overalls Creek confluence to the county road crossing upstream of the Wilson Creek and Harrison Fork confluence. From that point, the restoration reach extended upstream approximately 2670 ft along the pre-restoration channel centerline to a point approximately 500 ft upstream of Dunn Hollow. The supply reach extended upstream about 700 ft from the upstream limit of the restoration reach.

Downstream Reach. The confluence of Harrison Fork approximately 335 ft downstream of the ford affected the channel reach immediately downstream of the ford. The downstream reaches of Wilson Creek and Harrison Fork had both been affected by dredge-spoil berms and old stone walls located along the banks. Wilson Creek downstream of the Harrison Fork confluence flowed along the county road for 930 ft before it confluenced with Overalls Creek. Although a relatively wide (150–275 ft) valley exists along and to the south side of Wilson Creek, the channel was incised and deeply entrenched (F4 stream type). A detailed investigation of the cause of channel incision downstream of the confluence was not conducted, but the incised and entrenched conditions appeared to have been influenced by channel straightening, road building, and dredging.

Restoration Reach. Wilson Creek upstream of the county road was a generally straight stream positioned at the base of a steep valley slope. The streambed was composed of bedrock or a thin gravel veneer over bedrock. At a few locations, gravel deposits on bedrock formed long, straight riffles and dammed the water upstream to form bedrock-bottom pools. These gravel deposits appeared to be a consequence both of channel bends that followed bends in the valley and of local channel widening. During low-flow periods typical of summer and early fall months, Wilson Creek flow depths were less than a few inches over large reaches of bedrock. Where gravel deposits were 1.0–2.0 ft over the bedrock, flow was primarily below the gravel surface.

Based on the elevation in the Wilson Creek valley and the elevation of benches within the existing channel, Wilson Creek appeared to have incised 1–2 ft over the restoration reach.

A small (0.4 mi^2 watershed) unnamed tributary flowed through the valley of Dunn Hollow, crossed the Wilson Creek valley, and confluenced with Wilson Creek approximately 2230 ft upstream of the county road ford. The section of the Dunn Hollow tributary that crossed the Wilson Creek valley had been straightened, had incised, and was entrenched. The deepest incision was limited by a concrete ford, although this ford was in danger of being undermined and failing.

Upstream of the Dunn Hollow tributary confluence, a short series of thinly bedded siltstone and shale bedrock steps formed the bed of Wilson Creek. A section of stream upstream of these steps was less incised, was more sinuous, and had two relatively stable riffles and two deep pools (low-flow depth of 1.5-2.0 ft). The upstream extent of the restoration was located in the reach upstream of the bedrock steps.

Supply Reach and Upstream Channel Network. The visual assessment extended through the accessible stream network upstream of the project area. During this examination, observations were made of the valley bottoms, channel banks, channel substrate, and bedforms. The riparian zone along all but a short reach of channel in the developed part of the watershed consisted of a riparian buffer at least 30 ft wide on both sides of the channel. Evidence of channel manipulation extended throughout the wide valley-bottom area of Wilson Creek for at least 1 mile upstream and for the entire length of Wilson Creek to its confluence with Rolling Fork. Even though most of the valley bottoms were wide enough for a channel to meander away from the valley hill slope, the main Wilson Creek channel within and upstream of the restoration reach was positioned against the toe of the hillside, except for a few reaches where the channel crossed the valley.

The channel upstream of the restoration, classified as a C4/1 channel type, was incised to bedrock over much of its length, although floods frequently overtopped its banks. The 700-ft supply reach had three bends and an avulsing section of channel, but the remainder of the upstream channel was generally straight.

The depth and rate of channel incision may have been limited by the channel substrate. In the reaches positioned against the toe of the hillside, the substrate was composed of bedrock or a thin veneer of gravel over bedrock. The exposure of large reaches of bedrock in the straight channel created uniform shallow flow over large reaches. Channel incision over the bedrock also limited the extent to which gravels could deposit on the bedrock to form riffles. The depth of bedrock and the thinness of the gravel veneer, which was generally insufficient to fill pools with backwater, limited pool depths. At the few locations where the channel crossed the valley, pool depths increased, indicating that the bedrock near the center of the valley might be lower in elevation than along the valley hillsides. In those locations, the morphology was more typical of an alluvial channel, with thicker (3–4 ft) deposits of gravel forming riffles and damming water in pools.

The supply of gravel to Wilson Creek from the watershed appeared to be very low. The main sources of gravel were found to be exposed degrading bedrock in Wilson Creek, coarse sediment from steep tributaries and bedrock channels, and colluvium. Deposits consisting of large broken fragments of bedrock were observed downstream of steps in the channel bed and at the mouth of steep tributaries. These deposits did not appear to be mobilized frequently, and gravel derived from the deposits was limited. The shale bedrock fragments were susceptible to breakdown from weathering and abrasion. Only those exposed fragments in close proximity would supply gravelsized particles to the reach; the rest would break down to silt before being transported to the reach. Thin gravel deposits were found on bedrock channel on the inside of channel bends, along the margins of the channels, and at the mouth of tributaries. These gravel deposits were sparse, less than two feet thick, and of limited extent. Examination of eroding stream banks indicated only a thin layer of gravel, less than 1.5 ft thick, along the channel banks, except where tributaries created small alluvial fans and where colluvium entered the channel from small hillside slope failures. The thin layer of gravel and the lack of rapidly migrating banks upstream suggested that bank erosion would not be a major source of gravel-sized material to the restoration.

Supply Reach Sediment Sampling

Sediment samples representing the supplied bedload characteristics were obtained from a point bar approximately 650 ft upstream of the crossing. Bulk bar samples were obtained from the bar (Rosgen 1996) and sieve analysis was conducted to evaluate the sample gradation. Pebble counts (Bunte and Abt 2001) were conducted on a riffle downstream of the point bar to evaluate the surface size gradation of the bed.

Topographic and Thalweg Surveys

A topographic survey of the valley and channel was conducted from the confluence of Harrison Fork to two upstream boundaries: one in the Wilson Creek valley approximately 3300 ft upstream of the confluence, and a second 500 ft into the Dunn Hallow valley. The survey extended to the toe of the valley hill slope on each side of the valley and included 200 ft of channel downstream and 500 ft upstream of the proposed restoration reach. The accuracy of the survey was sufficient to create one-foot contours and 1 in = 30 ft mapping for construction purposes. Prerestoration valley bottom characteristics (Table 2) were developed from the topographic survey, and channel characteristics (Table 3) were obtained from cross sections that were part of the survey.

A detailed survey of the channel thalweg was also conducted. Contours present in the Wilson Creek valley indicated that, at one time in the past, Wilson Creek upstream of its confluence with Harrison Fork had been more sinuous and located more centrally in its valley flat.

Subsurface Investigation

Fourteen test pits were excavated to (1) determine the depth to bedrock, (2) examine alluvial strata, and (3) evaluate groundwater elevations. This subsurface investigation was completed in one day. The investigation revealed that (1) approximately 2 ft of sediment was deposited on top of what appeared to have been the floodplain prior to Euroamerican settlement of the region, (2) the bedrock was 1–2 ft lower in the central part of the valley than in the channel bed along the hillside, (3) the thickness of the gravel groundwater aquifer was on the order of 3 ft in the valley but less than 1 ft along the hillside.

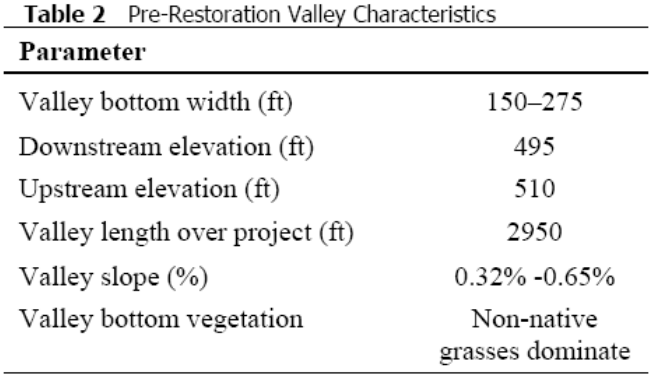

Table 2 Pre-Restoration Valley Characteristics

Parameter	
Valley bottom width (ft)	150–275
Downstream elevation (ft)	495
Upstream elevation (ft)	510
Valley length over project (ft)	2950
Valley slope (%)	0.32% -0.65%
Valley bottom vegetation	Non-native grasses dominate

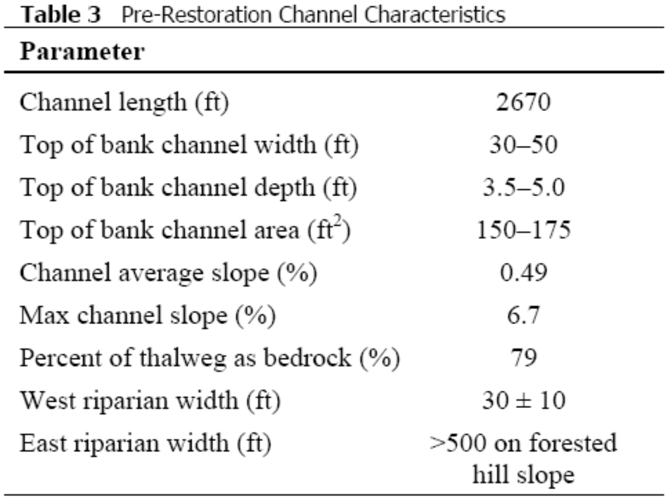

Table 3 Pre-Restoration Channel Characteristics

Parameter	
Channel length (ft)	2670
Top of bank channel width (ft)	30–50
Top of bank channel depth (ft)	3.5–5.0
Top of bank channel area (ft^2)	150–175
Channel average slope (%)	0.49
Max channel slope (%)	6.7
Percent of thalweg as bedrock (%)	79
West riparian width (ft)	30 ± 10
East riparian width (ft)	>500 on forested hill slope

Stream Morphology and Channel Evolution of Similar Streams in the Region

Streams in the region were examined to evaluate Wilson Creek's geomorphic similarity to other small streams of the region and to identify streams that could provide reference reaches for the stream restoration. Reaches of the following streams were examined using available mapping or they were examined in the field:

- Buffalo Creek (Nelson County)
- Cedar Creek (Nelson County)
- Crooked Creek (Bullitt County)
- East Fork Cox Creek (Bullitt County)
- Harrison Fork (Nelson County)
- Harts Run (Bullitt County)
- Kimbly Run (Nelson County)
- Lick Creek (Nelson County)
- Long Lick Creek (Bullitt County)
- Overalls Creek (Bullitt County)
- West Fork Cox Creek (Nelson County)
- Whittaker Run (Bullitt County)
- Wilson Creek (Nelson County)

All examined streams were undergoing evolutionary changes instigated by channel straightening and channel relocation. Each was found to have been affected by channel and valley modifications to the point that planform data could not be used as a reference. Throughout the Wilson Creek watershed, the streams appeared to have been moved against the toe of valley slopes and had incised through a combination of straightening and repeated dredging. In many reaches, the dredge-spoil levees and channel incision had resulted in deep channel entrenchment. Observations during an approximately 10-year recurrence-interval flow showed that the entrenched channels contained most of the flood flows within their banks and only minor portions of the total flow accessed adjacent valley flats. Many previously straightened streams were widening and remained in a state of gradual channel aggradation with the development of more sinuous planforms through gradual erosion of cohesive and root-reinforced channel banks.

At some locations, bedrock was exposed over long reaches of the channel bed. Where bedrock was not exposed, it was covered with a thin veneer of gravel. At least part of the substrate of every observed pool had some exposed bedrock. Deep pools occurred primarily in the center of the valley, and most pools were limited by the depth of a downstream gravel deposit that backed water onto the bedrock.

Conceptual Reference Reaches

Because a reference reach with a planform on which to base the design of the restoration channel could not be located, the use of a design method based primarily on geometric similitude (Rosgen 1998) was inappropriate. However, two conceptual reference reaches on which functional similitude could be based were identified on Wilson Creek. These conceptual reference reaches were used to identify morphological functions that could be incorporated into the restoration design. The first conceptual reference reach, located about 550 ft upstream of the restoration site, was a 200-ft reach of channel that crossed the valley bottom and consisted of one pooland-riffle sequence. The channel had been over-widened at some point in the past due to the construction of a now-abandoned roadway, and the over-widened channel formed a low-level deposition feature that was determined to be an actively forming floodplain. The pool in this reach was scoured to bedrock in a bend, and the downstream riffle dammed water in the pool to maintain a deep (3 ft) residual depth under low-flow conditions. The channel at this location was relatively narrow compared to other reaches, and vegetation on the bed and banks indicated gradual morphological change. A flow of 200 cfs was estimated to overtop the channel banks and flood the active floodplain. An assessment of sediment mobility in the same reach showed that boundary stress at about 200 cfs were approximately equal to the boundary stress required to mobilize bed material found on bars immediately upstream. The second conceptual reference reach consisted of a few locations in Harts Run and Overalls Creek where the channels in the heavily forested valley bottoms were not incised. In those locations, a common reach-scale morphologic pattern was observed: long, deep, single-thread pools connected by anabranching riffle sections. These non-incised reaches of Harts Run and Overalls Creek were heavily anabranched because of the interaction of large woody debris and the transport of gravel bedload sediments. Pools had been created by the damming effect of woody debris supported by live tree trunks in riffle sections. Where channels had aggraded such that they were no longer incised and large woody debris was present, anabranched channel networks had formed over significant lengths.

Evidence of this pool–anabranched riffle morphological pattern was also present in the avulsed upstream section of the Wilson Creek channel and in abandoned anabranched channels in floodplain areas away from the active channels. In more sinuous sections of Wilson Creek upstream of the restoration reach, narrow and short but deep (2–4 ft) pools had formed in bends where downstream riffle deposits dammed water upstream. The depth of the pools was limited by the difference in elevation between the crests of the downstream gravel riffles and the underlying bedrock.

Observation of Wilson Creek, Harts Run, and Overalls Creek during the period between 1999 and 2002 indicated that base flow was insufficient to cause surface flow over riffles during summer and fall low-flow periods. Water in the pools was supplied primarily by groundwater flow during these periods. Fish and other aquatic organisms that require surface water congregated in large numbers in the groundwater-supplied pools.

DESIGN

In stream restorations that seek to re-connect incised channels with their floodplains, two main approaches are generally possible: (1) retain the existing terrace contours and elevations or (2) excavate part of or the entire terrace to form a new floodplain at a lower level. Restoration following the first approach attempts to recreate floodplain and channel conditions that existed prior to channel incision. The second approach attempts to recreate the floodplain and, in some cases, the channel bed at an elevation substantially lower than existed prior to channel incision.

The first approach is most effective when channel incision is limited to the reach that will be restored. In cases where the channel downstream of the restoration is incised, however, this approach introduces at least three problems in the transition between the restoration and the incised downstream channel. First, the use of a downstream grade control structure to raise the grade of the channel is usually necessary in this approach in order to prevent the channel from reinitiating the process of incision. When grade control structures are required, the entire restoration upstream of the structure depends on the long-term stability of this structure. Second, flood flow on the floodplain must be transferred back into the downstream incised channel somewhere in the vicinity of the downstream grade control structure. Both the in-stream grade control structure and the topographic modification required to transfer flood flow back into the incised downstream channel are susceptible to failure because of the locally high gradients in the channel and on sections of the floodplain or along the downstream incised channel banks. When this approach is used, the base level of the restoration will always depend on the stability of the downstream structure and floodplain transition to the incised channel. Third, structures tend to cause vertical drops in the stream profile that have the potential to form fish passage barriers.

The problems posed by the first approach may be avoided by instead employing the second approach. By excavating the floodplain, the channel profile can be designed to match the grade of the downstream incised channel, and a gradual transition from the low-level floodplain to the incised channel downstream can be designed and constructed. Given the right floodplain slope, channel profile, and channel planform conditions, the downstream channel bed can serve as the base level for the restored channel and the use of grade control may be unnecessary.

The second approach was the one employed for the design of the Wilson Creek restoration. The intent of the Wilson Creek design was to anticipate the evolution that the existing straightened, relocated, and confined channel would have continued to undergo over the next several hundred years. Concepts described by Thorne (1999) for the latter phases of late-stage evolution of an incised alluvial channel were used as a guide for determining the floodplain and channel configuration that could have evolved. These concepts were modified based on observations of anabranched channels, interpretation of valley contours, and the proximity of underlying bedrock in the valley, which suggested that Wilson Creek had at one time been a sinuous or anabranched gravel-bed stream located in the area of lowest elevation in the valley bottom.

The goal of the restoration design was to create a sinuous and slightly aggrading gravel-bed channel with pool-riffle morphology that would • Transition to the grade of the downstream channel without the use of grade control structures

- Emulate the late-stage channel evolution model of Thorne (1999)
- Have the potential to evolve into an anabranched channel once floodplain vegetation matures
- Have a negligible impact on the channel stability of the downstream and supply reaches
- Provide improved, sustainable stream and wetland habitat

The geomorphic assessment of Wilson Creek and similar streams of the area led to the following specific design objectives:

- Develop a floodplain and sustainable channel geometry that increase the interaction

- of the channel with its floodplain by decreasing the flood level required to inundate overbank areas.
- Decrease the exposure of bedrock and increase the cumulative length of riffles with gravel substrate.
- Increase the number of deep (1.5–4.0 ft) pools and cumulative pool length.
- Increase groundwater/channel connectivity and associated low-flow habitat.
- Create riffles rather than steps.
- Establish native riparian zones and wetlands.

Because the restoration would not rely on the installation of grade control structures, which generally require that the construction contractor be trained and highly skilled in specific installation techniques, one additional objective was added:

- Increase the practicality of the demonstration project by designing for the use of construction techniques similar to those used by land-development or highway construction.

A combination of analytical and empirical assessment and design techniques was used to design the floodplain surface elevation and channel profile and cross-section dimensions.

Floodplain Surface Elevation

Modification of both floodplain and channel downstream slopes was necessary to create a stable stream throughout the restoration reach (Figure 1). To transition between the C4/1 channel upstream and the F4 channel downstream of the restoration, the restoration reach was designed to be a mildly entrenched C4 channel with low (2 ft) bank heights. The floodplain surface elevation was designed such that the floodplain was located approximately one bankfull depth (~2 ft) over the bedrock channel bed at the upstream and downstream bed elevations at the limits of the restoration. Existing floodplain slopes varied from 0.65% in the upstream portion of the restoration reach to 0.32% in the downstream portion of the reach. The floodplain slopes would be regraded to an approximately uniform 0.45%. The uniform slope would be created by a reduction of floodplain elevations in the upstream extents and an increase in slope along the downstream extents of the project. Floodplain elevations in the central portion of the project changed the least.

Transition from the upstream incised channel to the restored channel was accomplished through floodplain excavation and bank height reduction upstream of the in-channel restoration work. The reduction in bank height and floodplain elevation upstream would facilitate the transfer of flood flow into the floodplain before flows would enter the restored channel reach. It would also allow the matching of restored and upstream channel grades, which would avoid causing backwater in the upstream channel.

Transition from the un-entrenched C4 stream within the restoration to the F4 channel downstream of the restoration was accomplished by extending the floodplain excavation past the downstream limit of the restoration reach. Floodplain excavation would extend downstream of the country road crossing to a reach immediately upstream

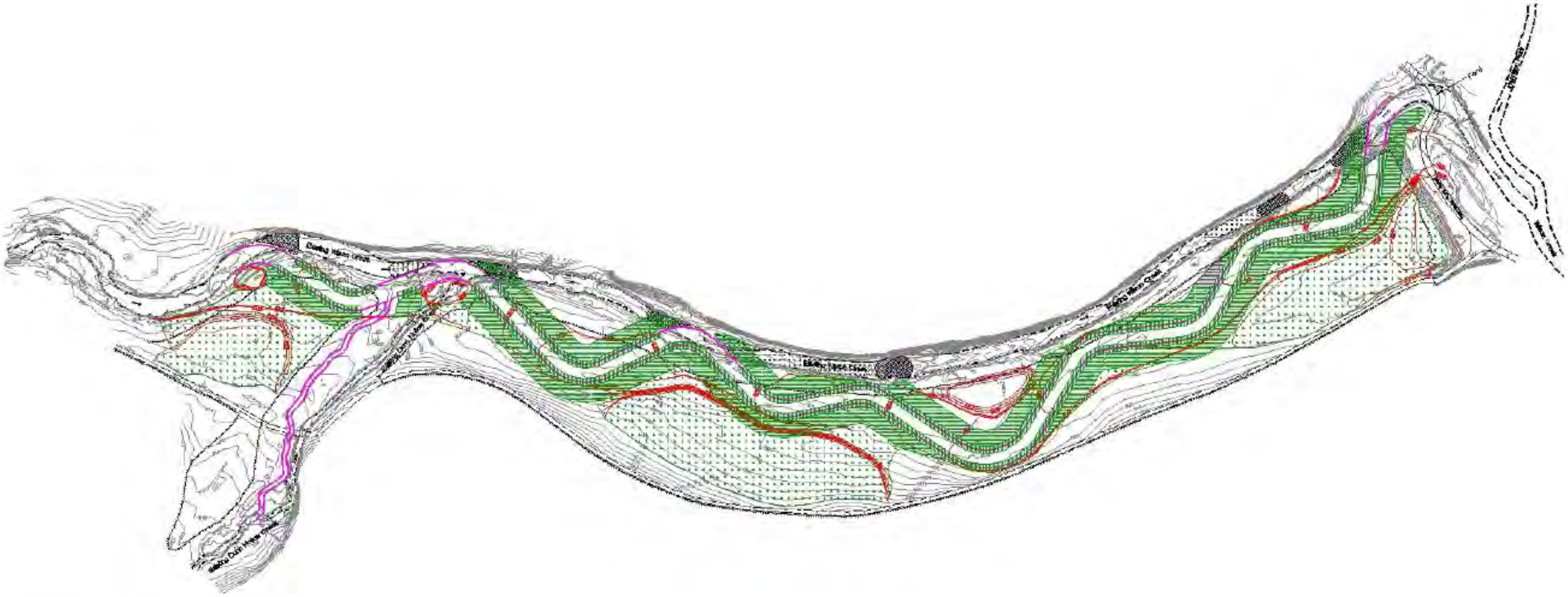

Figure 1 Wilson Creek design layout.

of the Harrison Fork and Wilson Creek confluence. The excavation of the floodplain to a height equal to the bankfull level would reduce flow velocities in the region of the ford and reduce the stresses on eroding bends upstream and downstream of the ford. Reduction in floodplain elevations would allow for the matching of streambed grades without the use of in-channel grade control structures.

With the floodplain slope changes, flood flow entering and leaving the project would not encounter sudden rises or falls in floodplain elevation. Also, flow would transition gradually from incised channel conditions upstream of the project to entrenched channel conditions downstream. Lowering of floodplain elevations at the extents of the project would reduce reliance on grade control structures to transition from incised or entrenched conditions outside of the project limits to non-incised and non-entrenched conditions within the restoration reach.

Channel Planform

The planform characteristics of the restored channel were based on evidence of prestraightening channel characteristics, valley slope constraints, valley topography, the transition to incised channels upstream and downstream of the restoration, and observations of upstream channel reaches. Surface contours of the valley bottom indicated the alignment of a sinuous Wilson Creek planform that preceded the apparent straightening and relocation of the channel to the toe of the east valley slope. These contours were used in part to determine the restored channel planform.

The contours indicated that the planform of the pre-straightening channel on the valley flat had been constrained by terraces. Existing terraces and excavation costs limited the design planform of the restoration. While channel belt width would be increased significantly by re-grading the floodplain, the restored belt width would remain constrained. Planform characteristics of the designed restoration channel followed the course of the pre-straightening channel over some reaches. Downstream and upstream channel incision, however, required that the designed reach have a more sinuous and lower-slope channel than suggested by the contours. The increased sinuosity and reduced slope were necessary to meet existing upstream and downstream channel elevations without relying on grade control structures.

The planform and profile characteristics of the pre-straightening channel were considered to be dependent on bank strength and in-stream woody debris provided by a mature riparian forest. Based on observations of similar-sized streams in the region, the suspected possible gravel-bed channel types that may have occurred in the Wilson Creek watershed valleys prior to channel straightening were DA4 (anabranched), E4 (low width-to-depth ratio and highly sinuous), and C4 (high width-to-depth ratio and moderately sinuous). Interaction of flow and transported sediments with channel obstructions such as beaver dams and woody debris jams probably influenced channel morphology in these valleys.

Observations of the upstream avulsing section of the Wilson Creek channel and observations made at Harts Run and Overalls Creek indicated that the interaction of large woody debris (LWD) and channel gravels was an important factor in the long-term morphology of similar stream channels in this region. The morphology of these channels, in particular their anabranching riffles, appeared to depend on (1) a very shallow alluvial cover over the entire valley bottom, (2) a local source of tree limbs from which debris jams could form, and (3) the root system of the mature trees.

The interaction of LWD and gravel deposits to form small but deep pools was therefore considered in the planform design. Without a mature forest across the valley bottom, a constructed pool and anabranched-riffle system would not be sustainable, regardless of the planform design. The channel could, however, be expected to evolve into an anabranched riffle-pool system given the right conditions: if the channel were to be constructed such that it would not incise and a mature forest were to become established on the valley bottom. To enhance the formation of an anabranched system, the channel was designed to allow the formation of multiple channels through channel avulsion on the floodplain. Development of the pool and multiple channel system would then likely occur over several decades.

The channel planform was designed to consist of simple, straight-riffle sections and constantradius bends. Because non-incised and non-entrenched channels in similar valley conditions (i.e., unforested valleys having similar slopes and widths) were not found to provide reference conditions, general geomorphic rules (FISWG 1998; Williams 1986) were used to determine the characteristics of the planform geometry: bend radius was maintained above 2.25 times the channel bankfull width, and the distance along the channel center-line between riffle crests varied from 5.7–10.1 times the bankfull width, averaging 7 times the bankfull width. The existing bedrockbottom channel length was increased from 2670 ft to 3147 ft in the designed channel.

Channel Profile

The design of the channel profile was based on an iterative procedure that included consideration of channel planform constraints, stream cross-section characteristics, mobility of bedload sediments under the estimated bankfull flow conditions, and the depth of pools and their proximity to u nderlying bedrock. Because reference reaches considered satisfactory for obtaining design information were not found, the profile design relied mainly on sediment mobility data. Channel cross-section geometry and bankfull flow conditions for the channel design were determined from measurement of flow conditions for which bedload sediments were found to be mobile over a one-year period. Riffles located in widening reaches of generally straight channel were found and used to examine the mobility of bedload material and cross-sectional characteristics of riffles. Data from a stream gauge station located in the adjacent Long Lick Creek watershed were scaled to the Wilson Creek watershed and also used to determine flow rates for nearbankfull flow conditions. Based on the Long Lick Creek gauge data and a series of observations of flow, bankfull indicators, and sediment mobility in Wilson Creek, bankfull flow was estimated as approximately 200 cfs.

The restoration stream profile was developed for distinct riffle-pool sequences. Riffle parameters were designed to mobilize the size fractions of the supplied material at approximately bankfull conditions. While the reach-average channel slope was set to approximately 40% less than that required to mobilize the largest particles in the supplied bed load, all riffle slopes were set at 0.7%, a value 17% higher than that required mobilize the larges particles of the load. Backwater effects of the downstream bends and bed elevation control caused by downstream riffle crests would cause friction slopes in riffles to be lower than riffle bed slopes. Consequently, a shift toward a state of gradual channel aggradation was anticipated, with the potential for future channel avulsion. The design of near-avulsion conditions was intended to create the potential for the future development of anabranched channel reaches (DA4 stream type) as riparian forests grow around the restored channel.

For design purposes, pools were considered to start at the entrance point and end at the exit point of each bend. The elevations of the pool thalweg at the entrance and exit were set to be equal. The deepest pool section was located at one-third of the arc-length distance from the downstream end of the bend. The elevation of the deepest point in each pool was based on the floodplain elevation and bedrock elevations determined from nearby test pits. The floodplain designed to meet the bankfull elevations at the project limits would be within no more than 6.0 ft of the underlying bedrock and that the maximum riffle-crest elevation would be approximately 4.5 ft above the bedrock. Scour of 4.5 ft in bends would be adequate to maintain pools with beds on the underlying bedrock, allowing penetration of the pools into the valley aquifer.

CONSTRUCTION

Construction occurred in three main phases: excavation of the floodplain and landscaping of terraces, construction of the restored channel and floodplain, and redirection and blockage of the pre-restoration channel. The majority of the floodplain excavation and landscaping of terraces was completed prior to construction of the channel. Channel segments were completed in sections. Final seeding of the entire project occurred as construction was completed. Construction tasks were generally completed in the order presented below.

Sediment and Erosion Control

All but 350 ft of the restored channel was constructed in-the-dry on the adjacent valley. An existing berm at the downstream end of the project was used to pond run-off from the construction area. A spillway near the downstream limit of the restoration reach channeled the pond water over a broad vegetated bank and into Wilson Creek.

Layout Survey

A layout survey was conducted to guide floodplain excavation and landscaping of terraces created from the excavated floodplain material. After the floodplain was excavated, 2-ft offsets of channel boundaries were marked.

Floodplain Excavation and Terrace Construction

Floodplain excavation associated with channel restoration extended from immediately upstream of the Harrison Fork and Wilson Creek confluence to a channel bend upstream of Dunn Hollow. To establish a floodplain 2–3 ft lower than the existing valley bottom, approximately 15,000 yds$_3$ of valley fill were excavated using a pan and a bulldozer. Terraces were formed mainly on the west side of the valley to replicate natural terraces. Soil was stockpiles near the existing channel to provide material for the construction of berms used to divert flow from the pre-restoration channel.

Depressions were excavated in the floodplain to create shallow wetlands; two of these were created in the shape of an abandoned section of channel. The wetlands were planted with wetland vegetation; tree stumps from riparian areas that were excavated for construction of three channel bends were added to enhance wetland habitat.

Channel Excavation and Construction

Stream channel relocation and restoration extended approximately 2650 ft upstream from a point 150 ft upstream of the county road crossing. Excavation of the channel to match the designed planform and coarse grading of the channel was completed using an 8-ft-wide pan. In all straight reaches, fine grading of riffle bed banks was completed using a bulldozer. A soil wrap constructed with a jute fiber erosion control blanket was created to protect banks along each riffle. The top and bottom of the jute blanket was staked into the streambed and along the top of the bank. Native herbaceous plant seed was placed in the soil of the wrap. Clean gravel from the prerestoration channel was scraped, excavated, transported to the constructed channel, and placed on the surface of the riffles. The scraped rock contained large pieces of broken bedrock and colluvial material that created an armor layer on the constructed riffles.

Pools were constructed in bends using three techniques that differed according to their locations relative to the existing or new channel. Where bends were constructed in the center of the valley, where no established vegetation was present, the thalweg of each pool was excavated to bedrock from the midpoint of the bend to a point approximately 20% of bend length further downstream. The sides and banks of each pool were then excavated to match the deepest section of the pool, the end of the riffles at upstream and downstream end of the bend, and the top of the banks. Jute blanket and willow stakes were placed on outside of bend banks. Two rows of willow stakes were driven through the blanket for the entire length of these bends. The inside banks of these bends sloped mildly from the floodplain to the thalweg and therefore required no treatment.

Bends that encroached on the riparian zone of the pre-restoration channel were constructed with near-vertical banks on the outside of the bend. The banks were intentionally left vertical to promote erosion into the root mass to rapidly develop undercut tree roots. Excavation and grading the channel bed and banks was similar to that of pools constructed in the center of the valley.

Bends constructed in the pre-restoration channel were formed by simply constructing a berm across the pre-restoration channel. Each berm was constructed to form the downstream end of a bend. Logs and tree limbs were buried in the upstream end of each berm to simulate a log jam and to improve the erosion resistance of the berm. Although similar berms were designed on the upstream side of the bend, these berms were not constructed. Instead, backwater areas were created by allowing a connection of the pre-restoration channel to the restoration channel on the upstream side of the bend. Because these pools were mainly formed by blockage of the existing pre-restoration channel, negligible excavation was required. Mature riparian vegetation was present on the inside and outside of the bends.

Log Vane Placement in Bends

Tree trunks from riparian areas that were excavated for construction of three channel bends were used in the constructed channel. To protect channel banks and to provide pool habitat, log vanes were placed in the outside of all bends where mature trees were not present. The log vanes were placed with approximately 40% of the log buried in the bank and 60% projecting upstream and into the pool such that the axis of the log formed an angle between 20 and 30 degrees to the tangent of the bank. The top surface of the log was set about 0.5 ft below the bankfull level in the bank. The log was sloped downward in the upstream direction at a rate less than 7% from horizontal. The placement of the log vanes generally followed the recommendations provided by Rosgen (2001), with two major exceptions: (1) the upstream end of the vanes were not buried in the streambed because the lengths of the available logs were insufficient and (2) large rocks were not placed over the section of the logs buried in the stream bank because the weight of the soil over the logs was assumed to be adequate to resist buoyant forces.

Berm Construction and Flow Diversion

Berms were placed in the existing channel to partition the pre-restoration channel into a series of ponds and wetlands and to prevent an avulsion of the restored channel back to the prerestoration channel. When channel construction neared completion, the berms used to create the bends that intersected the pre-restoration channel were constructed; their installation initiated the diversion of flow from the pre-restoration channel into the restored channel. Before flow was diverted, the floodplain of the restoration reach was seeded.

The core of each berm was constructed similar to the clay core of a dam to minimize seepage of the flow under, through, or around the berm. A trench was excavated to bedrock over the full length of each berm and keyed into the hillside. The excavated trench and the hillside key were filled with clayey silt from the bedrock to an elevation corresponding to the depth of the bankfull flow in the channel. The remainder of the berm was constructed from available fill material and compacted to the computed height of the 1.5-year, 5-year, or 100-year flood elevations, depending on the berm location and the intended function of the berm. Top-of-berm elevations were designed to allow the exchange of floodwater to the wetlands created in the pre-restoration channel or to allow conveyance of flood water to reduce flood flow elevations upstream.

RESULTS AND DISCUSSION

Monitoring of the stream restoration was conducted to evaluate whether design objectives were met and to evaluate the stability and potential evolution of the channel. Because the design objectives were based on changes in specific geomorphic features such as pool or riffle length, evaluation of them was based on a comparison of channel geomorphic parameters. These parameters were obtained primarily from pre-restoration and as-built channel thalweg surveys conducted in 2003 and 2004. Evaluation of channel stability was made based on visual observations and comparisons of channel thalweg surveys conducted between 2004 and 2006.

Comparison of Pre-Restoration and Restored Channels

Comparison of the pre-restoration channel thalweg obtained in spring 2003 and the restored channel thalweg surveyed in March 2004 (Figure 2) show that the restoration eliminated shallow, flat bedrock reaches and bedrock steps, that it increased the length of gravel riffle habitat, the number of pools, and the length and depth of pool habitat, and that it improved groundwater connectivity to pools.

Exposure of Bedrock

Design of the restored channel planform away from the locally high bedrock along the valley bottom margins and design of a channel profile that intersects bedrock only in the deepest points of the pools substantially reduced bedrock exposure in the restored channel bed. Pre-restoration channel reaches having little elevation variability correspond to bedrock thalweg reaches. Bedrock exposure in the thalweg of the pre-restoration channel was over 2100 ft, or approximately 79% of the pre-restoration channel length. Bedrock exposure in the restored channel occurs only in deep pools, except for the upstream transition from the restored channel to the upstream unrestored bedrock channel. As indicated by the variability of pool depths of the restored channel, bedrock exposure is less than 10% of the restored channel length. The bedrock exposure in the pre-restoration channel occurred in long, flat reaches with shallow flow depths. These long, flat, bedrock reaches may have restricted upstream migration or exposed migrating fish to predation during low-flow periods.

Cumulative Length of Gravel Riffles

The design of a stable pool-riffle channel morphology in Wilson Creek required long, relatively mildly sloping riffles that would not be eroded in the low bedload supply conditions. Consequently, riffle habitat was increased substantially by the restoration. Gravel riffles in the prerestoration channel are indicated by short, steep segments of thalweg immediately downstream of pools. In the restored channel, all of the steep-gradient channel reaches between pools are gravel riffles. The gravel riffle length changed from 350 ft in the pre-restoration channel to 1790 ft in the restored channel, representing a 3.9-fold increase in riffle habitat.

Number, Depth, and Cumulative Length of Pools

The design of a sinuous channel planform, pools that were in-phase with channel bends, and placement of the channel away from areas of elevated bedrock along the valley margins resulted in a substantial increase in the number, depth, and cumulative length of pools. The number of pools with a maximum residual pool depth greater than 1.5 ft increased from 3 in the prerestoration channel to 10 in the restored channel. Figure 2 shows a few very long pools in the pre-restoration channel; in the restored channel, pools are shorter but more widely distributed. The total length of pools changed from 1150 ft in the pre-restoration channel to 1360 ft in the restored channel, representing a 20% increase in pool habitat.

Groundwater Interaction and Connectivity to Pools

The channel planform and profile had been designed to maintain deep low-flow pool-riffle habitat and to increase groundwater levels. The restored channel thalweg shown in Figure 2 indicates that, for approximately the same location along the valley axis, the restored channel pools are deeper than those of the pre-restoration channel, with the exception of those pools that were constructed within the pre-restoration channel. Although pools for both channels are limited by shale bedrock, the bedrock elevation in the valley is non-uniform; a limited number of test pits indicated that the bedrock surface elevation tends to be higher along the valley hillsides and lower in the lowest elevation.

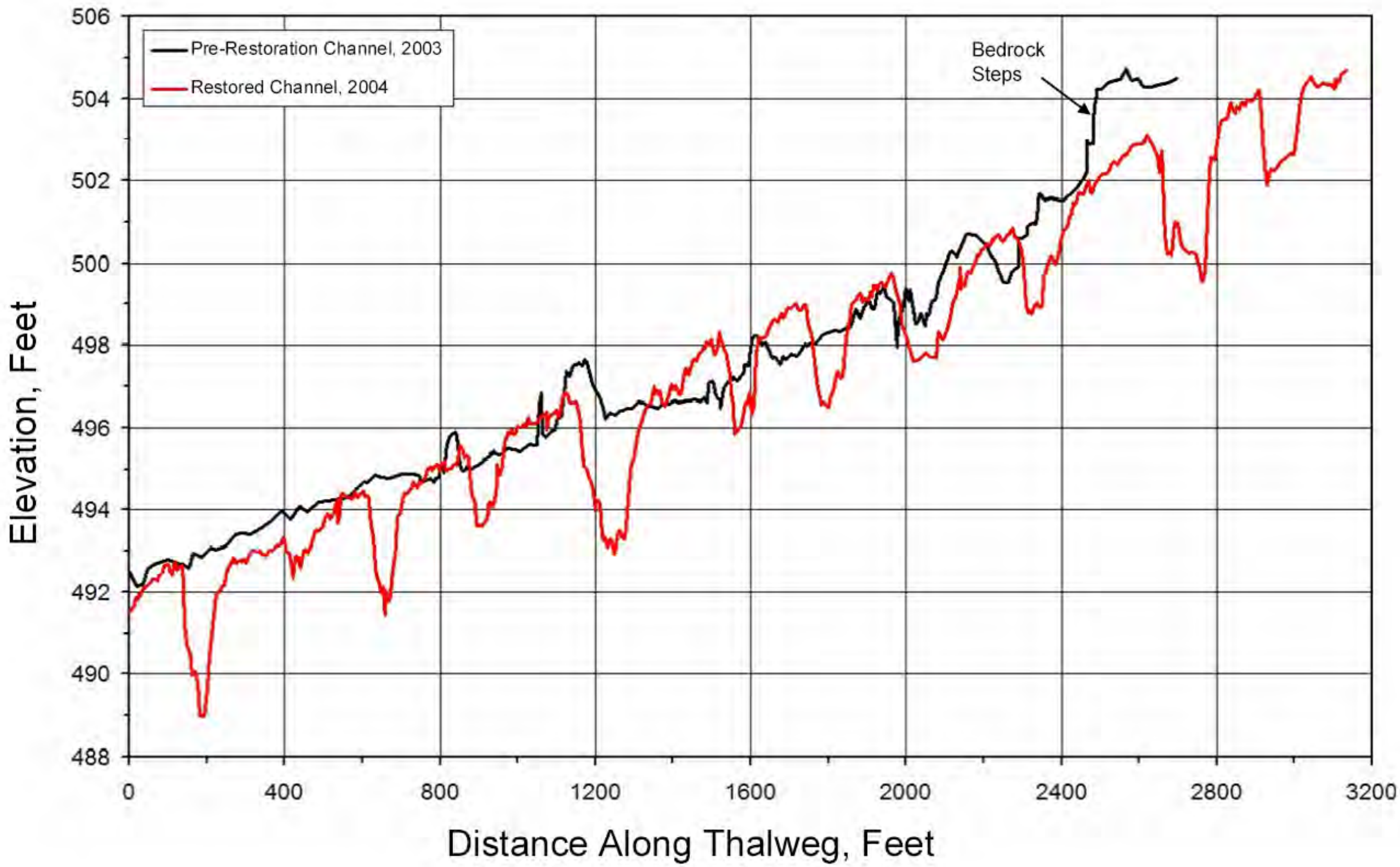

Figure 2 Comparison of the pre-restoration channel thalweg obtained in spring 2003 and the restored channel thalweg surveyed in March 2004.

regions of the valley bottom. Most of the pools of the restored channel are located in the lowest elevation regions of the valley

The shale bedrock is an aquitard, and the variation in its surface elevation across the valley affects the thickness of the gravel aquifer: the aquifer thickness is greatest where the bedrock elevation is lowest. Because the base levels of the pools in the restored channel are at lower elevations than those of the pre-restoration channel, the pools penetrate further into the valley aquifer. This greater access to the valley groundwater system should ensure that the pools remain at least partially filled during periods of low flow.

Evolution of the Restored Channel

Bank and Floodplain Erosion

The restoration design had anticipated that a pool–anabranched riffle system would develop over a period of several decades, following the development of a mature forest on the floodplain. Within a year of the completion of the restoration, however, anabranching channels had already formed. Their development was largely due to the lack of established vegetation and consequent bank erosion and floodplain soil loss during flood events. Three factors contributed both to the loss of newly sown vegetation and to the erosion of the newly constructed stream banks and floodplain: (1) the unexpected delay of seeding until October, which did not allow enough time for the vegetation to adequately cover the banks and floodplain before winter; (2) abnormally high precipitation during the winter following the restoration, which led to a higher-than-normal frequency of out-of-bank events; and (3) relatively low banks of the restored section, which were intended to allow for greater frequency of out-of-bank events even with normal precipitation levels but which also introduced a higher risk of erosion during the period preceding the firm establishment of vegetation on the banks and floodplain.

Observations made during and immediately after flood events indicated that as flow transferred from the channel into the floodplain, it accelerated as it passed over the top of the banks. As a consequence of the bank-overtopping flow and the lack of established bank vegetation, bank erosion occurred at many locations along the riffles, as shown in Figure 3. Erosion was most severe over the upper third of the banks of riffles, where flows overtopped the stream banks, and on the floodplain surface, where the flow

Figure 3 Flood flow overtops banks as it leaves the bend of the restored channel prior to sod placement. Note the erosion control matting is still in place at the toe of the bank downstream of the bend. Ruts have formed in the unvegetated floodplain and on the top of the bank near the flow indication arrows.

dispersed into the floodplain after overtopping the stream banks. After several floods, rills formed and concentrated flow leaving the channel. Erosion was initiated from the top of the bank, gradually forming rills that lowered the bank elevation, allowing rogressively concentrated flow to exit the channel. This concentrated flow formed several small channels in the floodplain during subsequent flow events. The lack of established vegetation on the floodplain surface and the absence of flow resistance and erosion protection of floodplain soil resulted in an excessive loss of floodplain surface material. Evaluation of this erosion process and pattern indicated the need for a change in the design of topography of the floodplain near the upper third of the riffles in order to prevent this type of erosion that could be likely to occur before bank and floodplain vegetation is established. In the summer of 2004, floodplain topography was modified and vegetation was established on the stream banks in the regions of the channel most susceptible to rapid bank erosion (Parola et al. 2005). The modification that most affected the post-restoration channel's profile and planform was placement of sod mats on the banks along riffles to rapidly establish bank vegetation. The sod placement required that construction equipment traverse sections of riffles in multiple directions, resulting in changes to the channel profile from the original as-built profile. As part of the sod placement process, survey monuments were inadvertently destroyed. New survey controls were installed, and the channel thalweg was resurveyed.

Restored Channel Thalweg Evolution

The channel thalweg was monitored to detect morphological trends in the channel streambed, specifically channel aggradation and degradation. Channel thalweg onitoring extended from a point approximately 430 ft downstream of the restoration reach to a point approximately 550 ft upstream of the restoration reach. Following placement of sod on the channel banks in 2004, surveys of the restored channel thalweg were conducted in October 2005 and October 2006. A survey of a central portion of the restored channel was completed in January 2005. Surveys of the channel thalweg in the transitions from the restored channel to upstream and downstream unrestored channel reaches were conducted in March 2004 and August 2007.

All of the surveyed thalweg elevation data is plotted with respect to distance along the channel centerline in Figure 4. Relating the thalweg elevation points to the centerline reduces the error that lateral movement of the thalweg and changes in the thalweg length between surveys would otherwise introduce in computing changes in thalweg elevations. Although use of the centerline stationing reduces the error associated with differences in thalweg position and length, local variation in streambed topography may result in point variation as high as 1.0 ft. Therefore, local differences of less than 1.0 ft between surveys for a single point along the centerline may not indicate morphological changes in the channel bed; differences between a series of points along segments of the profile, however, may indicate a trend of aggradation or degradation.

The least dynamic sections of the stream profile have been the riffles. Elevation changes on the order of 0.5 ft have occurred over Riffles 5, 7, 8, 11, and 12. The changes in Riffle 5 are associated with the channel’s response to a cable-anchored log with attached rootwad placed on the bed in the center of the channel. The crest of Riffle 7 decreased approximately 0.5 ft. Riffle 8 aggraded by approximately 0.5 ft over its entire length. The irregular convex slope of Riffle 11 indicated by the October 2005 survey changed to a more uniform slope in the October 2006 survey. The thalweg of Riffle 12 indicates degradation of about 0.5 ft over the downstream part of the riffle. Riffle 12 transitions from a bedrock bed of the upstream un-restored channel. Consequently, Riffle 12 was constructed as a thin (0.5 ft) layer of gravel over bedrock. The thin gravel layer has eroded in patches, exposing the bedrock.

The riffles were designed to facilitate the eventual transformation of the channel from a single thread channel to an anabranched channel and to avoid channel degradation in spite of the low sediment supply. The reach-averaged channel boundary stress was therefore designed to be slightly less than that required to mobilize the bed sediment at bankfull conditions. Although this design should have produced riffles that are slightly aggradational, the changes in channel thalweg elevations in riffles and pools do not indicate a consistent trend of either aggradation or degradation.

The lack of measurable aggradation on riffles over the short period of monitoring could be explained by an insufficient gravel supply and/or differences between the stress required for secession and that required for mobilization of gravels. Measurable changes in the channel thalweg on the order of 1 ft would require a substantial supply of gravel in size fractions that would be deposited in riffles. Dynamic conditions in pools indicate that the size fractions being supplied to the restoration may be smaller than those that would have deposited under boundary stress condition in the riffles. Moreover, because the boundary stress required to maintain transport is less than that required to initiate transport (Reid & Frostick 1984), sediment supplied to the restoration reach may be transported through the riffles even when the average channel boundary stress is less than that required to mobilize the largest size fractions in the supply.

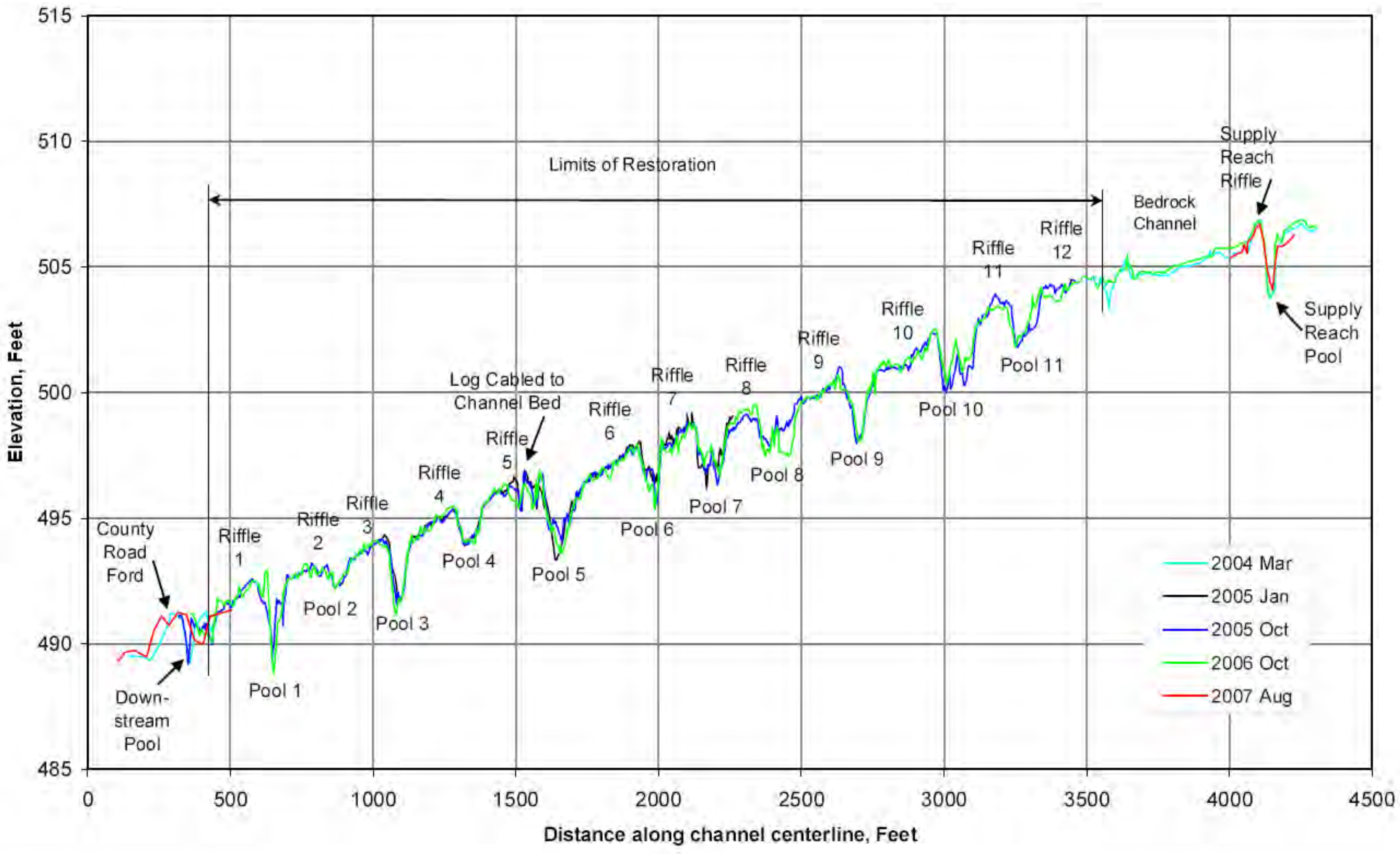

Figure 4 Surveys of the restored channel thalweg were conducted between March 2004 and August 2007. Thalweg surveys of the entire restoration reach were conducted in October 2005 and October 2006. All of the surveyed thalweg elevation data is plotted with respect to distance along the channel centerline..

Pools have been more dynamic than riffles, but change in the maximum pool depths has been negligible. Within the restoration reach, the most significant thalweg changes have occurred in Pools 1, 8, 10, and 11. The channel thalweg through these pools shows that segments of Pool 8 were scoured and segments of Pools 10 and 11 aggraded; the maximum residual depth, however, did not change substantially in these pools. The increase in bed elevation indicated in the downstream end of Pool 1 in the 2006 survey is the result of a mid-channel gravel bar. The thalweg of Pool 11 indicates deposition on the upstream end of the pool and extension of the pool into the riffle. These pools indicate only local adjustment through scour or deposition on the upstream or downstream end of the pool.

The thalweg surveys indicate little change in either the downstream or supply reaches. The pool downstream of the restoration reach has shifted upstream and aggradation has reduced the maximum residual pool depth by 0.7 ft. The changes in location and depth are due at least in part to channel maintenance for the county road ford. The channel is reconfigured after each flood event to provide a shallow, wide channel section that can be crossed safely. Changes in the thalweg elevation downstream of the ford are less than 0.2 ft. Upstream of the restoration reach, no changes in the thalweg were significant. The maximum change was less than 0.5 ft. The upstream bedrock channel limited degradation, and boundary stresses during flows that supplied sediment to the bedrock sections were sufficient to prevent aggradation on the bedrock, except in bars along the channel banks.

Channel, Floodplain, and Groundwater Interaction

If surface flow in the channel is sufficient to maintain flow over each riffle during low-flow periods, then the stream will maintain groundwater levels at or above the stream elevation; however, when streams have flow insufficient to maintain surface flow over the entire channel length, then other factors, such as the conductivity of the valley aquifer, begin to control the elevation of the phreatic surface. If surface water is to remain in the channel pools during low-flow periods, the stream must be built to access the valley groundwater. As observed in the geomorphic assessment, pools that penetrate into the valley groundwater aquifer are the most likely to maintain surface water during low-flow periods and may provide critical refugia during drought.

Because the Wilson Creek design established the floodplain elevation in close proximity to the groundwater, the channel was able to be designed such that pools penetrate into the groundwater, allowing them to remain at least partially filled during low flow periods. The maximum residual depth did not change significantly in any pool over the monitoring period, indicating that bend scour was adequate to prevent pool aggradation, which would have reduced low-flow pool depths.

Observations made during August 2007 showed that base flow from the Wilson Creek watersheds was insufficient to maintain flow over riffles. The pools, however, maintained surface water during the same period (Figure 5), suggesting that their depths allow them to access the valley groundwater aquifer even during low-flow periods. This also indicates that the groundwater remains in close proximity to the floodplain under low-flow conditions: Figure 5 indicates that the phreatic surface was within 2 ft of the surrounding floodplain elevation during the low flow conditions of August 2007.

The close proximity of groundwater to the floodplain and the low bank height of the channel facilitate the interaction of the stream, floodplain, and groundwater. The supply of water from inundation of the low-level floodplain and/or the close proximity of the phreatic surface is facilitating the development of seasonal wetlands. When flow events inundate the floodplain and the excavated depressions, leaves are caught on floodplain vegetation (Figure 6). A portion of the water detained in the depression will seep into the groundwater and may provide recharge to the channel. Thick accumulations of leaves in the depressions indicate the exchange of organic matter between the floodplain and channel. Five of these floodplain wetlands are developing wetland vegetation.

CONCLUSION

Due to the brevity of the elapsed monitoring period, the interpretation of the results of the restoration must be considered to be preliminary. Nevertheless, assessment of the restored channel suggests that the restoration has been successful. Four years after its construction, the restored reach of Wilson Creek continues to demonstrate a dynamically stable planform and profile. The channel retains an alluvial pool-riffle morphology, with bedrock exposure only in pools and at the transition to the supply reach. Floodplain depressions, gravel riffles, log vanes, and shorter, deeper, more widely distributed pools provide diverse wetland and channel habitat. In periods of low flow, the groundwater-fed pools remain at least partially filled, harboring fish and other aquatic organisms that require surface water. The continued evolution of channel and floodplain morphology will determine the sustainability of the restored habitat. Thus, a more extended period of monitoring will be required to definitely evaluate the results of the restoration and the implications of the methods it employed.

Figure 5 Restored floodplain and channel looking downstream at Pool 5 during the low-flow period of August 2007. Note the small difference in elevation between the left floodplain and the water surface of the pool maintained primarily by groundwater.

Figure 6 Excavated linear floodplain depression developing into a wetland. The photograph shows leaves caught on floodplain vegetation. Wetland vegetation and leaf pack are in the depression.

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Appendix E

Assessment of the effects of channel restoration on stream hydrology and nutrient retention

by

Paul Bukaveckas

(Virginia Commonwealth University)

Final Report

Project Title: **Channel Restoration and Riparian Reforestation along Wilson Creek: A Demonstration Site.**

Prime Contractor:

Bernheim Arboretum and Research Forest.
Project Officer: Mike Nolan (mnolan@bernheim.org)

Project Sub-component: **Assessment of the effects of channel restoration on stream hydrology and nutrient retention.**

Subcontractor:

Virginia Commonwealth University.
PI: Dr. Paul Bukaveckas, Department of Biology (pabukaveckas@vcu.edu).

Sponsoring Agency: **EPA**

Abstract:

Tracer and nutrient injection experiments were performed to quantify stream functioning in conjunction with a restoration demonstration project carried out at Wilson Creek (KY). A 1-km section of Wilson Creek was re-located from an incised and straightened channel along the margin of its former floodplain to a meandering constructed channel flowing along remnant floodplain contours. Forty-four solute injection experiments were conducted during a 4-year period (2002-2005) to measure water velocity, transient storage and nutrient retention in the channelized (pre-restoration) and naturalized (post-restoration) segments. Similar data were collected from a nearby reference stream (Harts Run) for comparative purposes. Portions of the restored reach exhibited improvements in water retention (lower water velocity and increased transient storage) relative to pre-restoration conditions. Restoration effects on water and nutrient dynamics were most apparent in a section of the new channel which passed through a portion of the old channel. Reductions in water velocity and gains in transient storage and nutrient retention within this sub-reach were due to the influence of a biogeochemically-active backwater area that had formed in a remnant of the old channel. Other segments of the restored channel (that were not connected to backwater areas) did not exhibit improvements in transient storage. However, retention of both nitrogen and phosphorus was substantially higher throughout the naturalized channel relative to pre-restoration values. Increased nutrient retention was attributed to abiotic complexation of P by exposed clay materials in the constructed channel, autotrophic (algal) demand for nutrients in the open (unshaded) sections of the new channel and heterotrophic (bacterial) demand for nutrients in the backwater area. Overall, water and nutrient dynamics in the naturalized channel were found to be more similar to those observed in the reference stream compared to conditions observed prior to restoration. Results from this study suggest that stream restoration provides a means for mitigating downstream transport of

nutrients and may be a useful component of basin-wide management efforts to reduce nutrient loading.

Introduction

Streams and their associated riparian ecotones provide important ecosystem goods and services through their role in the cycling of water, energy and materials (Palmer et al. 2004). Vital services include water storage, maintenance of biodiversity and mitigation of downstream nutrient transport. Restoration efforts typically rely on biotic attributes to measure success (e.g., fish and macroinvertebrate indices) while metrics related to stream functioning have received little attention (Muotka and Laasonen 2002; Nilsson et al. 2005). Recent interest in stream functioning has focused on nutrient retention due to societal concerns for adverse effects arising from nutrient delivery to downstream and coastal ecosystems (Howarth et al. 1996; Seitzinger et al. 2002). Nutrients are retained within streams through both abiotic and biotic processes. Abiotic mechanisms include the adsorption of phosphorus onto mineral surfaces while biotic processes reflect nutrient uptake by algae and bacteria. These mechanisms act to remove dissolved nutrients from stream water when nutrient demand exceeds the release of nutrients by re-mineralization (decomposition of organic matter). Nutrient removal can occur through short-term storage (e.g., in algal and bacterial biofilms) or, in the case of nitrogen, through loss to the atmosphere (conversion of nitrates to N_2 gas via denitrification). In running waters, nutrient removal is principally a benthic process carried out by algae and bacteria that colonize the surfaces of substrates which comprise the stream bed (inclusive of the hyporheic zone; Fellows et al. 2001; Sabater et al. 2002). The hyporheic zone is a subsurface feature within which water from the active (flowing) channel mixes with water held in interstitial spaces before returning to the channel (Bencala 2005). Streams by virtue of their high ratio of bottom area to overlying water are active sites for benthic and hyporheic processes and are thought to account for a disproportionate fraction of nutrient retention in river networks (Alexander et al. 2000).

Streams vary in their nutrient retention capacity owing to variable rates of biological activity (algal and bacterial metabolism) and to differences in their hydrologic and geomorphologic characteristics (Munn and Meyer 1990; Hall and Tank 2003). Biotic activity is principally constrained by water temperature (seasonal cycles) although other factors can influence the growth of algae and bacteria. These include light limitation of photosynthesis due to riparian shading and constraints on bacterial production imposed by variable quantity and quality of organic matter inputs from natural and anthropogenic sources. Hydrologic and geomorphologic factors of interest are principally those that determine the length of time that water (and associated solutes) resides within a stream segment. Water velocity is a useful metric to gauge the potential for biotic-abiotic mechanisms to influence stream nutrient concentrations. High water velocity limits opportunities for nutrient removal while reduced velocity conditions favor greater nutrient retention. Transient storage is a related hydrologic property that refers to the short-term retention of water (and solutes) within a stream segment. Transient storage zones include features within the active channel (e.g., backwater areas) and below the stream channel (hyporheos). Channel structures (e.g., debris dams) create backwater zones which increase transient storage and are thought to favor nutrient retention (Ensign and Doyle 2005). Other factors that influence transient storage are those related to the composition of streambed materials. Coarse materials (sand, gravel) favor the movement of water through interstitial spaces (hyporheic zone) thereby increasing water exchange with transient storage zones. Fine materials (silt, clay) have low hydraulic conductivity which limits opportunities for water exchange and nutrient removal.

Channel modification alters the hydrologic and biological properties of streams and may thereby influence nutrient processes. Channelization reduces the natural diversity of velocity and substrate conditions within stream channels and would be expected to diminish transient storage and nutrient retention (Nilsson et al. 2005). A comparison of channelized and natural stream reaches has shown that straightened channels exhibit higher and more homogeneous velocity conditions along their lateral (cross-channel) and longitudinal axes (Rhoads et al. 2003). Naturally curved channels create complex flow environments that are thought to favor diverse communities of macroinvertebrates and fish. Studies have shown that increased flow complexity also enhances hyporheic exchange (Hutchinson and Webster 1998). From these findings we hypothesized that the restoration of a previously channelized stream would restore stream functions related to transient storage and nutrient retention. No prior studies have attempted to document these potential benefits arising from the naturalization of stream channels. As part of a restoration-demonstration project carried out at Wilson Creek, transient storage and nutrient retention were quantified before and after restoration. Pre-restoration data served to characterize conditions in the channelized stream whereas post-restoration data were used to assess the effects of channel naturalization. Similar data were also collected from a nearby reference site. The overall goal was to determine whether stream restoration might contribute to broader (basin-wide) efforts to reduce downstream nutrient loadings. A secondary objective was to assess the utility of transient storage and nutrient retention as measures of restoration success.

Methods

Site Description. The study sites are located in an unglaciated area of low hills distributed across northwestern Kentucky and southeastern Indiana. Streams in this region exhibit rapid response to precipitation due to steep topography and underlying limestone bedrock formations. Scouring floods suppress primary consumer biomass resulting in high algal biomass (Riseng et al., 2004). The restoration site (Wilson Creek) is a third order stream located approximately 60 km south of Louisville, KY. Wilson Creek drains a 14.8 km^2 catchment which is 70% forested. Non-forested lands include pastures, row crops and low-density residential developments. The reference site (Harts Run) is a third order tributary which flows into Wilson Creek approximately 1 km below the site of restoration. The catchment of Harts Run (7.5 km^2) is 95% forested and entirely contained within the Bernheim Arboretum and Research Forest. Prior work at these streams has characterized algal communities and consumer dynamics (McCormick and Stevenson 1991a,b; Humphrey and Stevenson 1992; Holomuzki and Stevenson 1992; Rier and Stevenson 2002).

Like many streams in this region, Wilson Creek was channelized and relocated to the margin of its floodplain (adjacent to valley hillslope) for bottomland agriculture. This alteration resulted in a stream channel that was incised, entrenched and confined (bankful capacity comparable to a 10-yr event). Runs comprise nearly all of the study reach while pools and riffles represent less than 10% of the total length. Substrate is exposed bedrock (dolomitic limestone) with isolated patches of gravel and siltstone cobble. The 1-km reach selected for restoration included 6.5 ha of remnant floodplain. In recent decades, management of the floodplain has shifted from crop production for wildlife (e.g., millet) to warm season grasses (fescue) that are mowed for hay production. Like Wilson Creek, Harts Run has been impacted by agricultural activities in the floodplain. An important distinction is that the upper section of Harts Run was not re-located to the margin of the floodplain. Secondary re-sorting of bank and floodplain materials during the past 60-100 years has resulted in a meandering channel that is dominated by riffles and pools with gravel and cobble substrate (little exposed bedrock). Its selection as a reference site serves to quantify the condition attained by a stream that has recovered to a more natural state rather than to typify pristine conditions occurring prior to European settlement. Both Wilson Creek and Harts Run are shaded by a relatively mature riparian canopy (50+ yr) dominated by sycamores *(Platanus occidentalis)* and white oaks *(Quercus alba).*

Stream Restoration. A detailed description of channel design and construction is provided elsewhere in this report and briefly summarized here. The purpose of the restoration was to (1) provide a diversity of flow conditions (pool-riffle structure) within the constructed channel and (2) to re-connect Wilson Creek with its floodplain. Stream-floodplain connectivity was established by re-locating the channel to its floodplain and reducing its bankful capacity. Diverse flow conditions were attained by establishing channel meanders and installing in-stream structures. The design of the constructed channel followed Rosgen (1996) with parameter ranges for bank-full dimensions, meander belt width, meander radius and channel slope obtained from reference streams within the region. The morphometry and location of the designed channel was determined in part by historical considerations (as revealed by underlying deposits and micro-topography of the floodplain) and the desire to achieve a profile that would sustain long riffles with short runs into deep pools. Floodplain terracing was completed with a bulldozer while pools were excavating with backhoe to avoid compaction of alluvium. Riffles were lined with gravel taken from the old channel and jute or burlap fabric was used to stabilize banks. The meandering form of the designed channel resulted in a total stream length of 944 m (vs. 823 m prior to restoration). Re-vegetation of the floodplain focused on the establishment of native riparian, bottomland forest and wet meadow communities. Shrubs and trees adapted to occasional flooding were planted proximal to the designed channel. These included: native giant cane (*Arundinaria gigantean*), American sycamore *(Platanus occidentalis),* boxelder *(Acer negundo),* black willow *(Salix nigra),* dogwood (Cornus sp.) and northern spicebush (*Lindera benzoin*). The remainder of the floodplain was planted with native bottomland forest and native grass and forb species.

Response Parameters. The introduction of conservative (non-reactive) tracers is a well-established method to determine the rate at which water moves through a stream channel (nominal transit time) and the exchange of water with surface and sub-surface storage zones (transient storage; Stream Solute Workshop, 1990). Conservative tracers that are commonly used include dyes (e.g., rhodamine) as well as various forms of salt (chloride or bromide). While dyes can be measured to lower levels of detection, salt injections have the advantage that they can be monitored in real time using inexpensive instrumentation (by measurement of conductivity). By this method ‘transient’ storage represents exchange zones that are active in retaining solutes over the time course of the experiment (typically 1-2 hr in duration). The simultaneous addition of non-conservative solutes (nutrients) is used to quantify their downstream loss relative to the conservative tracer. Tracer concentrations decline gradually downstream due to dilution of stream water by groundwater while nutrient concentrations typically decline at a faster rate due to the combined effects of dilution and biotic/abiotic uptake. Nutrient uptake rates are derived from the difference in downstream loss rates between the conservative and non-conservative solutes (i.e., nutrient removal corrected for dilution). Negative uptake rates indicate a net loss of nutrients from stream water (net retention within the reach); positive uptake rates denote the net release of nutrients into stream water (net loss from the reach). Nitrogen and phosphorus are added in their inorganic forms (as phosphate, nitrate or ammonia). Ammonia is the more biologically active form of N (Peterson et al. 2001; Kemp and Dodds 2002), whereas nitrate is the dominant form of N associated with anthropogenic loading (Bukaveckas et al. 2005). In this study, the focus was on ecosystem services and mitigation of downstream nutrient transport and therefore nitrate was used in injection experiments.

Study Design. Transient storage and nutrient retention were measured during a spring index period (mid-April to mid-June) to characterize stream functioning over a range of discharge, canopy and temperature conditions. Pre-restoration data were collected in 2002 and 2003 and post-restoration data were collected in 2004 and 2005 (reference site data collected throughout the 4-year study). Fixed study reaches were established at the reference (Harts Run), channelized (Wilson Creek, pre-restoration) and naturalized (Wilson Creek, post-restoration) streams. Since discharge was higher at Wilson Creek, longer sub-reaches were used so that transit times would be comparable. Sub-reach lengths were fixed across experiments despite changing discharge and transit time in order to obtain reach-specific measurements of nutrient and water dynamics that were comparable through time. At Harts Run, the two sub-reaches (length = 110 and 150 m) were located in a meandering channel that was dominated by riffles and pools with gravel and cobble substrate (little exposed bedrock). At Wilson Creek, two sub-reaches (length = 185 and 240 m) were located near the top and bottom of the 1-km section that was selected for restoration. These reaches were characterized by a greater prevalence of bedrock substrate and lack of riffles or pools. In the naturalized channel, two sub-reaches (length = 180 and 210 m) were delineated in the lower half of the 1-km restored section to characterize the functioning of the designed channel. A third sub-reach (length = 100 m) was added in the upper section of the restored segment where the new channel was routed through a remnant of the old channel. Because the new (designed) channel was higher in elevation, this section of the old channel became a deep pool which accumulated depositional materials (sand and silt). This pool was connected by a re-circulating zone to a backwater area contained within a remnant of the old channel. Experiments conducted on this sub-reach (hereafter, “hybrid” channel) served to assess the functioning of the old channel where it had been incorporated into the new channel. A total of 44 experiments were performed at the reference (N = 13), channelized (N = 14) and designed (N = 17) streams during the 4-year study. No consistent differences in measured properties were observed between the two replicate sub-reaches in each stream and therefore data were pooled for the reference, channelized and naturalized sites. An exception was the "hybrid" reach which differed from the two sub-reaches that were not connected to remnants of the old channel. These data were treated separately in subsequent analyses.

Measurement of Transient Storage and Nutrient Retention. Injection experiments were performed by simultaneously adding a solution of salt (NaCl) and nutrients ($NaNO_3$ and Na_2HPO_4) to a well-mixed section of stream. The rate of injection varied depending on discharge which was determined at the start of the experiment by measuring velocity and cross-sectional area. The injection rate was adjusted to attain a target increase (in-stream concentration) of 500 µg NO_3-N L^{-1}, 60 µg PO_4-P L^{-1}, and 7 mg Cl L^{-1}. Changes in salt concentration were monitored continuously (30 s intervals) at two locations downstream using an electrical conductivity meter equipped with a data logger (Hydrolab). Salt injection yielded a typical rise in conductivity of 20-25 µS cm^{-1} over a background of 400-500 µS cm^{-1}. Once conductivity readings reached a plateau (typically 45 min after start of injection), water samples were collected for salt and nutrient analyses at 6-8 locations spaced at 20-30 m intervals over the length of the sub-reach. Nutrient analyses followed standard methods (APHA, 1998) using filtered samples and automated procedures (Skalar San Plus) for the determination of NO_3 (cadmium reduction) and soluble reactive phosphorus (SRP; ascorbic acid). Chloride analyses were performed manually using the ferricyanide method (APHA 1998).

Data Analyses. Hydrodynamic properties were quantified using a one-dimensional advection-dispersion, transient storage model that has previously been used in similar studies (Hart et al., 1995). The model assumes uniform flow conditions during the injection experiment and therefore we avoided periods immediately following rain events. For each injection, model-derived estimates of water velocity (v m min^{-1}), exchange rate of water between the channel and transient storage (k_1 min^{-1}) and the exchange rate of water between transient storage and the main channel (k_2 min^{-1}) were obtained. Parameter estimates were derived iteratively by solving for a least-squares best fit between modeled and measured conductivity values. A metric of transient storage is derived from the ratio of the exchange coefficients (k_1/k_2). This value is equivalent to the ratio of storage zone cross-sectional area to stream cross sectional area (i.e., larger values denote greater transient storage). Stream discharge (Q_S L s^{-1}) was estimated for the top (injection site) and bottom of the sub-reach based on the rate of injection, the concentration of salt in the injection solution and the measured increase in stream Cl. The difference in discharge between the upper and lower monitoring location was used to estimate the rate of groundwater entering the stream (Q_{GW} L s^{-1}; expressed per unit distance to normalize for variable reach lengths across experiments). Several parameters are commonly used to describe nutrient uptake in streams based on downstream changes in N and P concentrations. The first order uptake rate coefficient (k_N, k_P) is calculated as the slope of the regression of the natural logarithm of the concentration of NO_3-N or PO_4-P (corrected for background and dilution) versus distance. Background correction was based on an average value of samples collected prior to and after the injection experiment. Dilution rates were determined from downstream declines in the conservative tracer (Cl). When nutrient concentrations decline faster than Cl concentrations, uptake rates are negative (net retention of nutrients within the study reach). If Cl concentrations decline faster than nutrient concentrations, uptake rates are positive and denote a net loss of nutrients from the reach. The uptake length (S_w m) is the average distance traveled by a nutrient ion before uptake. Uptake lengths were calculated as the inverse of k_N or k_P when statistically significant negative uptake rates (net retention) were observed.

Statistical Analyses. Interpretation of data from individual experiments is by least squares regression which yields an estimate of the probability that the uptake rate coefficient (k_N, k_P) is significantly different from zero (positive or negative). Meta-analyses of the pooled dataset is complicated by several factors. First, statistical inferences are generally problematic in ecosystem restoration projects which are often un-replicated and rely on repeated measures designs (multiple measurements obtained from a single experimental unit). Second, the pooled dataset has a high incidence of non-significant values (e.g., when uptake rates were below limits of detection; see Discussion). It may be inappropriate to calculate derived metrics such as the uptake length (S_w) from non-significant uptake rate coefficients. However, exclusion of these data would result in a biased average value. This is analogous to a common problem in water quality analyses when values that are below limits of detection are removed prior to estimation of average concentrations. For the purpose of this study, average values of the uptake rate coefficients were based on the full dataset in order to compare among the three sites. We also report the frequency of significant uptake rates observed at each site. A repeated-measures ANOVA was used to analyze the full dataset and determine whether there were significant differences in transient storage and nutrient retention among the reference, channelized and restored sites. Derived values (uptake length) were calculated when statistically significant negative uptake rates were observed.

Results

Stream discharge conditions and nutrient concentrations on dates when injection experiments were performed are summarized in Table 1. The catchment area of Wilson Creek is approximately two-fold larger than that of Harts Run and corresponding differences were observed in average discharge conditions. The mean and range of discharge conditions observed in Wilson Creek was similar during both the pre- (mean = 125 L s^{-1}) and post- (mean = 111 L s^{-1}) restoration periods. The range of discharge conditions (10 – 300 L s^{-1}) corresponds to 58% (by calendar year) of the daily mean discharge conditions and accounts for 53% of the annual discharge (based on most recent USGS data available for this site; 1999-2000). Nitrate concentrations were lower at the reference site relative to Wilson Creek as might be expected from differences in land use (see Site Description above). Soluble reactive phosphorus (hereafter, SRP) was generally similar in both streams.

Sample Results

Results from a typical injection experiment illustrate the primary data that were used to characterize hydrologic conditions in each of the study reaches (Figure 1). The time series of conductivity measurements shows an initial rapid rise at the upstream probe (closest to the point of injection) followed by a similarly rapid decline at the end of the injection period (ca. 60 min in this experiment). Conductivity readings were stable during the injection period indicating a uniform rate of solute injection and stream discharge (as required by the hydrodynamic transport model). The conductivity response curve obtained at the downstream monitoring location (furthest from the injection point) differs from the upstream curve in three respects (location, height and shape) which are the basis for calculating velocity, groundwater inputs and transient storage (respectively)..

a) The location of the peak (along the x axis) is indicative of the amount of time required for the injected solutes to traverse the length of the study reach (210 m in this example). The point in time at which the downstream conductivity rise reaches half of its maximum value is the nominal transit time (ca. 30 min) and is used to calculate the average water velocity (ca. 7 m min^{-1}) for the reach.

b) The downstream peak in conductivity is smaller than the upstream peak due to the dilution by groundwater of the salt-nutrient solution as it travels over the length of the reach. The height of each peak is used to obtain a precise estimate of discharge at the top and bottom of the study reach (since the salt concentration of the injection solution, the rate of injection, and the increase in salt within the stream are all known values). The difference in discharge between the upper and lower monitoring location was used to estimate the rate of groundwater entering the stream (expressed per unit distance to normalize for variable reach lengths across experiments). For the experiment illustrated here, groundwater discharge was 0.00004 $\mathrm{m}^2\ \mathrm{s}^{-1}$ (units reflect m^3 of groundwater entering the stream per m of channel length). Groundwater inputs resulted in an increase in stream discharge from 50 L s^{-1} to 58 L s^{-1} and corresponded to a 16% dilution of the tracer-nutrient pulse.

c) The shape of the downstream conductivity pulse differs from that of the upstream monitoring location in that the initial rise and subsequent decline are more gradual. The delayed rise represents a lag effect due to Cl ions entering transient storage zones within (backwater areas) and beneath (hyporheic zone) the stream channel. The slower decline in conductivity at the end of the injection experiment is due to the gradual release of these ions from storage zones. The hydrodynamic transport model uses the inflexion at the rise and fall of the downstream pulse to derive the terms k_1 and k_2 (see above) whereby greater inflexion is indicative of greater transient storage. The ratio of these terms is indicative of the proportion of transient storage area relative to the cross-sectional area of the stream (= 0.237, in this experiment).

Downstream trends in salt and nutrient concentrations for a typical experiment are shown in Figure 2 to illustrate the means by which nutrient retention estimates were derived. Chloride concentrations declined gradually downstream due to dilution by groundwater. Nutrient concentrations (NO_3, SRP) declined more rapidly due to the combined effects of dilution and biotic-abiotic uptake. The declines in N and P were normalized relative to Cl to derive dilution-corrected estimates for the loss in mass of N or P per unit distance downstream. Least squares regressions of the normalized values were used to derive retention coefficients (k_N, k_P, m^{-1}) and to determine whether these rates were statistically significant. For the sample data in Figure 2, the regressions accounted for 77% and 83% of the variation in N and P (respectively) and the uptake rate coefficients were significantly different from zero ($p < 0.02$). The uptake rate coefficient for SRP was larger ($k_P = -0.00304\ \mathrm{m}^{-1}$) than that for nitrate (k_N, $= -0.00122\ \mathrm{m}^{-1}$) corresponding to a shorter uptake length for P (329 m) relative to N (823 m). Negative values for uptake coefficients denote net retention of N and P during this experiment.

Restoration Effects on Hydrology

Velocity, transient storage and groundwater inputs at the reference (Harts Run), channelized (Wilson Creek pre-restoration) and naturalized (Wilson Creek post-restoration) sites are summarized in Table 2. The reference stream exhibited lower average water velocity and greater transient storage relative to the channelized site. In its pre-restoration state, Wilson Creek exhibited two-fold higher average water velocity relative to the reference site and half of the average transient storage. Variation in water velocity was related to discharge whereas transient storage was not (Figure 3). Stream discharge accounted for 62% of the variation in water velocity for the pooled data set (all sites; $p < 0.001$). Average groundwater inputs were similar for the reference and channelized streams and were correlated with stream discharge (Figure 4).

The naturalized channel exhibited water velocity and transient storage values that were intermediate to those observed in the reference and channelized streams. Differences in average values between pre- and port- restoration periods were primarily due to the low velocity and very high transient storage observed in the “hybrid” sub-reach (segment of the new channel that was connected to remnants of the old channel; Figure 3). In five experiments conducted in this sub-reach, transient storage values were consistently high over a range of discharge conditions ($k_1/k_2 > 0.5$) and included two of the highest values measured ($k_1/k_2 > 1.0$) during this study. Water velocity in this sub-reach was lower than would be expected based on discharge in four of the five experiments (values below regression line). Groundwater inputs were highest at the hybrid reach and average water velocity was comparable to that observed in the reference stream. Portions of the newly constructed channel that were not connected to remnants of the old channel exhibited average water velocity and transient storage values that were comparable to those observed in the channelized stream. These segments also exhibited the lowest groundwater inputs. Differences in water velocity and transient storage among the three sites (Harts, Wilson pre/post) were found to be statistically significant based on a oneway repeated measures ANOVA ($p < 0.001$, $p = 0.04$; respectively). Differences in groundwater inputs among the three sites (pooling all data for the naturalized channel) were not significantly different.

Restoration Effects on Nutrient Retention

Solute injections performed at the reference stream showed net retention of P (negative uptake rates) in ten of twelve experiments and net loss of P (positive uptake rates) in two experiments (Figure 5). All P uptake rates measured at this site were statistically significant. The average uptake rate was -0.00193 P m^{-1} (all experiments) and corresponded to an average uptake length of 761 m (for $k_P < 0$, $N = 10$). By comparison, nitrate injections yielded only seven negative uptake rates (from twelve experiments) and of these, five were significantly different from zero. Five experiments yielded positive uptake rates (net release of N) of which one was significant. The average uptake rate for N was lower than for P (k_N, $= 0.00012\ \mathrm{m}^{-1}$; all data) and corresponded to a longer uptake length (1310 m; for $k_N < 0$ and $p < 0.05$; N = 5). These findings indicate that the reference stream was typically a net sink for both N and P but that uptake rates for N were low and often below limits of detection.

The channelized site exhibited substantially lower average uptake rates for both N (-0.00005 m^{-1}) and P (-0.00073 m^{-1}) relative to the reference site. For P, five of seven experiments reveled net retention (negative uptake) and two exhibited net release (all were significant). The average uptake length among experiments exhibiting negative rates was 1135 m. For N, six of nine experiments yielded negative uptake values but of these only two were statistically significant (uptake length = 817 m). Two of the three experiments that yielded positive uptake rates were significant. Experiments conducted in the naturalized (post-restroration) channel exhibited higher average uptake rates for both N (-0.00162 m^{-1}) and P (-0.00263 m^{-1}) relative to the channelized stream. The average values for N and P uptake also exceeded those observed in the reference stream. For P, all seventeen experiments revealed negative uptake rates and eleven of these were statistically significant. The average uptake length for these experiments was 354 m. For N, fifteen of the seventeen experiments exhibited negative uptake coefficients and eleven of these were statistically significant. The average uptake length for these experiments was 1386 m. Of the two experiments exhibiting positive uptake rates, only one was significant. Highest nutrient uptake rates were measured in the “hybrid” channel. Experiments in this sub-reach yielded 3 of the highest N uptake rates and 3 of the 4 highest P uptake rates. Uptake lengths for these experiments averaged 178 m (for N) and 207 m (for P). Uptake rates in the designed channel were lower than those measured in the “hybrid” channel but exceeded average values for the channelized and reference streams.

Discussion

Results from tracer and nutrient injection experiments suggest that restoration of the Wilson Creek channel resulted in improvements in stream functioning. Transient storage and nutrient uptake rates in the naturalized channel were on average higher than those measured during its channelized state and approximated the values obtained at the reference site. Average water velocity was generally lower in the restored channel despite similar discharge conditions during the pre- and post- restoration monitoring periods. The following section considers specific design features of the naturalized channel that may account for the observed changes in transient storage and nutrient retention. The utility of measuring transient storage and nutrient retention as metrics of success in stream restoration assessment is also considered.

Restoration effects on water and nutrient retention were most apparent in the sub-reach of the naturalized channel that passed through a segment of the old channel (“hybrid” reach). In this sub-reach, a recirculation zone exchanged water between the active channel and a backwater area that formed in a remnant of the old channel. Experiments conducted in this sub-reach yielded estimates of transient storage that were consistently higher than those observed elsewhere in the designed channel and included the highest values of transient storage and nutrient uptake measured in this study. Prior work on New Hampshire streams has demonstrated that side pools along the channel margin have much longer hydraulic retention than those in the active channel (Hall et al. 2002) and may therefore have a disproportionate influence on water and solute dynamics. High nutrient uptake rates in this sub-reach suggest that the backwater area was a biogeochemically active zone. Accumulation of organic materials (predominantly leaf litter) within the backwater likely resulted in higher areal rates of bacterial metabolism relative to the active channel. Bacterial denitrification, coupled with the gradual exchange of water between the storage zone and active channel, could account for high N retention in this reach. As this sub-reach was well-shaded by remnants of the riparian canopy, it is unlikely that autotrophic (algal) uptake could account for elevated nutrient retention. Occasional samples collected in the backwater area revealed lower nutrient and dissolved oxygen concentrations in comparison to the active channel (J. Jack, unpubl. data). These data further support the hypothesis that heterotrophic (bacterial) activity in the backwater resulted in higher nutrient demand. An alternative explanation is that processes occurring within the section of the old channel that was now part of the new (active) channel accounted for elevated transient storage and nutrient retention within the this sub-reach. Because the new (designed) channel was higher in elevation, this section of the old channel became a deep pool which accumulated sand and silt deposits. While unconsolidated materials play an important role in hyporheic processes in riffles, their importance in pools is likely reduced by the lack of a prominent head gradient (to force water into the subsurface zone) combined, in this case, with the low hydraulic conductivity of relatively fine deposits. Therefore, it is unlikely that processes in the active channel could account for the observed effect and we conclude that high transient storage and nutrient retention in this sub-reach was due to the influence of the biogeochemically-active backwater area.

With the exception of the hybrid channel, measurements of water velocity and transient storage for the naturalized channel were generally similar to those observed prior to restoration. Several aspects of the design for the naturalized channel and the means by hydrologic conditions were characterized in this study may account for the lack of response in these parameters. First, the naturalized channel was narrower (5.5 m) in comparison to the pre-restoration channel (width = 7.3 m). The morphometry of the designed segment arose from a desire to achieve a deeper channel (at base flow) with more complex hydrologic and substrate conditions (pool-riffle structure). A consequence of this design was that the specific discharge (flow divided by width) was higher in the naturalized channel. Higher specific discharge would be expected to result in higher water velocity due to reduced effects of sheer stress along the bottom and sides of the channel. The fact that water velocity declined somewhat relative to the channelized state (from 11.9 m min^{-1} to 9.4 m min^{-1}) is likely due to the influence of the constructed pools. Second, it is important to recognize that the method employed here to measure water velocity (based on solute transit time) yields a whole-reach average value that integrates lateral and longitudinal variation within the channel. This metric does not reflect the complexity of flow conditions within the channel; an attribute that is likely important for attaining other restoration objectives (e.g., maintenance of biodiversity).

To more accurately depict restoration effects over the length of the naturalized segment, values for specific sub-reaches were weighted according to the proportion of the designed channel for which they were representative. Using the length and average water velocity for the hybrid reach (7.0 m min^{-1}) and applying the average value for the two sub-reaches that did not include the old channel (9.4 m min^{-1}) to the rest of the restored segment yielded an average transit time of 104 min (at mean discharge observed during the injection experiments). By comparison, the average transit time of Wilson Creek in its channelized state was 69 min (for similar discharge conditions). The ca. 50% increase in water transit time reflects the combined effects of slower water velocity and the increased length of the meandering channel. Slower water velocity would be expected to favor higher nutrient retention by allowing biogeochemical processes a longer opportunity to influence the chemistry of through-flowing water. A similar calculation for groundwater inputs yielded an areal-weighted average for the naturalized channel (0.00012 m^2 s^{-1}) that was considerably lower relative to pre-restoration (0.00020 m^2 s^{-1}) and reference (0.00019 m^2 s^{-1}) values. It was anticipated that re-location of the channel would result in higher groundwater inputs to the restored stream due to lower bedrock elevation in the floodplain and the presence of unconsolidated deposits underlying the constructed channel (vs. bedrock substrate in the incised channel). Solute dilution measurements suggest that groundwater inputs per unit distance were 40% lower in the restored channel though this reduction would be partially offset by the 15% increase in stream length for the meandering channel. Declines in groundwater entering the restored channel may reflect the loss of inputs from seeps located along the hillslope adjacent to the channelized segment.

The areal-weighted average for transient storage in the naturalized channel (k_1/k_2 = 0.26) did not differ appreciably from that of the channelized condition (k_1/k_2 = 0.28). Pre- and post- restoration transient storage values for Wilson Creek were well below that of the reference stream (k_1/k_2 = 0.55). It was anticipated that the restored channel would exhibit higher transient storage due to the complex flow conditions created by the pool-riffle structure and the presence of unconsolidated materials underlying the constructed channel (vs. bedrock in the incised channel). In particular, use of gravel/cobble materials to line the constructed riffles would be expected to increase transient storage through exchange with the hyporheic zone. However, an off-setting factor may have been the presence of predominantly clay materials within floodplain soils as these have low hydraulic conductivity. Although the naturalized channel did not attain the transient storage conditions observed in the reference stream, these values may not be indicative of the long-term potential for this site. The data presented here were collected during the first two years following restoration and several processes may act to influence transient storage in future years. First, although the designed channel included some in-stream features, these were large woody structures (stumps, logs) that were intended to promote the formation of debris dams. Input and retention of riparian materials over time would be expected to build in-stream structure and increase transit storage (Ensign and Doyle 2005). Similarly, secondary re-sorting of the streambed and selective transport of finer (clay) materials would increase hydraulic conductivity and result in greater transit storage over time.

Naturalization of the Wilson Creek channel resulted in an increase in nutrient retention despite the fact that transient storage was largely unaffected. Average values for P uptake coefficients were threefold higher in the restored stream relative to the channelized stream and exceeded the average value for the reference site. Nitrogen uptake rates exhibited a larger proportional increase with average values in the naturalized channel 30-fold higher than the channelized stream and 10-fold higher than the reference stream. Average uptake rates for the restored channel were enhanced by the very high nutrient retention measured in the “hybrid” channel (particularly for N). However, average values for sub-reaches in the designed channel also exceeded those measured prior to restoration. Areal-weighted estimates (as for transient storage above) of P uptake in the naturalized channel (-0.00236 m^{-1}) corresponded to an uptake length of 424 m (vs. 518 m and 1370 m for the reference and channelized sites, respectively). The areal-weighted estimate of N uptake (-0.00104 m^{-1}) corresponded to an uptake length of 962 m (vs. 8333 m and 20000 m for the reference and channelized sites, respectively). Increased nutrient retention in the naturalized channel may be due to abiotic complexation, biotic demand or both. Abiotic complexation is more likely to influence P retention since nitrate has a low sorption potential. Excavation of the new channel exposed clay materials and as these have a high sorption capacity, may have contributed to higher P retention. Biotic demand includes uptake by both autotrophs (algae) and heterotrophs (bacteria). The proportionately greater increases in N retention likely reflect enhanced denitrification in the backwater area formed by the remnant stream channel. Autotrophic production may have been stimulated by higher light levels following re-location of the stream channel to the open (afforested) floodplain. Higher light conditions relative to the shaded (pre-restoration) channel may have stimulated autotrophic production and resulted in greater demand for both N and P. Sabater et al. (2000) reported a similar finding following the removal of riparian vegetation along a Mediterranean stream. High P uptake rates were correlated with increases in benthic algal production and attributed to higher light levels following the loss of canopy shading.

Tracer and nutrient injection experiments performed at the reference, channelized and naturalized sites were found to be a useful means for characterizing stream functioning in the context of restoration assessment. Reach-scale estimates of water velocity, transient storage and nutrient retention were found to be sensitive to geomorphologic differences between the channelized and reference streams and to design features of the naturalized channel. Velocity estimates were based on solute transit time and found to be strongly dependent upon discharge conditions. Their utility for characterizing restoration effects is therefore dependent upon capturing a similar range of discharge conditions before and after channel modification. Transient storage estimates were not found to be sensitive to discharge and may reflect diverse storage zones that become active in water exchange during different phases of the stream hydrograph. Transient storage values were quite uniform across a range of discharge conditions (excluding “hybrid” sub-reach) such that only 3-4 experiments were required to yield an average value within 10% of that attained from all experiments (10+) at a given site. The reliability of the method and its potential utility as an indicator of hydrologic processes relevant to stream functioning (in-stream structure, hyporheic exchange) suggest that transient storage may be a useful metric for assessment of restoration success. An unresolved issue is the relationship between transient storage and nutrient retention as some prior reports have suggested a positive association whereas others have not (Hall et al. 2002). Data from this study does not resolve this issue. The channelized stream exhibited lower transient storage and nutrient retention relative to the reference site but naturalization of the channel resulted in higher nutrient retention without increases in transient storage.

Despite uncertainty about the importance of transient storage for nutrient retention, findings from the Wilson Creek study suggest that naturalization of stream channels results in greater retention of both N and P. Two factors should be considered in interpreting the broader significance of our findings. First, nutrient uptake rates measured in this study reflect in-stream processes for periods when discharge is at or below bank-full capacity. Although restoration of floodplain connectivity was a central feature of the designed channel, nutrient uptake within the floodplain was not measured due to logistical factors that limit the utility of injection experiments during flood conditions (e.g., need for stable flow and uniform lateral mixing). As the restored channel enters its floodplain more frequently (vs. incised pre-restoration channel) and floodplain areas are known to be biogeochemically active (particularly for denitrification; Baker and Vervier 2004), our findings likely represent a conservative estimate of gains in nutrient retention arising from restoration. Second, data collected in this study represent the short-term (2 year) effects of restoration which may or may not be indicative of long-term response. Development of in-stream structures through the accumulation of woody debris and secondary sorting of bed materials would likely lead to greater transient storage and may further enhance nutrient retention over time. Concurrent succession of the riparian plant community would be expected to promote a shift from autotrophic to heterotrophic nutrient demand due to increases in litter inputs and canopy shading. Long-term monitoring will be required to assess the net effect of hydrogeomorphic and biotic responses on nutrient retention in the restored reach. Despite these limitations, our findings suggest that stream restoration may be a useful management strategy in the context of basin-wide efforts to reduce nutrient loading by promoting nutrient retention.

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Table 1. Stream discharge conditions and nutrient concentrations on dates when solute injection experiments were performed at Harts Run (reference site) and Wilson Creek (pre- and post- restoration). Values are the mean and range for all experiments performed in the spring index period (April 2 – June 16) during 2002-2005. N denotes the number of injection experiments performed at each site.

		Harts (all) (N = 13)	Wilson (pre) (N = 14)	Wilson (post) (N = 17)
Discharge (L s^{-1})				
	Mean	59	116	109
	Range	19 - 102	52 - 210	54 - 268
Nitrate (µg N L^{-1})				
	Mean	63	375	469
	Range	13 - 209	156 - 524	271 - 949
SRP (µg P L^{-1})				
	Mean	7.5	11	7.2
	Range	2 - 16	4 - 18	4 - 11

Table 2. Average velocity, transient storage and groundwater inputs at the reference (Harts Run), channelized (Wilson Creek – Pre) and restored (Wilson Creek - Post) sites. Post-restoration data for Wilson Creek are further divided for study reaches in the newly constructed channel (‘New’) and those connected to remnants of the old channel (‘Hybrid’). Data shown are average values for all injection experiments performed at each site (%’s denote groundwater inputs as a proportion of stream discharge).

	Velocity	Storage	Groundwater	
	(m min^{-1})	(k_1:k_2)	(m^2 s^{-1})	(%)
Harts Run				
All data	6.1	0.550	0.00019	21%
Wilson Creek (Pre)				
All Data	11.9	0.281	0.00020	30%
Wilson Creek (Post)				
All Data	8.7	0.405	0.00017	20%
New channel	9.4	0.191	0.00010	17%
Hybrid	7.0	0.918	0.00030	28%

Figure 1. Variation in stream conductivity observed during a typical injection experiment. Data shown were collected on May 24, 2004 from the designed channel (Wilson Creek post-restoration). Values are normalized relative to background (pre-injection = zero) to show the response of conductivity to injection of the salt-nutrient solution. Time series are adjusted for elapsed time (zero = start of injection).

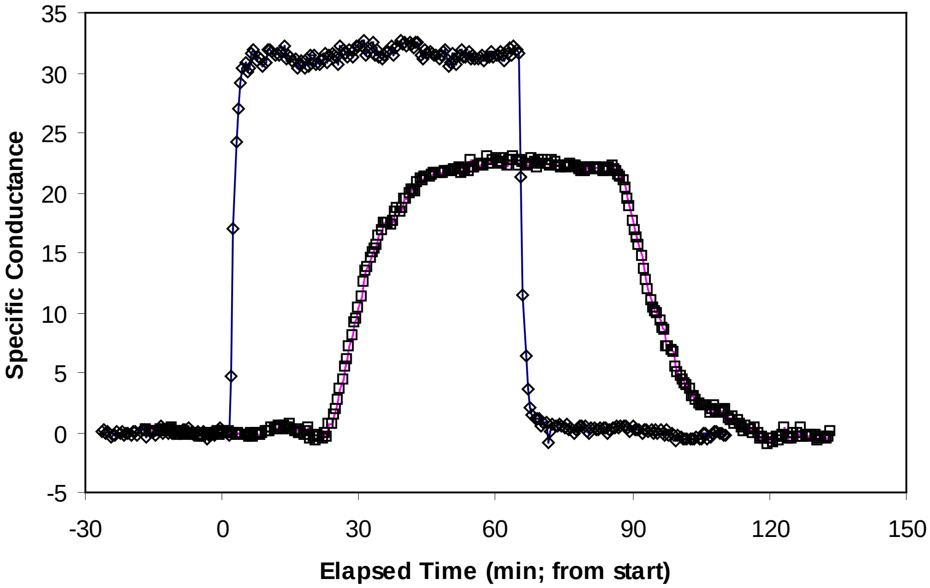
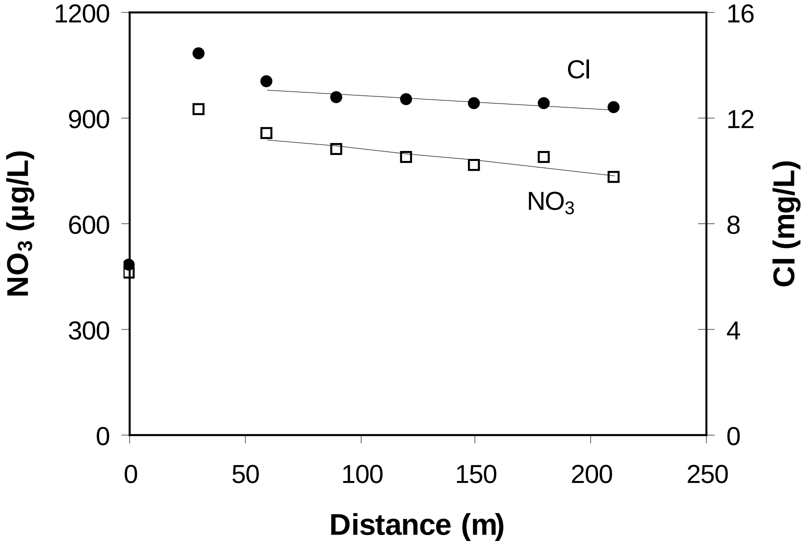


Figure 2. Downstream declines in chloride and nutrient (N, P) concentrations observed during a typical injection experiment (Wilson Creek, designed channel, May 24, 2004). Fitted lines are least-squares regressions. Values on the y-axis (distance = 0) denote background concentrations at the start of the injection.



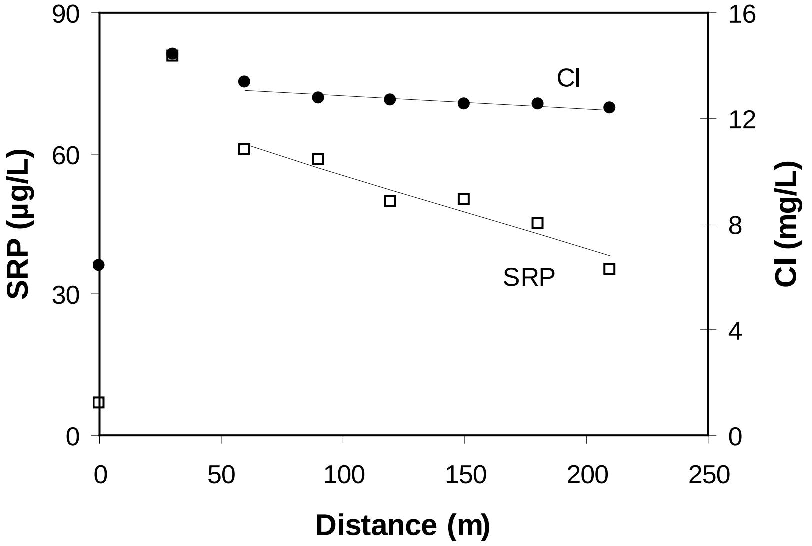


Figure 3. Water velocity (upper panel) and transient storage (lower panel) as a function of stream discharge at the reference (Harts Run), channelized (Wpre) and restored (Wpost) sites. Velocity and transient storage were derived independently from the measured increase in stream Cl concentrations and the speed with which Cl travels downstream during injection experiments. The line shown for velocity vs. discharge is a least squares regression ($R^2 = 0.62$; $p < 0.001$). Values shown in red are for a sub-reach of the restored channel that was connected to a backwater formed by remnants of the old channel (“hybrid” channel).

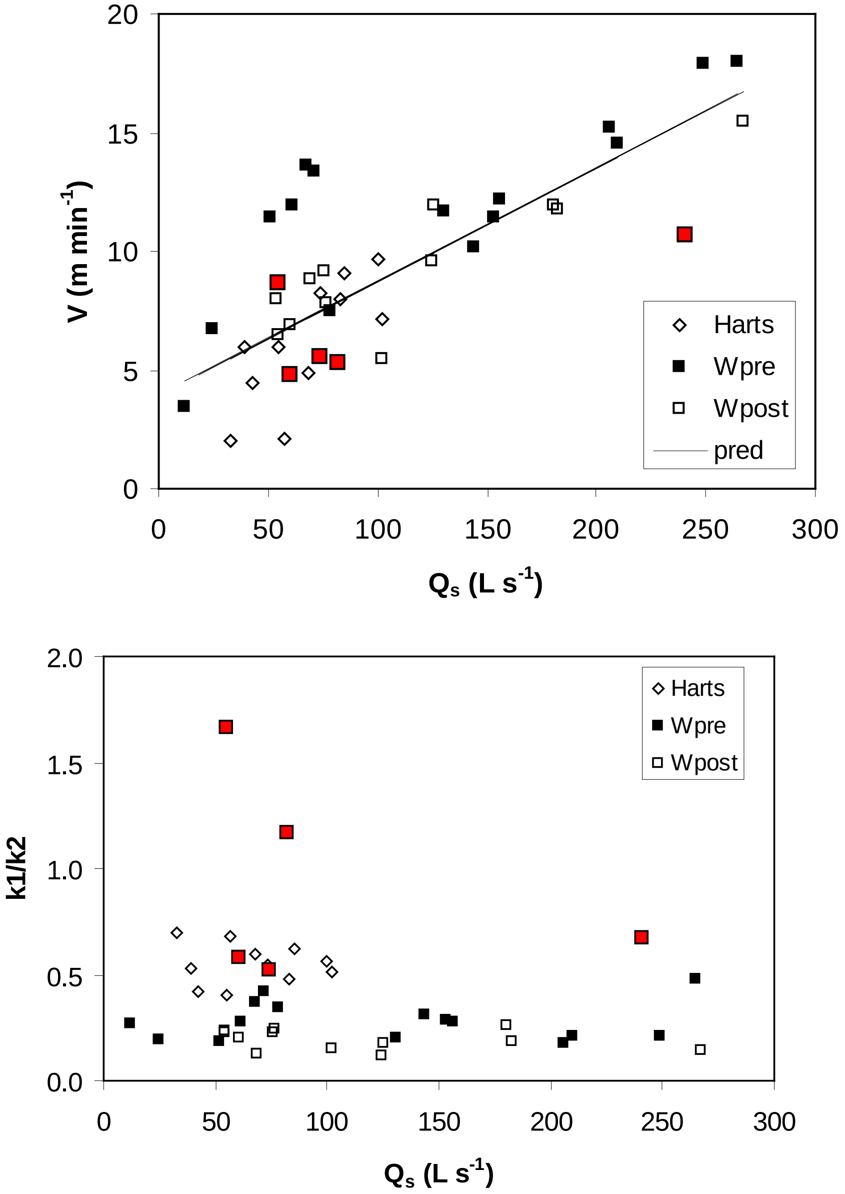


Figure 4 Stream discharge as a function of groundwater inputs at the reference (Harts Run), channelized (Wpre) and restored (Wpost) sites. Discharge and groundwater inputs were derived from measured increases in stream Cl concentrations during injection experiments. The lines are least squares regressions for data from Harts Run (lower line; $R^2 = 0.32$, $p = 0.054$) and Wilson Creek (pre-restroration; upper line; $R^2 = 0.60$, $p = 0.001$). Values shown in red are for a sub-reach of the restored channel that was connected to a backwater formed by remnants of the old channel ("hybrid" channel).

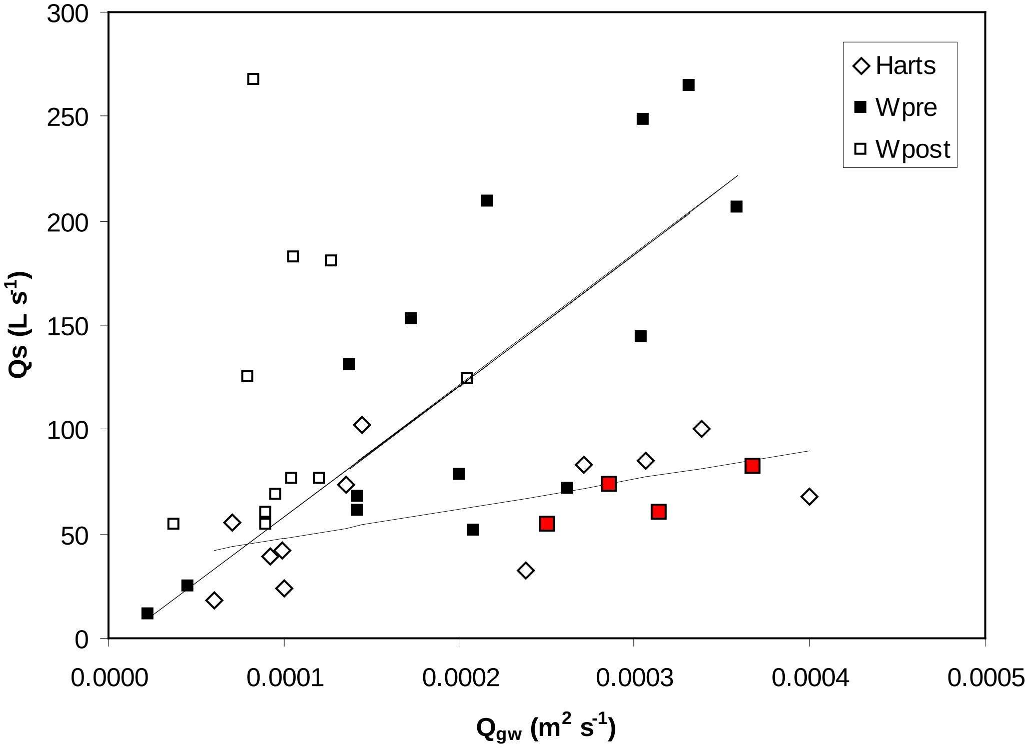


Figure 5. Phosphorus uptake rate coefficients for the reference (Harts Run), channelized (Wilson Creek, pre-restoration) and naturalized (Wilson Creek, post-restoration) sites. Solid symbols denote coefficients that are significantly different from zero. Arrows in lower panel denote a sub-reach of the naturalized channel that was connected to a backwater area formed by remnants of the old channel ("hybrid" channel).

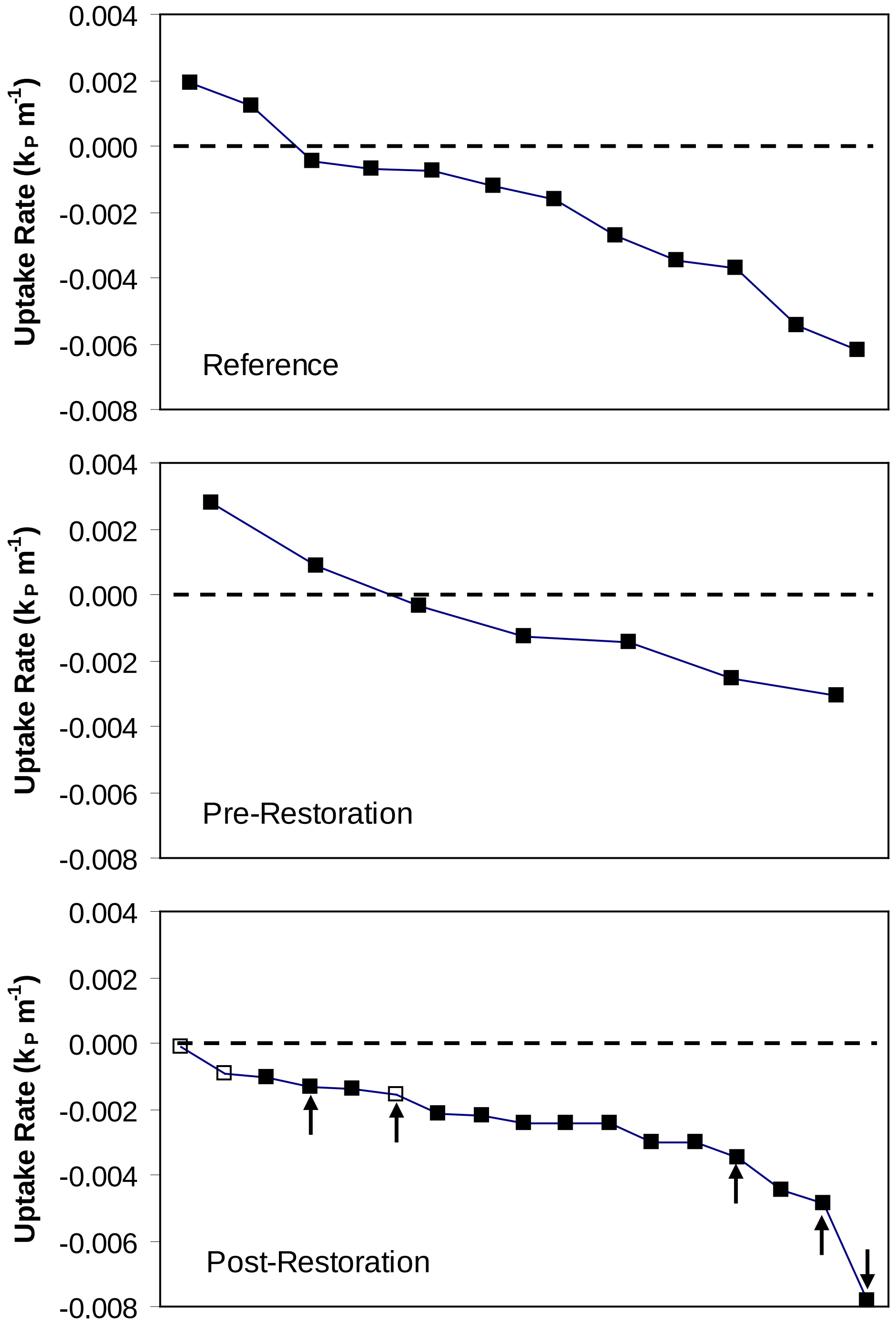
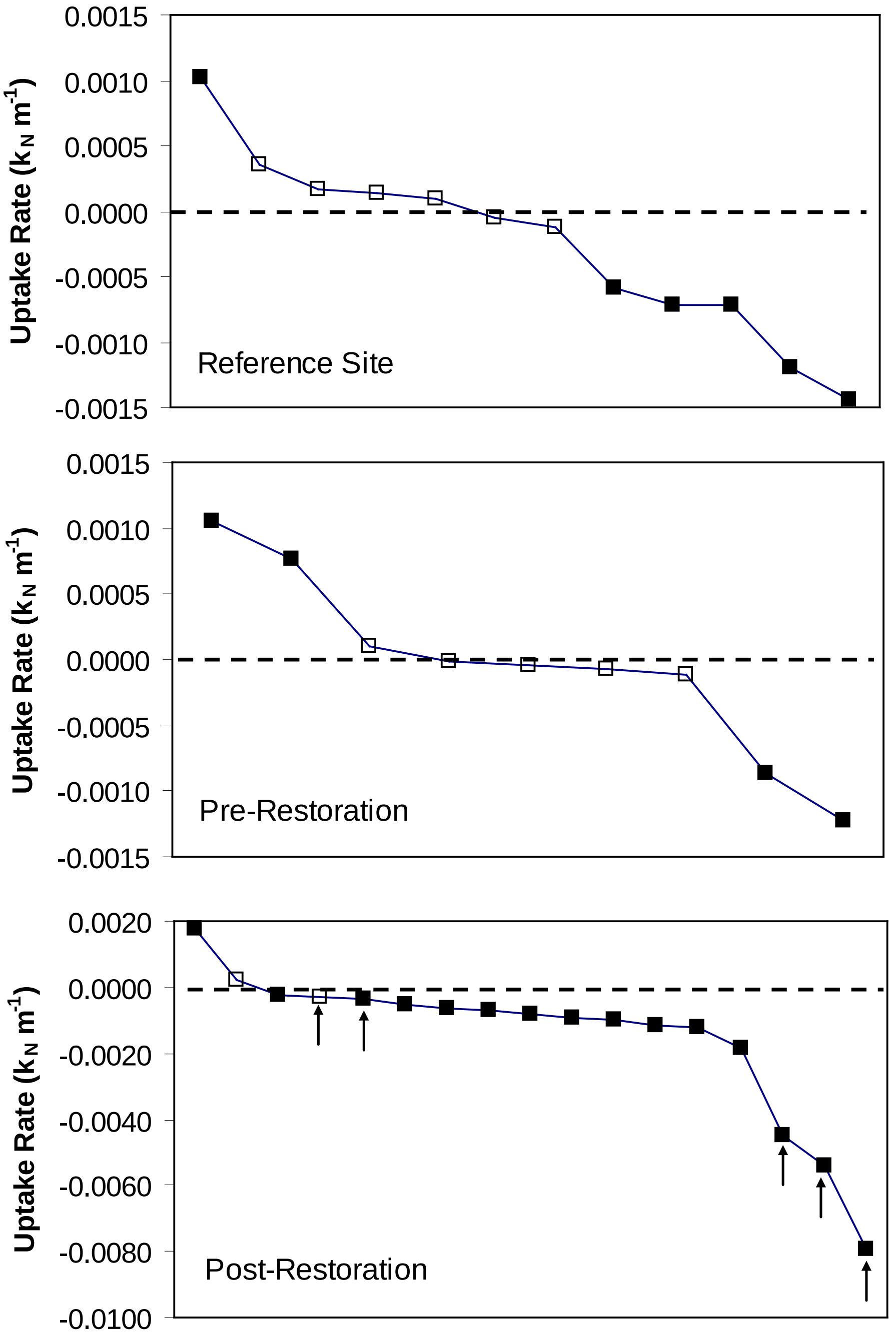


Figure 6. Nitrogen uptake rate coefficients for the reference (Harts Run), channelized (Wilson Creek, pre-restoration) and naturalized (Wilson Creek, post-restoration) sites. Solid symbols denote coefficients that are significantly different from zero. Arrows in lower panel denote a sub-reach of the naturalized channel that was connected to a backwater area formed by remnants of the old channel (note difference in y-axis scale).



Appendix F

Biological Response to Channel Restoration and Riparian Reforestation Along Wilson Creek Watershed, Nelson/Bullitt Counties, Kentucky, USA: Final Report

by

Rodney Pierce
(Kentucky Environmental and Public Protection Cabinet, Department for Environmental Protection, Division of Water, Watershed Management Branch)

Biological Response to Channel Restoration and Riparian Reforestation Along Wilson Creek Watershed, Nelson/Bullitt Counties, Kentucky, USA: Final Report

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December 1, 2006
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ABSTACT

Bernheim Research Forest and Arboretum and the University of Louisville received a §319(h) nonpoint source pollution control grant (Grant #C9994861010) to perform a demonstration project to restore the meandering of the channel and riparian zone of Wilson Creek (Kentucky, USA) using natural channel design approach. The restoration restored 2700 ft of stream channel. The restoration transformed the stream channel from its low sinuosity, entrenched and bedrock substrate to a sinuous alluvial stream position near the valley center. In order to assess the biological response to the channel relocation of Wilson Creek, fish, macroinvertebrates and algae were collected from three 100 m reaches. Biological communities have responded positively to the restoration and have reached or exceeded pre-restoration conditions. Only minor disturbances were detected in the downstream fish community following the restoration. Overall the channel restoration of Wilson Creek has been a success.

INTRODUCTION

In 2003, a channelized reach of Wilson Creek (Kentucky, USA) was relocated using a natural channel design approach. The relocated channel restored 823 m (2700 ft) of stream channel. Channelization of Wilson Creek and destruction of the adjacent riparian forest resulted in physical impairment of the stream and increased nutrient loading. The primary physical impairments of the stream were incision and widening. The wider, deeper channel resulted in lower groundwater levels and reduced frequency of floodplain flooding.

Bernheim Research Forest and Arboretum and the University of Louisville applied for and received a §319(h) nonpoint source pollution control grant (Grant #C9994861010) to perform a demonstration project to restore the meandering of the channel and riparian zone. The restoration transformed the stream channel from its low sinuosity, entrenched and bedrock substrate to a sinuous alluvial stream position near the valley center. By redirecting a currently channelized stream into its previous drainage, the project goals were to: 1. reconnect the stream to its floodplain; 2. raise groundwater levels that support and create adjacent wetlands; 3. create floodplain ponds; and 4. reestablish a primarily gravel streambed substrate.

In order to assess the biological response to channel relocation of Wilson Creek, Division of Water biologists monitored the biological response to channel relocation. Monitoring objectives of this study were to: 1. quantify recovery rates of species within the new channel; 2. characterize any upstream/downstream biological impacts associated with channel construction; 3. Compare biological communities between the new channel and old channel. Funding for this project was conducted under a §319(h) grant from the United States Environmental Protection Agency (grant #C999486101-0).

METHODS

Study Area

Wilson Creek is a 55.9 km long, 4th order tributary of the Rolling Fork of the Salt River that drains portions of Bullitt and Nelson counties, Kentucky and is within the Knobs-Norman Upland (71c) ecoregion (Woods et al. 2002) (Figure 1). The Wilson Creek watershed encompasses an area of 105 km^2. Land use in the watershed is primarily forested (79.5%), with agriculture (16.2%), urban (0.9%) and other landuses (4%) making up the landscape (USGS 2000).

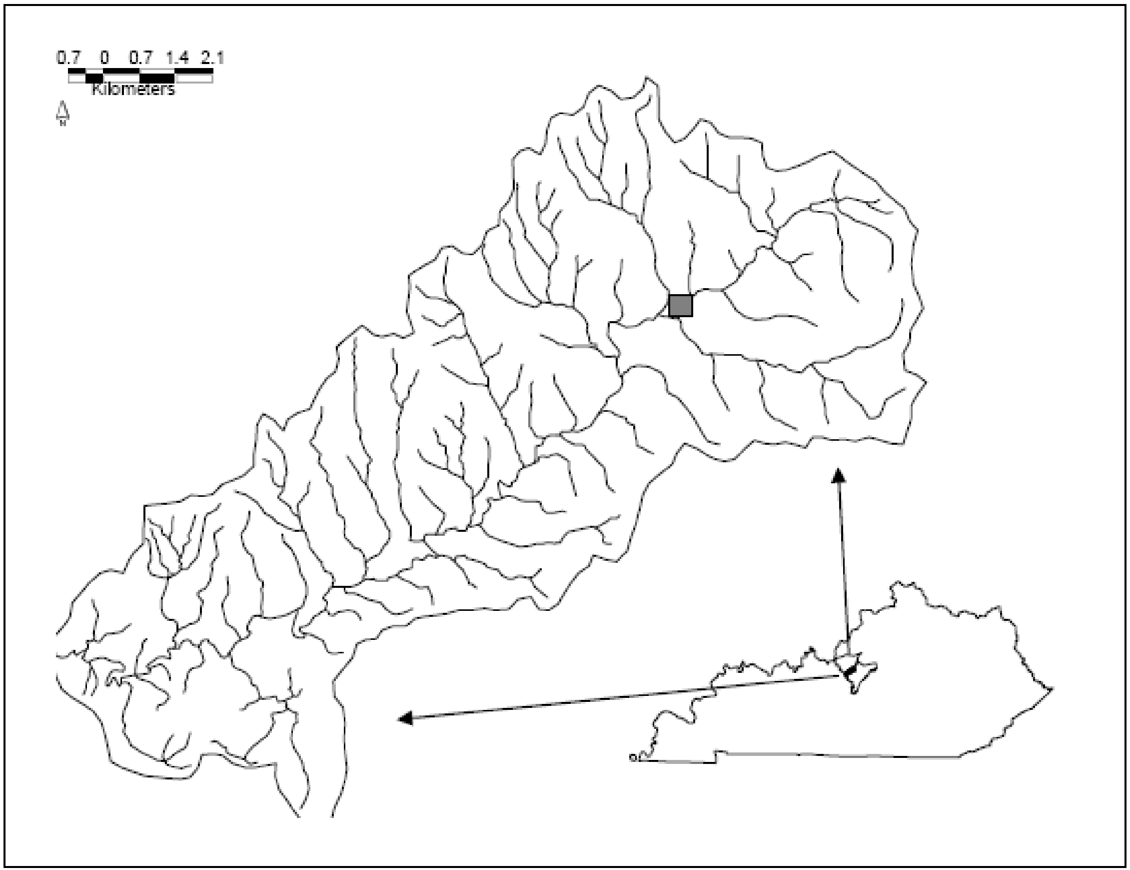

Figure 1. Wilson Creek Watershed, Nelson/Bullitt Counties, Kentucky, USA. Shaded region represents project location.

Survey Dates

Sampling was conducted prior to construction of the new channel (July and September 2003) and then again following construction (March, July and September

2004, April 2005 and March 2006). In order to address seasonal effects, samples were collcted during the spring (March), summer (July) and fall (September). July and September samples were not collected during 2005 due to drought conditions that dried riffles. Sampling concluded in March 2006. Channel construction was considered complete on 1 January 2004.

Site Selection

Three sites were selected (upper, lower and middle sites) (Figure 2). At each site a 100 m reach was established. Within each reach, 20 m transects (n=6) were established (Figure 3). Sites were selected based on previous KDOW sample location (KDOW unpublished data) and the location to restoration activities (above, below, and within the relocation area) (Table 1) (Figure 2). When construction was completed (1 January 2004) a new site was established laterally in the new channel to the site in the old channel.

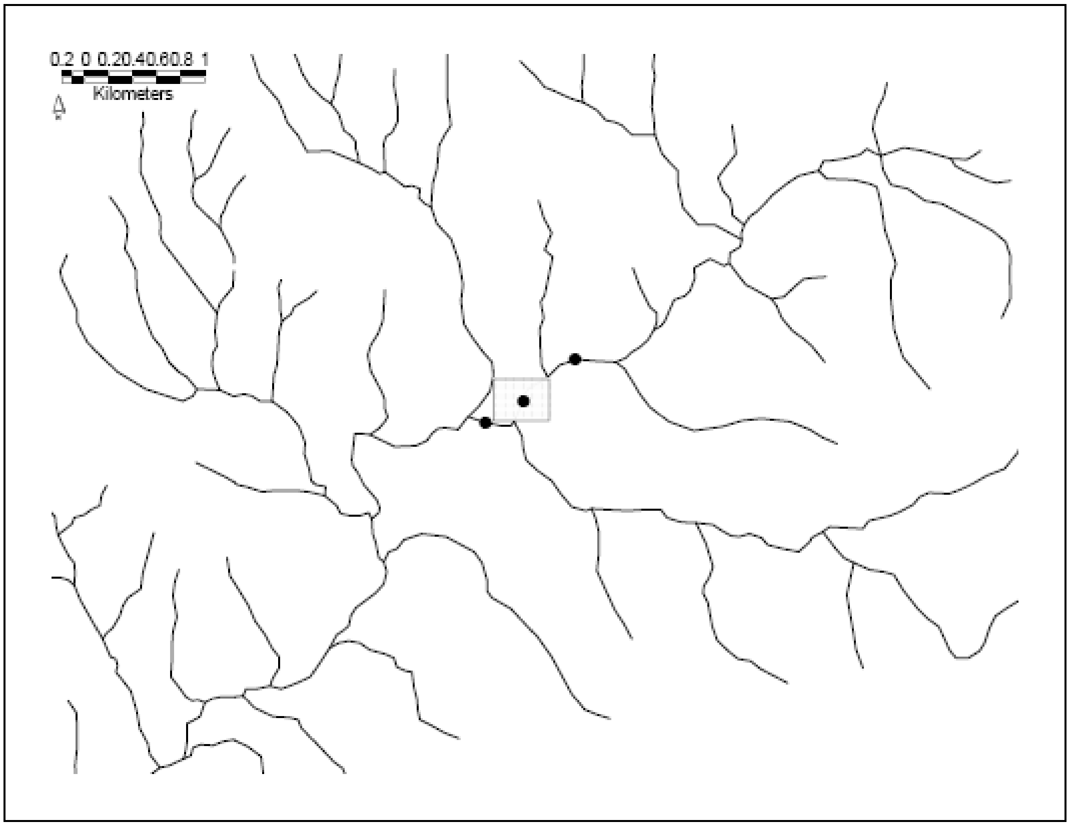

Figure 2. Detailed project location in the Wilson Creek Watershed, Nelson/Bullitt Counties, Kentucky, USA. Shaded area represents channel relocation area. Circles represent existing sample location: Upper, Middle and Lower.

Parameter Coverage

Fish, macroinvertebrates, and algae were collected from each 100 m reach. Fish were collected with a single pass using backpack electrofishing equipment and a seine (KDOW 2002). Samples were timed (s) to determine catch per unit effort (CPUE).

Within each 100 m reach sampling “blocks” were established (n=5). “Blocks” represented the area between transects. Within each “block”, one seine haul was performed in a downstream fashion (Figure 3). A total of five seine hauls were performed, one in each 20 m “block”, at each reach. All easily identified fish were identified and measured (mm) in the field and released, all others were preserved in 10% formaldehyde and returned to the laboratory for identification (species). Fish were assessed with the Kentucky Index of Biotic Integrity (KIBI) (Compton et al. 2003) (Table 2). Macroinvertebrates were collected semi-quantitatively by compositing four 0.25 m kicknet samples (KDOW 2002). A sub-sample of 300 organisms was processed in the laboratory. All macroinvertebrates were identified to lowest possible level (genus) and assessed with the Kentucky Macroinvertebrate Bioassessment index (MBI) (Pond et al. 2003 and KDOW unpublished data) (Table 2). Algae were collected by natural scraping and assessed with the diatom biotic index (DBI) following KDOW (2002) (Table 2). Habitat was assessed at each site using the rapid bioassessment protocols (RBP) described in Barbour et al. (1997) and KDOW (2002) (Table 3) during biological surveys. In addition to the RBP protocols the following were collected at each transect (Figure 2): wetted width, canopy cover (using a densiometer), riparian zone (left/right bank width) and visual determination of the two dominate substrates (fines (silt, clay and sand), gravel, cobble, boulder, and bedrock). The upper and middle sites were considered headwater sites and the lower site was considered a wadeable site for the purposes of assessment with the KIBI, MBI, DBI and habitat (KDOW 2002, Compton et al. 2003 and Pond et al. 2003). All parameters were sampled at each site the same day or two consecutive days.

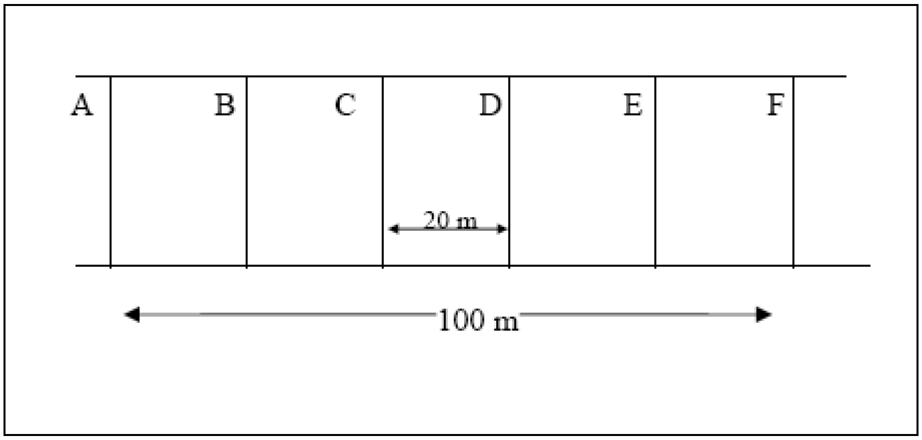

Figure 3. Example sample reach with 20 m transects.

RESULTS AND DISCUSSION

Fish

A total of 4,563 individual fish were collected representing 27 taxa (Tables 4,5 and 6). Fish abundance (CPUE) (fish/s)) increased from the downstream site to the upstream site (Figure 4). CPUE was higher during the summer and fall samples at the middle and upstream sites. Spring CPUE was consistent throughout the project for the downstream and upstream sites. An upward trend in CPUE during spring samples at the middle site was observed (Figure 5). Most sites had excellent or good KIBI scores (Table 7 and Figure 6) during all sample events except for the upstream site (July and September 2004 and March 2006) and the middle site (September 2004 and 2006) which received fair KIBI scores. The fair KIBI scores for the upstream site (July and September 2004) and middle site (September 2004) samples were probably related to seasonal effects of sampling headwater streams during the summer and fall (Compton et al 2003). The middle and upstream sites scored excellent and good (respectively) during the spring (2005) sampling event. The middle and upstream sites KIBI score of fair during the spring of 2006 were likely the result of drought conditions that dried the stream during the summer of 2005. KIBI scores were similar for the restored and old channel immediately after construction of the new channel (spring 2004). By the spring of 2005, KIBI scores were excellent in the new channel. Drought conditions during the summer of 2005 may have limited recovery of the new channel. Bayley and Osborne (1993) reported that there was no difference in pre- and post-drought fish biomass or richness and that recovery occurred within one year in an eastern Illinois stream. The new channel in Wilson Creek is expected to return to pre-construction condition or exceed them as the spring 2005 sampling event indicates. The downstream site pre-construction and spring 2004 KIBI scores were excellent. However, all other KIBI scores have been good. Although these scores are acceptable, some stress in the fish community is evident downstream following relocation of the Wilson Creek channel upstream.

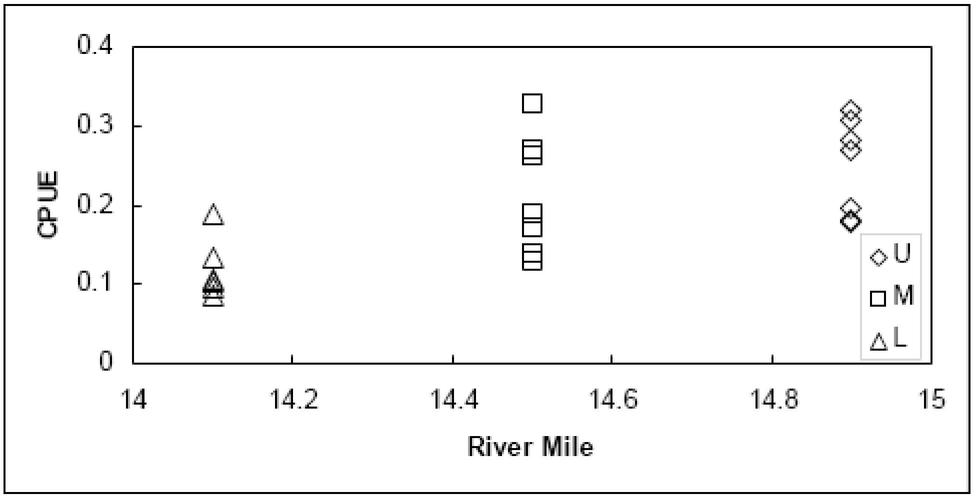

Figure 4. Catch per unit effort (CPUE fish/s) at three sampling locations (upper = U, middle = M and lower = L) in the Wilson Creek Watershed, Nelson/Bullitt Counties, Kentucky, USA.

Figure 5. Spring post-BMP catch per unit effort (CPUE fish/s) at the middle sampling location in the Wilson Creek Watershed, Nelson/Bullitt Counties, Kentucky, USA.

Figure 6. KIBI scores at three sampling locations (upper = U, middle = M and lower = L) in the Wilson Creek Watershed, Nelson/Bullitt Counties, Kentucky, USA.

Macroinvertebrates

MBI scores ranged from 52 to 65 at the upper and middle sites (headwater) and scored fair or good ratings (Table 8 and Figure 7) and ranged from 66 to 75 at the lower site (wadeable) and received fair or good ratings (Table 9 and Figure 7). The upper site scored good during all spring sampling events. Fair ratings were observed during the July and September sampling events, except for the September 2003 event that scored good. These fair ratings could be related to sampling outside the index period for the

MBI (Pond et al. 2003). The middle site scored fair ratings during all sample events except for the July 2004 and March 2006 events that scored good. The down stream site scored fair during the pre-construction period and the last three sampling events (September 2004, March 2005 and March 2006) scored good during the post-construction period.

Some seasonal effects from sampling macroinvertebrates at the headwater sites is evident with the fair ratings obtained at the upstream sites during the July and September sampling events. The macroinvertebrate community is stable at the upstream site with the good ratings obtained during the spring samples events. The macroinvertebrate community at the middle is starting to improve with the two good ratings obtained in the post-construction period. The downstream site has shown the most improvement during the post-bmp period with last three of five samples rating as good. No downstream impairment has been observed in the macroinvertebrate community. The macroinvertebrate community is responding positively to the restoration.

Figure 7. MBI scores at three sampling locations (upper = U, middle = M and lower = L) in the Wilson Creek Watershed, Nelson/Bullitt Counties, Kentucky, USA.

Algae

DBI scores ranged from 61 to 84 and scored excellent or good ratings at the three sampling locations in Wilson Creek (Table 10 and Figure 8). All sites, during the spring 2005 sample event, scored good ratings. These lower ratings may be related to sampling during the spring with cooler water that prevented growth of diatom communities (L. Panayotoff, pers. com.). Benthic algae should continue to improve to excellent scores as the riparian zone at the middle site matures. No downstream impairment has been detected in the benthic algae community.

Figure 8. DBI scores at three sampling locations (upper = U, middle = M and lower = L) in the Wilson Creek Watershed, Nelson/Bullitt Counties, Kentucky, USA.

Habitat

Habitat scores ranged from 110 to 153 at the three sampling locations in Wilson Creek (Table 11 and Figure 9). Habitat scores ranged from110 to 129 at the lower site and received a partial support rating for all sample dates. The middle site habitat scores ranged from 114 to 150 and received non support and partial support ratings for all sample dates except for spring 2006 witch was supporting but threatened. Habitat condition is expected to improve as the riparian zone matures. Habitat scores ranged from 140 to 153 at the upper site. The upper site received a supporting but threatened for all sample dates except for the spring 2005 and 2006 dates witch received a partial support.

Percent canopy cover ranged from 9 to 96% for the three sampling locations in Wilson Creek (Figure 10). The upper (91 to 93%) and lower (88 to 96%) site percent canopy cover remained constant throughout the project. The middle site percent canopy varied between the pre- and post-construction periods (9 to 91%). Pre-construction percent canopy at the middle site was 80 and 91%. However, post construction percent canopy cover ranged from 9 to 18%. As the riparian zone matures in the channel construction zone, the percent canopy cover should improve to resemble the lower, upper and pre-construction middle sites.

Dominant substrate remained constant at each site (Figure 11). Substrate size increased from the lower site to the upper site. The lower site was composed of gravel and sand with some cobble. The upstream site was composed of mainly cobble with exposed bedrock. The middle site was similar to the upstream site during the preconstruction period, with gravel/cobble mixture over bedrock. However, the postconstruction channel was composed of a mixture of cobble, gravel and sand with no exposed bedrock. Channel width remained constant at the upper and lower sites, except for a seasonal difference noted at the upper site. Channel width at the upper site was greater during the spring rather than the fall or summer, although not significant

(ANOVA P>0.05). No differences were detected any time at the lower site (ANOVA P>0.05). Mean channel width decreased during the post-construction period as compared to the July 2003 sample event (d.f. 6, 41; F=5.68; P=0.003) (Figure 12).

Figure 9. Habitat scores at three sampling locations (upper = U, middle = M and lower = L) in the Wilson Creek Watershed, Nelson/Bullitt Counties, Kentucky, USA.

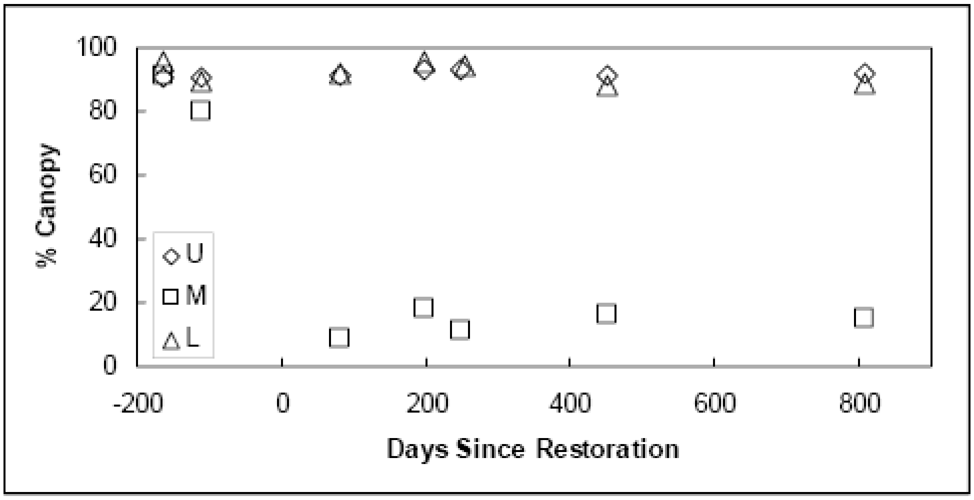

Figure 10. Percent canopy cover at three sampling locations (upper = U, middle = M and lower = L) in the Wilson Creek Watershed, Nelson/Bullitt Counties, Kentucky, USA.

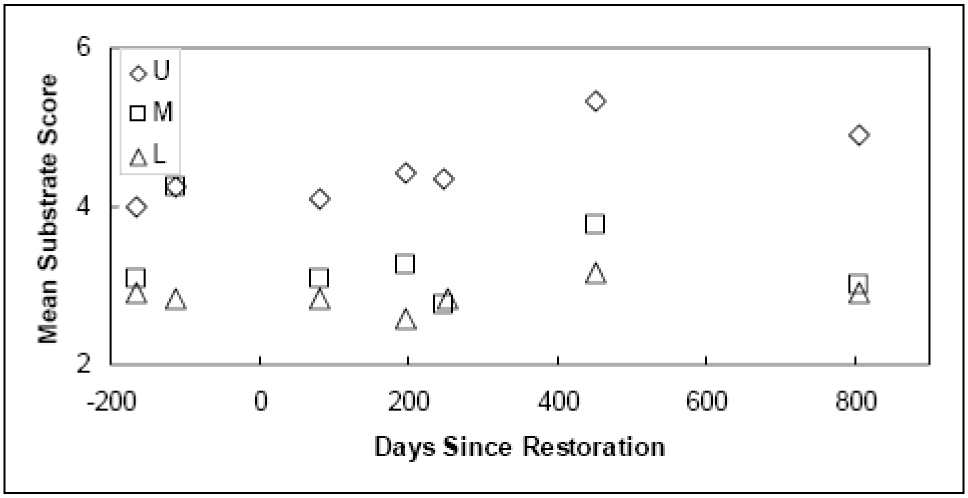

Figure 11. Mean substrate scores at three sampling locations (upper = U, middle = M and lower = L) (1=fines, 2=gravel, 3=cobble, 4=boulder and 6=bedrock) in the Wilson Creek Watershed, Nelson/Bullitt Counties, Kentucky, USA.

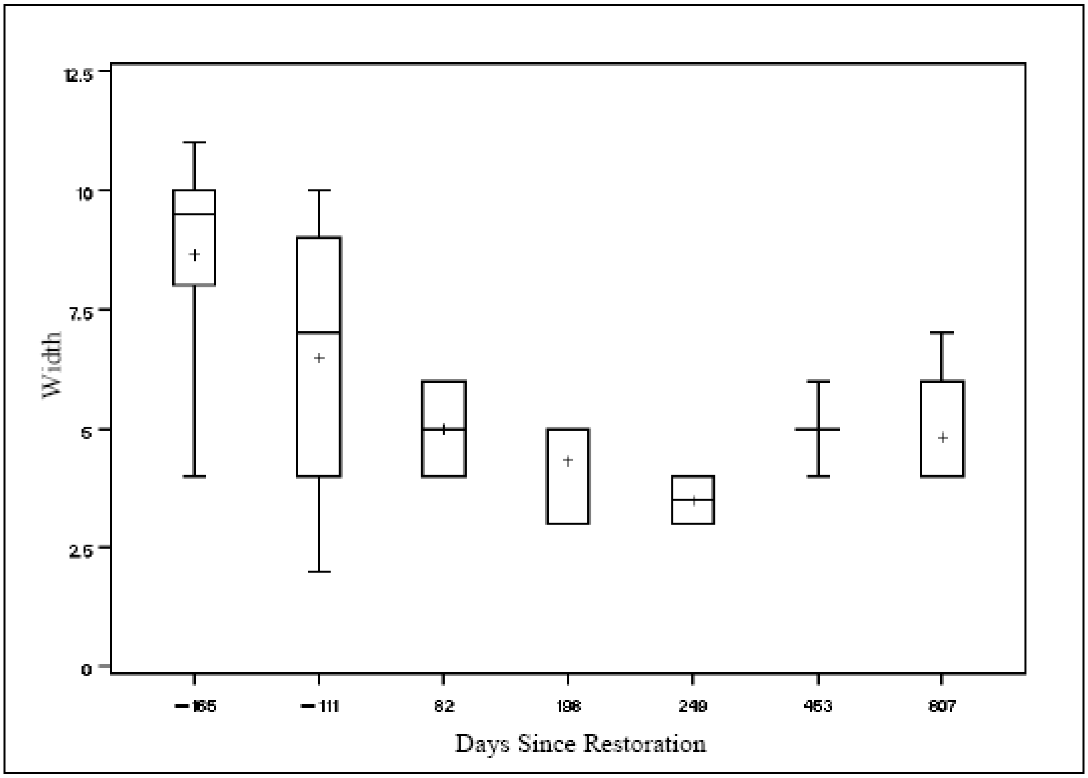

Figure 12. Mean stream width (m) at the middle sampling location in the Wilson Creek Watershed, Nelson/Bullitt Counties, Kentucky, USA.

FINDINGS AND RECOMMENDATIONS

1. The fish community has reacted positively within the restoration zone.
2. Some stress was evident in the downstream fish community.
3. The macroinvertebrate community is responding positively within the restoration.
4. The macroinvertebrate community has responded positively downstream of the restoration.
5. Benthic algae communities remained stable throughout and after the restoration.
6. Habitat conditions within the restoration zone should continue to improve as the riparian zone matures.
7. The upper reaches of Wilson Creek would benefit from a similar restoration activity.
8. Continue to monitor the restoration of Wilson Creek by incorporating the three sample locations into the five year rotating basin cycle. If resources are available, sample all three periods (spring, summer and fall). If resources are limited, recommend sampling macroinvertebrates and fish during the spring and algae during the summer.
9. Continue to encourage natural channel design into stream restoration projects.
10. Future monitoring of restorations would benefit from a quantitative habitat assessment.

ACKNOWLEDGEMENTS

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Table 1. Station locations for sampling sites in the Wilson Creek Watershed, Nelson/Bullitt Counties, Kentucky, USA, Ecoregion 71c.

StationID	Location	River Mile	Order	Catchment	Latitude	Longitude
DOW12034007	0.3 MILES ABOVE HARRISON FORK CONFLUENCE - old channel	14.5	3	5.9	37.87282	-85.59819
DOW12034008	0.1 MILES BELOW HARRISON FORK CONFLUENCE-Low Site	14.1	3	9.6	37.86995	-85.60231
DOW12034009	0.69 MILES ABOVE HARRISON FORK CONFLUENCE-upper site	14.9	3	5.1	37.87605	-85.59256
DOW12034010	New Channel 0.3 mi above Harrison Fork Confluence	14.5	3	5.9	37.87284	-85.59884

Table 2. Criteria for KIBI, MBI and DBI ratings for Kentucky Ecoregion 71(c).

Score	KIBI	MBI Headwater	MBI Wadeable	DBI
Excellent	67	72	81	67
Good	53	63	72	55
Fair	35	41	49	50
Poor	17	20	25	<50
Very Poor	<17	<20	<25	

Table 3. Habitat rating scores for Kentucky Ecoregion 71(c).

Score	Headwater	Wadeable
Full Support	155	145
Supporting but Threatened	145	131
Partially Supporting	138	105
Not Supporting	<137	<104

Table 4. Number collected, mean total length (mm) and standard deviation of fish collected at the upper site (DOW12034009) in the Wilson Creek Watershed, Nelson/Bullitt Counties, Kentucky, USA.

FFinalID	7/17/2003	9/11/2003	3/23/2004	7/15/2004	9/10/2004	4/4/2005	3/28/2006
Ambloplites rupestris			1(70)0	5(120)17.8	2(133)12	1(160)0	1(182)0
Ameiurus natalis							
Campostoma anomalum	67(48)23.7	17(77)21.5	21(70)15.5	106(48)23.5	88(71)85.8	58(68)23.5	68(72)24.5
Catostomus commersonii	7(120)39.7	6(103)40.4	1(85)0	6(124)7.5	7(135)17.7	1(118)0	1(85)0
Cottus carolinae	30(47)4.1	39(52)5.2	48(86)13	24(69)28.1	44(58)13.4	20(96)11.3	11(86)22
Esox americanus							
Etheostoma blennioides					1(62)0	2(70)10.6	
Etheostoma caeruleum	10(51)5.4	11(53)6	26(56)4.4	11(55)7.6	8(52)8.7		23(41)6.7
Etheostoma flabellare	35(48)8.5	16(49)9	10(52)10.8	37(53)9.1	28(51)10.2	23(55)12	8(53)8.5
Etheostoma lawrencei	45(48)4.7	39(48)5.5	15(55)6.3	27(52)5.1	18(50)8.7	10(51)7.3	13(48)5.6
Etheostoma nigrum	2(47)0.7	1(48)0	1(52)0	2(141)9.2		1(52)0	2(144)25.5
Etheostoma zonale							
Fundulus notatus							
Hypentelium nigricans	1(42)0	3(115)83.7	2(176)132.9		2(176)19.8	9(197)62.7	
Lepomis cyanellus	3(83)17.2	1(110)0	1(116)0	3(89)11.4	2(74)34.6	5(122)22.9	1(73)0
Lepomis macrochirus	7(51)15.9	4(50)10		4(61)16.4	18(90)23.6	1(145)0	1(98)0
Lepomis megalotis	1(50)0		2(54)0	1(104)0	4(106)2.2	2(121)7.1	1(128)0
Luxilus chrysocephalus	18(68)14.8	28(72)16.9		29(92)14.7	18(97)10.8	6(121)15.2	19(76)29.3
Lythrurus fasciolaris	1(55)0	5(33)3.4	4(68)8.5		19(30)3		14(64)11.5
Micropterus punctulatus	2(63)0.7						
Micropterus salmoides				2(69)0.7			2(157)40.3
Moxostoma duquesnei							1(72)0
Moxostoma erythrurum							
Notropis buccatus							
Phoxinus erythrogaster	10(47)4.1		4(63)2.4				
Pimephales notatus	6(62)15.9	16(48)20.1	21(56)12.5	11(57)10.9	19(66)9.1	6(82)8.9	17(53)15.8
Semotilus atromaculatus	54(89)42.1	95(88)36.1	33(87)41.1	57(106)38.3	101(125)38.2	37(121)32.9	33(93)32.4

Table 5. Number collected, mean total length (mm) and standard deviation of fish collected at the middle site (DOW12034007 and DOW12034010) in the Wilson Creek Watershed, Nelson/Bullitt Counties, Kentucky, USA.

FFinalID	7/16/2003	9/10/2003	3/23/2004	7/15/2004	9/10/2004	4/4/2005	3/28/2006
Ambloplites rupestris	12(113)55.7	5(75)7.8			2(101)31.8		1(180)0
Ameiurus natalis		1(120)0					
Campostoma anomalum	7(35)2.1	5(70)14.9	24(65)12.1	123(54)22.4	130(49)16.1	30(100)30.5	96(62)21
Catostomus commersonii	1(203)0	3(70)13.4		3(106)43	6(149)41.2		
Cottus carolinae	22(43)3.7	21(60)23.6	24(88)11.9	66(45)8.1	12(56)12.6	16(87)12.7	5(89)14.3
Esox americanus							
Etheostoma blennioides	3(71)2.6	1(97)0	1(53)0	7(46)11	1(46)0		
Etheostoma caeruleum	26(48)5.3	14(52)6.1	15(56)6.7	30(41)11.3	25(40)4.4	33(52)8.9	46(45)8.1
Etheostoma flabellare	28(49)4.5	29(46)8.1	2(61)9.2	36(35)7.9	27(40)8.3	35(48)9.4	21(48)11.4
Etheostoma lawrencei	4(45)6.9	6(51)2.7	10(58)5.3	3(58)4	8(41)11.4	9(53)9.1	34(42)6.8
Etheostoma nigrum		3(40)7.6	1(50)0		1(50)0		1(41)0
Etheostoma zonale							
Fundulus notatus	1(58)0	2(43)16.3					
Hypentelium nigricans	1(201)0	2(79)4.9	2(129)89.1	3(137)8.5	2(125)62.9	1(202)0	3(173)96.5
Lepomis cyanellus	37(68)28.3	1(51)0					4(70)21.1
Lepomis macrochirus	22(91)32.8	29(49)6.8		1(50)0	2(77)17		1(34)0
Lepomis megalotis		42(60)11.9		1(65)0	2(90)6.4		2(78)11.3
Luxilus chrysocephalus	1(67)0	4(77)1.7	15(93)13.9	1(115)0	6(112)13.2	6(104)15.9	41(72)35.9
Lythrurus fasciolaris	60(53)7		4(73)10	14(66)5.9	14(69)8.3	2(76)1.4	10(60)11.4
Micropterus punctulatus	3(88)57	2(88)5.7					
Micropterus salmoides				3(67)27.5	4(114)31.5		
Moxostoma duquesnei						1(138)0	
Moxostoma erythrurum							
Notropis buccatus			3(64)16.4	1(69)0			
Phoxinus erythrogaster							
Pimephales notatus	4(44)4.3	17(55)6.5	6(57)14.4	10(65)12.1	19(47)20.4		54(44)12.4
Semotilus atromaculatus		11(93)8.6	9(88)41.2	21(85)41	37(85)34.9	8(144)38.2	25(85)37.9

Table 6. Number collected; mean total length (mm) and standard deviation of fish collected at the lower site (DOW12034008) in the Wilson Creek Watershed, Nelson/Bullitt Counties, Kentucky, USA.

FFinalID	7/17/2003	9/10/2003	3/23/2004	7/15/2004	9/15/2004	4/4/2005	3/29/2006
Ambloplites rupestris	9(161)40.1	10(156)37.2	14(167)37.1	18(141)42.2	5(152)40.5	2(147)33.9	12(159)21.1
Ameiurus natalis			3(192)14.8		1(127)0	1(173)0	
Campostoma anomalum	1(28)0		4(146)41.8	3(48)18.2	1(51)0	7(58)19.8	
Catostomus commersonii	5(180)79.5	3(242)15.1	13(250)26	6(243)39.9	2(249)29.7	22(266)33.3	
Cottus carolinae	17(36)3.2	24(44)6.1	35(76)11.6	10(46)26.6	7(64)29	17(78)16.1	3(73)24.6
Esox americanus	3(238)3.5	1(242)0		4(274)8.8	1(250)0		
Etheostoma blennioides	1(26)0	1(50)0	1(55)0				
Etheostoma caeruleum	24(44)4.8	32(48)4.9	21(47)4.5	11(50)6.3	9(45)9.7	7(44)6.2	19(40)7.2
Etheostoma flabellare	17(41)9.9	33(42)7.8	15(53)9.8	12(42)9.9	10(48)4.4	20(50)11.4	18(52)10.5
Etheostoma lawrencei			6(49)5.6			1(54)0	2(50)0
Etheostoma nigrum	1(40)0	2(44)10.6	10(41)4.1		2(43)3.5	3(44)1.7	
Etheostoma zonale			1(40)0				
Fundulus notatus		1(29)0					1(61)0
Hypentelium nigricans	10(220)72.4	6(258)23.7		2(228)48.1	1(265)0	2(132)26.2	
Lepomis cyanellus	2(102)50.9	1(125)0		1(73)0	5(52)14	10(62)8	16(72)15
Lepomis macrochirus	20(99)32.4	16(70)47.1	19(119)38.1	3(98)16.8	9(80)27.6	12(94)27.6	16(96)39.1
Lepomis megalotis	24(95)27.4	28(111)32.1	40(111)31.1	23(107)27.3	22(108)28.2	34(99)33.5	26(111)15.9
Luxilus chrysocephalus			2(157)4.9		1(139)0	2(186)43.1	1(198)0
Lythrurus fasciolaris	35(52)10.9	12(27)3.2		20(48)12.9	8(52)14.9		
Micropterus punctulatus	3(244)34.2	2(242)33.2	8(186)44.3	1(237)0	1(284)0	6(196)67.3	2(249)68.6
Micropterus salmoides			1(250)0	1(43)0	1(255)0	3(188)100.2	2(282)40.3
Moxostoma duquesnei	1(276)0		3(202)67		1(254)0	9(237)49.1	1(297)0
Moxostoma erythrurum					1(191)0		
Notropis buccatus							
Phoxinus erythrogaster							
Pimephales notatus	2(46)0.7	1(32)0	1(85)0	1(58)0	6(32)3.8		2(35)4.9
Semotilus atromaculatus	1(64)0		1(227)0			3(194)67.9	

Table 7. Raw and calculated KIBI metrics at three sampling locations (upper, middle and lower) in the Wilson Creek Watershed, Nelson/Bullitt Counties, Kentucky, USA.

			Raw Metric Values							Calculated Metric Scores							
SiteID	CollDate	TNI	NAT	DMS	INT	SL	%INSCT	%TOL	%FHW	NAT	DMS	INT	SL	%INSCT	%TOL	%FHW	KIBI
DOW12034007	7/16/2003	232	16	5	1	5	72.0	18.5	64.7	86.0	79.8	41.2	68.8	96.5	95.1	6.9	65
DOW12034007	9/10/2003	198	19	6	1	5	60.6	33.3	56.6	96.7	90.5	41.2	68.8	83.6	80.6	20.1	64
DOW12034010	3/23/2004	112	13	6	1	4	50.9	29.5	46.4	75.4	90.5	41.2	60.8	72.5	84.4	36.6	64
DOW12034010	7/15/2004	323	16	5	1	5	49.5	12.4	49.8	86.0	79.8	41.2	68.8	71.0	100.0	31.0	65
DOW12034010	9/10/2004	308	17	6	1	5	29.9	27.3	58.8	89.6	90.5	41.2	68.8	48.6	86.5	16.5	59
DOW12034010	4/4/2005	140	11	4	2	4	69.3	10.7	27.1	68.3	69.0	54.2	60.8	93.4	100.0	68.0	74
DOW12034010	3/28/2006	344	15	5	1	3	35.5	36.3	61.0	82.5	79.8	41.2	52.8	54.9	77.6	12.8	53
DOW12034008	7/17/2003	177	18	5	2	5	73.4	17.5	58.2	85.5	73.0	46.9	61.4	91.7	91.6	32.4	75
DOW12034008	9/10/2003	174	17	5	2	5	80.5	12.1	43.7	82.0	73.0	46.9	61.4	99.7	97.0	56.0	77
DOW12034008	3/23/2004	199	19	7	2	6	66.8	20.1	53.8	89.1	94.5	46.9	69.4	84.2	89.1	39.6	79
DOW12034008	7/15/2004	116	15	3	1	3	67.2	10.3	64.7	74.9	51.5	33.9	45.4	84.6	98.7	21.9	65
DOW12034008	9/15/2004	94	20	4	2	6	64.9	26.6	69.1	92.6	62.3	46.9	69.4	50.0	50.0	14.6	62
DOW12034008	4/4/2005	161	18	5	2	5	57.8	32.9	55.3	85.5	73.0	46.9	61.4	73.9	76.4	37.1	70
DOW12034008	3/29/2006	122	15	4	2	4	57.4	31.1	64.8	74.9	62.3	46.9	53.4	73.4	78.2	21.7	65
DOW12034009	7/17/2003	299	17	5	2	5	41.8	31.8	35.8	91.8	81.8	56.4	71.1	64.3	83.6	49.2	68
DOW12034009	9/11/2003	281	14	5	1	4	40.6	53.4	25.6	81.2	81.8	43.4	63.1	62.9	62.3	65.7	63
DOW12034009	3/23/2004	196	16	5	2	5	55.1	31.6	29.1	88.3	81.8	56.4	71.1	79.4	83.7	60.1	72
DOW12034009	7/15/2004	324	15	4	1	4	31.5	34.3	49.4	84.7	71.0	43.4	63.1	52.5	81.1	27.0	56
DOW12034009	9/10/2004	379	16	5	1	5	32.7	43.5	45.1	88.3	81.8	43.4	71.1	53.9	72.0	34.0	59
DOW12034009	4/4/2005	203	16	6	1	5	42.4	28.6	41.4	88.3	92.5	43.4	71.1	64.9	86.7	40.1	66
DOW12034009	3/28/2006	216	17	4	2	5	33.8	34.3	57.9	91.8	71.0	56.4	71.1	55.2	81.1	13.2	58

Table 8. Raw and calculated MBI metrics at the upper and middle sampling locations in the Wilson Creek Watershed, Nelson/Bullitt Counties, Kentucky, USA.

		Raw Metric							Calculated Metrics							
StationID	CollDate	TR	EPT	mHBI	m%EPT	%Ephem	%C+O	%ClngP	TR	EPT	HBI2	m%EPT	%Ephem	%C+O	%ClngP	MBI
DOW12034009	7/17/2003	25	9	5.2	37.2	25.3	5.8	68.6	49.0	33.3	60.8	42.8	38.0	94.8	90.9	59
DOW12034009	9/11/2003	27	11	4.7	54.2	16.0	7.8	78.1	52.9	40.7	67.8	62.4	24.0	92.8	103.4	63
DOW12034009	3/23/2004	35	16	4.3	60.1	15.0	6.1	51.2	68.6	59.3	72.6	69.2	22.6	94.5	67.9	65
DOW12034009	7/19/2004	19	8	4.4	44.9	23.3	5.2	74.8	37.3	29.6	71.0	51.7	35.0	95.4	99.0	60
DOW12034009	9/10/2004	13	7	4.5	49.7	1.9	10.4	96.4	25.5	25.9	70.1	57.2	2.9	90.2	127.7	57
DOW12034009	3/22/2005	33	18	4.2	38.8	7.9	15.8	69.7	64.7	66.7	74.7	44.7	11.9	84.8	92.4	63
DOW12034009	3/28/2006	31	15	3.3	59.5	7.3	13.9	53.3	60.8	55.6	85.5	68.5	11.0	86.7	70.6	63
DOW12034007	7/17/2003	27	8	5.2	53.2	31.1	11.0	59.2	52.9	29.6	60.8	61.2	46.8	89.6	78.4	60
DOW12034007	9/10/2003	24	9	4.8	46.3	34.9	14.4	64.8	47.1	33.3	65.9	53.3	52.5	86.2	85.8	61
DOW12034010	3/23/2004	28	14	3.8	62.4	8.9	7.0	46.5	54.9	51.9	79.6	71.8	13.3	93.6	61.6	61
DOW12034010	7/19/2004	21	10	5.3	63.7	57.4	5.6	39.9	41.2	37.0	60.4	73.3	86.4	95.0	52.9	64
DOW12034010	9/10/2004	23	8	5.0	26.3	21.0	6.9	74.4	45.1	29.6	63.6	30.3	31.6	93.8	98.6	56
DOW12034010	3/22/2005	36	15	4.9	43.1	20.4	39.4	23.8	70.6	55.6	64.9	49.6	30.7	61.0	31.5	52
DOW12034010	3/28/2006	33	13	4.3	68.6	27.6	8.8	33.9	64.7	48.1	72.9	79.0	41.5	91.8	44.9	63

Table 9. Raw and calculated MBI metrics at the lower sampling locations in the Wilson Creek Watershed, Nelson/Bullitt Counties, Kentucky, USA.

		Raw Metric						Calculated Metrics						
StationID	CollDate	TR	EPT	mHBI	m%EPT	%C+O	%ClngP	TR	EPT	HBI2	m%EPT	%CO	%ClngP	MBI
DOW12034008	7/17/2003	25	9	5.0	50.6	7.4	60.1	41.0	40.9	72.1	69.3	93.5	81.2	66
DOW12034008	9/10/2003	22	10	4.9	42.2	7.1	84.7	36.1	45.5	73.5	57.8	93.8	114.5	70
DOW12034008	3/23/2004	29	9	3.8	28.8	7.3	72.6	47.5	40.9	89.5	39.5	93.6	98.1	68
DOW12034008	7/19/2004	23	12	4.4	38.7	1.0	74.4	37.7	54.5	81.4	53.0	100.0	100.6	71
DOW12034008	9/15/2004	23	7	4.5	53.3	4.9	90.8	37.7	31.8	79.8	73.0	96.1	122.8	74
DOW12034008	3/22/2005	23	14	3.8	54.1	7.6	59.2	37.7	63.6	89.3	74.2	93.3	80.0	73
DOW12034008	3/29/2006	33	15	3.7	51.0	13.5	56.1	54.1	68.2	91.8	69.9	87.4	75.8	75

Table 10. Raw and calculated DBI metrics at three sampling locations (upper, middle and lower) in the Wilson Creek Watershed, Nelson/Bullitt Counties, Kentucky, USA.

		Raw Metrics						Calculated Metrics						
StationID	CollDate	TR	PTI	Diversity	%NavNitSur	FGR	CGR	TR	PTI	Diversity	%NavNitSur	FGR	CGR	DBI
DOW12034007	7/16/2003	59	2.9	1.0	17.6	4	8	57.8	84.4	70.4	84.6	50.0	61.5	68
DOW12034007	9/10/2003	94	2.7	1.3	30.8	5	10	92.2	78.4	88.1	71.0	62.5	76.9	78
DOW12034008	7/16/2003	103	3.0	1.1	18.5	5	10	100.0	87.5	76.4	83.7	62.5	76.9	81
DOW12034008	9/10/2003	92	2.7	1.2	30.6	4	11	90.2	78.1	81.9	71.2	50.0	84.6	76
DOW12034008	3/23/2004	66	3.0	0.9	18.6	5	9	64.7	87.8	61.9	83.6	62.5	69.2	72
DOW12034008	7/19/2004	101	3.2	1.0	17.2	5	10	99.0	91.4	69.5	85.0	62.5	76.9	81
DOW12034008	9/15/2004	105	3.0	1.5	29.0	4	12	100.0	85.8	100.0	72.9	50.0	92.3	84
DOW12034008	3/22/2005	66	2.8	1.0	39.8	3	8	64.7	80.8	68.9	61.8	37.5	61.5	63
DOW12034008	3/29/2006	67	3.1	0.7	12.2	5	9	65.7	90.5	51.5	90.1	62.5	69.2	72
DOW12034009	7/16/2003	79	2.7	1.1	22.2	4	8	77.5	77.9	77.0	79.9	50.0	61.5	71
DOW12034009	9/11/2003	75	2.6	1.1	35.8	3	8	73.5	74.4	77.5	65.9	37.5	61.5	65
DOW12034009	3/23/2004	58	2.9	0.8	18.6	5	8	56.9	83.1	56.7	83.6	62.5	61.5	67
DOW12034009	7/19/2004	87	2.9	0.9	25.6	2	9	85.3	82.8	66.3	76.4	25.0	69.2	67
DOW12034009	9/10/2004	96	2.8	1.1	26.0	4	11	94.1	82.2	73.8	76.0	50.0	84.6	77
DOW12034009	3/22/2005	64	2.7	1.3	50.2	4	5	62.7	76.9	88.3	51.1	50.0	38.5	61
DOW12034009	3/28/2006	67	2.8	0.9	20.6	6	7	65.7	82.0	65.2	81.5	75.0	53.8	71
DOW12034010	3/23/2004	57	2.9	1.0	26.4	5	9	55.9	82.8	69.4	75.6	62.5	69.2	69
DOW12034010	7/19/2004	80	3.3	0.8	12.6	4	11	78.4	94.7	53.5	89.7	50.0	84.6	75
DOW12034010	9/10/2004	84	2.5	1.2	49.2	2	11	82.4	72.3	81.3	52.2	25.0	84.6	66
DOW12034010	3/22/2005	63	2.5	1.2	52.8	4	8	61.8	72.9	83.4	48.5	50.0	61.5	63
DOW12034010	3/28/2006	53	3.0	0.8	17.4	4	7	52.0	85.6	58.4	84.8	50.0	53.8	64

Table 11. Raw and calculated habitat metrics at three sampling locations (upper, middle and lower) in the Wilson Creek Watershed, Nelson/Bullitt Counties, Kentucky, USA.

StationID	CollDate	Bank StaLB	Bank StaRB	BankVeg P-LB	BankVeg P-RB	Cha FlowS	Chan Alter	Embedd	EpiFau Sub	Freq Of Riffles	RipVeg ZW-LB	RipVeg ZW-RB	SedDep	Vel/Dep Regime	Habitat
DOW12034007	7/16/2003	8	9	9	9	14	13	16	12	6	10	5	12	13	136
DOW12034007	9/10/2003	8	7	10	7	15	13	7	6	10	10	1	8	12	114
DOW12034008	7/16/2003	7	8	8	9	16	14	14	11	5	4	3	9	12	120
DOW12034008	9/10/2003	3	5	2	3	16	15	15	13	8	4	3	10	13	110
DOW12034008	3/23/2004	7	7	5	5	15	13	12	12	8	5	3	12	16	120
DOW12034008	7/15/2004	6	8	6	7	18	15	16	11	10	3	4	12	13	129
DOW12034008	9/15/2004	5	8	5	8	13	15	14	15	12	3	4	10	12	124
DOW12034008	4/4/2005	4	4	2	2	17	15	14	13	13	2	4	12	14	116
DOW12034008	3/29/2006	5	7	6	7	18	13	11	15	8	4	3	12	13	122
DOW12034009	7/16/2003	9	9	9	8	14	18	13	12	16	10	8	10	17	153
DOW12034009	9/11/2003	9	9	9	9	11	19	16	13	17	10	5	10	16	153
DOW12034009	3/23/2004	8	8	6	6	14	15	14	15	16	10	5	13	16	146
DOW12034009	7/15/2004	8	8	8	8	16	15	16	16	15	10	3	11	16	150
DOW12034009	9/10/2004	9	9	8	8	12	13	16	17	15	10	4	15	16	152
DOW12034009	4/4/2005	7	6	7	6	16	13	15	17	14	10	2	13	17	143
DOW12034009	3/28/2006	8	8	7	7	13	13	11	15	15	10	4	11	18	140
DOW12034010	3/23/2004	8	10	1	0	20	16	13	11	19	8	0	16	15	137
DOW12034010	7/19/2004	8	10	5	5	16	16	16	10	17	8	1	16	16	144
DOW12034010	9/10/2004	8	9	3	3	16	16	13	10	18	5	3	10	12	126
DOW12034010	4/4/2005	7	7	5	5	17	16	12	11	16	8	2	14	10	130
DOW12034010	3/28/2006	7	8	6	8	18	16	14	12	17	9	5	14	16	150

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Appendix G

Fish, Aquatic Macroinvertebrate Communities, and Leaf Litter Breakdown Studies

by

Jeff Jack

(University of Louisville)

Summary of Research at Wilson Creek Restoration Project: Assessment of Fish, Aquatic Macroinvertebrate Communities and Leaf Litter Breakdown

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Introduction

Stream restorations are often justified based on expected improvements in habitat or biodiversity but few restorations are systematically studied to assess their "success". A channelized section of Wilson Creek (Kentucky, USA) was relocated to a new, meandering channel using a natural channel design approach. Fish, aquatic macroinvertebrate communities and leaf litter breakdown were sampled for one year before and two years after the relocation and compared to an upstream, unrestored site in Wilson and to two control streams in nearby watersheds (reference sites).

Methods

Before relocation, fish riffle and pool and riffle invertebrate samples were taken in Wilson Creek upstream of the restoration site, at the restored reach and in Long Lick. Sampling was repeated in March 2004 and in April 2006 with an additional reference site at Harts Run. Macroinvertebrate samples were sorted and identified to genus for most insects, Chironomidae were left at the family level, and non-insects were identified to the ordinal level or higher. Species richness, EPT Richness, %EPT, a modified Hilsenhoff Biotic Index, and the Kentucky Macroinvetebrate Bioassessment Index (KMBI) were calculated for each site. The KMBI is a multimetric index averaging scores from six metrics (Taxa Richness, EPT Richness, EPT abundance, Modified Hilsenhoff Index, %Chironomids and Oligochaetes, and %Clingers) to assess ecological integrity. Fish were collected using Kentucky Division of Water (KDOW) methods and identified in the field. KDOW fish IBIs were calculated for all samples.

To assess ecological function in the stream, we used a leaf litter breakdown assay. American sycamore (*Platanus occidentalis* L.) leaf litter bags were placed along riffles in the restored reach, in an upstream reference site and in two reference streams. Bags were collected for nine months, and mass loss, C:N dynamics and the fungal sterol ergosterol were measured.

Results

Invertebrate metrics generally increased at all sites from 2002-2006 (Fig. 1.) Invertebrate densities increased greatly in the restoration and in Wilson Creek upstream of the restoration, but decreased in Long Lick from 2002-2006. Estimated areal densities were much higher in the restored section than in most other studied reaches. In 2006, EPT relative abundances increased at all sites and KMBI scores increased in the restored section of Wilson Creek and Long Lick, but decreased 1 point in the upstream section of Wilson Creek. The restored section of Wilson Creek, upstream reference site, and Long Lick all had similar 2006 KMBI scores, but were ≈10 points lower than scores from Hart’s Run.

Wilson Creek fish communities were always more diverse than either of the control streams. Kentucky Fish Index of Biotic Integrity (IBI) scores in Wilson were Excellent for the pre-restoration fish community. Despite the extensive disturbance associated with the relocation, the Wilson Creek fish community rapidly colonized the new channel (new R9 and R1sites; Figure 2). The R9 site had more species than any other site, as well as a number of taxa only found in that location, such as topminnows, and high densities of largemouth bass. This may be due to its close connection with a large constructed backwater, which is providing habitat that was not present in the original channelized stream. The IBI scores were high for all sites and in the “Excellent” category for Wilson Up and R9 so the disturbance associated with channel construction has not had any obvious negative effects on the fish community to date. Based on the results of the egg surveys and field observations, fish are using the restoration sites for spawning. Preliminary data from 2005 spring spawning surveys indicate that egg densities and egg mass numbers are an order of magnitude higher in the restoration section than in the reference streams. This may be linked to a broader range of substrate particle sizes available in the restoration area compared to the reference streams or the old bedrock channel. These preliminary results suggest that fish may rapidly colonize restored stream reaches and that habitat enhancements designed into restorations can in some cases provide a rapid and positive response from the fish community. Several new species have been seen in the restoration area which were not previously collected in this part of Wilson Creek including golden redhorse (*Moxosotma erythrurum*), smallmouth bass (*Micropterus dolomieu)*,yellow bullhead catfish *(Ameiurus natalis)*, and red belly dace (*Phoxinus erythrogaster*).

For the litter assay, both the Wilson Creek restoration and reference sites showed similar mass loss rates with 1.15% and 1.17% of litter lost per day respectively. The two reference streams varied considerably over time when seen in comparison, where Harts Run lost 0.59% of litter per day and Long Lick Creek lost 0.4% of litter per day (Fig 3). All four sites showed a marked decrease in molar C:N over the first month, then showed a slower decrease over the course of the next eight months (Fig 4.). Over the course of the project ergosterol, a marker for fungal colonization, increased with a sharp increase in colonization in most sites the spring of 2004 (Fig. 5).

Conclusions

The restored reach of Wilson Creek was recolonized rapidly by macroinvertebrates and biometric scores were comparable to high quality reference reaches soon after the restoration was complete. The enhancement of riffle habitat in the restoration has greatly enhanced the biomass and total numbers of macroinvertebrates in the restored reach compared to reaches of equivalent size in the Wilson upstream and in the reference streams. Invertebrate riffle biodiversity still has not attained the values determined for the upstream section of Wilson Creek, but this difference may lessen over time as colonization continues. The response of the fish community to the restoration was also rapid and positive. After a large habitat reconstruction project, expectations were that the disturbance would initially inhibit fish re-colonization. The opposite was found in that the newly heterogeneous environment that was created from the old bed rock channel provided for increased community complexity. The leaf litter assay indicated that this, and presumably other, ecological functions returned rapidly to pre-restoration levels and in some instances were enhanced by the restoration.

The enhancement of habitat in streams through techniques such as natural channel design can be effective in enhancing the ecological integrity and function of even high quality waters. More restorations should be monitored so that "lessons learned" can be incorporated into future projects.

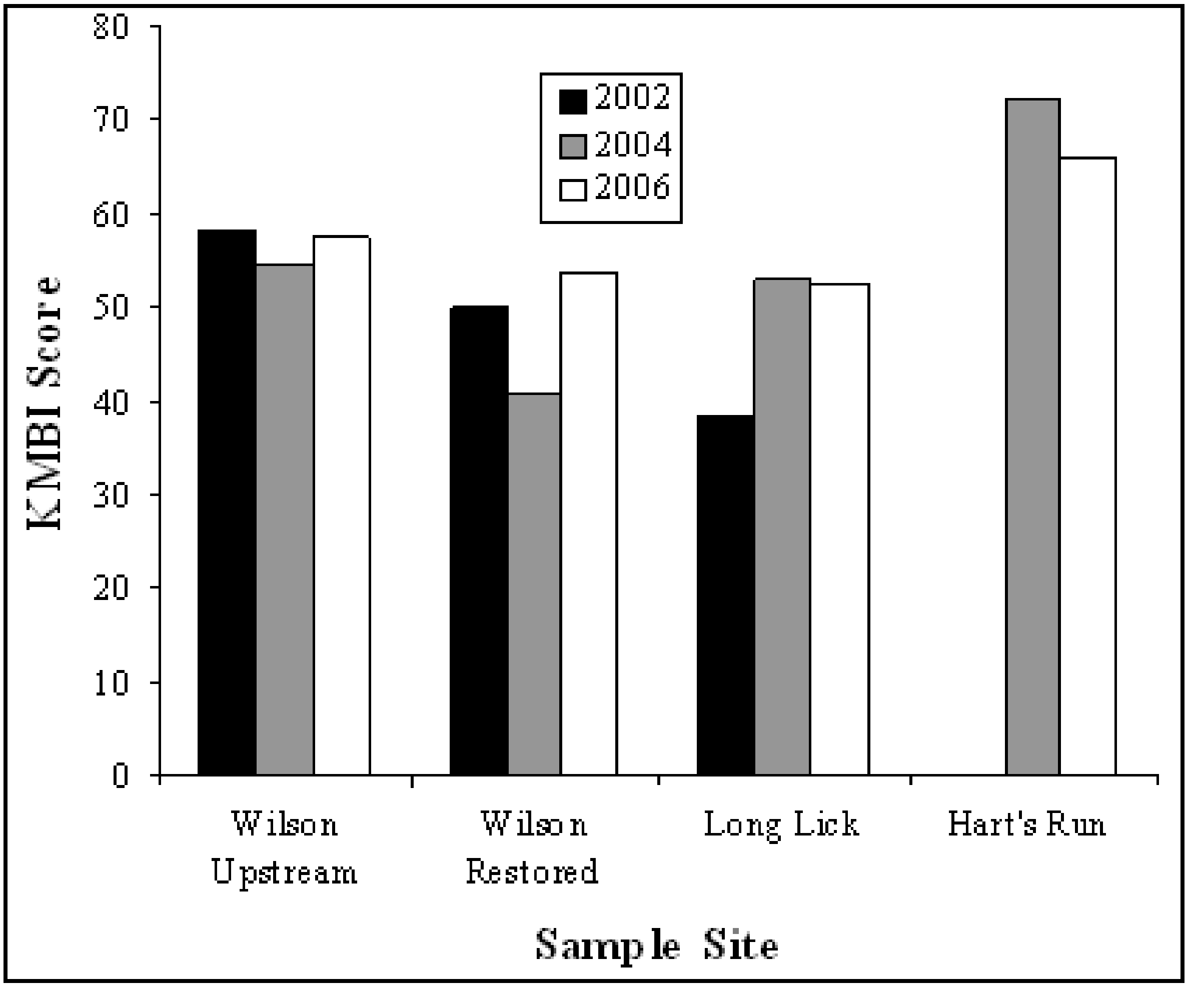


Figure 1. KMBI scores for the restored reach of Wilson Creek and the three reference sites

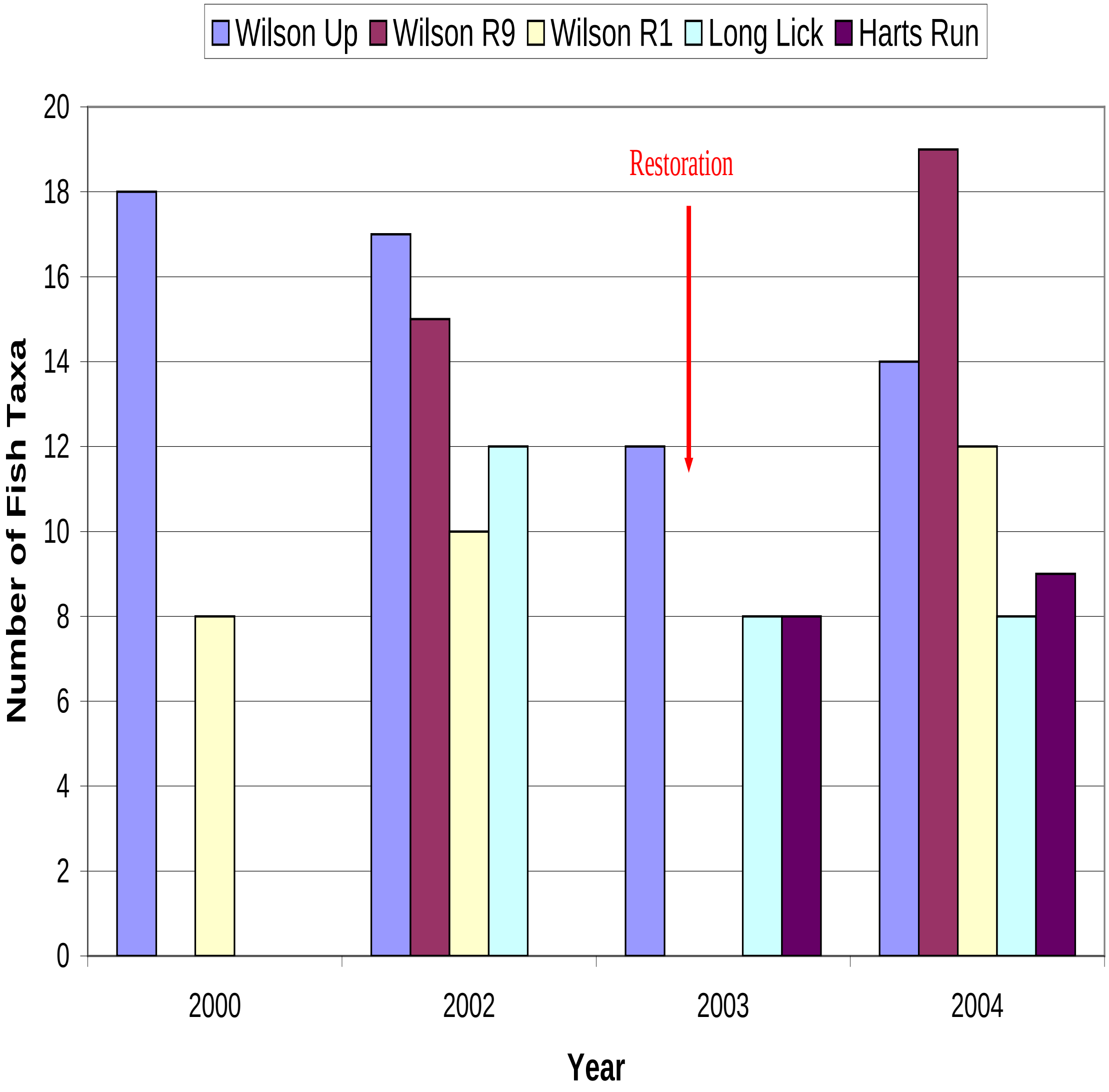
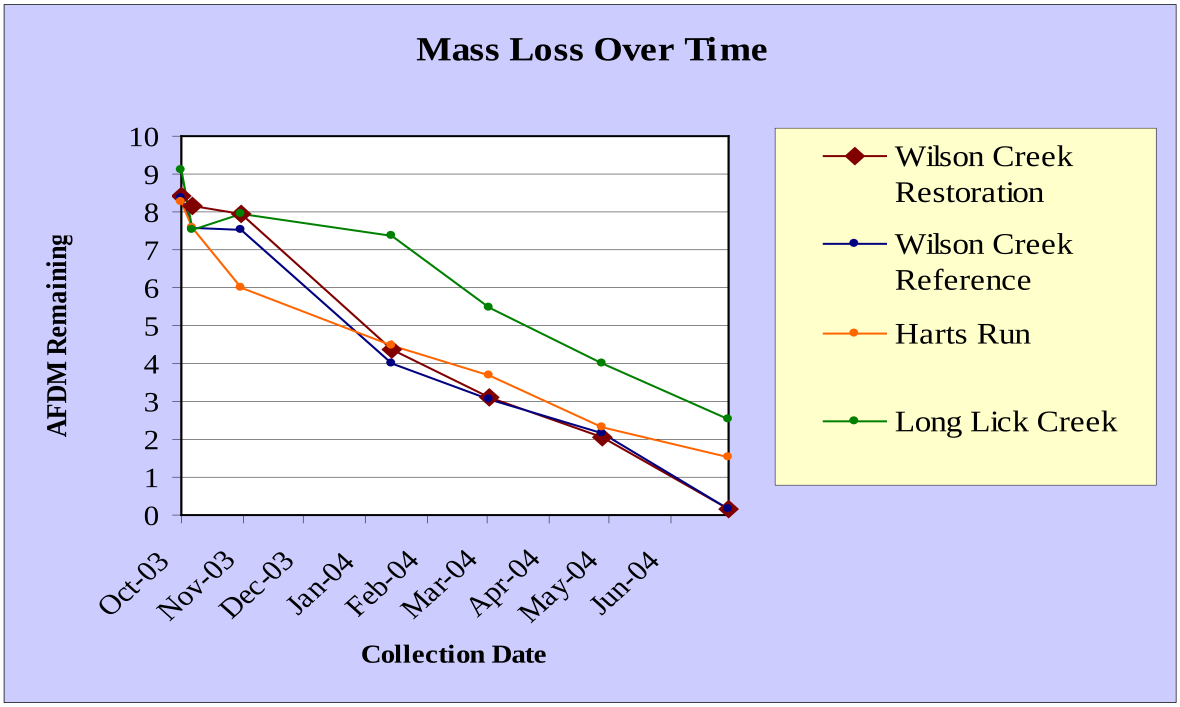


Figure 2. Fish IBI score in Wilson Creek and reference sites, pre- and post restoration.



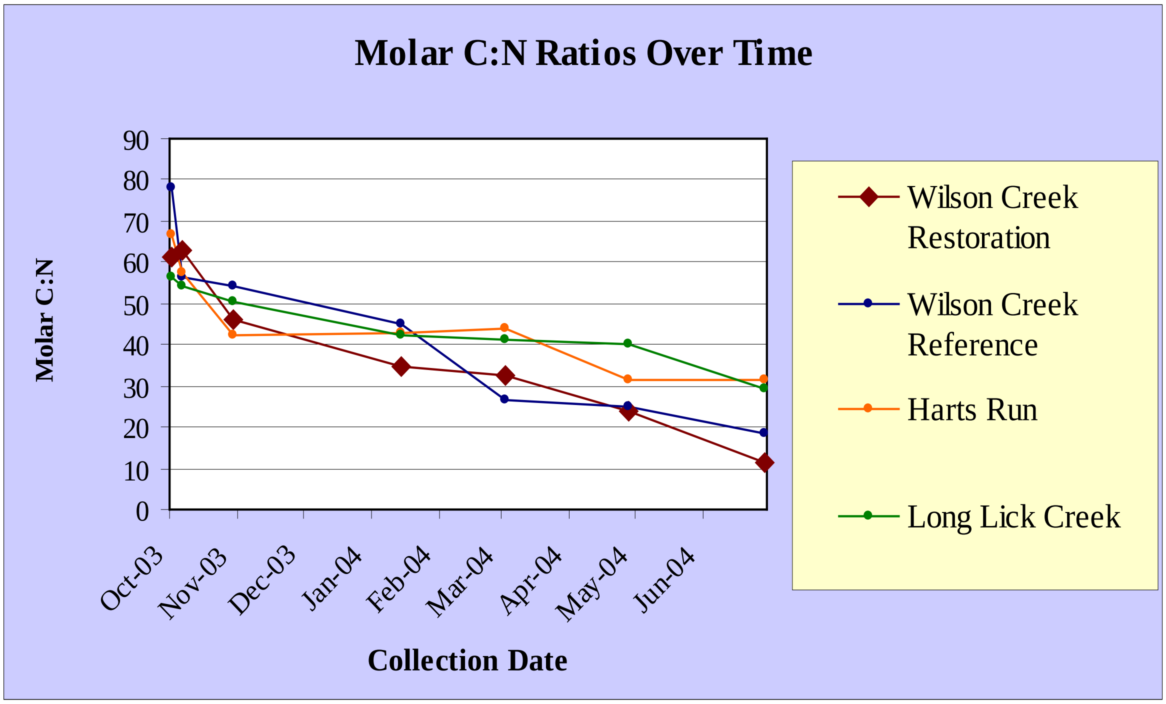


Figure 4. Molar C:N ratios of leaf litter

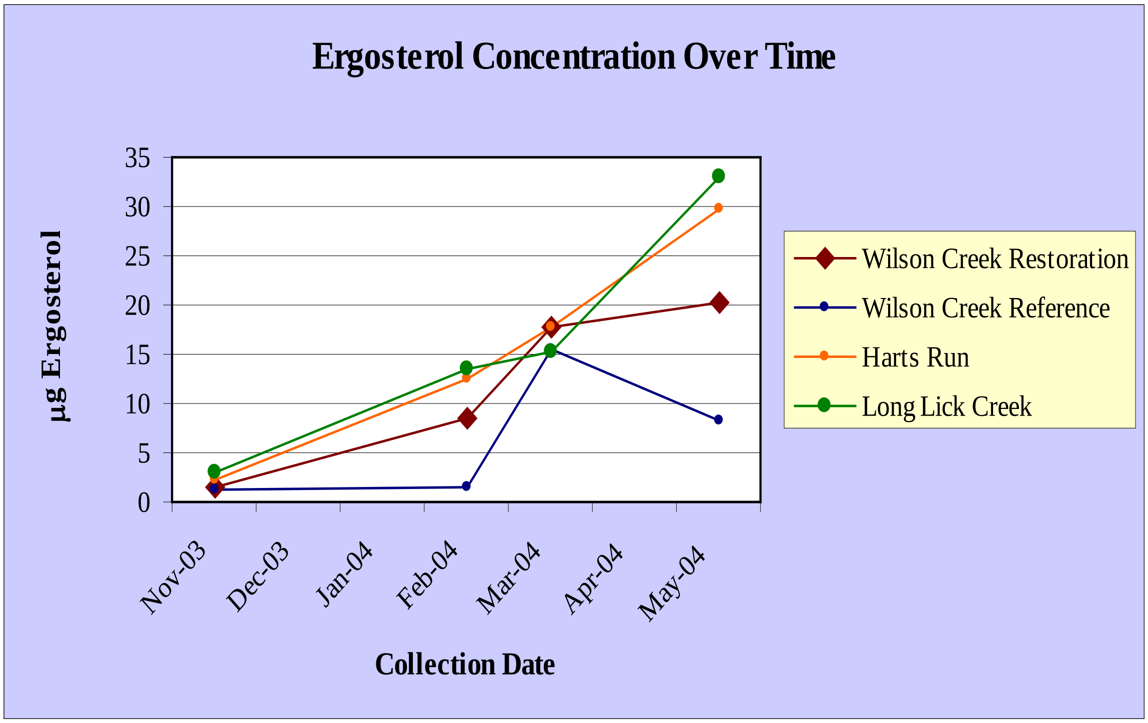


Figure 5. Ergosterol concentrations in leaf litter

Appendix H

Vegetation Photo-Monitoring

Vegetation Photo Monitoring of Wilson Creek (CD)
Photo Documentation of Channel Restoration (CD)
Vegetation Photo Monitoring (Raw photo file) (CD)

Appendix I

Educational Outputs

Listing of Educational Programs and Attendance
Educational Brochure
Workshop Announcement
Workshop Agenda
Visitor Center Computer Flash (on a CD)
Visitor Center Graphic Panels (on CD)

Listing of Educational Programs and Attendance
Wilson Creek Stream Restoration
2003-2007

Type: **Teacher Training**
Date: 7/23/03
Number of Participants: 27
Comments: Used ecological restoration, in the context of the Wilson Creek project, to illustrate "change over time". This was the theme for a 5-day seminar designed for teachers of visually impaired students. Bernheim presented for 1 day in the week long course. The day included a primer on ecological restoration, a site tour, a demonstration of educational activities suitable for visually impaired children. Core concepts included stream restoration and its benefits for plant and animal habitat and reduction of non-point source pollutants.

Type: **Visiting Group (Adult)**
Date: 10/04/03
Group: Tibetan Drepung Gomang Monks and their hosts.
Number of participants: 18
Comments: Following a public program at the site of the new Visitor Center the visiting monks were taken to the stream restoration site. They received a program on the project (translated by their official translator) and the group did a blessing ceremony of the site which was video taped and photographed.

Type: **Half-Day (College)**
Date: 10/9/03
Number of Participants: 11
Comments: University of Louisville Students enrolled in stream ecology (Biology 524 & 624), taught by Dr. Jeff Jack, visited the Wilson Creek stream restoration. Students discussed changes in stream position in the valley in the past and the advantages of reconnecting the stream with the floodplain.

Type: **Half-Day (Private Landowner)**
Date: 10/23/03
Number of Participants: 15
Comments: Landowners neighboring Bernheim Arboretum and Research Forest were given a tour of the Wilson Creek stream restoration site shortly (less than 1 week) after flow was introduced to the entirety of the channel. We discussed the long-term benefits stream restoration for water quality and aquatic wildlife habitat. During site tour we discussed channelized stream reaches relating to water quality and channel degradation and methods/concepts important in restored riparian zones (erosion control fabric, placement of coarse woody debris, utilization of native vegetation, groundwater levels, stream access to floodplain).

Type: **Half-Day (Private Landowner)**
Date: 10/25/03
Number of Participants: 13
Comments: Participants viewed a presentation on ecological restoration, which was framed in the context of stream restoration at Bernheim. Next, we toured the stream restoration site and discussed riparian degradation, restoration techniques, measuring project success. Species lists for the Wilson Creek restoration were given to landowners interested in planting native species in degrades riparian zones on their property.

Type: **Half-Day College**
Date: 11/20/03
Number of Participants: 11
Comments: Chris Barton, hydrologist at UK's Department of Forestry, brought his watershed management class to discuss water quality management through restoration. During the visit the class discussed riparian revegetation and restoration techniques, floodplain/channel interaction, nonpoint source pollutants, restoration costs/benefits, development of the hyphoreic zone in restored streams. The site tour gave future natural resource managers (this class is a core forestry requirement) an opportunity to view and discuss attributes of a large stream restoration project.

Type: **Visiting Group (Adult)**
Date: 12/13/03
Number of Participants: 10
Comments: Students enrolled in Naturalist in Training Program toured the Wilson Creek restoration site as a part of a program on natural areas in Bernheim. Bernheim's NIT program is designed to train volunteer interpreters to relay information on the natural world to the general public. NIT volunteers were given information on stream and riparian degradation in Kentucky, the potential benefits of riparian and stream restoration, restoration techniques, and measurement of project success.

Type: **Visiting Group (College)**
Date: 2/7/04
Number of Participants: 8
Comments: BellSouth employees enrolled in an adult education biology course through McKendree College attended a lecture on restoration ecology at Bernheim Arboretum and Research Forest. The lecture focused on explaining ecological restoration in terms of the Wilson Creek stream restoration. Topics covered include effects and extent of riparian degradation, riparian restoration and revegetation techniques, and measuring project success.

Type: **Visiting Group (K-12 Students)**
Date: 2/7/04
Number of Participants: 15
Comments: Presented a short overview of the Wilson Creek stream restoration to troop leaders of Boy and Cub Scouts of America in an attempt to get scouts from urban areas to plant trees at the stream restoration site. The overall goal of the presentation was not necessarily to solicit volunteer labor, but to establish a relationship with urban scouting groups who will not otherwise be exposed to stream restoration and concomitant educational experiences.

Type: **Half-Day College**
Date: 2/7/04
Number of Participants: 8
Comments: Students from a University of Kentucky stream restoration class co-taught by Dr. Richard Warner and Carmen Agouridis will tour the Wilson Creek stream restoration site at Bernheim Forest. Topics covered will include degradation of riparian and stream in Kentucky, riparian restoration and revegetation techniques, and measuring restoration success.

Type: **Visiting Group (K-12)**
Date: 5/13/04
School: Meredith Dunn School, Louisville
Number of participants: 17 students, 4 adults (7th grade)
Comments: Stream site visit with hands-on activities.

Type: **Full-Day Professional**
Date: 5/24/04
Number of Participants: 37
Comments: University of Louisville professors Dr. Art Parola, Dr. Jeff Jack, and Dr. Paul Bukaveckis, along with Bernheim contractor Adam Dattilo, gave presentations on the Wilson Creek stream restoration project to professionals representing federal agencies (USACOE, USDA, National Parks Service), state agencies (KDFW, Kentucky Division of Forestry, Kentucky Division of Water) and private engineers/environmental consultants. Topics covered were stream ecology and biological function in the context of restoration. Channel design and revegetation of a restored site, and sources of funding for restoration and riparian habitat enhancement.

Type: **Visiting Group (K-12 Students)**
Date: 5/25/04
School: St. Leonard School on Zorn Ave, Louisville
Number of Participants: 22
Comments: Dr. Art Parola led a field trip for 15 6th graders, 4 parents and 3 teachers

Type: **Full-Day Private Landowner**
Date: 6/19/04
Number of Participants: 12
Comments: University of Louisville professors Dr. Art Parola, Dr. Jeff Jack, and Bernheim contractor Adam Dattilo gave presentations on the Wilson Creek stream restoration project to private landowners from central Kentucky. Topics covered were stream ecology and biological function in the context of restoration. Channel design and revegetation of a restored site, and sources of funding for restoration and riparian habitat enhancement.

Type**: Visiting Group (K-12)**
Date: 7/24/04
School: Governor's Scholars Program (Based at Centre College)
Number of Participants: 28 students, 6 adult leaders
Comments: Orientation talk, powerpoint, discussion about water issues. Site visit by bus. 1.5 hrs on site.

Type: **Teacher Training**
Date: 7/27-28//04
Number of Participants: 32
Comments: Teachers enrolled in the Salt River Watershed Academy for Educators were led by University of Louisville professors Art Parola and Russ Barnett on a site tour of the Wilson Creek discussing where the group discussed the purpose and design of the stream restoration project. Other educational programs conducted on site included:

- Jean Watts (Lexington Community College) lead teachers in a stream habitat assessment, and Ashley Osborne (University of Kentucky) aided teachers in chemical water testing.
- Tree identification (Doug McLaren, UK)
- Fish identification (KY Dept. of Fish and Wildlife Resources)
- Herbaceous plants (Mary Carol Cooper, KDFWR and Portia Brown, Wild Ones) and soils (Amanda Abnee, UK)
- Aquatic insects (Blake Newton, UK)

Type: **Off-Site Presentation**
Date: 8/23/04
Number of Participants: 23
Group: Partnership for a Green City, Louisville
Comments: Presentation of Stream Restoration Project for Education Committee

Type**: Half-Day Professional**
Date: 9/07/04
Group: Sixth Symposium of the International Urban Planning and Envrionment Association.
Number of Participants: 23 people

Comments: This international group with participants from Holland, Japan, England, Mexico, Germany and the US was arranged by Russell Barnett at the University of Louisville. Members of this organization are responsible for urban planning and education efforts throughout the world. The program included a lecture, powerpoint presentation, site visit and following tour of sustainable design practices at Bernhim led by Claude Stephens.

Type: **Full-Day Professional**
Date: 9/21//04
Number of Participants: 16
Comments: University of Louisville professors Dr. Art Parola, Dr. Jeff Jack, and Bernheim contractor Adam Dattilo gave presentations on the Wilson Creek stream restoration project to professionals representing federal agencies (USDA), state agencies (KDFW, Kentucky State Nature Preserves Commission, Kentucky Division of Water), local governments (LaGrange City Government, Warren County Government) and private engineers/environmental consultants. Topics covered were stream ecology and biological function in the context of restoration. Channel design and revegetation of a restored site, and sources of funding for restoration and riparian habitat enhancement.

Type: **Conference Presentaion**
Date: 11/5/04
Number of Participants: 156
Organization: South East Native Plant Conference
Comments: Presented a program about the project to the conference in cooperation with Adam Datillo.

Type: **Visiting Group (Adult)**
Date: 11/17/04
Number of Participants: 11
Organization: Eastern Kentucky P.R.I.D.E.
Comments: Presented the Stream Restoration Project to this group.

Type: **Visiting Group (College)**
Date: Fall semester
Number of participants: 15
Comments: Dr. Jeff Jacks of U. of Louisville brought students to stream site for a program. Also he had student projects at the site:

- 2 students studying zooplankton
- 3 graduate students studying leaf litter decomposition

Type**: Landowner**
Date: 3/07/05
Organization: Elizabethtown Garden Club
Number of Participants: 32
Comments: Project summary, powerpoint, hand-outs and talk. Delivered to members of the EGC at their regular monthly meeting.

Type**: Visiting Group (College)**
Date: 3/18/2005
Number of Participants: 8
Comments: Thomas More College professor Dr. John Ferner accompanied a group of eight students. Bernheim Director of Education Claude Stephens gave a presentation about the stream restoration covering the biology and physical comparisons of the pre- and post-stream bed restoration. Re-vegetation and funding sources also were discussed.

Type: **Visiting Group (Adult)**
Date: 3/22/05
Number of Participants (12)
Group: Group of architects from Berry Architects, Louisville. VC and Stream Site

Type**: Visiting Group (K-12)**
Date: 4-20-05
School: St. Christopher (Lebanon Junction, KY)
Teacher: Nancy Peden
Number of students: 20
Grade level: 6-8
Visit to site: Yes

Type**: Visiting Group (College)**
Date: spring 2005
Number of Participants: 9
Program: 8 days in the field at the stream site with Art Parola

Type**: Visiting Group (K-12)**
Date: 5/9/05
School: : St. Leonard School on Zorn Ave, Louisville
Teacher: Mary Parola
Number of students: 24
Grade level: 6
Visit to site: Yes, they also planted wetland plugs in the wetland areas.

Type: **Visiting Group** (**K-12)**
Date: 5/12/05
School: H.S. from Lebanon
Number of Participants: 32
Comments: 1.5 hour stream site investigation with hands-on activities. Program led by Claude Stephens

Type**: Professional**
Date: 5/15/2005
Number of Participants: 13

Comments: Kentucky Water Watch participants had a half-day workshop at the stream restoration site.
Type: **Off Site Presentation**
Date: 5/17/05
Number of Participants: 27
Organization: Louisville Sierra Club
Comments: Presented Visitor Center and Stream Restoration overview.

Type: **Visiting Group (Scout)**
Date: 6/7/05
Number of Participants: 23
Organization: Boy Scout
Comments: Site Visit program

Type: **Visiting Group (College)**
Date: 6/11/05
Number of Participants: 37
Organization: Bulldogs in the Bluegrass, Yale College students
Comments: Site Visit

Type**: Half-day College**
Date: 6/11/05
Number of Participants: 19
Program: Seminar with Bill Vesely and Art Parola
Students are with the American Society of Chemical Engineers. They planted wetland plugs.

Type: **Professional**
Date: 6/14/05
Organization: US Green Building Council, Kentucky Chapter
Number of participants: 11
Comments: Architects, engineers, urban planners and others. State chapter members. Program by Claude Stephens. Site visit.

Type**: Visiting Group (College)**
Date: 7/11/05
Organization: Bulldogs in the Bluegrass
Number of Participants: 38
Comments: Yale University students working in Louisville as interns for the summer.

Type: **Professional**
Date: 7/14/05
Organization: US Green Building Council, Kentucky Chapter
Number of Participants: 27

Comments: Architects, Engineers and Designers visited the Visitor Center and Stream Restoration site to learn how the built environment affects non-point pollution and specific strategies used in mitigation.

Type: **Professional**
Date: 8/10/2005
Organization: Salt River Water Watch Basin Group
Number of Participants: 15
Comments: Part of training program; Claude Stephens presenter
Type: **Visiting Group (K-12)**
Date: 9/23/05
Number of Participants: 65
Program: Dr. Drip Drop – Non-Point Water Education School Program

Type: **Visiting Group (K-12)**
Date: 9/28/05
Number of Participants: 53
Program: Dr. Drip Drop

Type: **Visiting Group (K-12)**
Date: 10/11/05
Number of Participants: 123
Program: Dr. Drip Drop

Type: **Visiting Group (K-12)**
Date: 10/12/05
Number of Participants: 47
Program: Dr. Drip Drop

Type: **Visiting Group (K-12)**
Date: 10/18/05
Number of Participants: 74
Program: Dr. Drip Drop

Type: **Visiting Group (K-12)**
Date: 10/19/05
Number of Participants: 53
Program: Dr. Drip Drop

Type: **Visiting Group (K-12)**
Date: 10/21/05
Number of Participants: 38
Program: Dr. Drip Drop

Type: **Visiting Group (K-12)**
Date: 10/27/05

Number of Participants: 68

Type: **Visiting Group (Adult)**
Date: 4/8/06
Number of Participants: 14
Group: Louisville church group.
Program: VC and Stream Site

Type: **Visiting Group (Adult)**
Date: 4/11/06
Number of Participants: 24
Group: Visiting Museum Professionals
Program: VC and Stream Site

Type: **Visiting Group (K-12)**
Date: 4/20/06
Number of Participants: 107
Program: Dr. Drip Drop

Type: **Visiting Group (K-12)**
Date: 5/4/06
Number of Participants: 103
Program: Dr. Drip Drop

Type: **Visiting Group (K-12)**
Date: 5/8/06
Number of Participants: 37
Program: Dr. Drip Drop

Type: **Visiting Group (K-12)**
Date: 5/10/06
Number of Participants: 75
Program: Stream Site Visit

Type: **Visiting Group (K-12)**
Date: 5/11/06
Number of Participants: 83
Program: Stream Site Visit

Type: **Visiting Group (K-12)**
Date: 5/13/06
Number of Participants: 135
Program: Dr. Drip Drop

Type: **Visiting Group (Adult)**
Date: 5/13/06
Number of Participants: 14
Program: Stream Site visit

Type: **Visiting Group (K-12)**
Date: 5/19/06
Number of Participants: 68
Program: Dr. Drip Drop

Type: **Off Site Presentation**
Date: 6/17/06
Number of Participants: 38
Group: KYANA (Geology Club)
Program: Presentation on Wilson Creek project

Type: **Off Site Presentation**
Date: 6/17/07
Number of Participants: 308
Group: UofL Earth Day event
Program: Display at event

Type: **Visiting Group (K-12)**
Date: 6/21/06
Number of Participants: 27
Program: Stream Site Visit

Type: **Visiting Group (K-12)**
Date: 7/6/06
Number of Participants: 32
Program: Dr. Drip Drop

Type: **Visiting Group (Adult)**
Date: 7/8/06
Number of Participants: 29
Group: Bulldogs in the Bluegrass, Yale College interns

Type: **Visiting Group (K-12)**
Date: 8/3/06
Number of Participants: 56
Program: Water Ecology and Dr. Drip Drop and Stream Site visit

Type: **Visiting Group (K-12)**
Date: 8/14/06
Number of Participants: 9
Group: Clifton Neighborhood group

Program: Stream Site visit and VC tour

Type: **Visiting Group (K-12)**
Date: 9/21/06
Number of Participants: 45
Program: Dr. Drip Drop

Type: **Visiting Group (Adult)**
Date: 10/13/06
Number of Participants: 5
Group: Birmingham Botanical Garden
Program: Stream Site visit and VC tour

Type: **Conference Presentation**
Date: 10/27/06
Number of Participants: 110
Group: Association of Science and Technology Centers
Program: Tours of Site and presentation on the project

Type: **Visiting Group (K-12)**
Date: 11/9/06
Number of Participants: 28
Program: Stream Site Visit

Type: **Professional**
Date: September 2005
Group: EPA, State Nature Preserves Commission, TNC
Number of Participants: 27

Additional Educational Efforts

First Saturday Programs

Discovery stations focused on the Wilson Creek Stream Restoration Project, the Visitor Center Stream Aquarium, amphibians and other related topics set up in the Visitor Center on each first Saturday of the month as part of our monthly programming. This effort began on 4/1/06.

Number of Participants (FY 2006/2007): 1544
Number of Participants (FY 2007/2008): 1899+

Bernheim Web Site

Information about the Wilson Creek Stream Restoration Project available on the Bernheim web site at www.bernheim.org

Visitor Center Display Information

Information about the Wilson Creek Stream Restoration Project, a stream aquarium, flash animation about stream organisms and periodic discovery stations are available in the Visitor Center every day.

Bernheim Mobile Labs

Bernheim Mobile Labs are used to deliver Wilson Creek Stream Restoration content when used and many off site events such as the Louisville Zoo Earth Day and with the Jefferson County Public Schools partnership with Operation Brightside. As of 10-1-07 these labs have reached over 3000 people with content related to the Wilson Creek Stream Restoration Project.

Wilson Creek Brochure

Bernheim printed and distributed 1500 copies of the Wilson Creek brochure. A second printing of the brochure has been ordered and over the course of the next several years we will distribute these copies as well.

SUMMARY BY AUDIENCE

Audience	Goal	Actual
Student Groups (K-12) (*)	**1440**	**1517**
Teachers	**60**	**59**
College Level	**250**	**164**
Landowner	**150**	**84**
Professional	**150**	**169**
Additional audiences served:		
Adult visiting groups	**none**	**137**
Conferences	**none**	**266**
Off-site Presentations	**none**	**369**
Visitor Center Education Efforts	**none**	**4000+**
Mobile Lab Education Efforts	**none**	**3000+**
Wilson Creek Brochure	**none**	**1500**
Wilson Creek Brochure (2nd order)	**none**	**1500**
Bernheim Web Site	**none**	**unknown**

Educational Brochure

Dr. Parola of the U of L Stream Institute with a class at the restoration site

Educational Activities

The restoration site is used for educational programs and workshops on stream ecology and stream restoration. It serves as a living laboratory to educate professional groups, college biology classes, and K–12 students by prior arrangement. County Extension Agents use the site for training sessions in agriculture and natural resource management.

The Wilson Creek Restoration Site is an important educational tool to help individual landowners understand what they can do to restore streams and improve water quality and wildlife habitat. Something as simple as fencing out cattle and planting appropriate native trees can lead to improvements in the health of a stream.

Wilson Creek is recognized as a Kentucky stream with very good water quality. This project helps ensure the stream's future ability to purify water and maintain good habitat, especially as development occurs upstream.

This work was funded in part by a grant from the U.S. Environmental Protection Agency under §319(h) of the Clean Water Act through the Kentucky Division of Water to Bernheim (Grant M-02173434)

What You Can Do

Streams do more than move water from one place to another. They also:

- filter pollutants from runoff
- recycle nutrients
- absorb and gradually release floodwater
- recharge groundwater and
- provide habitats for micro- and macro-invertebrates as well as wildlife

Streams and their associated wetlands and floodplains are essential to healthy environments, but human impact has altered stream quality in a variety of ways.

Even if you only have a drainage ditch on your land there are things you can do to help streams keep our water clean. You can:

- Help a stream meander instead of just flowing straight.
- Plant water vegetation along its banks. Examples would be trees such as sycamore and willow, shrubs such as buttonbush and spicebush, and plants such as Joe-Pye weed and swamp milkweed.
- Even a grassy swale through your yard could be planted as a "rain garden." Just search for "rain garden" on the web for great information on creating a rain garden.
- Use less fertilizers and herbicides on your lawn. Natural lawns are healthier for the environment, grow more slowly (need fewer mowings) and have a higher diversity of plants that require less water in summer.

For further information see Bernheim's website at www.bernheim.org. You can find more information on Bernheim's restoration of Wilson Creek as well as a list of plants appropriate to stream restoration in this region.

Bernheim
ARBORETUM AND RESEARCH FOREST
State Highway 245
Clermont, Kentucky 40110

THE Wilson Creek Stream Restoration PROJECT

History

Wilson Creek again flows through a valley in Bernheim Arboretum and Research Forest much as it did before European settlers came to the area. But between then and today, the stream took a very different course.

Sometime in the past 200 years, the stream channel was realigned along one side of the valley to follow a straightened course. This was most likely done to allow for farming the fertile bottomland. This change resulted in a stream channel that allowed water to cut quickly through the watershed. The faster flowing water carried away top soil and allowed fewer impurities to filter out.

Stream Restoration

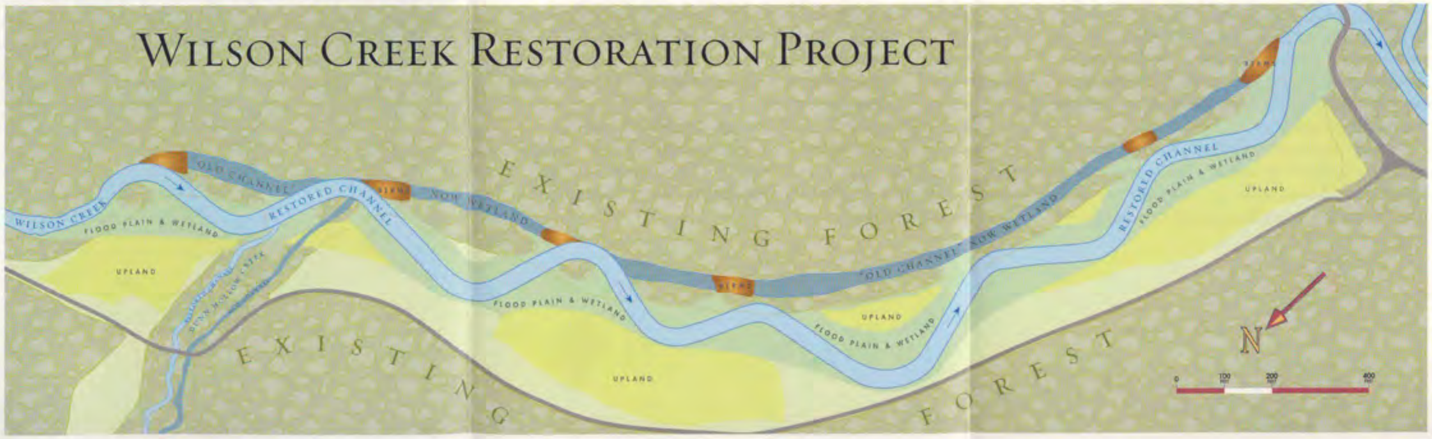
In 2003, after more than a year of planning, the stream was restored to its natural meandering channel thanks to the efforts of Bernheim, and researchers at the University of Louisville Stream Institute.

Aerial photographs and test cores helped locate the old stream bed. Some 2,700 feet of stream was realigned adding about 500 feet to its course through the valley. The restored stream was designed to allow the banks to overflow and spread out to periodically interact with the floodplain. Low areas along the floodplain were designed as seasonal wetlands. Cobblestones collected from along the stream were placed in the streambed and logs were placed along the way to secure the banks. These activities restore habitats for the complex interactions of organisms that make up a healthy stream community.

The restored channel is once again able to overflow its banks to interact with the floodplain. This allows sediments, nutrients and toxins to be filtered from the water before it moves downstream. The channelized stream had dug down to bedrock creating steep banks. Water moved rapidly downstream carrying away soil and possible pollutants. Reconnecting the stream to its floodplain creates conditions that protect our soil, keep our stream communities healthy and protect our water quality.

Once the streambed was restored, more than 40 different plant species were planted along the bank and in the surrounding floodplain. The majority of the species came from seed collected at Bernheim with assistance from the University of Kentucky College of Agriculture. Most of the trees were grown from local seed types at a Kentucky Department of Forestry nursery before being transplanted at the site.

The Wilson Creek project provides an experimental model that will be monitored over time in order to help us learn how to better protect our valuable resources.



Workshop Announcement

What: Stream Channel/Riparian Corridor Restoration Workshop
When: Monday, May 24, 2004 from 9:00 am to 5:00 pm
Where: Bernheim Arboretum and Research Forest Visitors Center
Cost: Free, Lunch Provided
Limit: 40 Participants

Bernheim Arboretum and Research Forest would like to extend an invitation to Kentucky natural resource professionals for a day dedicated to education on stream channel and riparian restoration. With funding from the US Environmental Protection Agency, Bernheim has recently completed construction on more than a ½ mile section of stream located on Bernheim property. Before restoration work, the impacted section of Wilson Creek was channelized, or artificially straightened. Where the old section of Wilson Creek closely followed the valley slope, the restored stream reach now meanders throughout the valley bottom. The restored reach was designed to duplicate natural conditions (pre-European settlement) found before wholesale manipulation of streams occurred in Kentucky. Natural conditions provide for water quality, wildlife habitat, and other ecological benefits not found in channelized streams and otherwise degraded riparian corridors.

Since ecological restoration of stream corridors is a relatively new discipline, Bernheim would like to provide Kentucky's natural resource professionals the opportunity to discuss stream restoration with the designers and managers of the Wilson Creek project. University of Louisville and Bernheim professionals will be on hand to make presentations on the biology and ecology of riparian corridors, restoration design, and potential sources of funding. Presentations will be followed by a tour of the restoration site. Lunch will be provided free of charge. Hope to see you there!

Registration Deadline is May 10th

Call Bernheim at (502) 955-8512 to make reservations

Bernheim is on Hwy 245, in Clermont KY. From I 65, take Exit 112 and go 1 mile east.

Workshop Agenda

Professional Stream Restoration Workshop at Bernheim Forest
May 24, 2004

Topic	*Presenter*	*Time*
Workshop Introduction	Adam Dattilo (Bernheim)	9:00-9:05 am
Introduction to Watersheds and Water Quality in KY	Amanda Abnee (Extension Associate)	9:05-9:15 am
Introduction to Wilson Creek Restoration	Adam Dattilo	9:15-9:20 am
Stream Function/ Water Quality: Why Restoration?	Dr. Paul Bukaveckas (University of Louisville)	9:20-10:05 am
Break		10:05-10:10 am
Stream EcologyWhy Restoration?	Dr. Jeff Jack (University of Louisville)	10:10-10:55 am
Break		10:55- 11:00 am
Channel Design: Costs & Measures of Success	Dr. Art Parola (University of Louisville)	11:00-11:45 am
Revegetation Design: Costs & Measures for Success	Adam Dattilo	11:45-12:15 am
Lunch		12:15-12:45 pm
Sources of Funding	Adam Dattilo	12:45-1:15 pm
Travel to Site		1:15-2:00 pm
Site Tour		2:00-4:25 pm
Group Wrap-Up	Adam Dattilo	4:25-4:30 pm
Travel to Visitors Center		4:30- 5:00 pm

Bernheim Visitor Center Stream Restoration Graphics

Education Programs Props

Flash Animation of the Stream Project

Mobile Learning Lab

(Folders are located on the same CD as this file)