Report as of FY2007 for 2006WV76B: "In-Stream Turbidity and Suspended Sediment Changes Following Improvements to a Forest Road and Harvesting (WRI-82)"

Publications

Project 2006WV76B has resulted in no reported publications as of FY2007.

Report Follows

Title: Changes to In-Stream Turbidity Following Construction of a Forest Road in a Forested Watershed in West Virginia

Report: Annual Report

Reporting Period Start Date: March 1, 2006

Reporting Period End Date: February 28, 2007

Principal Authors: Jingxin Wang and Pamela J. Edwards

Date Report was issued: May 2007

USGS award number: WRI-82

Name and address of submitting department: Division of Forestry and Natural Resources. 317E Percival Hall, PO Box 6125, Morgantown, WV 26506-6125.

1. Research

Abstract

In 1999, a study was initiated in two forested headwater channels to compare and contrast changes to in-stream suspended sediment and turbidity following the construction of a forest haul road. Turbidity (NTU), suspended sediment concentrations (SSC) (mg L^{-1}) and streamflow (L s^{-1}), were measured throughout May 2005. Both catchments are ephemeral/intermittent tributaries of the Left Fork of Clover Run in the Cheat River watershed. To exclude inputs of hillside sediment both catchments were continuously lined with silt fence from constructed gauging/sampling stations to the upper most portions of their drainage network. In July 2002, construction of a 0.93 km (0.58 mi) road (FS 973), encompassing 1.3 ha (3.3 ac) of the 32.7 ha (80.8 ac) treatment watershed, was initiated. FS 973 was completed in September 2003. Data were separated for comparison by road construction initiation (i.e. pretreatment and post-treatment), although, some analysis focused solely on the construction period independently. During the construction period, several tons of sediment were deposited in the stream channel. Following construction, the treatment watershed's stream turbidity, in relation to both watersheds pretreatment period and in respect to the reference watersheds post treatment period, increased significantly. While the highest turbidity value recorded in the treatment watershed (2352 Nephelometric turbidity units (NTU)) was 6.4 times larger than the highest turbidity sampled in the reference watershed, it was sampled during low streamflow (<1.4 L s^{-1} or <0.05 ft^3s^{-1}(CFS)). Fourteen post-treatment samples exceeded 100 NTU at discharges greater than 56.5 L s^{-1} (2.0 CFS) when the treatment watersheds average streamflow was 5.5 L s^{-1} (0.20 CFS). The reference watershed's samples stayed within expected ranges throughout the duration of this study. Turbidity increased significantly due to the construction of FS 973, specifically due to the prolonged period in a pioneered condition, construction of three culverted stream crossings, an inadequate cross-drain, and a constructed stream channel.

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Executive Summary

A forest road was constructed through a watershed in summer 2002 and was left in poor condition from fall 2002 through mid-summer 2003. During mid-summer of 2003 the condition of the road was improved through installation of water control features, sediment traps, seeding of the fill slopes and cut banks, and graveling of the driving surface.

Turbidity and suspended sediment levels in both the control and treatment watersheds fell within expected ranges during the 3 pretreatment years prior to road construction. Both parameters increased to very high levels on the treatment watershed prior to its finalization. After road improvements were made, reductions in turbidity and suspended sediment were observed on the treatment watershed.

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 if recovery was linear, exponential, or if turbidity levels off at a level higher than pretreatment at some point in time.

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, affects run-off, and increases effective channel lengths in headwater watersheds (Reinhart 1964, Binkly 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 JTU (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).

Turbidity is the primarily water quality parameter used to asses water quality in the East. "West Virginia water quality regulations permit no more than a 10 NTU increase from baseline conditions, specifically, "No point or non-point source to West Virginia's waters shall contribute a net load of suspended matter such that the turbidity exceeds 10 NTU's over background turbidity when the background is 50 NTU or less, or have more than a 10% increase in turbidity (plus 10 NTU minimum) when the background turbidity is more than 50 NTUs. This limitation shall apply to all earth disturbance activities and shall be determined by measuring stream quality directly above and below the area where drainage from such activity enters the affected stream. Any earth disturbing activity continuously or intermittently carried on by the same or associated persons on the same stream or tributary segment shall be allowed a single net loading increase." (USEPA 2006).

Experimental Methods

In-stream suspended sediment, turbidity, and streamflow (i.e. stage and velocity) in two headwater streams were measured since 1999. Both streams are located within the Clover Run Watershed, Monongahela National Forest, north central West Virginia (Fig. 1). This design adopts the typical paired watershed design (e.g. reference and treatment watersheds) to evaluate the effects of road construction on water quality (i.e. turbidity and suspended sediment).

Monitoring stations (Fig. 2) were constructed in both watersheds to facilitate this study. The monitoring stations were constructed at the watersheds outlet to house automated samplers, which collected suspended sediment samples and stream stage and velocity measurements. Silt fences (Fig. 3) around the active stream channels were installed in both watersheds, from the monitoring stations to the upper most portions of their drainage networks. In the beginning, the primary goal of this study was to measure to-stream sediment delivery, hence, the silt fence lining the stream channels, although, due to a number of events that led to a substantial amount of sediment being deposited in the stream channel, which is thoroughly described in a later section, the primary focus of this study shifted towards measuring changes to in-stream suspended sediment.

Data from a weather station (1973-2004) located approximately 3.4 air kilometers away (operated by the US Forest Service's Northern Research Station), indicate the average precipitation for the area is approximately 161 cm yr^{-1}. The months of April through July generally receive the most precipitation, while September through November generally receives the least precipitation. The largest rainfall events are typically the result of tropical storms and hurricanes moving inland from the Atlantic Ocean. In addition, convective thunderstorms commonly produce intense periods of rainfall during the summer. Snowfall is common between November and March although can occur earlier or later. During the dormant season, a snow pack can remain on the ground for the majority of the winter or periodic rain-on-snow or fluctuating temperatures can produce intermittent ground coverings (Edwards, P.J. Submitted).

Water samples have been collected and streamflow (i.e., stage and velocity) has been measured in the treatment and reference streams since 1999. Housing for stream gauging and sampling equipment (Fig. 2) was constructed in both watersheds near their mouths. Five-minute streamflow velocity and stage readings were recorded at both stations using an American Sigma 950 flow meter. Stream water samples were collected for turbidity analyses. Daily samples were collected with an American Sigma model 900s automatic sampler in each watershed. Stormflow samples were collected with an Isco model 2700 automatic sampler in each watershed. The Isco model 2700s were actuated using precipitation rather than stage and then sampled on pre-set time intervals following the first sample to obtain a better representation of sediment responses during storms (Edwards and Owens 1995). Funnels

Stormflow sampling started November 2, 1999 and lasted until June 4, 2002 in both watersheds. One-hundred and fifty-three storms were sampled during pretreatment. Of these 70 were paired storms – that is, they were sampled on both the treatment and reference watershed. Stormflow sampling in the reference watershed started again on November 1, 2002 and lasted until April 30, 2005. Treatment watershed storm sampling started again on October 15, 2002 and lasted until April 30, 2005. One-hundred and thirty-four storms were sampled during post-treatment. Of these forty-two were paired storms. Samples were not collected from June 4, 2002 to October 15, 2002 for safety purposes during construction.

Stream velocity and stage measurements were made on 5-minute intervals since October 1, 1999. The velocity measurements from the American Sigma equipment were unstable and inaccurate, but the stage readings remained quite stable following calibration. Consequently, discharge was estimated from the stage measurements using Manning's equation in HEC-RAS software (www.hec.usace.army.mil/software/hec-ras/). These calculations were made by the Forest Service. Stage < 2.0 cm (0.8 in) could not be measured accurately because of equipment limitations. Samples collected during these streamflows represented anywhere from 8 to 45 percent of the routine and storm samples during pre and post-treatment periods. These samples are referred to as samples collected when streamflow was below detection limits. Streamflow also could not be calculated when the streams were frozen or when samplers malfunctioned (Edwards, P.J. Submitted). Turbidity analysis relative to streamflow was nonexistent due to some large variations in streamflow regressions and peak streamflow comparisons. Streamflow is presented in liters per second ($L\ s^{-1}$).

Road (FS 973) construction in the treatment watershed began July 8, 2002 and lasted throughout September 2003. FS 973 extended for 0.93 km (0.58 mi), encompassing 1.3 ha (3.3 ac) of the 32.7 ha (80.8 ac) treatment watershed. FS 973 extended for another 2.6 km (1.6 mi) after exiting the treatment watersheds drainage divide. Road construction is defined as the day heavy machinery began working within the treatment watershed to the day the haul road met BMP standards within the treatment watershed. Except for seeding, mulching, fertilizing, blowing hay, and installing a check dam on October 22, 2002 and May 7, 2003, road construction was ceased between October 15, 2002 and May 7, 2003 to avoid the winter months and the wet spring months.

During FS 973 construction, three permanent culverts and two temporary culverts were used to form three stream crossings. The fills over these crossings reached 9 m (30 ft). The first temporary culvert, later removed and replaced with the first permanent culvert, was used to proceed further into the watershed. The second temporary culvert was inadequately draining a steep tributary, therefore, it had to be removed. FS 973 construction was a slow process because the fills over the culverts were large (i.e. up to 15 m (50 ft)), thus the fillslopes had to be meticulously constructed and compacted, some road cuts lead into large portions of bedrock that needed to be cut through and properly sloped, a culvert failed and had to be removed while the stream had to be diverted to another culverted stream crossing via a constructed rip-rap channel, and the treatment watershed was relatively remote and the number of trucks was limited, therefore, graveling the road became a very slow process.

Water samples were processed for turbidity at the US Forest Service's Timber and Watershed Libratory in Parsons, West Virginia. Turbidity, in nephelometric turbidity units (NTU), was determined using a Hach Ratio Turbidimeter, which was calibrated using formazin standards (Edwards, P.J. Submitted). The samples were first shaken to distribute the sediment throughout the bottle. A sub sample was then poured into a small glass tube. The sides were wiped free of fingerprints and other dirt, and the glass tube was placed in the turbidimeter. After approximately 5 seconds, the turbidity value was recorded.

After measuring turbidity, the sub-sample was poured back into the original bottle so suspended sediment concentrations could be calculated. Before measuring suspended sediment concentrations, the entire sample was weighted. The bottle, lid, and sample were weighed then subtracted from the known bottle and lid weight to obtain the weight and of the water/sediment sample. Each sample was filtered through one or more pre-dried and pre-weighted ashless GF/C glass microfiber filters using vacuum filtration. The bottles were rinsed several times, and each time the rinse water was filtered. The number of filters needed depended on the amount of sediment in the bottle. Although, most samples required only 1-3 filters, a few required 30 or more. All samples were then dried at 100 ºC (212°F) for 2 hours then re-weighed. This weight minus the initial dry filter weight is the combination of the organic and inorganic material (g/L). The filters were then combusted in a muffle furnace for 1 hour at 550 °C (1022°F) and then re-weighed. This weight plus a 0.001 filter correction for filter loss during combustion, minus the initial dry filter weight, is the amount of inorganic material (g). The dry weight minus the combusted weight plus a 0.001 filter correction is the amount of organic material. These samples were determined using U.S. EPA method 160.2. All analysis involving suspended sediment concentrations used both organic and inorganic material.

Statistical Analysis Systems (SAS 1988) was used to analyze these data. Nonparametric methods primarily were used because the data were not normally distributed. Wilcoxon signed-rank tests and median scores (Proc NONPAR1WAY) were used to transform the data to an ordinal scale to make statistical conclusions about the location differences (higher lower or no difference (random)) between both watersheds' turbidity. Median scores were used to test for differences between watersheds turbidity.

The relationship between turbidity and SSC (TS ratio) was created to compare the turbidity of a sample to the suspended sediment concentration. This ratio compares two different types of water clarity measurements and samples between watersheds were of different volumes, therefore, any conclusions formed should be viewed with skepticism. However, sample volumes averaged by month and by storm were not significantly different between watersheds pretreatment and post-treatment periods. Parametric analyses were used on non-normal untransformed data in the form of regression analysis only. Log base 10 transformations were used to increase data normality and express changes to variability. Statistical significance was tested at 0.05 level.

Results and Discussion

The reference watershed's storm and routine samples prior to construction were statistically more turbid than the treatment watershed's. The reference watershed's routine samples contained more sediment by weight relative to its turbidity index. Storm samples and TS ratios were similar between watersheds. The reference watershed produced less turbidity per sediment than the treatment watershed. This is probably the result of past disturbance in the reference watersheds (i.e. roads, farming, and timbering) as the reference watershed generally had larger median substrate than the treatment watershed (Bills 2005).

Substantial variation to streamflow occurred from pretreatment to post-treatment. Several studies have measured changes to streamflow following timber removal (Hornbeck et al. 1993, Jones and Grant 1996). Few studies have intensively measured streamflow changes due to road construction, therefore, streamflow responses due to road construction are uncertain. Roads theoretically increase the efficiency of water transfer from hillsides to stream channels by intercepting subsurface streamflow and precipitation then directing the intercepted water directly to stream channels and/or in more concentrated levels onto the hillside below (Reinhart 1964, Wemple et al. 1996). Streamflow measurements and classes were not used rigorously to analyze turbidity because streamflow was modeled and deviated substantially from predicted values. For example, one predicted peak stormflow level differed between watersheds by 280 L s^{-1} (10 cfs) when the average streamflows were less than 28 L s^{-1} (1 cfs). The Forest Service employees who created the model would be better suited to evaluate any changes to streamflow due to road construction, therefore any analysis that uses streamflow such as turbidity and streamflow relationships and/or SSC and streamflow relationships should be viewed with skepticism.

The results of this study demonstrated the effects of road construction on water quality. Several studies have identified roads as the primary source of to-stream sediment during forest operations and have identified road to stream interactions as the most problematic within the road network (Irvin and Sullivan unpublished data, in Bilby et al. 1989, Wemple et al.1996). This study isolated most of the road network from the stream channel (e.g. silt fence), therefore, the majority of sediment that entered the treatment watershed's stream channel was the result of stream crossing construction. FS 973 occupies 4.1 percent of the treatment watershed and stream crossings occupy less than one percent of the treatment watershed.

Average and median turbidities for these watersheds were below 5 NTU during pretreatment. Turbidity is noticeable around 5 NTU (Strausberg 1983, in Edwards Submitted) therefore, these streams normally have clear water. Prior to treatment, the treatment watershed's stream samples (2680) exceeded 25 NTU 29 times or 1 percent of the time and the reference watersheds samples (3059) exceeded 25 NTU 55 times or 2 percent of the time.

Maximum pretreatment turbidities were less than 400 NTU in both watersheds. They occurred during the largest storm events or during summer thunderstorms. Turbidities were elevated throughout the summer months during pretreatment. Stormflows that produced larger turbidities were relatively short-lived and storms samples overall produced clockwise hysteresis. Clockwise hysteresis is an indicator of a sediment supply limitation.

In July 2002 road construction was initiated within the treatment watershed. Very few samples were collected between July 2002 and July 2003, therefore, changes to in-stream turbidity during the 1st year post-treatment are unknown. Several studies site that the largest deviations to background levels occur within the first few months following disturbance (Hornbeck and Reinhart 1964, Fredriksen 1970), however, this may not be the case here as mitigation structures could have trapped and stored and disturbed sediment. However, sediment that does reach the stream channel during disturbances typically flushes quickly during the first couple of storms. In Oregon, sediment concentrations were measured 250 times expected levels during the first storm post-treatment, 9 times larger 2 months later, and remained elevated 2 to 3 times expected levels 2 years later (Fredriksen 1970). In West Virginia, average turbidity was 12.9 and 149.5 times larger during forest operations than first year after treatment from a clearcut and diameter limit harvest, respectively. Average turbidity was 38.0 and 6.0 times larger after the first year post-treatment than the second year post-treatment (Hornbeck and Reinhart 1964).

These samples were too few or occurred during insignificant times to provide an adequate account of turbidity during the first few storms post-treatment. However, if pretreatment values were increased to the same magnitude as in Hornbeck and Reinhart 1964 during treatment, then average turbidity values could have been as high as 255 and 525 NTU for routine and storm samples respectively. These values would be deemed excessively high by all the past literature however, it does show the potential changes to both stormflow and routine during the first few storms during treatment.

The reference watershed stayed within normal background levels after treatment even though the treatment watershed's average and median turbidities were above 5 NTU. Fourteen percent of the turbidities exceeded 25 NTU in the treatment watershed. Elevated turbidities were the result of stream crossing construction. Areas in stream crossings were less than 1 percent of the treatment watershed using 10 m aerial photographs.

Maximum turbidity in the treatment watershed following treatment reached 2,352 NTU and occurred during the initiation of a storm event. The treatment watershed's turbidities were less seasonally dependent, that is, the largest average monthly turbidity, occurred more so in late fall and during the winter months. The treatment watershed's stormflow turbidities were substantially elevated during the initiation of all storm events and are believed to be the result of precipitation impact remobilizing easily suspended channel sediment. Stormflows produced larger peak, average, and median turbidity values. Stormflow turbidities were relatively longer-lived and even maintained and increased after peak stormflow. Several storms produced counter-clockwise hysteresis towards the end of the 1st year post-treatment. Counter-clockwise hysteresis is an indicator of an energy limited situation and an abundance of sediment in the stream channel.

Conclusions

This study illustrates that significant increases to average turbidity during forest operations are not exclusively the result of similar increases to average SSC. For example, the treatment watershed routine and storm samples average SSC was 1.4 and 1.0 times the pretreatment levels post-treatment while average turbidity was 4.5 and 9.9 times the pretreatment levels post-treatment, respectively. By comparison, the reference watershed routine and storm samples average SSC were 0.7 and 0.5 times the pretreatment levels post-treatment while average turbidity were 1.0 and 1.2 times the pretreatment levels post-treatment, respectively. SSC measurements are an inadequate indicator of water quality as decreases to water clarity were probably the result of smaller inorganic and organic sediment that weighed less than average pretreatment sediments.

The TS ratio indicated that the treatment watersheds turbidities were significantly lower during pretreatment although less sediment per weight produced them. The reference watershed was transporting relatively more sediment with less turbidity. After treatment, the TS Ratio increased to 1.4 as the majority of turbidity values were larger than the SSC values. Towards the end of the post-treatment sampling period the TS ratio drops to around 0.5 as the majority of the turbidity values were half the SSC values. This indicates a considerable shift to sediment properties that influenced turbidity and SSC concentrations. The TS ratio went from the highest levels to the lowest levels relative to pretreatment levels in 2 years or by the 3rd year post-treatment. Although, turbidity is a better predictor of SSC than streamflow, the relationship between SSC and turbidity changed substantially between sample types, pretreatment and post-treatment periods, and levels of turbidity to warrant the use of several different regressional relationships.

Prior to treatment, average daily rainfall was a statistically significant predictor of average stormflow turbidity. Average daily precipitation explained 11 and 38 percent of the variation to average stormflow turbidity during pretreatment. Average daily precipitations were not a statistically significant predictor of average stormflow turbidity during post-treatment. The relationship did not return to pretreatment values for the duration of this study. There was no statistical significance between the two parameters in the reference watershed.

Stream crossing have to be constructed with better soil conservation practices. This road extended throughout the treatment watershed before the crossings were finalized. Time study analysis may be useful to help contractors increase road production and efficiency while decreasing costs associated with road construction while increasing soil conservation. Although, these crossings are legally defined as non-point sources of pollution, this study illustrates that very specific points along the road network were mainly responsible for water quality degradation. Bridges should be used instead.

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2. Publications

"In –stream turbidity changes resulting from forest haul road construction" Planned for submission to Journal of the American Water Resource Association. Currently out for external review prior to journal submission, as per Forest Service requirements.

A masters thesis and at least 2 resulting journal articles from that thesis are anticipated within the next ~6 months. Thesis completed in May 2007.

3. Information Transfer Program

Wang, J. 2006. "Sustainable forest operations in West Virginia's watersheds." West Virginia Water Conference 2006 – Ensuring water resources for West Virginia's Future. October 11-13, 2006. Stonewall Resort, Roanoke, WV.

4. Student Support

William Sharp, M.S. Student (Graduates May 2007)

Category	Number of Students supported With 104b Base grant	$ Value of students supported With 104b base grant	Number of students supported With matching funds	$ Value of student support with matching funds	Total number of students supported	Total $ value of student support
Masters	1		1		1	

5. Noticeable Achievements and Awards

Wang, J.	2006	Determining Factors Contributing and Controlling Sediment Delivery to Stream Channels.	Monongahela National Forest	$33,355

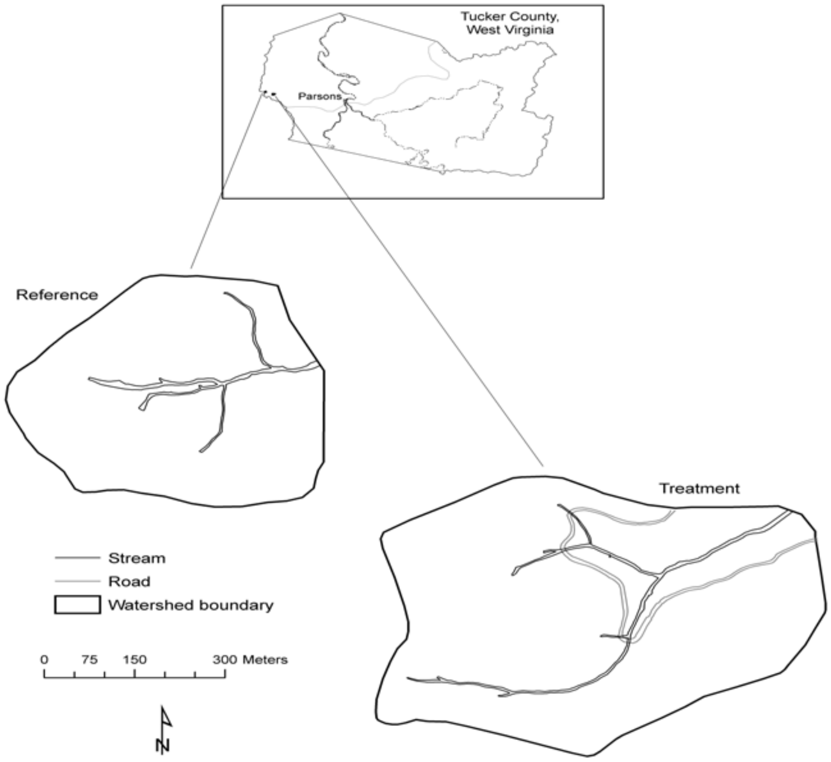

Figure 1. The study area and delineated watersheds illustrating the general aspect of both watersheds.

Figure 2. A constructed monitoring station used to collect water samples and record streamflow velocity.

Figure 3. Example of the sediment fence that was lined around all stream channels in both watersheds. Picture was taken while standing on a stream crossing.