

Chapter 20

Spring Creek Watershed, Pennsylvania: National Institute of Food and Agriculture–Conservation Effects Assessment Project

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Four project objectives were divided by activity in the Pennsylvania National Institute of Food and Agriculture–Conservation Effects Assessment Project (NIFA–CEAP), Analysis of Best Management Practice (BMP) Implementation Performance and Maintenance in Spring Creek, an Agriculturally-Influenced Watershed in Pennsylvania:

1. Landscape characterization—coarse and fine resolution geographical information system analyses:
 - To determine at what spatial scale (coarse [30 m (98 ft)] versus fine [<1 m (<3.3 ft)]) remote data resolution; reach [smaller area] versus subwatershed [larger area]) the performance of BMPs can be assessed and subsequently aggregated on a watershed basis
2. Hydrologic and landscape modeling of BMP performance:
 - To quantify the relative importance of agricultural uplands, riparian zones, and stream channels as sediment sources and to quantify the relative benefits of upland, riparian, and in-stream BMPs on stream sediment loads
3. Ground-based monitoring and ecological analyses:
 - To determine if reach-level measures of abiotic (substrate composition) and biotic (macroinvertebrates and fish) variables are useful surrogate measures of water quality to describe effects of BMPs on stream ecosystems
 - To determine if reach-level abiotic and biotic variables vary spatially with regard to the number of BMPs implemented upstream of study reaches
 - To assess the time required to measure stream responses to BMPs over a range of 1 to 12 years
4. Socioeconomic analyses and outreach:
 - To explore the factors that affect effective farmer adoption of BMPs and citizen perceptions of water quality
 - To develop methods for integrating and communicating the complexity of water quality measures derived from multiple measures and multiple sites to stakeholders by watershed

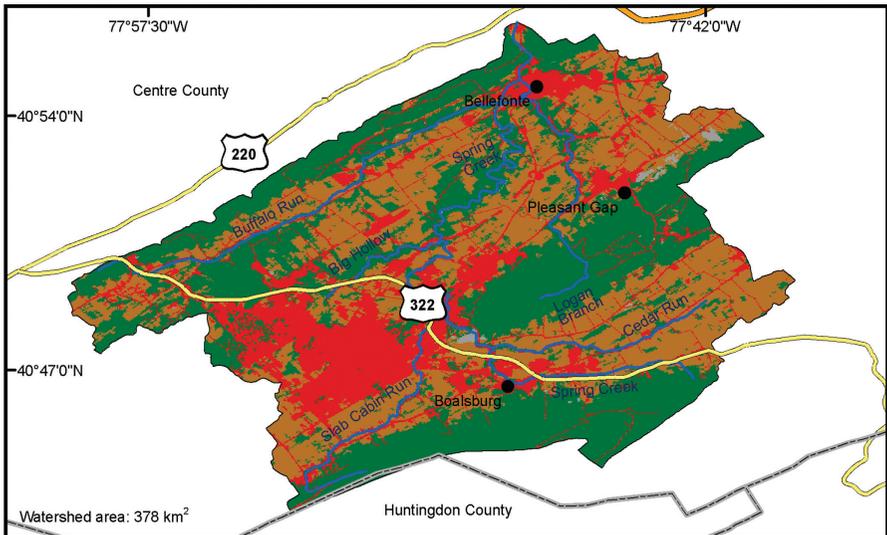
- To increase understanding of water quality changes resulting from implementation of BMPs by communicating study results through various media (e.g., workshops, Web sites)

Watershed Information

The 378 km² (146 mi²) Spring Creek Watershed is located in Centre County, central Pennsylvania, in a limestone valley within the Ridge and Valley Physiographic Province (figure 20.1). Spring Creek flows into Bald Eagle Creek, a tributary to the west branch of the Susquehanna River.

The primary focus of the NIFA–CEAP Pennsylvania study was in the headwaters of the Spring Creek Watershed, an 11-digit hydrologic unit code with five 14-digit hydrologic unit code subbasins, plus the mainstem. Three study basins were defined within the watershed: Spring Creek, Cedar Run, and Slab Cabin Run. These basins are adjacent and share similar geology and soils, although there are some differences between streams originating on the ridges versus the valleys. The headwaters of the upper Spring Creek and Slab Cabin Run basins originate on Tussey Mountain. Streams flowing from this forested sandstone ridge are typically low in pH (<7.0) and alkalinity. When these streams reach the valley floor, groundwater inputs from

Figure 20.1
Spring Creek Watershed, Pennsylvania, land use and stream networks.



Legend

Agricultural land	Urban
Forest	Other
Water	



Scale: 1:275,000

limestone aquifers alter their chemistry. Headwaters of Cedar Run originate in the valley floor. Valley streams have a relatively high pH, high total alkalinity, and high calcium concentrations.

Streams of the Upper Spring Creek Watershed are primarily first- and second-order streams draining from the forested slopes of Tussey Mountain to the valley floor, where the mainstem of Spring Creek flows as a third-order stream prior to its confluence with Cedar Run, also a third-order stream. The Upper Spring Creek Watershed terminates at the confluence with Cedar Run in Oak Hall. This reach of Spring Creek is designated as a High Quality Cold Water Fishery and Class A Wild Trout Stream that currently contains wild trout.

A great deal is documented about the surface and groundwater hydrology of the Spring Creek Basin in Fulton et al. (2005). Springs, many of which are large, are the primary source of streamflow in the basin; snowmelt is also an important contributor. A number of small tributaries carry mountain runoff into basin-valley streams. However, during low to moderate flow conditions, most or all of this runoff enters sinkholes and fractures near the base of the ridges that delimit Spring Creek Basin. Portions of Spring Creek Basin are subject to variable-source hydrologic conditions. These areas, generally downslope of areas with high infiltration rates and underlying bedrock of reduced permeability, become sources rather than sinks of surface water runoff during sufficiently saturated soil conditions. Streamflow in Spring Creek has a large base-flow component. Meanwhile, groundwater is important in the Spring Creek Basin because it is the source of most water supplies and it sustains the high quality, cold water streamflow in Spring Creek.

Streamflow in the Spring Creek Basin is recorded continuously at three US Geological Survey (USGS) streamflow gaging stations, three Pennsylvania Cooperative Fish and Wildlife Research Unit streamflow gaging stations, and six Spring Creek Watershed Community streamflow gaging stations. Annual mean discharge values reported at USGS gages on Spring Creek range from $1.9 \text{ m}^3 \text{ s}^{-1}$ ($67 \text{ ft}^3 \text{ sec}^{-1}$) to $6.5 \text{ m}^3 \text{ s}^{-1}$ ($230 \text{ ft}^3 \text{ sec}^{-1}$).

Some of the soils in the Spring Creek Watershed are derived from residual material weathered from shale of the Ridge and Valley Physiographic Province. The Berks-Weikert association consists of well-drained soils derived from acidic shale bedrock, while other soils were developed in residual and colluvial materials weathered primarily from limestone (Hagerstown-Opequon-Hublerburg, Morrison, Opequon-Hagerstown, and Murrill associations). Sandstone residual and colluvium-derived soils are represented by the Hazleton-Laidig-Andover and Ungers associations. Predominant soil associations are the Hagerstown-Opequon-Hublerburg and Hazleton-Laidig-Andover, which represents 78% of the Spring Creek Basin.

The Spring Creek Basin has a temperate climate characterized by hot, humid summers and cold winters. The climate on the floor of the basin typically is milder than the surrounding higher elevations but is influenced by cold air drainage from the bordering ridges, which contributes to reduced minimum temperatures. The average annual precipitation for Centre County (1961 to 1990) is 1,060 mm (41.7 in). The average monthly snowfall for State College, Pennsylvania, is approximately 1,120 mm (44 in). The average annual air temperature in State College is 9.7°C (49.4°F). The highest monthly mean temperature is 22°C (71.7°F) in July, and the lowest monthly mean temperature is -3°C (26.5°F) in January. Additional detailed climate data are reported in Fulton et al. (2005).

The Upper Spring Creek Watershed is approximately 3,393 ha (8,385 ac) in size and includes nearly 7.5% of the Spring Creek Watershed's total area. Dominant land use within the Upper Spring Creek Watershed is forest (58%), followed by agriculture (21%), and

residential (10%) land uses. Land use within 100 m (328 ft) of stream courses has been characterized for the three subbasins.

Aerial photography has been used extensively to track land-use changes in the Spring Creek Watershed. Currently, 75% of all headwater streams are within forested land-use areas. Historic data from 1938 to 2010, which include current LiDAR (light detection and ranging) data with 1 m (3.3 ft) resolution, has shown a decided shift from agriculture to urban land uses. From 1957 to 2006, agricultural lands decreased from over 20,235 ha (50,000 ac) to about 12,343 ha (30,500 ac), whereas developed land increased from 4,047 ha (10,000 ac) to 12,141 ha (30,000 ac), indicating an even split between agricultural and developed land uses. Impervious surfaces accounted for 13% of the total land area in Spring Creek as of 2006. This is not surprising as the watershed is home to approximately 94,000 people, 14 municipalities, and the University Park campus of Pennsylvania State University.

Water Quality Information

Water quality in Spring Creek is impaired by sediment and nutrients. Five stream sections have been recommended for inclusion on the Section 303(d) of the Clean Water Act (USEPA 2011) list as impaired due to pollution from agricultural sources. Approximately 26 km (16 mi) of Spring Creek were already listed as impaired by the Pennsylvania Department of Environmental Protection in 2002. The majority of impairments were attributed to nonpoint source pollution coming from urban and agricultural sources and to poor physical conditions caused by degraded or absent riparian buffers.

Findings of an earlier study showed that poor reproductive success of brown trout (*Salmo trutta*) in a 16 km (9.9 mi) section of Spring Creek was related to a high proportion of fine sediment in substrates used for spawning. Fine sediment reduced the amount of suitable spawning habitat, and where brown trout spawned, embryo survival was low. Surveys of headwater tributaries to Spring Creek revealed that two subbasins with substantial proportions of unfenced riparian pastures were the likely sources of fine sediment.

In order to improve fish habitat, fine sediments needed to be reduced. Determining how best to reduce these fine sediments was the goal of the ground-based monitoring and ecological analyses activity within this project. The specific objectives involved in this activity included the following:

1. To determine if reach-level measures of abiotic (substrate composition) and biotic (macroinvertebrates and fish) variables are useful surrogate measures of water quality to describe effects of conservation practices on stream ecosystems
2. To determine if reach-level abiotic and biotic variables vary spatially with regard to the number of conservation practices implemented upstream of study reaches
3. To assess the time required to measure stream responses to conservation practices over a range of 1 to 12 years

The Pennsylvania NIFA–CEAP water quality monitoring was based on a two-way paired-watershed design. The experiment was established in 1991. Two treatment streams (Cedar Run and Slab Cabin Run) and one reference stream were monitored under baseline conditions during 1991 and 1992. The use of a reference stream was critical in this project because it allowed researchers to determine differences between community responses to conservation practice implementation and natural variation. Data from the reference stream were compared each year with the two treatment streams in order to account for variation in climatic influences, such as

precipitation and temperature. Controlling for the effects of weather (which influence both control and treatment watersheds) permitted researchers to attribute changes observed in treatment stream communities to conservation practice implementation, rather than to differences in weather.

Fencing and stream crossing installations occurred between the fall of 1992 and summer of 1998. Posttreatment monitoring occurred from 2001 to 2003, Phase I (Carline and Walsh 2007), and from 2005 to 2007, Phase II. Monitoring was a combination of site and stream reach for the grazed and ungrazed pastures that were fenced (treated) and not fenced (untreated) and subwatershed outlet monitoring. Stream sampling sites for each treatment basin included two grazed reaches and two ungrazed reaches (eight sites), plus a control for a total of nine sites. Reach-monitoring stations were selected to monitor treated and untreated areas.

The Cedar Run treatment watershed consisted of 69% agriculture in the subbasin. There were 2.5 km (1.6 mi) of unfenced pasture before restoration, and the surface area of the riparian pastures was 44 ha (109 ac), with a livestock density that averaged about 4 animals ha⁻¹ (1.6 animals ac⁻¹) between 1991 and 2003. The Slab Cabin Run treatment watershed was 40% agricultural with 4.1 km (2.5 mi) of unfenced riparian area, prior to restoration. Stream bank erosion was evident in all pastures. Average surface area of the riparian pastures was 76 ha (188 ac), and livestock density ranged from 5.3 to 5.6 animals ha⁻¹ (2.2 to 2.3 animals ac⁻¹). The reference stream, Upper Spring Creek, had 22% of its area in agricultural production and no unfenced riparian areas, while the remaining 56% of the land area was in forest.

The primary monitoring scale was stream reach. The stream sampling sections were variable in length (150 to 250 m [492 to 820 ft]) with an average of three riffle pools. Eight or more width measurements were conducted per section. Stream bank vegetation, channel morphology, substrate, and macroinvertebrate communities were evaluated at four reach sampling stations for potential localized changes in grazed stream reaches and in reaches immediately downstream after treatment. Stream bank vegetation was estimated during Phase I monitoring as 0%, 25%, 50%, and 100% and was denoted by vegetation type—herbs, shrubs, or trees.

To monitor hydrologic and water quality characteristics, gaging stations were established at the subwatershed outlets during the prerestoration phase of the study. Water levels were recorded during the prerestoration period from September 1991 through August 1992 and during the postrestoration phase from January 2001 to January 2003 (Phase I) as well as during Phase II to monitor streamflow discharge. Water level recorders measured stream stage at 30-minute intervals. Stream discharge was measured 10 to 15 times over a wide range of stage values at each gaging station to develop rating curves. Some additional hydrologic characteristics were monitored in the restoration areas during the pre and postsampling periods, but some data were missed and had to be estimated from downstream gaging stations (Slab Cabin Run).

Stream monitoring included stormflow and water quality variables (total suspended solids [TSS] and nutrient concentrations) as well as substrate (percent fines), macroinvertebrates (density and community metrics), and fish (brown trout density and community composition). Baseflow samples were collected quarterly at 14 sites in Spring Creek Watershed and were analyzed for TSS, turbidity, chloride, nitrate (nitrate-nitrogen), phosphorus (orthophosphate), total phosphorus, and total nitrogen. Thirteen stream sites were monitored continuously for stage; three of these sites are the USGS stations described previously. Water quality data were initially held at Pennsylvania State University but were later turned over to the Clearwater Conservancy, a local nonprofit land trust.

Substrate was monitored in May (1992, 2000, 2001, 2002, and 2005), macroinvertebrates were monitored in May and August (1992, 2001, 2002, 2005, and 2007), and fish were monitored in May and August (1992, 2001, 2002, 2005, and 2007). Macroinvertebrate sampling was conducted to determine density, richness, and diversity of macroinvertebrates. Samples were collected in triplicate using a Surber sampler in riffles. Macroinvertebrate data were compared to the reference stream to account for climatic variations. Fish were sampled using electroshock so that brown trout density could be determined. The ecological monitoring data were kept by Pennsylvania State University as a Microsoft Excel spreadsheet.

Land Treatment

Agricultural land use of areas within the 100 m (328 ft) riparian corridors in the Spring Creek Watershed varied by subbasin: Upper Spring Creek (17%), Cedar Run (46%), and Slab Cabin Run (37%). Cedar Run had conservation practices on 98% of the stream miles, while Slab Cabin Run had only 67% of the stream miles treated (table 20.1).

Land treatment in the treated watershed focused on three conservation practices: creating narrow vegetated buffers, installing graveled stream crossings, and installing riprap to armor eroding stream banks. The intent was to determine the effectiveness of these practices at restoring fish habitat.

Implementation of conservation practices occurred between 1992 to 1995 for the Slab Cabin reach and between 1993 to 1998 for the Cedar Run reach. Landowners had little choice in selecting conservation practices; participating property owners could only determine fencing width and placement. Riprap was placed on eroding, vertical stream banks where warranted. Stream bank (exclusion) fencing (1 to 3 m [3 to 10 ft] wide corridors), construction of animal crossings, animal accesses to one side of the stream, and bank stabilization were the primary restoration techniques. In the past implementation project, fencing was done at no cost to the landowners, who were required to sign agreements ensuring that they maintained all improvements for 10 years. In Cedar Run Basin, 2,000 m (6,562 ft) of fencing and 14 stream crossings were installed, and 245 m (804 ft) of banks were stabilized. In Slab Cabin Run Basin, 2,740 m (8,990 ft) of fencing and 26 stream crossings were installed, and 1,875 m (6,152 ft) of banks were stabilized. The fencing was electrified with wires extended across the streams. Riparian vegetation grew back without planting.

A high level of treatment was achieved because the original researcher, Bob Carline, was well respected, had excellent communication skills, and established a one-on-one relationship with each of the participants. This is an example of the importance of a trusted local advisor for

Table 20.1

Subwatershed percent land use and percent of streams buffered.

Subwatershed	Stream treated (BMPs) (%)	Size (total ha)	Agricultural land use (%)	Forest use (%)	Residential/commercial (%)
Spring Creek	0	653	17	45	38
Cedar Run	98	699	46	19	35
Slab Cabin Run	67	625	37	36	27

increasing conservation practice implementation. All properties were inspected in 2003; two landowners in the Slab Cabin Run Basin had not maintained their fencing. During the post-implementation period (2003), it was determined that 98% of the Cedar Run fencing remained, while only 61% remained in Slab Cabin Run. These results point to the importance of continued education to ensure adequate maintenance of conservation practices.

Three separate land-use studies were conducted in addition to the paired-watershed study. One of these studies was done to determine the effectiveness of a cross vane structure installed in an incised section of Slab Creek Run in the marsh area. In 2007, eight cross vanes were installed. In situ water quality monitoring was initiated in both the upstream and downstream positions to determine its effectiveness.

Another study examined the land-use information at both coarse (conventional digital elevation model [DEM]) and fine scales (LiDAR) relative to flow path. This study used digital data to explore flowpaths to riparian buffers and examine the effect of topographic data resolution on stream corridor characteristics using DEMs and LiDAR in order to characterize and fine-tune the placement of conservation practices. Coarse (30 m [98 ft]), intermediate (10 m [33 ft]), and fine (1 m [3.3 ft]) resolution data were analyzed for a straight-line perpendicular flow path and topographic flow path at each location. Topographically based flow paths were, not surprisingly, longer than straight line paths, and the observed actual flowpath length was a function of data resolution. Low resolution DEMs had the longest flow path percent difference (from a straight-line path) of 91% or 48 m (158 ft), followed by the finest scale LiDAR measurements of 71% or 19 m (62 ft), and by the intermediate resolution DEMs of 49% or 30 m. The data suggest that it is critical to identify the topographic flow path from the pollution source to the stream when siting a buffer. Although 1 m DEM data provides more robust results, 10 m DEMs are adequate for siting conservation practices.

The third study examined the effect of topographic data resolution on estimates of stream corridor characteristics related to sediment transport. Work by Baker et al. (2006) used easily obtained data to study drainages in the Chesapeake Bay. Coarser resolution data were less capable than LiDAR data of determining stream characteristics (stream cross-section and floodplain) and allowing stream simulation models to be used for estimates of stream processes, such as gully erosion, stream bank erosion, and floodplain deposition. It was determined that the LiDAR data are preferred for simulation models in order to better predict gully and stream bank erosion and floodplain deposition.

Model Application

Few watershed assessment tools consider stream processes as primary controls of stream-flow and water quality; most focus on hillslope processes. The objective of the modeling was to estimate the relative importance of hillslope erosion, gully erosion, stream bank erosion, and floodplain deposition to stream sediment loads. Although not stated explicitly, modeling objectives appeared to include evaluation of how landscape characteristics influence sediment loading in the Spring Creek tributaries and whether sediment delivery was primarily from hillslope, gully, or stream bank erosion and whether floodplain deposition influenced sediment loads.

This project compared modeled results from the European Sediment Network (SedNet), a watershed model that explicitly estimates gully and stream bank erosion as well as hillslope erosion, to observed sediment loads and results from the Soil and Water Assessment Tool (SWAT).

The SWAT model was selected because of its capability to assess effects of field-scale BMPs on watershed discharge estimates. The SWAT dynamic simulation model provides a basis for evaluating management impacts given interannual and seasonal variations of temperature and precipitation. Accordingly, SWAT is widely used to support watershed management, including most of the NIFA–CEAP study sites. In addition, both the SedNet and SWAT models are semiempirical models, which include algorithms to represent specific hydrologic processes but yet are not overly complex and difficult to implement. Like most watershed models, both SWAT and SedNet have limited capacity to represent groundwater transfers. Because of the focus on sediment delivery, which is regulated largely by surface processes, the investigators believed the SedNet and SWAT models still were appropriate for the Spring Creek Watershed.

The SWAT model used land-use data derived from 1993 aerial photography, 10 m (33 ft) digital elevation data, and the State Soil Geographic (STATSGO) soils database. The model was calibrated with flow observations at the Spring Creek Houserville gage station (USGS station 01546400). A 20 ha (49.4 ac) threshold was used to define the upstream ends of the stream network, resulting in 386 SWAT subbasins. The hydrologic response of each SWAT subbasin was based on the dominant land cover, soil type, and slope class. Temperature and precipitation data from three weather stations in the Spring Creek Watershed were used to run the model over a twelve-year period, from 1990 through 2002.

The SedNet model was developed using the same subbasin outlets generated from the SWAT application. Gullies and stream reach characteristics for each subbasin were generated from 1 m (3.3 ft) resolution LiDAR data. Similar to the SWAT application, the STATSGO soils database, Pennsylvania State University land-use data, and the USGS gage data were used to implement and calibrate SedNet.

Both SWAT and SedNet were very difficult to calibrate, likely because of the karst geology and consequential importance of groundwater dynamics to regulating streamflow. The limited storm-based suspended sediment samples also could explain the large errors and uncertainty in both model predictions. For SWAT, the most sensitive calibration parameters affecting model performance included the baseflow factor, canopy structure, curve number, and soil evaporation factor; other important parameters included the surface water to groundwater transport delay, groundwater plant transfer, groundwater threshold depth, and shallow aquifer threshold depth. The calibrated SWAT model had a Nash-Sutcliffe coefficient of 0.63, indicating the model adequately described hydrologic processes controlling stream discharge. An estimated 4% bias highlighted the model's tendency to overestimate stormflow, especially under high flow conditions. Baseflow was underestimated by SWAT. At one sampling site, the actual sediment load for the 1992 adjusted water year was 1,100 Mg (1,212 tn), while the predicted load was over 6,000 Mg (6,614 tn). Conversely, SedNet underestimated sediment delivery.

With SedNet, sediment loads derived from bank erosion were determined from estimates of bankfull cross-section dimensions, reach slope and length, and riparian condition. Fine-scale topography data were used to map stream channels and estimate stream dimensions along the entire stream network. Empirical models describing changes in bankfull conditions based on watershed area were also used. Riparian conditions were characterized from land-cover data in floodplains, which were defined as areas within 2 m (6.6 ft) of the adjacent surface water body. For low-order, headwater streams, estimates of bankfull discharge generally were two to five times greater than the SWAT estimates. Sediment yields estimated by SWAT, however, were as much as ten times higher than the SedNet stream bank erosion estimates. Results highlight

stream sections predicted to produce significantly higher sediment loads using factors such as smaller stream reaches or reaches with lower topographic gradients and more extensive riparian vegetative cover.

The SWAT and SedNet models were applied to the upper Spring Creek Watershed, which includes both the treatment and reference watersheds. Upper Spring Creek Watershed is referred to as the reference watershed. Impacts from large land-use changes were evaluated using SWAT, specifically to investigate whether flow and sediment discharge predicted using alternate land management scenarios were likely to be discernible after accounting for the uncertainty in the calibrated model. The modeling effort focused on an evaluation of land-use impacts on flow and suspended sediment delivery to three gaged outlets in the Spring Creek Watershed. A time series of land-use and land-cover conditions were used to evaluate how human impacts across the watershed might confound streamside efforts to improve water quality during the study period (1990 to 2002). In addition, the sensitivity of the SWAT and SedNet models to the land-use and land-cover input was assessed by generating hypothetical land-use and land-cover datasets, in which all croplands had been converted to development or forest, and characterizing the effects on the predicted outflows. Climate change impacts were not evaluated.

There was very little individual land-use data available across the watershed, which influenced the scenarios selected. Changes in predicted flow and sediment discharge were quantified based on land-cover data for the Spring Creek Watershed from 1993, 2000, and 2006. Throughout that time period, developed lands increased from 22% to 26%, while croplands decreased from 34% to 30%. Two additional land-cover scenarios were simulated: all croplands in the 1993 land-cover dataset were converted either to forest or development. The differences in discharge expected from land-use changes were compared to the errors between predicted and observed discharges in the model calibration.

When SWAT was used and land use was changed (e.g., converting to all croplands or to all developed land), the flow predictions changed in the correct direction, but the absolute magnitude of predicted changes was compared to the error or uncertainty in the model predictions. Predictions from the SedNet model were much more sensitive to land management, especially in the riparian area. An all-forest cover scenario reduced predicted sediment by 90%, and an all-agriculture scenario increased predicted sediment by 26%. SedNet-estimated sediment yields were approximately 50% lower than the SWAT predictions.

For the SWAT model, effects of land management in hillslope areas based on the hypothetical land-use scenarios were also considered. The limited sensitivity, or change in the modeling results in response to these best (all-forest) or worst case (all development) scenarios, suggested that flow and sediment predictions would not change in response to incorporating more-detailed conservation practice information applied across a small subarea of the watershed segments. The model's limited capability likely reflects the complex hydrologic setting, and in particular, the role of karst springs in regulating flow throughout the stream network. Limited water quality data at the gage stations also limited the ability to fine-tune both the SWAT and SedNet models. For the SedNet model, animal enclosures in the riparian and floodplain areas were represented by converted cropland or barren areas relative to naturally vegetated zones.

The SWAT and SedNet models, taken together, suggest that stream banks contribute as much sediment, or more, than upland erosion. Bank erosion driven by slope of stream reach and land cover in the stream reach appears to be an important source of suspended sediment. Results from the SedNet model also suggest that floodplain deposition limits sediment delivery

to downstream gage stations. The predictions were consistent with the field data, which showed that riparian best management practices improved water quality at the treatment site but have limited effects on water quality in down-gradient reaches.

No individual uncertainty analyses were used with either model. Comparing the results of both models, however, provided a basis for assessing uncertainty in the model predictions. This approach accounts for uncertainty in the underlying conceptual structure of each model.

Water Quality Response

This project documented the effectiveness of a set of restoration practices: narrow, vegetated riparian buffers, stream crossings, and stream bank stabilization on grazed lands. Total suspended solids and fine sediments did decline in the fenced pastures, and macroinvertebrate habitat improved; however, fish community structure did not change, and although there was no apparent increase in reproductive success, brown trout numbers for fish ages one and older increased, particularly in Cedar Run. Nutrient concentrations remained unchanged, and the streams have not been delisted.

Phase I Monitoring

According to Carline and Walsh (2007), the grazed stream banks almost completely revegetated after fencing. Stream width remained unchanged, except at one location (Slab Cabin Run restored site 3), and stream depth significantly decreased in one ungrazed sampling site (Cedar Run) and one treated site (Slab Cabin Run restored site 3). Percent fines decreased for both Cedar Run ungrazed and grazed sites but actually increased for the Slab Creek Run restored site 3 location. An additional sampling in 2005 after higher flows indicated lower fines. Below-average streamflows in Slab Cabin Run after conservation practice implementation may have been responsible for the lack of change. Taken together, the conservation practices increased vegetation but did not change stream morphology. The effect on fines was location dependent.

After riparian treatments, suspended sediments during baseflow and stormflow decreased by 47% to 87% in both streams. The watershed TSS data strongly suggest that the exclusionary fencing, stream crossings, and riprap reduced stream bank scouring.

Macroinvertebrates were primarily Amphipoda and Diptera in Spring Creek; Amphipoda, Isopoda, and Diptera in Cedar Run; and Isopoda, Coleoptera, and Diptera in Slab Creek Run. Macroinvertebrate diversity did not improve after restoration in either treated stream. Relative to Spring Creek, macroinvertebrate densities increased in both treated streams by the end of the posttreatment sampling period. Total taxa richness and Ephemeroptera, Plecoptera, and Trichoptera (EPT) taxa richness were highly variable and did not display consistent trends. Despite drought conditions that may have altered physical and biological effects of riparian treatments, goals of the riparian restoration to minimize erosion and sedimentation were met.

Phase II Monitoring

Brooks et al. 2011 reported that baseflow and stormflow TSS concentrations decreased from pre to postconditions in Cedar Run (17.75 to 1.0 mg L⁻¹) and Slab Cabin Run (29.3 to 1.0 mg L⁻¹). However, nutrient concentrations remained essentially constant over time. Orthophosphorus concentrations were 0.0003 mg L⁻¹ in Spring Creek, 0.0004 mg L⁻¹ in Cedar Run, and 0.02 mg L⁻¹ in Slab Cabin Run. Nitrate-nitrogen concentrations were 2.5 mg L⁻¹ in Spring

Creek, 4.4 mg L⁻¹ in Cedar Run, and 2.6 mg L⁻¹ in Slab Cabin Run. There was a significant decline in percent fines in both treatment streams: from ~26% to ~10% in Cedar Run and from ~25% to ~15% in Slab Cabin Run. After conservation practice implementation, percent fines increased above pretreatment percentages in Slab Cabin Run. By 2007, however, there was a significant reduction in fines, but it is believed that the response in Slab Cabin Run was delayed due to drought. Cedar Run has stable baseflows due to groundwater discharges, compared to Slab Cabin Run, which is a losing stream during dry periods.

Nested multiple regression models were used to test whether communities in treatment streams differed significantly between years, streams, and/or sites with respect to macroinvertebrate density, taxa richness, EPT richness, and Shannon diversity index. Community composition of macroinvertebrates was stable over the sampling period and was similar for all three streams. The three orders, Diptera, Amphipoda, and Isopoda, represented two-thirds of all species sampled. Three other orders, Ephemeroptera, Trichoptera, and Coleoptera, were consistently found in low numbers during the sampling for all streams.

Macroinvertebrate densities from both May and August samplings increased in treatment streams following restoration, although the response was delayed in Slab Cabin Run. Ratios of macroinvertebrates in the reference restored stream decreased from around 3 (1992) to 0.75 (2007) for Cedar Run and 4 (1992) to 1.5 (2007) for Slab Cabin Run (May sampling). The August sampling demonstrated similar ratio changes: 2.1 (1992) to 0.5 (2007) for Cedar Run and 2.9 (1992) to 0.6 (2007) for Slab Cabin Run.

There was an interaction between year, stream, and site effects for taxa richness, EPT richness, and diversity, thus masking any main effects. When the data were reviewed by site effects, the furthest downstream sampling site in Cedar Run demonstrated a significantly higher EPT richness and taxa richness after conservation practice implementation than the pre-restoration period. In addition, several EPT genera were found that were not present prior to fencing (*Ephemerella*, *Drunella*, *Ceratopsyche*, *Cheumatopsyche*), order Diptera, and class Gastropoda. Likewise, Slab Cabin Run demonstrated significantly higher taxa and EPT richness at the furthest downstream monitoring site. Mayfly (*Ephemerella*, *Eperorus*) and caddisfly (*Cheumatopsyche*) genera, riffle beetles (*Optioservus*, *Promoresia*), and snails (Gastropoda) were only present posttreatment.

Samples taken in May indicated that there were no apparent changes in fish community composition from 1992 through postconstruction years in any of the streams; the most abundant species were slimy sculpins, brown trout, and white suckers. Over the sampling period, density of age-one and older brown trout increased significantly in Cedar Run (95% higher); because the density of brown trout age one and older decreased in the Upper Spring Creek, the two streams had about the same density of fish (~67 trout 100 m⁻¹ [20 trout 100 ft⁻¹]). In the Slab Cabin Run, although trout density increased slightly during the posttreatment phase, populations were low. Brown trout samples taken in August did not reveal any consistent increases in trout less than one year in age. This measure is indicative of reproductive success.

Results from the paired water quality study showed mixed results for the different constituents or biological indicators monitored. Conservation practices to exclude cows from streams and stabilize banks reduced TSS and fines in the treatment watersheds—Cedar Run and Slab Cabin Run. However, nutrient concentrations were unchanged. In addition, fish composition and brown trout (less than one-year old) populations were not affected by treatment, although the numbers of brown trout (greater than one-year old) increased significantly in the treatment watersheds.

Macroinvertebrate densities increased significantly after conservation practices were introduced, but due to drought, some of the benefits from the conservation practices were not immediately evident. Because site, year, and stream interacted, it was difficult to show changes in EPT or taxa richness. This study indicates the importance of a good water quality design and that it is important to monitor for many years after practice implementation to ensure sufficient time for tracking the effects of rainfall variability on stream abiotic and biotic components.

In work separate from the paired-watershed study, a cross vane structure was installed in an incised section of Slab Creek Run in the marsh area, and in situ water quality monitoring was initiated in both the upstream and downstream positions. For the study, pH, temperature, dissolved oxygen, and turbidity were monitored. Stream discharge was estimated from a nearby USGS gage, and turbidity was converted to TSS, which allowed sediment loads to be calculated for two monitored storm events. Based on these two sampling events, the cross vanes reduced sediment load by 5% to 19%.

Socioeconomic Analysis

Riparian landowner perceptions and attitudes towards streams and riparian areas were investigated using qualitative and quantitative methods:

1. In-depth, semistructured interviews were conducted of 16 riparian landowners (five farmers, six hobby farmers, and five nonfarmers). The study included nonagricultural landowners for a comprehensive picture of adoption behaviors and processes in the Spring Creek Watershed.
2. A mail survey of riparian landowner attitudes in Spring Creek Watershed was implemented in 2009. Data showed that there were approximately 700 agricultural or residential riparian property owners. A simple random sample selected 500 landowners for the survey, of which 175 responded (38%).

Interview data revealed that both agricultural and nonagricultural landowners had implemented riparian buffers. Agricultural landowners often implemented their buffers through policy-sponsored programs, such as the Conservation Reserve Enhancement Program (CREP) or more local restoration initiatives, while nonagricultural landowners with buffers implemented these buffers under their own impetus or sought out these programs for themselves. Agricultural properties enrolled in CREP often had more “complete” buffers than non-CREP buffered streams, meaning that these buffers often spanned the entire length of the stream and extended farther from the edge of the stream.

A major obstacle of riparian buffer adoption was landowners’ outcome expectations or the degree to which landowners perceived a riparian buffer on their property could evoke change. Riparian landowners who perceived that buffers improved water quality were more likely to adopt those practices than landowners who did not. Low outcome expectations were often associated with small parcel sizes and low awareness of nonpoint water quality impacts. These low outcome expectations point to one major obstacle of widespread riparian buffer adoption: government agencies (e.g., Soil and Water Conservation Districts, federal programs) and environmental organizations (Chesapeake Bay Foundation, local watershed groups) target agricultural landowners for conservation practice implementation and fail to effectively reach nonagricultural landowners for riparian buffer implementation or restoration.

The mail survey echoed qualitative findings. Survey responders consisted of traditional farmers (15%), hobby farmers (16%), and nonagricultural landowners (69%). Thirty-three percent of the respondents had less than 0.4 ha (1 ac) of land abutting the stream, 26% had 0.4 to 4.0 ha (1 to 10 ac), 14% had 4.0 to 16 ha (10 to 40 ac), and 17% had greater than 16 ha (40 ac). A comparison across landowner types indicated the following:

- Traditional farmers perceived they were more knowledgeable about the stream on their property than hobby farmers.
- Traditional farmers had heard significantly more about riparian buffers than residential riparian landowners.
- Nonagricultural landowners rate water quality of the stream on their property significantly higher than traditional farmers.
- Traditional farmers are significantly more likely to agree than residential landowners that buffer maintenance is too time consuming.

Overall, the mail survey indicated that agricultural landowners were 94% more willing to adopt riparian buffers than nonagricultural landowners, given other factors. Willingness to adopt riparian buffers (which may have included riparian fencing, vegetative plantings, or stream setbacks) increased with stronger neighborhood friendships, after the other factors listed above were accounted for. In addition, landowners who believed that buffers would contribute to water quality protection demonstrated increased adoption willingness, after the other factors listed above were accounted for. Two obstacles related to buffer characteristics were identified:

1. Buffers take up too much space, especially for small, residential properties.
2. Buffer vegetation is inconsistent with aesthetic norms in mixed land-use areas, such as mowed lawns or park-like conditions.

Some riparian landowners responded to the survey that they did not have creeks on their property. This response was likely due to the following:

- Incorrect surface water hydrology data
- Urban development and associated channel relocation or stream burial
- Landowner perception that they do not have a stream where surface flows are present
- Landowner perception that intermittent or ephemeral streams are not actually streams

Outreach

This project did not involve formal extension or extensive outreach activities because education was handled by the Canaan Valley Institute of Applied Research and Technical Outreach in West Virginia. No formal extension publications were developed for this project, but there was one landowner meeting in June of 2010 toward the end of the project. The intent of this meeting was to discuss the buffer survey and to provide results from the paired-watershed study. Invitations were through the mail, and turnout was low, although some landowners interested in potential restoration of riparian areas did attend. In addition, Robert Brooks and Susan Yetter (Pennsylvania State University), and Robert Carline (retired from Pennsylvania State University) conducted a webinar on September 1, 2010, called Assessing BMPs in the Spring Creek Watershed, for the Pennsylvania State University Agriculture and Environment Center. Several dozen practitioners from agencies and conservation organizations participated in the discussion following the presentation.

Spring Creek Watershed National Institute of Food and Agriculture–Conservation Effects Assessment Project Publications

This project's results have been appeared in numerous conference presentations and in other publications. The list of these publications is provided below.

Publications

- Armstrong, A., R. Stedman, and J. Shortle. 2009. Progress Report: Riparian Landowner Behavior in the Spring Creek Watershed, Pennsylvania. November 23, 2009.
- Armstrong, A. and R.C. Stedman. 2012. Landowner willingness to implement riparian buffers in a transitioning watershed. *Landscape and Urban Planning*105: 211–220.

Presentations

- Armstrong, A., and R.C. Stedman. 2010. water quality conservation and private landowners: Why landscape matters. Rural Sociological Society Annual Conference, August 2010.
- Armstrong, A., R.C. Stedman, J.A. Bishop, and P.J. Sullivan. 2011. What's a stream without water? Landowner perceptions of intermittent streams as disproportionate sources of water quality pollution. 2011 Land Grant and Sea Grant National Water Conference, Washington, DC, January 2011.
- Armstrong, A., R.C. Stedman, and J. Shortle. 2009. Landowner adoption of riparian best management practices along the urban-rural gradient. Rural Sociological Society Annual Conference, August 2009.
- Armstrong, A., R.C. Stedman, J. Shortle, and R. Brooks. 2009. Linking landowners to wetlands: Attitudes and Perceptions of Riparian Buffers. Poster. Society of Wetland Scientists Annual Conference. Awarded honorable mention, best poster, June 2009.
- Goslee, S.C., and D.A. Piechnik. 2010. Monitoring pasture best management practices in Spring Creek Watershed of central Pennsylvania. Northeastern Pasture Consortium Meetings, Fairlee, VT, February 2010.
- Piechnik, D.A., and S.C. Goslee. 2011. Best management practices in Spring Creek Watershed. Northeastern Pasture Consortium Meetings, State College, PA, February 2011.
- Piechnik, D.A., and S.C. Goslee. 2011. Evaluating watershed-scale effects of agricultural land use and best management practices on water quality in Spring Creek. USIALE, Portland, OR, April 2011.
- Piechnik, D.A., S.C. Goslee, and T.L. Veith. 2010. Assessing performance of conservation based best management practices: Coarse vs. fine-scale analysis. Meetings of the Ecological Society of America, Pittsburgh, PA, August 2010. <http://precedings.nature.com/documents/5248/version/1>.
- Piechnik, D.A., S.C. Goslee, and T.L. Veith. 2010. Assessing performance of conservation-based best management practices: Coarse vs. fine-scale analysis. Rural-Urban Interfaces, Atlanta, GA, April 2010.
- Piechnik, D.A., S.C. Goslee, and T.L. Veith. 2010. Assessing performance of conservation based best management practices: Coarse vs. fine-scale analysis. USIALE, Athens, GA, April 2010.
- Piechnik, D.A., S.C. Goslee, and T.L. Veith. 2010. Landscape characterization & coarse vs. fine-grained bmp assessment. USDA ARS Pasture & Watershed Management Seminar Series, May 2010.
- Yetter, S.E., R.F. Carline, and R.P. Brooks. 2009. Evaluation of abiotic and biotic responses to best management practices in small agricultural streams of the Spring Creek Watershed in central Pennsylvania. USDA Cooperative State Research, Education, and Extension Service National Water Conference, St. Louis, MO, February 10, 2009.

Thesis

- Armstrong, A. 2010. River of Dreams? Factors of Riparian Buffer Adoption in a Transitioning Watershed. Master's thesis, Cornell University.

Fact Sheet

Piechnik, D.A., and S.C. Goslee. 2011. USDA-ARS Fact Sheet: GIS-Based Approach Improves Accuracy of Placing Pasture Best Management Practices.

Outreach Poster and Presentations

Carline, R.F., and S.E. Yetter. 2010. Stream Responses to Riparian Restoration in the Spring Creek Watershed, PA. Pennsylvania State University & Canaan Valley Institute, State College, PA, June 2010.

Piechnik, D.A., and S.C. Goslee. 2010. Best Management Practices in Spring Creek Watershed. Pennsylvania State University & Canaan Valley Institute, State College, PA, June 2010.

Project Web Site

Riparia. <http://www.riparia.psu.edu>.

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Project Personnel

Robert P. Brooks (ecologist, Pennsylvania State University) was the project investigator. Coproject investigators included Robert F. Carline (retired, Pennsylvania State University), Kathleen Boomer (research ecologist, Smithsonian), Donald Weller (senior scientist, Smithsonian), and George Constantz (Pennsylvania State University). Other participants included Susan E. Yetter (ecologist, Pennsylvania State University), Richard Stedman (sociologist, Cornell), James S. Shortle (economist, Pennsylvania State University), Tammie Veith (agricultural engineer, USDA Agricultural Research Service), Sarah Goslee (ecologist, USDA Agricultural Research Service) Denise Piechnik (postdoctoral fellow, USDA Agricultural Research Service), Hannah Ingram (research support technician, Pennsylvania State University), Ann Armstrong (graduate student, Cornell University), Joseph A. Bishop (research associate, Pennsylvania State University), and Kristin Mielcarek (watershed circuit rider, Canaan Valley Institute).

The original project was due to the efforts of one individual, who worked with the land-owners to install conservation practices. The work was conducted by a loose aggregation of organizations. The Clearwater Conservancy was the nominal head of this work that consisted of the Pennsylvania Fish and Boat Commission, University Area Joint Authority (wastewater treatment plant), Pennsylvania Department of Environmental Protection, Cooperative Extension, and the Chesapeake Bay Foundation.

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- USEPA (United States Environmental Protection Agency). 2011. Clean Water Act Section 303. Water Quality Standards and Implementation Plans. <http://water.epa.gov/lawsregs/guidance/303.cfm>.