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Assessing Changes to In-Stream Turbidity Following Construction of a Forest Road in West Virginia

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ABSTRACT

Two forested headwater watersheds were monitored to examine changes to in-stream turbidity following the construction of a forest haul road. One watershed was used as an undisturbed reference, while the other had a 0.92-km (0.57-mi) haul road constructed in it. The channels in both are intermittent tributaries of the Left Fork of Clover Run in the Cheat River watershed of West Virginia. To meet the objectives of another part of the study, silt fence was installed continuously along the banks of the streams from sampling stations at the catchments' mouths to the headwaters of each stream network; however, the silt fence became ineffectual at and near stream crossings during road construction, thereby allowing substantial amounts of sediment to reach the channel. Daily and stormflow sampling began in fall 1999 using automatic collectors and continued through and beyond the period of road construction which began in July 2002 and ended in September 2003. Turbidity (NTU) was measured from those samples. Following road construction, treatment watershed turbidities increased significantly for both daily and stormflow samples. However, the increases in stormflow turbidities were much greater than those occurring for daily samples. Turbidity values for both daily and stormflow samples appear to be decreasing exponentially, but neither returned to pre-construction levels by the end of the study period.

KEYWORDS. Turbidity, Water quality, Forest road construction, Ephemeral drainages, Suspended sediment.

INTRODUCTION

Turbidity, the refractive index of a solution, is an indirect measure of in-stream suspended sediment concentrations (Anderson and Potts 1987). Although, turbidity can be affected by dissolved air, solution color, particle size and shape, and solution concentration, it often is a better predictor of in-stream suspended sediment concentrations than discharge (Anderson and Potts 1987).

Road construction and use are recognized as the primary sources of sediment production during forest operations (Hornbeck and Reinhart 1964). Roads accelerate erosion, affect run-off, and increase effective channel lengths in headwater watersheds (Reinhart 1964, Binkley and Brown 1993, Jones and Grant 1996, Wemple et al. 1996). One year after road construction in north central West Virginia, treatment watershed maximum turbidity exceeded maximum reference watershed turbidity by 3,700 Jackson turbidity units (Hornbeck and Reinhart 1964). Turbidity increases were primarily attributed to the poorly located skid roads and skidding in streams (Kochenderfer and Hornbeck 1999).

Roads intercept subsurface flow and precipitation, which can accelerate the transfer of hillside water to stream channels (Reinhart 1964, Wemple et al. 1996). Some road sections therefore have

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been classified as channel extensions -- that is, they drain intercepted precipitation and subsurface water directly into a stream channel. Channel lengths have increased up to 40 percent due to these road and stream linkages (Wemple et al. 1996). Eighty-eight percent of road run-off emptied into ephemeral/intermittent streams in western Washington and Oregon (Bilby et al. 1989). These processes can directly and indirectly affect the quality of streamflow by increasing sediment supply to streams, increasing in-stream sediment and turbidity, reducing channel storage, decreasing channel stability, and affecting storm streamflow responses (Hornbeck and Reinhart 1964, Cornish 2001, Wemple et al. 1996).

The largest increases to in-stream suspended sediment and turbidity occur during road construction and maintenance (Hornbeck and Reinhart 1964, Swift 1988). During and one year following construction, streamflow becomes turbid more frequently, where more than fivefold increases in in-stream suspended sediment and turbidity have been reported (Hornbeck and Reinhart 1964, Fredriksen 1970). Turbidity and sediment tend to decrease most rapidly within the first two years post-treatment (Rice and Wallis 1962, Hornbeck and Reinhart 1964, Megahan and Kidd 1972). After a few years, recovery rates decrease and elevated turbidity and sediment may persist for years (Hornbeck and Reinhart 1964).

The adverse effects caused by increasing in-stream sediment have initiated the use of better construction practices. For example, best management practices (BMPs) are mandated by the 1977 Clean Water Act and state law during forest operations. Water quality degradation following forest operations decreases with the use of the better construction practices (Kochenderfer and Hornbeck 1999). Although these methods do decrease to-stream sediment transport, inadequate background sampling can mischaracterize BMP effectiveness (Edwards et al. 2004). Storm sampling is required to characterize sediment and turbidity in steep headwater stream channels, as variation between storm exports can be as large as or larger than variation between annually exported sediment values (Kochenderfer et al. 1997).

Turbidity is a common water quality parameter used to assess water quality in the East. West Virginia water quality regulations permit no more than a 10 NTU increase from baseline conditions when the baseline turbidity is 50 NTU or less, which characterizes most headwater channels in Appalachian forested watersheds.. Therefore, the objectives of this study were to: 1) describe turbidity before and after haul road construction, 2) determine if or when in-stream turbidity levels decreased after construction of a haul road in the treatment watershed, and 3) if possible, given the short pre- and post-treatment periods, evaluate the pattern of recovery in stream water quality.

MATERIALS AND METHODS

Study Background and Design

This study adopts the paired watershed design (e.g. reference and treatment watersheds) to evaluate the effects of road construction on water quality (Hewlett and Pienaar 1973). Both the reference and treated watersheds are located within the Clover Run watershed, Monongahela National Forest, north central West Virginia. The reference watershed is 20.2 ha, and the treatment is 32.7 ha. Their respective channel lengths, including ephemeral headwaters are 905 m and 1265 m.

The analyses described in this paper are part of a larger study primarily aimed at quantifying sediment delivery to headwater channels in managed and unmanaged watersheds. As a result, silt fence was installed to line the entire stream network in each watershed to eliminate hillside contributions of sediment (Stedman 2008). However, during the period of road construction (described later), the silt fence in the three stream crossings and their approaches were overtopped or knocked down by the construction of the crossings and adjacent fillslope construction. During this period, based on sediment stored in check dams installed downstream of the crossings, several tons of sediment were estimated to have reached the channel in the treated watershed by mechanical means or by water-driven erosion and dry ravel. Prior to road construction, turbidity measurements were made to examine in-stream contributions of sediment. Once road construction began and the silt fence was temporarily rendered ineffectual, the objectives of in-stream monitoring shifted to examine the effects of these stream crossing inputs of sediment to the channel.

Sample Collection

Stream sampling stations were constructed at the outlets of both watersheds in fall 1999. Automatic samplers were used to collect daily streamflow and stormflow samples throughout each storm event. Samples collected each day, or routine samples, were collected with an American Sigma model 900 automatic sampler in each watershed; while most of these samples were collected during nonstorm periods, the timing of some routine samples coincided with storm events. Stormflow samples were collected with an ISCO model 2700 automatic sampler in each watershed. The ISCO samplers were actuated using precipitation rather than stage, and then sampled on pre-set time intervals to obtain a thorough representation of turbidity behavior during storms (Edwards and Owens 1995).

In the treatment watershed, the stream reach used for sample collection had a bedrock bottom. Because of the presence of bedrock substrate, sediment did not accumulate in the sampling area and the samplers did not pick up sediment from the stream bottom. Therefore, turbidity values measured in the treatment watershed were those present in the water column. By contrast, a more stable control reach was constructed in the reference watershed, which included a pool area, such that during drier periods, the pool collected some sediment which resulted in some artificially elevated turbidity levels in samples collected during those periods. Samples known to be substantially affected by streambed sediment accumulations were removed from the reference watershed data set. All water samples were processed for turbidity at the USDA Forest Service's Timber and Watershed Laboratory in Parsons, West Virginia. Turbidity, in nephelometric turbidity units (NTU), was determined using a Hach ratio turbidimeter, which was calibrated using formazin standards (Edwards et al. 2009).

Water sampling began November 2, 1999 and continued through June 4, 2002 in both watersheds. At that time, haul road construction began in the treatment watershed. Sampling was suspended in both watersheds at that time, and then restarted for storms on October 15, 2002 and for routine samples May 29, 2003 in the treatment watershed. Stormflow and routine sampling, respectively, were restarted on November 1, 2002 and May 29, 2003 in the reference watershed. Sampling continued in both watersheds through April 30, 2005. The pretreatment period for both watersheds includes the time prior to haul road construction, and the post-treatment period extends from the restart of sampling in 2002 to the last sample collected. Eighty storms were sampled during pretreatment. Of these 46 were paired storms – that is, they were sampled on both the treatment and reference watershed. Eighty-five storms were sampled during post-treatment, and 42 were paired storms.

Road Construction

Haul road construction began in the treated watershed on July 8, 2002. The road was a cut-and-fill type of road with three culverted stream crossings. A few days before road construction began, the silt fence in the proposed crossing areas was cut and removed to ease culvert installation. However, 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 just before construction of each crossing began. They did this because they were concerned about damaging or covering the silt fence in the crossing approaches during fillslope construction. Consequently, soil could reach the stream within the lengths of the fillslope approaches where the silt fence had been removed. The silt fence was reconstructed along the channel at the first stream crossing on October 1-2, 2002, and at the second and third stream crossings on April 10, 2003. Silt fence was never installed across the upstream or downstream faces of the crossings, so the crossings themselves remained the primary sources of hillside sediment to the stream after silt fence reconstruction.

The 0.92-km long road was pioneered (i.e., roughed in) in 2002, but it was not completed until later summer 2003. During pioneering, the stream crossings were completed only to the degree needed to allow equipment to access the portions of the road further out the watershed. From July 23-25, 2002, a pair of undersized temporary culverts were placed side-by-side in the first stream crossing and partially backfilled to allow heavy equipment to travel over them. These were removed on September 4, 2002 and replaced with a single, larger diameter permanent culvert. No temporary culverts were installed in the second and third stream crossings, and the permanent culverts in each were installed September 9-10, 2002 and September 12-13, 2002, respectively.

The fills over the three stream crossings and fillslopes in the approaches remained unvegetated over the 2002/2003 winter. The crossings were hydroseeded on May 7, 2003, followed by an application of chopped mulch. Reasonably thick grass and herbaceous vegetation became established relatively quickly. In late summer 2003, the road was surfaced with limestone gravel.

Statistical Analyses

Statistical analyses primarily involve pretreatment vs. post-treatment comparisons of turbidities within watersheds. Because multiple stream water samples were collected during storm events, for the stormflow samples, the value used to examine the influence of stream crossing construction was the maximum change in turbidity (i.e., the difference between the background and largest turbidity values encountered during the storm).

Statistical Analysis Systems (SAS Institute 1988) software was used to perform the statistical comparisons. Nonparametric methods primarily were used because the data were not normally distributed. Wilcoxon two-sample tests and mean scores (Proc NPAR1WAY) were used to transform the data to an ordinal scale and test for statistical differences in watershed turbidity between treatment periods.

RESULTS

Routine Sampling

Turbidity levels in the routine samples collected during the pretreatment period in the reference watershed averaged 4.0 NTU, and had a standard deviation of 6.5 NTU (Table 1). Twenty samples exceeded 25 NTU and two samples exceeded 50 NTU (86 and 96 NTU) during the pretreatment period. Of these >25 NTU samples, only the sample with a turbidity of 96 NTU was collected during a storm event, which occurred in March 2002.

Table 1. Descriptive statistics and nonparametric statistical comparisons between treatment periods for routine turbidity samples.

Watershed	Period	N	Turbidity (NTU)		Wilcoxon mean score*
			Mean	Std. Dev.	
Reference	Pretreatment	1128	4.0	6.5	712 a
	Post-treatment	512	9.0	21.1	1038 b
Treatment	Pretreatment	1110	1.6	5.0	588 a
	Post-treatment	463	7.2	12.1	1264 b

*Within watersheds, values followed by different letters are significantly different at alpha=0.05.

Pretreatment routine samples in the treatment watershed averaged 1.6 NTU, with a standard deviation of 5.0 NTU (Table 1). Only 2 samples exceeded 25 NTU (61 and 147 NTU) during the pretreatment period. Both of these were collected during periods of very low streamflow.

Post-treatment reference watershed routine samples averaged 9.0 NTU, with a 21.1 NTU standard deviation (Table 1). Forty samples exceeded 25 NTU. Thirty-five of the 40 samples occurred in July-September 2004. Twenty samples exceeded 50 NTU and three samples exceeded 100 NTU (102, 154, and 345 NTU). Fifty percent of the samples that were >25 NTU occurred during very low streamflow, including the three samples greater than 100 NTU, which fell within a 30-day period in August-September 2004.

Treatment watershed routine samples averaged 7.2 NTU following road construction, with a standard deviation of 12.1 NTU (Table 1). Thirteen samples exceeded 25 NTU, six exceeded 50 NTU, and three samples exceeded 100 NTU (107, 111, and 123 NTU). Seven percent of the turbidities >25 NTU were sampled during very low streamflow.

Before road construction, the treatment watershed routine turbidities were significantly lower than the reference watershed routine turbidities based on Wilcoxon mean scores (905 vs. 1330; $P<0.0001$). After road construction, the routine turbidities increased on the treated watershed so that the Wilcoxon mean score for the treatment watershed became greater than that of the reference watershed (528 vs. 451; $P<0.0001$).

The largest turbidities consistently occurred during the summer months in both watersheds. The average treatment watershed turbidity for May-September 2003 was 12.8 NTU, which was 5.6 times greater than the pretreatment level (2.3 NTU). The treatment watershed 2004 post-treatment mean (5.7 NTU) was 2.5 times the pretreatment level. The May through September mean decreased 2.2 times from 2003 to 2004 (Table 2).

Table 2. Changes to post-treatment May through September mean turbidity relative to pretreatment May through September mean turbidity for the treatment watershed.

	Pretreatment	Year 2003 Post-Treatment	Year 2004 Post-Treatment
Treatment watershed May-September	2.3 NTU	12.8 NTU	5.7 NTU
Increase from pretreatment mean		5.6 times	2.5 times
Decrease from year 2003 post-treatment mean			2.2 times

Stormflow Sampling

Reference watershed stormflow samples during pretreatment had a mean maximum increase of 19 NTU (i.e., difference between background and maximum storm turbidity), with a standard deviation of 22 NTU (Table 3). Treatment watershed stormflow samples during pretreatment had a mean maximum increase of 27 NTU, with a standard deviation of 59 NTU (Table 3).

Post-treatment, the reference watershed stormflow samples had a lower mean maximum increase of 14 NTU, with a standard deviation of 22 NTU (Table 3). Pre- and post-treatment Wilcoxon mean scores were not significantly different for the reference watershed. By contrast, treatment watershed stormflow samples following road construction had a mean maximum increase of 182 NTU, with a standard deviation of 384 NTU (Table 3). The post-treatment maximum increase was 6.7 times higher than the pretreatment increase on the roaded watershed, and the Wilcoxon mean scores were significantly different.

Table 3. Descriptive statistics and nonparametric statistical comparisons between treatment periods for maximum change in turbidity for each storm.

Watershed	Period	N	Change in turbidity (NTU)		Wilcoxon mean score*
			Mean	Std. Dev.	
Reference	Pretreatment	54	19	22	60 a
	Post-treatment	58	14	18	53 a
Treatment	Pretreatment	72	27	59	55 a
	Post-treatment	69	182	384	88 b

*Within watersheds, values followed by different letters are significantly different at alpha=0.05.

Over time, the treatment watershed showed an improving trend with first and second year post-treatment mean maximum turbidity increases during sampled storms continuing to decline (Fig. 1); however, the turbidity in the roaded watershed remained elevated at the end of the study compared to turbidities encountered prior to road construction. These available short-term results suggest that stormflow turbidities are returning to pretreatment conditions via an exponential decay pattern (Fig. 1).

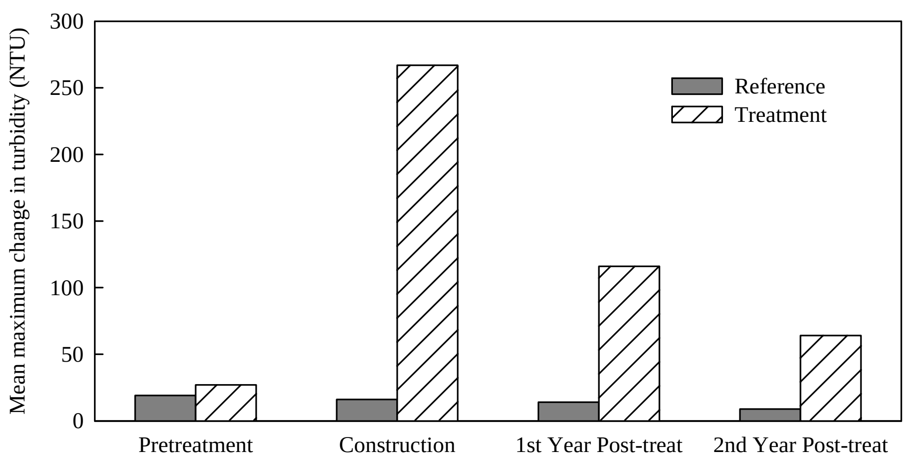

Figure 1. Mean maximum change in turbidity for storm events by watershed and treatment period. Construction = July 8, 2002-Sept. 2003; 1st Year Post-treat = Oct. 2003-Sept. 2004; 2nd Year Post-treat = Oct. 2004-April 2005.

CONCLUSIONS

The reference watershed routine (i.e., daily) samples in the pretreatment period were statistically more turbid compared to the treatment watershed. However, prior to road construction, both watersheds had mean turbidities below 5 NTU. Turbidity is visible to the human eye at about 5 NTU (Strausberg 1983); therefore, these streams normally run clear during baseflow. While there were statistically significant increases in routine sample turbidity following road construction, they were relatively small compared to changes that occurred during stormflow. The average change between background and peak turbidities during storms rose from 14 NTU prior to road construction to 182 NTU following road construction.

Over time, both the routine and stormflow turbidity levels declined exponentially, but they did not return to pretreatment conditions by the end of the study period. The majority of the sediment inputs were from the stream crossing areas and their approaches, but as the fillslope inputs of sediment were restricted by silt fence reconstruction and the remaining crossing fills became revegetated, sediment inputs declined. Long-term turbidity increases over pretreatment level will be attributable to residual sediment inputs from the construction that have been stored in the channel and are flushed out periodically.

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