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**RECOMMENDATIONS FOR CONSTRUCTING FOREST  
STREAM CROSSINGS TO CONTROL SOIL LOSSES**

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**ABSTRACT:** Stream water samples were collected once daily and throughout storms from a small forested watershed in north central West Virginia for approximately 8 years. The turbidities of the samples were measured to determine how water quality changed in response to the construction of three associated stream crossings. The influence of the crossings and the immediate approaches to the crossings could be isolated in this study because sediment inputs from the hillsides of the watershed were restricted by silt fence that was installed along the entire stream perimeter, except in those crossings and approaches to the crossings. Turbidity results prior to, during, and following crossing construction provided valuable information on the short- and longer-term effects that stream crossings can have on water quality. Based on the results of this study, recommendations to reduce soil losses from future crossing construction efforts in steep terrain were developed. These recommendations include: employing full-bench construction, especially where road approaches are at small angles to the stream; requiring the immediate installation of permanent culverts rather than allowing the initial installation of temporary culverts; requiring that in-stream equipment operation pads, if needed, be constructed of large, clean, nonfriable stone; and altering contract language so that soil covering is required within a specified limited number of days after disturbance is started, rather than within a set amount of time after the disturbance in the area is completed.

**KEY TERMS:** culverts; fillslopes; full-bench construction; stormflow; stream turbidity.

**INTRODUCTION**

Sediment is the most common pollutant associated with forestry (Dissmeyer 1994). While harvesting and other silvicultural treatments typically do not cause substantial erosion or sedimentation (Yoho 1980), associated activities, particularly road, trail, and log landing construction and use provide the greatest potential for stream sedimentation (Kochenderfer 1977). Roads, skid trails, and landings have extensive soil exposure and disturbance and are most prone to soil compaction, overland flow, and soil loss. Because these activities are central to many forestry field operations and they can substantially elevate in-stream sedimentation, it is important that they be well planned and carefully executed to avoid excessive nonpoint source pollution. Best management practices (BMPs) are important tools for controlling nonpoint source pollution during forestry operations, but refinements to the practices or improvements to their application from research and case studies are important for better achievement of Clean Water Act objectives.

In this paper, we describe the effects of stream crossing construction on in-stream turbidity. Based on those findings we provide recommendations that could be applied in the future to similar situations to reduce water quality impacts from the construction and presence of stream crossings.

**METHODS**

In fall 1999, an 8-year-long study was initiated on a 32.7-ha forested headwater watershed in the Cheat Ranger District of the Monongahela National Forest, Tucker County, West Virginia. The primary focus of the study was to quantify annual sediment delivery along the entire length of a small stream in the watershed that was to undergo haul road construction and later harvesting. However, stream water samples also were taken at the mouth of the watershed throughout the 8 years to examine in-stream sediment characteristics during various runoff conditions. This paper and the accompanying recommendations focus on the turbidity results from that in-stream monitoring.

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Stream water samples were collected once a day with an American Sigma model 900 automatic collector, except for the period from June 8, 2002 through May 28, 2003 and when water levels were frozen or prohibitively low to collect a water sample. Stream water also was collected throughout precipitation events using an ISCO model 2700 automatic sampler. During the growing season (May to October), stormflow samples usually were collected on 30-minute intervals, whereas dormant season stormflow samples were taken at either 30- or 60-minute intervals if the stream was not frozen and/or the air temperatures did not freeze the uptake lines. If the stream remained frozen for months at a time, stormflow sampling was discontinued until spring melt. Stormflow samples also were not collected from June through September 2002.

The in-stream uptakes for both daily and stormflow samplers were positioned in the thalweg of a bedrock control section. The bedrock provided a "clean" location for sample collection; that is, sediment did not accumulate on the bedrock, so sampling, especially during low flows, could be accomplished without risk of collecting deposited sediment off of the stream bottom.

Stream water samples were processed at the USDA Forest Service's Northern Research Station Timber and Watershed Laboratory in Parsons, WV. Turbidity (NTU) was determined using a Hach model 18900 turbidimeter. The instrument was calibrated using stabilized formazin standards.

Because the experimental design for monitoring sediment delivery in the main part of the study allowed us to isolate the influence of the stream crossings on soil losses, we provide a brief description of the design. The stream network in the watershed was lined continuously with silt fence just upslope from the top of the bank to capture sediment delivered from the hillside (Stedman 2008; Fig. 1). This silt fence effectively eliminated most of the hillside contributions of soil to the stream prior to road construction, so that initial turbidity levels were predominantly from in-stream erosion (i.e., bed and bank). However, once road construction began in summer 2002, soil from the three stream crossings (Table 1) was able to reach the channel. This is because just before road construction activities reached each stream crossing, the silt fence was cut and removed between the in-stream survey stakes designating the inlet and outlet positions of the culverts.

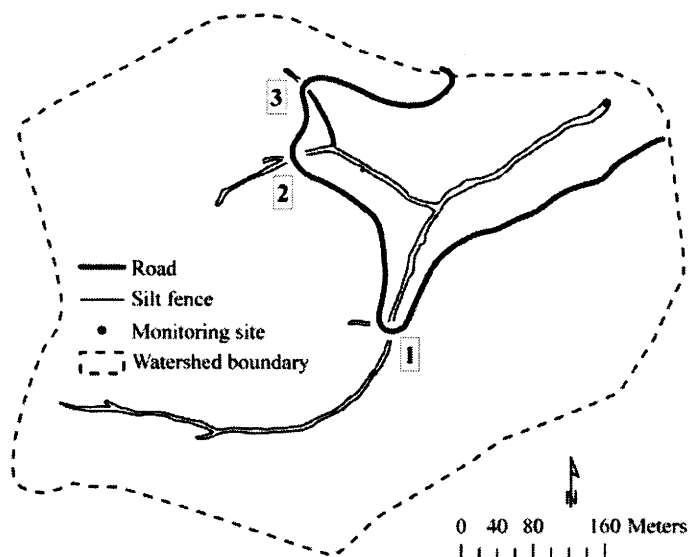


Figure 1. The study watershed with numbered stream crossings.

Furthermore, unbeknownst to us, the road construction contractors detached an additional length of the upstream and downstream sections of the silt fence on the left and right sides of the stream at each crossing (Table 1) just before soil disturbance began because they were concerned that the fence would be damaged or covered by the construction of the fillslopes in the approaches to the crossings. Consequently, for a period of time, soil could reach the stream within lengths of fillslope approaches where the silt fence had been removed. The silt fence was reconstructed at the first stream crossing on October 1-2, 2002, and at the second and third stream crossings on April 10, 2003. The fence was installed parallel to the channel to where it intersected the crossing fills, so it again restricted soil movement to the stream from the fillslope approaches. However, silt fence was not installed across the upstream or downstream faces of the crossings (i.e., the fence on the right and left sides of the channel was not connected), so the crossings themselves remained the primary sources of soil delivery to the channel after the silt fence was reconstructed.

Table 1. Stream Crossing Characteristics.

| Stream Crossing<br>(Culvert Diameter)<br>(m) | Position /<br>Side of Channel | Fill Height<br>Over Culvert<br>(m) | Slope of<br>Fillslope<br>(%) | Road Approach<br>Angle<br>(deg) | Silt Fence Length Pulled<br>Back During Construction<br>(m) |
|----------------------------------------------|-------------------------------|------------------------------------|------------------------------|---------------------------------|-------------------------------------------------------------|
| 1 (1.52)                                     | Upstream                      | 4.0                                |                              |                                 |                                                             |
|                                              | Left                          |                                    |                              | 15                              | 13.7                                                        |
|                                              | Right                         |                                    |                              | 7.5                             | 13.7                                                        |
|                                              | Downstream                    | 7.4                                |                              |                                 |                                                             |
|                                              | Left                          |                                    | 75.9                         |                                 | 14.0                                                        |
| 2 (1.22)                                     | Right                         |                                    | 72.5                         |                                 | 23.2                                                        |
|                                              | Upstream                      | 3.7                                |                              |                                 |                                                             |
|                                              | Left                          |                                    |                              | 46                              | 7.6                                                         |
|                                              | Right                         |                                    |                              | 42                              | 7.6                                                         |
|                                              | Downstream                    | 7.9                                |                              |                                 |                                                             |
| 3 (0.91)                                     | Left                          |                                    | 81.0                         |                                 | 7.3                                                         |
|                                              | Right                         |                                    | 68.4                         |                                 | 12.2                                                        |
|                                              | Upstream                      | 2.0                                |                              |                                 |                                                             |
|                                              | Left                          |                                    |                              | 39                              | 7.3                                                         |
|                                              | Right                         |                                    |                              | 24                              | 10.4                                                        |
|                                              | Downstream                    | 4.5                                |                              |                                 |                                                             |
|                                              | Left                          |                                    | 55.7                         |                                 | 9.1                                                         |
|                                              | Right                         |                                    | 73.4                         |                                 | 9.1                                                         |

Neither road construction nor stream crossing construction was completed in 2002. Instead, the entire 1.9-km road length was pioneered (i.e., roughed in) in 2002. The stream crossings were completed only to the degree needed to allow equipment to access the portions of the road further out in the watershed. Initially a pair of undersized, temporary culverts was installed in the first stream crossing (July 23-25, 2002); these were removed and replaced by a single 1.5-m diameter permanent culvert on September 4, 2002. Permanent culverts were installed at the second and third crossings during pioneering on September 9-10, 2002 and September 12-13, 2002, respectively.

The fills over all three stream crossings remained unvegetated over the 2002/2003 winter. They were hydroseeded on May 7, 2003 with Kentucky 31 fescue (*Festuca arundinacea*), orchard grass (*Dactylis glomerata*), and Ladino clover (*Trifolium repens*) at a rate of 79 kg of each species per ha, followed by liming and fertilization. Chopped straw mulch then was blown onto the crossings. Reasonably thick vegetation became established relatively quickly after seeding.

During the later portion of summer 2003, 10.2-cm diameter limestone gravel was applied to the road surface, including the entire width of the stream crossing road surfaces. Generally, the stream crossings received thicker applications of gravel than the rest of the road. This was primarily because the crossings were at lower elevations than their approaches so that the crossings tended to collect water and remain wet and soft, and therefore, susceptible to rutting.

## RESULTS

The turbidities for the daily samples are shown in Figure 2a. The majority of these samples were collected during baseflow, so in general most of the values are relatively low due to the low detachment and transport energy associated with these flows. Prior to the construction of the stream crossings, turbidity levels generally were <20 NTU, with a least square mean of 1.8 NTU. There were only two obviously elevated turbidities prior to crossing construction; these occurred in 2001 (Fig. 2a). The first was associated with a sample that was collected during a storm event, and the greatest daily pretreatment turbidity value (147 NTU) was associated with a sample taken during a period in which a leaf jam formed in the sample uptake area. This apparently affected the turbidity; approximately 32 percent of the associated total suspended solid concentration of that sample was organic material (unpublished data).

By contrast, after daily sampling resumed in spring 2003 (i.e., after road and crossing pioneering had begun but prior to their completion), the frequency of elevated turbidity values increased noticeably (Fig. 2a). This alteration in turbidities occurred despite that most daily samples continued to be collected during baseflow conditions. Thus, the increases were attributable to increasing sediment supplies to the stream rather than differences in flows at the time of sampling. Elevated values continued to be present through at least 2006. Pairwise comparisons of the least square mean values for the three time periods all were significantly different at  $P < 0.0001$ .

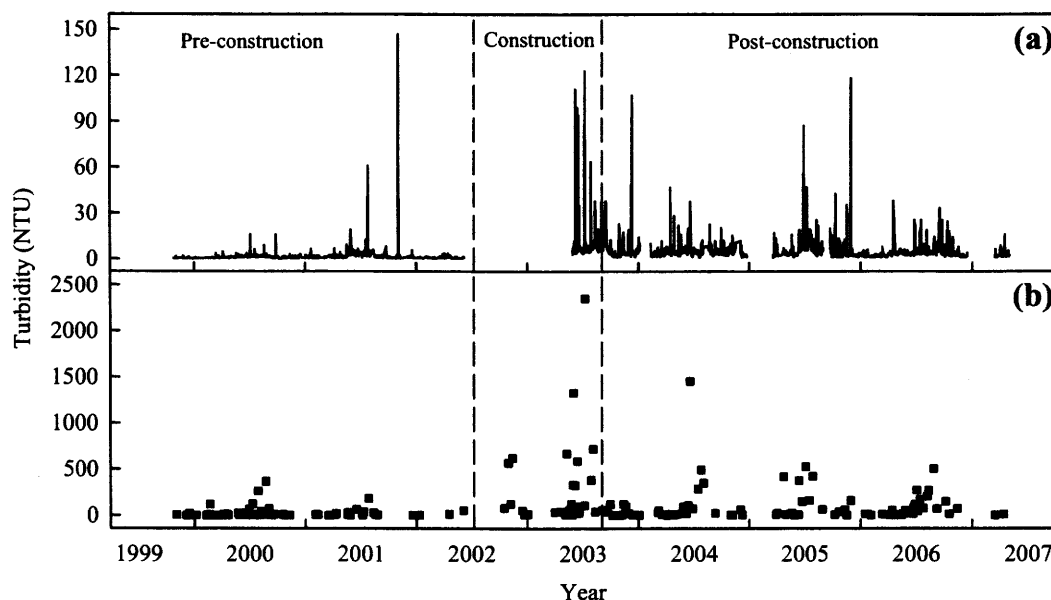


Figure 2. (a) Daily turbidity values and (b) peak storm turbidities for the periods before, during and after road construction.

The turbidities of many of the samples collected during stormflow were generally greater than daily samples. Peak turbidities prior to soil disturbance typically were less than 100 NTU, and usually much less than 100 NTU (Fig. 2b). Only five peak turbidities exceeded 100 NTU during that time, with the highest being 366 NTU in August 2000. The least square mean peak stormflow turbidity prior to constructing the road and crossings was 27 NTU.

Stormflow sampling resumed soon after road/crossing construction began, and the turbidity values for the period of active road construction, July 8, 2002 – September 30, 2003, showed increases. The least square mean value for peak turbidities during the construction period was 276, which was significantly greater than pre-disturbance peak turbidities. Ten storms were sampled during the road construction period that had peak turbidity values greater than 250 NTU, and 2 were greater than 1000 NTU. The storm with the highest turbidity (2,352 NTU) occurred on July 8, 2003. It had an estimated recurrence interval of 1.5 yr based on historical flow data from a nearby watershed, and was the second largest runoff event of water year 2003 (Bill 2005).

The least square mean peak turbidity fell significantly to 103 NTU after the road and crossing construction was completed, which was less than half what it was during road construction. The post-construction least square mean peak turbidity was not significantly different from the pre-disturbance mean ( $P=0.1309$ ). Peak turbidities exceeding 300 NTU accounted for only 10 percent of storms after construction was completed compared to about 30 percent of storms during construction.

## DISCUSSION

A substantial amount of the soil that was delivered to the stream was observed to be from direct mechanical additions during the construction of the fillslopes in both the approaches to the crossings and the fills in the crossings (over the culverts). That is, sizeable portions of the soil that the bulldozer pushed onto the fillslopes and crossing fills rolled down slope into the stream. The greatest contributions were associated with the first crossing. All of the fillslopes were high and steep, but the first one also had the smallest approach angles to the crossing (Table 1), which seems to be important to controlling mechanical sediment delivery (Stedman 2008).

In addition to the fill material that entered the channel during construction, channel excavation for culvert installation also contributed soil to the channel. Each crossing was installed during very low summer baseflows, but the small volume of streamflow that was present was not pumped from or diverted around the crossings during construction, so unconsolidated soil was available for entrainment in the water column even by low discharges. The first stream crossing had greater soil contributions during crossing construction than the other two because of the large height difference between the streambed

and the final crossing elevation. The required fill was so deep (Table 1) that the track hoe used to construct the crossing could not operate from the road surface. Instead, a pad of soil was intentionally bulldozed into the stream from which the track hoe could operate. The existence, operation on, and eventual removal of this pad provided an easily available source of soil to the stream. Soil introduction to the first crossing was exacerbated further by having two excavation/culvert installation periods, first for the pair of undersized temporary culverts and later for the permanent culvert.

Over the winter and spring months prior to re-vegetation, bare soil dominated the crossing surfaces and fills. Rills were visible on the crossing surface and continued down over the crossing fills to the stream. However, even after graveling was completed in summer 2003 and vegetation became established on the crossing fills in May/June 2003, runoff from the surface onto the fills still was visible and rilling continued throughout the remainder of the study. The crossings have provided this long-term source of runoff and associated erosion because they are at a lower elevation than the approaching road surfaces, so water naturally drains to the crossings. Even though there were broad-based dips and wing ditches near the crossings, water regularly accumulated over the crossing fills, making them very wet or saturated for long periods. This situation was so severe that part of the downstream fill over the first stream crossing slumped and delivered additional soil into the stream in June 2004.

All of these additions of soil were reflected in the elevated turbidity levels that were measured throughout and following the period of approach and crossing construction. Soil erosion rates decreased significantly following re-vegetation of the fillslopes (Stedman 2008), and thus, presumably also following re-vegetation of the crossing fills. However, the continued presence of rill erosion on those fills provides a chronic long-term source of erosion, albeit at probably much lower levels than during construction and prior to re-vegetation. However, the large inputs of soil that did result over the approximate 1-1.5 years of construction created legacy sources of sediment that will take years to flush from the watershed (Reid 1982). In the meantime, they may have detrimental affects on overall aquatic health in this channel, and eventual flushing merely may redistribute the problems downstream.

#### ADAPTIVE MANAGEMENT RECOMMENDATIONS

The design of this study provided a unique opportunity to isolate and focus on the influence of stream crossing construction on sediment delivery. In many instances, sedimentation during crossing construction is considered a necessary consequence of the activity. However, because the levels of sediment originating from those very limited discrete sources can be quite high, we should not simply accept high inputs as a necessity of stream crossing construction in forest roads; instead, we should use the information gained in this study to improve the construction of stream crossings. The long-term monitoring involved is particularly well suited for guiding decision making and developing each of the adaptive management recommendations provided below.

First, to reduce soil losses from similar crossing construction efforts in steep terrain, employing full-bench construction in the approaches to crossings would substantially reduce mechanical additions, particularly where road approaches are at small angles to the stream. Full-bench construction differs from typical cut-and-fill construction by eliminating the construction of fillslopes. Instead, the road is cut back further into the hillside and the road surface is composed entirely of residual material so the original hillside remains undisturbed with no fill on top of it on the down-slope side of the road. Excavated material from the road is taken and used elsewhere, either on the road surface or as fill for turn outs, etc. Full-bench construction is a common BMP, but it is rarely practiced in the East.

Second, the installation of temporary stream crossing culverts should not be allowed, where a permanent culvert will be installed later. Repeating in-stream disturbance is unnecessary in these situations, and installing only permanent culverts would reduce the amount of disturbance, and also may provide the added benefit of allowing re-seeding or soil covering to be accomplished more quickly.

Third, in-stream operation of equipment should be avoided whenever possible, but when it is necessary, soil never should be added to the channel as an operational pad. If an operating surface must be constructed, it should be composed of large, clean, nonfriable stone, and it should be removed upon completion of the activity so it does not interfere with the natural hydraulics of the channel. Graded stone should not be used, because the fines that it includes can be left behind or entrained in the water column and result in the same negative effects that soil fines create.

Fourth, road and crossing construction should be performed in as short a period as possible. Rather than pioneering the entire length of a road, it should be constructed and completed in sections. Completion in this case should mean applying all of the BMPs as is reasonable at the time. If conditions are unsuitable for seeding, temporary, but adequate soil cover (gravel, mulch, geotextile, etc.) should be applied to reduce erosion until permanent cover can be accomplished or established. In many instances, agency policy or standardized contract language may be too inflexible to require road contractors to build a road in sections, so full road-length pioneering may be the norm. In these cases, contract language should be written to require adequate, temporary soil covering to be completed within a specified limited number of days after soil disturbance

has been initiated. In many cases, contract language is written to require soil covering within a specified number of days after the road construction is completed or the disturbance of the area is completed. Allowing long durations of time to pass before BMPs in general, and soil cover in particular, are installed should not be tolerated as standard operating procedures because there is too much data in the literature, including this study, illustrating the need to apply BMPs in a timely manner.

These recommendations may seem obvious and elementary, but the practices with which these recommendations are associated are not uncommon. Thus, the application of these and similar recommendations could have a significant effect on reducing stream sedimentation and improving aquatic health.

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