Influences of High-flow Events on a Stream Channel Altered by Construction of a Highway Bridge: A Case Study

Lara B. Hedrick\textsuperscript{1,*}, Stuart A. Welsh\textsuperscript{2}, and James T. Anderson\textsuperscript{3}

Abstract - Impacts of highway construction on streams in the central Appalachians are a growing concern as new roads are created to promote tourism and economic development in the area. Alterations to the streambed of a first-order stream, Sauerkraut Run, Hardy County, WV, during construction of a highway overpass included placement and removal of a temporary culvert, straightening and regrading of a section of stream channel, and armourment of a bank with a reinforced gravel berm. We surveyed longitudinal profiles and cross sections in a reference reach and the altered reach of Sauerkraut Run from 2003 through 2007 to measure physical changes in the streambed. During the four-year period, three high-flow events changed the streambed downstream of construction including channel widening and aggradation and then degradation of the streambed. Upstream of construction, at a reinforced gravel berm, bank erosion was documented. The reference section remained relatively unchanged. Knowledge gained by documenting channel changes in response to natural and anthropogenic variables can be useful for managers and engineers involved in highway construction projects.

Introduction

Natural stream channels are achieved by allowing streams to develop a stable dimension, pattern, and profile. In a stable system, the streambed neither aggrades nor degrades, and its sediment load is consistently transported (Allen 1995, Schumm 1977). Alteration of the natural stream channel may lead to channel instability, which occurs when a streambed is degraded by scouring processes, or excessive sediment deposition leads to aggradation (Rosgen 1996).

Wolman (1967) initially categorized stages of stream channel change in response to urbanization. The first stage is equilibrium and stream channel stability. As development and construction begin in the second stage, sediment delivery rates increase leading to channel aggradation. The third stage is an urban landscape with increased areas of impervious surfaces leading to decreased sediment inputs and channel degradation due to flash discharges with low sediment yield (Wolman 1967). Subsequent studies on effects of urbanization indicate that stream channels respond to early stages of construction with an increase in sediment influx resulting from erosion of exposed,
unvegetated channel banks (Urbana and Rhoads 2003) and the land surface due to recontouring and leveling (Wohl 2000). Enlargement of the floodplain can occur as sediment material the stream cannot carry is deposited as floodplain alluvium (Graf 1975). Additional responses to increased urbanization include channel widening (Colosimo and Wilcock 2007, Grabel and Harden 2006, Hammer 1972), channel incision (Booth 1990, Doyle et al. 2000), erosion of unarmoured banks, and aggradation of the streambed (Colosimo and Wilcock 2007, Grabel and Harden 2006, Hess and Johnson 2001).

Road construction along stream corridors, including road crossing and stream channel alteration, changes the structure, function, and stability of stream channels (Albanese and Matlack 1998, King and Ball 1965). Road crossings such as bridges and culverts can influence stream hydraulics and sediment transport (Duck 1985; Johnson 2002, 2006). Bridges and culverts often restrict flow across the floodplain due to high embankments or approaches to the bridge or culvert. Bridges can either be single span, with no pillars in the stream, or multiple span, with one or more pillars in the stream. Pillars in the stream alter the natural flow regime and cause scouring upstream, and deposition downstream. A stream channel that was straightened and constricted with steep banks may not allow flow to intercept the floodplain. The importance of the floodplain is to dissipate the energy of flows exceeding the effective discharge (Ward et al. 2002). If a culvert is present, water can back-up upstream creating localized channel widening. If the flow is forced to remain in the channel instead of intercepting the floodplain, it will increase the sheer stress and velocity, resulting in bank erosion and failure, and streambed degradation (Graf 1975, Johnson 2002, Richardson and Davis 2001).

Roads that cross a stream at mid-slope and bridge spans built on cut-and-fill material can be sources for debris flows. Debris flows are rapid movements of soil, sediment, and organic matter down steep stream channels. Heavy rains can trigger landslides of the fill material and, if near a stream, can result in a debris flow. Debris flows can move downstream, encounter a road or culvert, and either continue movement of fill downstream or deposit it. The major impact of debris flows is movement and rearrangement of sediment. Debris flows mainly occur during floods and are most severe on small, steep stream segments (Jones et al. 2000). If the stream cannot carry the sediment load, it may be deposited on the floodplain, creating new sediment bars, and enlarging current ones by vertical accretion (Graf 1975).

The stability of a stream is associated with a balance between variables such as width, depth, velocity, slope, sediment volumes, and sediment sizes. Changes in a stream's dimension, pattern, and profile due to changes in these variables can result in deteriorated water quality (Trimble 1997, US EPA 1994), reduction in quality and diversity of habitat, negative impacts on aquatic communities (Jones et al. 1999, Rabeni and Smale 1995), and land loss through erosion (Hammer 1972, Rosgen 1996). Monitoring a stream over time can be used to determine if the stream is aggrading, degrading, or
laterally eroding, and can provide information on stream response to alteration. This article presents a case study of a first-order stream that was altered by channelization, placement and then removal of a culvert, and creation of a reinforced gravel berm in association with construction of a highway overpass. During construction of a highway overpass across the stream, four periods of high flows were documented. We predicted that changes to the streambed associated with road construction would cause a decrease in stream stability that we would be able to document through measurements of longitudinal profile and stream cross-sectional area. Our objectives were to collect data from a reference reach upstream of the construction zone and an altered reach within and downstream of the construction zone, and compare these to determine if construction activity and channel alteration affected streambed response to high-flow events.

Site Description

Sauerkraut Run, a tributary to the Lost River, is located in the eastern panhandle of West Virginia (Fig. 1). The average bankfull width of the stream is 7.20 m (± 1.45 m), average water depth is 0.20 m (± 0.13 m), and stream slope is approximately 2%. This first-order stream is paralleled by a rural road and is culverted in several locations. Sauerkraut Road was included into the state highway system by legislative action in the 1930s. Prior to that, it was maintained by the county as a dirt and gravel road. In 1999, it was surface-treated with asphalt, and the downstream-most section of the stream was channelized.

Construction over Sauerkraut Run began in April 2002, and a new temporary culvert was placed across the stream in the construction zone for access by heavy machinery and construction crews. Streamside vegetation was cleared along a 100-m stretch within the construction zone, and a reinforced gravel berm was created to direct the stream flow through this channelized reach (Fig. 2).

During this study, Sauerkraut Run experienced four high-flow events. Flow measurements were obtained from a USGS gauge located on Waites Run, a neighboring tributary of the Lost River. There was a high correlation ($r^2 = 0.98$) between flow data collected on site and data obtained from the USGS gauge. High flows during November 2002 scoured the streambed downstream of the temporary culvert, changing the morphology of the streambed. A second high-flow event occurred as a result of Hurricane Isabel’s influence in September 2003. The eastern panhandle of West Virginia received 7.5 to 10 cm of total precipitation between September 19 and 21, 2003 (Southeast Regional Climate Center, www.sercc.com). In December 2003, a third period of high flow was recorded. During the first week of September 2004, heavy rains and high flows resulting from the effects of Hurricane Frances caused Sauerkraut Run to reach flood stage. The stream washed out many of the state crossings and pre-existing culverts, and ran over the road in several places. The West Virginia Department of Highways
repaired the road and stabilized pre-existing culverts during the week of September 6–10, 2004. They also removed the temporary culvert within the construction zone.

**Methods**

**Longitudinal profile**

We surveyed a longitudinal profile of Sauerkraut Run during July 2004, October 2004, November 2005, and March 2007. The survey covered 670 m of stream length, beginning one channel unit upstream from the most-upstream cross section, at the head of a pool, and continuing to the State Route 55 bridge located downstream from highway construction (Fig. 2). Channel units are homogeneous areas in a channel that differ in depth and velocity from adjoining areas. The term is generally used for small to midsize streams and refers to pools and riffles (Bisson et al. 2006). The longitudinal profile...
consisted of a reference reach (approximately 330 m) and an altered reach (approximately 337 m) (Fig. 2). We surveyed the longitudinal profile with an engineering level (Transit Level by David White, Universal LT8-300P model 8871) and survey (stidia) rod and established permanent benchmarks where necessary along the stream to enable the surveyor to view the rod throughout the length of the profile. Elevations were referenced to the local benchmark with an assigned an elevation of 30.5 m. At the beginning of each channel.

Figure 2. Locations of cross-sectional surveys along the longitudinal-profile survey of Sauerkraut Run.
unit (head of riffle, head of run, head of pool), features including left bankfull, left edge of water, thalweg, water surface, right edge of water, and right bankfull, were surveyed.

Cross-sectional surveys

We established four cross sections on Sauerkraut Run, two in each of the reaches: a reference reach upstream of construction, and an altered reach downstream of construction (Fig. 2). Reference Reach 1 cross section was located 7.5 m upstream from a permanent culvert on Sauerkraut Run; Reference Reach 2 cross section was located 78 m upstream of the construction site and had unaltered banks of native vegetation and a riparian zone width of 45 m; Altered Reach 1 cross section was located 108 m upstream from the site of a temporary culvert (removed in September 2004) at a reinforced gravel stream bank; and Altered Reach 2 cross section was located downstream from the temporary culvert, and 23 m upstream from the State Route 55 bridge crossing. We originally surveyed cross sections in 2003, and resurveyed them in 2004, 2005, and 2007. We took distance and elevation readings at 0.305-m intervals, at obvious breaks in the slope, and at major features associated with the stream, including bankfull, edge of water, thalweg, and any bar formations. At each cross section, a permanent benchmark (a piece of 1.25-cm diameter rebar driven into the ground) was established on a stable site above the bankfull channel, and elevations were referenced to the local benchmark.

Changes over time in cross sections determine vertical stability of the streambed, and differences over time in the longitudinal profile document changes in stream length, gradient, riffle frequency, and maximum pool depth. We determined the change in cross-sectional area ($\Delta A$) as scour or degradation (a negative value) or as fill or aggradation (a positive value). We also used four indices described by Olson-Rutz and Marlow (1992) to assess changes in stream cross sections: net percent change in area, absolute percent change in area, width/depth ratio, and Gini coefficient.

- Net percent change in area ($\Delta A\%$) quantifies the net change in cross-sectional area of a transect. It can be a positive or negative value depending on whether the channel is experiencing aggradation and degradation. However, if erosion in one part of the channel equals the amount of deposition in another, the value could approach zero, indicating little change in the stream channel. The absolute percent change in area ($|\Delta A\%|$) quantifies cumulative channel change ($|\Delta A\%| = \text{erosion} + \text{deposition}$), and represents the total amount of streambed material movement between two surveying dates.
- The width/depth ratio ($w/d$) is a relative index of channel shape. Width is the total distance across the channel, and depth is the mean depth of the channel. Channels with high $w/d$ ratios tend to be shallow and wide, and those with low $w/d$ ratios tend to be narrow and deep. The Gini coefficient ($G$) describes changes to channel cross-sectional shape. The direction and magnitude of change in the Gini coefficient over time describes whether a channel is becoming wider and shallower or narrower and deeper in response to changes in cross-sectional area.
to management or natural events. Wide, flat channels have low G values, and deep, narrow channels have G values near 1. When the Gini coefficient is calculated from pre- and post-treatment scenarios, the difference (diff) in G (G_{diff} = G_{post} - G_{pre}) describes the direction of channel change. Positive differences indicate the channel is becoming deeper and narrower. Negative differences indicate the channel is becoming shallower and wider. (Olson-Rutz and Marlow 1992).

Measurements were taken at identical points along the transect to compare different dates. Data collected were aligned at 0.305-m intervals, and any points missing were extrapolated using distance and depth from closest known points on either side. Data may have become misaligned in the field when important features, such as gravel bars, were surveyed in at smaller increments than 0.305 m.

Stream cross-section measurement dates were given a designation of post high-flow or normal flow. Post high-flow designation meant that a high-flow event occurred during the time period between the two sampling events, otherwise a designation of normal flow was used. Flow data were obtained from a USGS gauge located on Waits Run, a neighboring tributary of the Lost River. We compared stream cross-sectional area, and other indices (ΔA% and |ΔA%|) for post high-flow and normal-flow cross sections at reference and altered locations using analysis of variance (ANOVA).

At three of the cross sections (Reference Reach 1, Reference Reach 2, and Altered Reach 2), three metal-link scour chains were established across the stream (Laronne et al. 1994, Lisle and Eads 1991). The chains were installed vertically in the streambed and included a duckbill anchor attached to a 0.6-m long section of galvanized chain driven into the streambed with a drive rod. We removed extra exposed chain with a pair of metal cutters so that only two links remain exposed. One scour chain was placed near the right edge, one near the center of the stream, and one near the left edge of the stream. Locations of the scour chains were surveyed in as features in the cross sections. Scour was monitored by counting the number of chain links exposed after a high-flow event. We measured fill by determining the thickness of the sediment layer deposited on top of the originally exposed links. Scour chains also can be used to detect scour-before-fill. When a streambed is first scoured it will expose some links that will lie horizontally. If the streambed is then subjected to sediment deposition, those links will be buried.

**Results**

**Longitudinal profile**

Within the 330-m reference reach there was a braided section approximately 61 meters in length and located at 223 m (Figure 3A). This section had three channels: a right, left, and mid-channel. During the first two surveys in August and September 2004, most water flowed down the middle channel. In November 2005, most of the flow was down the channel on river right. The reaches upstream and downstream of the braided channel had
Figure 3. Longitudinal profile of Sauerkraut Run showing (A) the thalweg on the entire reach surveyed; (B) the thalweg of the reference reach; and (C) the thalweg of the altered reach from 2004 through 2007. Elevations were referenced to the local benchmark with an assigned elevation of 30.5 m.
degraded approximately 0.1 to 0.3 m, and the middle channel was closed due to a debris jam. The channel on river right was approximately 0.3 to 0.6 m lower in elevation than the middle channel. In March 2007, we surveyed the center channel again. A gravel bar and snag pile had closed off the right channel, and most of the stream flow was traveling back down the center channel. The length of the middle channel was classified as a long riffle in August 2004. When it was surveyed again in September 2004, we noted several small pools. In 2007, the middle channel was again classified as one continuous riffle, and the channel thalweg had aggraded approximately 0.6 m (Fig. 3B).

The altered reach of Sauerkraut Run from the reinforced gravel stream bank (Altered Reach 1) downstream to the State Route 55 bridge (330 to 677 m) went through several changes during the 4 years of the study (Fig. 3C). The temporary culvert was removed in September 2004. Upstream of the temporary culvert was a long, straight channelized riffle section. Once the culvert was removed, the riffle section upstream remained at the same elevation; however, the thalweg aggraded (Fig. 3C) downstream, as a result of artificial regrading of the stream channel with removal of the culvert. The scour pool located below the culvert was filled. Our survey in November 2005 indicated the long riffle section was forming several small pools, and the entire altered reach degraded between 0.3 to 0.6 m. A small pool was formed at the bend in the stream below the removed culvert. More degradation (about 0.3 m) occurred upstream of the culvert location between 2005 and 2007, and a deep pool was scoured out at the bend downstream of the removed culvert, similar to the pool surveyed in July 2004.

Cross-sectional surveys

Three cross-sectional surveys were taken at Reference Reach 1 and Altered Reach 1, and five were taken at Reference Reach 2 and Altered Reach 2. Two survey periods were designated as high flow: the period between October 18, 2003 and February 22, 2004 and the period between June 11, 2004 and September 26, 2004. The discharge on Waites Run was 4.90 m$^3$ per second (173 cfs) on 11 December 2003. The average for December 2003 was 1.03 m$^3$ per second (36.5 cfs). Discharge on Waites Run was 7.05 m$^3$ per second (249 cfs) on September 9, 2004, 2.89 m$^3$ per second (102 cfs) on September 9, 2004, and 4.16 m$^3$ per second (147 cfs) on September 18, 2004. Average for September 2004 was 1.12 m$^3$ per second (39.5 cfs). Reference 2 and Altered 2 were measured on February 22, 2004, and all cross sections were surveyed on September 26, 2004. Data from cross-section measurements were separated into four categories: reference normal flow ($n = 5$), reference post high-flow ($n = 3$), altered normal flow ($n = 5$), and altered post high-flow ($n = 3$; Table 1).

There was little change in cross-sectional area post high-flow events at Reference Reach 1 and 2 (Fig. 4) with slight aggradation taking place. There was little to no change in w/d or in channel shape ($G_{w/d}$). Cross-section surveys taken post high-flow in the altered reach indicated more cross-sectional
Table 1. Stream cross-sectional measurements associated with the reference reach and altered reach on Sauerkraut Run, Hardy County, West Virginia. ΔA is the measured change in area, ΔA% is the change in percent of stream cross sectional area, |ΔA%| is the absolute value of the percent change in stream cross sectional area. Values with different letters within a column are significantly different (P < 0.05).

| Number of cross sections measured | Area (m²) | ΔA% (P) | |ΔA%| (P) |
|----------------------------------|----------|---------|---|---|
| Reference normal flow            | 5        | 0.86 (0.23) | 1.76 (0.47) | 3.91 (0.45) |
| Reference post high-flow         | 3        | 0.53 (0.31) | 1.05 (0.61) | 4.88 (0.76) |
| Altered normal flow              | 5        | 0.97 (0.41) | 1.99 (1.02) | 5.18 (0.94) |
| Altered post high-flow           | 3        | 5.98 (1.98) | 12.42 (4.45) | 24.14 (7.08) |
Figure 4. Stream cross-sectional profiles of the reference reach before and after high-flow events on Sauerkraut Run, Hardy County, WV. $\Delta A\%$ is the change in percent of stream cross sectional area, $|\Delta A\%|$ is the absolute value of the percent change in stream cross sectional area, $w/d_{\text{pre}}$ is the width to depth ratio before high flow, $w/d_{\text{diff}}$ is the difference in the width to depth ratio before and after high flow, and $G_{\text{pre}}$, $G_{\text{post}}$, and $G_{\text{diff}}$ relate to the Gini coefficient.
amounts of sediment prior to installation of sediment fencing than sites located in the reference reach in 2003 (Hedrick et al. 2007). This stream reach also incurred slight channel aggradation. Channel aggradation is a

Figure 5. Stream cross-sectional profiles of the altered reach before and after high-flow events on Sauerkraut Run, Hardy County, WV. Notation is as defined in Figure 4.
common scenario in early stages of road construction and urbanization (Graf 1975, Gregory et al 1992, Hammer 1972). Urban and Rhoades (2003) compared channelized to natural stream reaches of the Embarrass River in Illinois. The greatest influence on the change in channel location throughout the Embarrass watershed was straightening of the channel, and main channel response was characterized by a slight net aggradation. This result was attributed to an increase in sediment influx resulting from erosion of exposed, unvegetated channel bank.

We also photo-documented changes to the streambed downstream of the temporary culvert in 2002 and 2003. The streambed was dominated by cobble and boulder substrate in spring 2002. High flows in November 2002 moved the large alluvial material and degraded the streambed (Fig. 6). In September 2003, heavy rain related to effects of a hurricane created flows that aggraded the streambed in Altered Reach 2 and deposited a gravel bar on river right (Fig. 6). This gravel bar was surveyed in the first cross section conducted in October 2003.

Sauerkraut Run responded to effects of road construction, including channelization and disruption of the floodplain, with changes varying from aggradation, entrenchment, channel widening, and bed degradation. Channel

Figure 6. Photos of Altered Reach 2 on Sauerkraut Run indicating changes in streambed. The white dot indicates the same tree in each photo. Photo 7-5-02 shows large alluvial material; photo 4-5-03 shows removal of that material following high flow; photo 10-12-03 shows deposition of gravel bed; and photo 12-21-03 shows removal of gravel bed following high flow.
adjustment due to human activity may be of different kinds and spatially discontinuous, and variability can occur along the length of the channel that is changing as a result of urbanization (Gregory et al. 1992). Even small changes in imperviousness of the surrounding land associated with construction can cause severe increases in stream channel instability (Bledsoe and Watson 2001). Changes such as increases in width and bed degradation in the downstream altered reach of Sauerkraut Run were similar to changes found in other studies involving road construction.

Channel widening has been documented by studies conducted in a variety of areas and levels of urbanization. Hammer (1972) found an initial increase in sediment followed by an increase in discharge, downcutting, and channel widening in an urbanizing watershed in eastern Pennsylvania. Pizzuto et al. (2000) also studied streams in Pennsylvania. Their study of paired urban and rural catchments did not differ in slope of bed or mean bankfull depth. However, bankfull width was larger for urban channels. Similar results were found by Hollis and Luckett (1976) in southeast England, Neller (1988) in New South Wales in Australia, and Henshaw and Booth (2000) in Puget Sound in Washington. Grabel and Harden (2006) studied the impacts of human-induced changes to the channel of Second Creek in Knoxville, TN. Changes included deliberate channel realignment and channelization of some reaches. Cross sections indicated a downstream trend of increasing width and area. Channel widening resulting from bank erosion was the dominant accommodation to higher volume peak flows in Second Creek.

Most channel changes in Sauerkraut Run were related to peak flow events. Major degradation of the downstream channel and increased bankfull depth occurred between 18 October 2003 and 20 February 2004, following a period of high flow in December 2003. Between 11 June 2004 and 26 September 2004, the stream bank on the left of Altered Reach 1 located at the reinforced gravel bank was severely eroded. This erosion should have widened the stream channel; however, deposition of a gravel bar on the right side actually caused the streambed to become entrenched. The armored bank on the right side of the Altered Reach 2 cross section also was eroded, causing channel widening. Stream channel changes resulted from high flows due to the effects of Hurricane Frances. Little change was documented at Reference Reach 1 cross section (a small amount of deposition was noted), and no change occurred at Reference Reach 2 cross section. In the reference reach of Sauerkraut Run, the stream is connected to its flood plain and not constricted by artificial stream banks. Entrenchment continued at the Altered Reach 1 cross section site, and thalweg depth increased between September 2004 and November 2005.

Similar results to high flows were found by Robinson and Barry (2001), who conducted a series of cross-sectional surveys on streams on the Wenatchee National Forest before and after flooding, and by Gaeumen et al. (2005), who documented channel widening and bed aggradation of gravel bed channels in the Duechesne River, UT during a period of flooding
between 1981 and 1987. In a study in the central Appalachians, Hicks et al. (2005) found that a brief flash flood produced significant channel change in the small catchment of Saul’s Run, WV.

Nelson et al. (2006) described changes to urban stream channels located in the piedmont region of Pennsylvania and Maryland following high flow from Hurricane Agnes in 1972. In the Patuxent River basin in Maryland, channel widening, removal of all but the coarsest material in the streambed, and destruction of the floodplain vegetation took place. In other areas, dominated by bedrock outcrops and coarse bed and bank material, such as the Conestoga basin in southeastern Pennsylvania and Dead Run in Baltimore County, MD, little change to stream cross sections was noted (Nelson et al. 2006). Western Run, in north-central Baltimore, also experienced channel widening during Hurricane Agnes. However, within one year of the flood, channel cross-sections were rapidly recovering back to pre-flood dimensions (Costa 1974).

Changes in the streambed can impact the health and habitat available for fish and benthic macroinvertebrates. Aggradation and excessive stream sedimentation can alter community composition and abundance of aquatic biota (Jones et al. 1999, Rabeni and Smale 1995), decreases reproductive success and survival of fishes (O’Conner and Andrew 1998, Scrivener and Brownlee 1989), decreases survival of benthic macroinvertebrates due to deposition of silt on the gills (Lemly 1982), and impacts feeding performance of fishes (Sweka and Hartman 2001). Degradation of streambeds may eliminate existing habitat and change stream substrate composition. Benthic macroinvertebrate abundance generally increases across the particle series of sand–gravel–pebble–cobble. However, a more functional relation can be made between invertebrate abundance and substrate heterogeneity. Abundances are least in homogeneous sand or silt, or in large boulders and bedrock. A mixture of gravel, pebbles, and cobble provide the best habitat for benthic macroinvertebrate abundance (Brusven and Prather 1974, Minschall 1984).

Hedrick et al. (2007) calculated the West Virginia Stream Condition Index (WV-SCI) scores for benthic macroinvertebrate samples collected on Sauerkraut Run. The WV-SCI is a multi-metric index developed specifically for West Virginia wadeable streams (US EPA 2000), and includes six normalized metrics using family level data — EPT (Ephemeroptera, Plecoptera, Trichoptera) taxa, total taxa, % EPT, % Chironomidae, % of the top two dominant taxa, and HBI (Hilsenhoff Family Biotic Index). The normalized metric scores range from 0 to 100 and are categorized as >78–100 = very good, >68–78 = good, >45–68 = fair, >22–45 = poor, and 0–22 = very poor. The WV-SCI scores from samples collected downstream of construction in July and October 2002 indicated benthic macroinvertebrate communities in “fair” biotic condition. These samples were collected prior to sediment fencing at the construction site and during a time period when sediment accumulation was significantly greater at the downstream site (Hedrick et al.
The WV-SCI scores increased to “good” following implementation of sediment control; however, scores of “fair” were recorded again in December 2003 following the episode of high flow and scouring of the stream bed. The WV-SCI scores from samples collected upstream remained good to very good throughout the study.

Unlike other studies involving streams impacted by road construction and urbanization, Sauerkraut Run has not been affected by many of the factors associated with urbanization that follow post construction. With the exception of the stream reach within the construction zone, which was straightened and had streamside vegetation removed (Fig. 7), riparian areas were relatively unharmed. There was no increase in impervious surfaces and currently no increase in the residential homes along the stream. Streams altered by incision and channelization tend to degrade until the critical bank height is exceeded and the bank fails. This failure increases channel width and sediment load. However, over time, streams will move toward a new equilibrium, and incision will cease (Fischenich and Morrow 2000, Henshaw and Booth 2000). Most stable reaches are associated with colonization of natural vegetation or when degradation halts because substrates become

Figure 7. Photos of the temporary culvert placed in Sauerkraut Run in April 2002 and removed in September 2004. Arrows indicate location of culvert; black dot indicates the same rock in the photos. Photo 7-5-02 shows area upstream of culvert prior to vegetation removal; photo 10-18-03 shows area upstream of culvert after vegetation has been removed; photo 6-18-04 shows plunge pool downstream of culvert; and photo 9-26-04 shows regarded section of stream following removal of culvert with plunge pool removed.
coarse enough to prevent further incision. Henshaw and Booth (2000) found that streams in developed and developing watersheds in the Puget Sound area, WA, stabilized within 10 years. Some streams stabilized in as little as three years if land use remained constant.

Without further impacts, the streambed in the altered reach of Sauerkraut Run may continue to stabilize, and habitat in the form of pool and riffle complexes may form. However, bank armourment and disconnection of Sauerkraut Run with the floodplain could continue to create a sediment imbalance, forcing the stream to erode still-exposed banks during periods of high flow. Although the reference section upstream of construction showed little change in morphology in response to high flows, cross-sectional profiles of the altered reach indicated changes including channel widening, aggradation, and then degradation of the stream bed. The upstream reference reach is connected to the floodplain and has a healthy riparian buffer of mature trees and vegetation along both banks. This study demonstrates the importance of the flood plain and riparian buffer to stream channel stability. When the culvert was removed in September 2004, the streambed was regraded with gravel material, the elevation was increased by 0.3 m, and a long riffle section was created. Over the next year, as the stream channel adjusted, elevation degraded and several small pools were created. The altered reach would benefit from natural channel design, including the addition of meanders and riffle/pool complexes, and improvement of the riparian zone by planting of trees along the channelized section that passes under the overpass. Riparian vegetation will help prevent the stream from widening and will protect the banks from future erosion. Bernard et al. (2007) provide a comprehensive guide on stream restoration and channel design that could be useful in developing a stream channel and riparian area that would be less likely to become unstable, erode, and cause further sedimentation. Little data has been collected on response of streams in the Appalachian area to highway construction. This study will be useful to managers and engineers throughout the remainder of the highway project currently underway as well as other construction projects in the future.

Acknowledgments

We thank the West Virginia Division of Highways for providing partial support for this research, and Jim Hedrick and Will Ravenscroft for help in collecting data. Reference to trade names does not imply endorsement of commercial products by the US government. This paper is scientific article number 3020 of the West Virginia University Agriculture and Forestry Experimental Station.

Literature Cited


