**Title**
Collaborative research and watershed management for optimization of forest road best management practices

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**Publication Date**
2003-08-24

# COLLABORATIVE RESEARCH AND WATERSHED MANAGEMENT FOR OPTIMIZATION OF FOREST ROAD BEST MANAGEMENT PRACTICES

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**Abstract:** The Coweeta Hydrologic Laboratory, USFS Southern Research Station, worked with state and local agencies and various organizations to provide guidance and tools to reduce sedimentation and facilitate restoration of the 1900km$^2$ Conasauga River watershed in northern Georgia and southern Tennessee. The Conasauga River has the most diverse aquatic ecosystem of any river in the region and is currently being considered for designation as a Federal wild and scenic river. The watershed is encircled and dissected by highways and roads, and receives intense recreational, industrial, and agricultural use from the surrounding human population.

Unpaved roads have been found to account for more than 80 percent of stream sedimentation in the forested lands of this region. Collaborative efforts of research and management focused on developing sediment yield models, prioritizing road restoration, and reducing sediment yields from roads to streams. Model development facilitated identification of highly erosive roads and prediction of sediment yield reductions following reconstruction of forest roads.

We monitored sediment yield and transport from a wide variety of existing forest roads during autumn 2001. We used these data for model validation. We then used the model to characterize roads by erosion susceptibility and to prioritize roads for reconstruction. During the summer of 2002, we completed reconstruction and installation of best management practices along more than 20 miles of forest roads. We monitored sediment yield from these roads through autumn 2002. Simulated estimates of sediment yield from the reconstructed roads were severely limited by the resolution and quality of available data and the sediment transport algorithms employed in the model. Despite a 46 percent increase in rainfall from the pre to post-treatment period, road reconstruction reduced sediment yield by 70 percent.

## Introduction

The Conasauga River Watershed, figure 1, encompasses 1,870 square kilometers of the Blue Ridge Ecosystem in northern Georgia and southeastern Tennessee. This watershed, host to over 90 species of fishes and 42 species of mussels, has the most diverse aquatic ecosystem of any river in the region (Freeman, et al. 1996). The Conasauga, along with neighboring mountain watersheds in this region, provide water for millions of people in Georgia and Tennessee. Recreational usage of the Conasauga is intensive. Thousands of annual visitors use it for kayaking, canoeing, swimming, fishing, hunting, hiking, mountain climbing, mountain biking, swimming and camping. Currently, water quality and aquatic ecology of the Conasauga River are suffering from excessive sedimentation caused by erosion of streambanks, agricultural lands, development, and gravel roads (Freeman, et al. 1996). Erosion from gravel roads accounts for more than 85 percent of the contemporary sediment threatening water quality of streams in this region (Van Lear, et al. 1995).

The USDA Forest Service has designated the Conasauga River watershed as one of fifteen Community-Based Watershed Restoration Partnership programs. This has provided resources to protect and improve the quality of land and water resources within the Conasauga River Watershed. As part of this project, the Forest Service located and characterized threats to the headwater streams and the Conasauga River in the national forest lands of the Chattahoochee and Cherokee National Forests (Roghair, et al. 2001). While approximately half of the area is designated as wilderness and provides water of exceptional quality (Ivey and Evans. 2000), stream sedimentation from gravel roads and private land development is degrading water quality and aquatic ecosystems in the Conasauga River (Roghair, et al. 2001; Henley, et al. 2000). The primary means to reduce runoff, erosion, and sedimentation caused by forest roads is through the implementation of road improvement projects, best management practices and, where necessary, closing roads (Sun, et al. 2003).

Due to limited resources, it was important that road improvement projects be prioritized. The prioritization was based upon the severity of sediment erosion and transport, sediment impacts on water quality, road usage levels and potential effectiveness of restoration. Our goal was to determine the ability of a watershed-scale erosion model to assess sediment production, delivery to streams, and predict restoration effectiveness. In this study, we determined the ability of such a model to:

1. Accurately estimate forest road erosion and sediment routing to streams
2. Allow users to prioritize roads for restoration by severity of sedimentation
3. Quantify the effectiveness of road restoration for reducing stream sedimentation

## Site Description

### Geology and Soils

The study area is located in the Blue Ridge Mountains. Bedrock is primarily sedimentary and metamorphic, and soils in the study area are largely of metamorphic crystalline bedrock origin. The loamy mountain soils are highly erodible when exposed (Van Lear, et al. 1995).

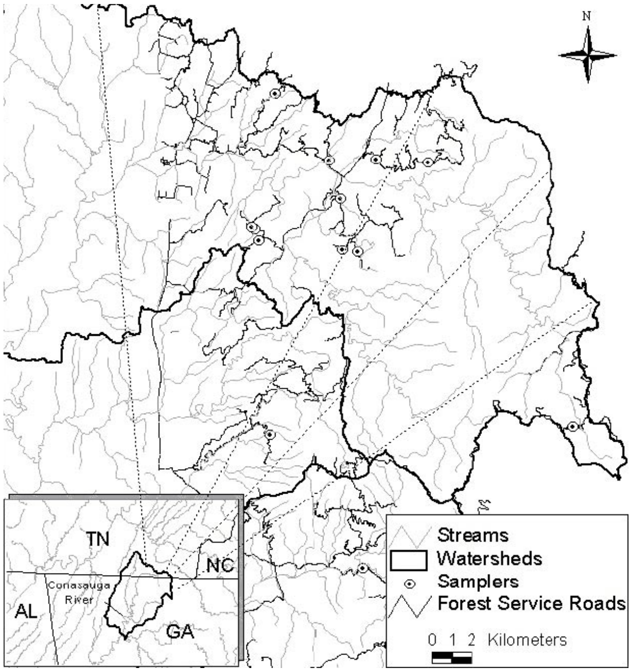

Fig. 1. Conasauga watershed and study site locations in the southern Appalachians.

*Climate and hydrology*

Elevation and terrain strongly influence climate, precipitation patterns, soil depth, soil moisture, solar insolation, growing season and the natural distribution of vegetation in the southern Appalachians. High precipitation and mild temperatures place this region in the marine, humid temperature classification of Koppen's climate system (Swift, et al. 1988). Average annual rainfall at upper elevations is 230cm per year while lower elevations receive approximately 180cm of rainfall per year. Ridgelines and upper elevation south facing slopes tend to be drier while slopes with northern aspects are moist and cool (Van Lear, et al. 1995). Due to higher rainfall, shallower soils and steeper hydraulic gradients, water yields and stream flow response in this region increase with watershed elevation (Swift, et al. 1988).

### Land Use

While forest harvesting in this region began in the late 1800's, much of the Conasauga Watershed was still forested at the turn of the century. An inventory of land use in 1900 and 1901 indicated that the mountainous areas in the southern Appalachians were typically forested with merchantable timber densities of 1,000 to 10,000 board feet per acre (Ayres and Ashe 1904). Forest harvesting increased greatly in the early 1900's and spread throughout the entire region. With the clearing of land, the conversion of valley bottoms and riparian areas to farming and grazing became widespread. By the end of the 1920's, all of the forests in the Conasauga watershed had been harvested. Forest harvesting practices at that time greatly accelerated rates of soil erosion and stream sedimentation (Riedel, et al. 2003). The harvesting of merchantable timber and soil erosion left the landscape barren; much of it was abandoned. The U.S. Forest Service was given the task of restoring the southern forests. In the 1920's, the Forest Service purchased thousands of acres of these "waste-lands" including the mountainous headwaters regions of the Conasauga River. In the early 1930's, these lands were incorporated into the Chattahoochee (Georgia), Cherokee (Tennessee), Pisgah and Nantahala National (North Carolina) Forests. These lands were reforested and have been continuously managed by the Forest Service to the present day (Ivey and Evans 2000).

## Methods

### Pre-treatment Road Erosion and Runoff Monitoring

During late summer 2001, we instrumented 13 forest roads in the Conasauga watershed with overland flow samplers. The road sites were selected to be representative of road usage levels, surface types, slopes, types and severity of erosion, maintenance practices and proximity to streams (table 1). At each site we surveyed roadbed slope, contributing surface area, distance between samplers, the slope along transects between samplers and roadbed characteristics. The usage intensity for each road is based upon national forest road management and usage data. We categorized usage intensity as: closed - official traffic only; gated - seasonal public access; slight - open, few vehicles per day, no outlet; moderate - multiple vehicles, recreation area access; intensive - numerous vehicles, thoroughfare access; ORV - off-road vehicle recreation trail. The third column in Table 1 presents the typical maintenance schedule for each road. The numbers of samplers installed at each site are listed in column 4. The roadbed materials specified in the fifth column are: native – native soil; improved – native soil amended with aggregate; aggregate – full aggregate base. The next two columns present the slope of the road that contributes runoff to each sampler and the total contributing area above each sampler. The last column is the estimated runoff curve number (RCN) for each road, as described in the data analysis section.

The overland flow samplers employed in this study are of custom design developed at the USDA Forest Service Coweeta Hydrologic Laboratory (Clinton and Vose 2002). Each sampler consists of three pieces, an intake, a hose, and a storage vessel. The intake is a stainless steel trough with a 30cm x 10cm rectangular inlet orifice and a 10cm diameter exit orifice. Each intake has a two-stage approach apron on the upstream side of the inlet orifice. The first stage of the apron is installed below grade, and the second stage is installed at grade to direct flow into inlet orifice. Flanges that prevent flow from circumventing the sampler border the sides of the inlet orifice. Water and sediment that enter the orifice flow by gravity, through the outlet, through a flexible connecting hose and into an 18-liter storage vessel. Each storage vessel has an exhaust port to allow air to be freely displaced by entering water. This maintains entrance velocity of the sampled runoff.

Table 1.
Pre-treatment site characteristics and sampling intensity. Runoff curve number represents tendency of the road surface to generate runoff.

| Site | Usage intensity | Maint. per Year | Samplers | Roadbed | Road Slope (%) | Road Area ($m^2$) | Runoff Curve No. |
|---|---|---|---|---|---|---|---|
| Horse trail | Closed | 0 | 5 | Native | 3 | 441 | 87 |
| Double culverts | Closed | 0 | 4 | Native | 8 | 391 | 87 |
| Doc Howell | Gated | 0 - 1 | 4 | Native | 2 | 502 | 89 |
| Jigger Creek | Gated | 0 - 1 | 4 | Native | 13 | 90 | 89 |
| Doogan Mtn | Slight | 2 | 3 | Improved | 11 | 334 | 91 |
| Beach Bottom | Slight | 2 | 5 | Improved | 12 | 403 | 91 |
| Cowpen Mtn | Moderate | 2 | 5 | Aggregate | 15 | 254 | 91 |
| Three Forks | Moderate | 2 | 4 | Aggregate | 18 | 168 | 91 |
| Sina Branch | Moderate | 2 | 4 | Aggregate | 15 | 316 | 91 |
| Alaculsy Branch | Moderate | 2 | 5 | Aggregate | 14 | 512 | 91 |
| Double Branch | Intensive | 2 - 3 | 5 | Aggregate | 13 | 485 | 94 |
| Taylor Branch | Intensive | 2 - 3 | 5 | Aggregate | 10 | 513 | 94 |
| Rocky Flats | ORV | 0 | 5 | Variable | 13 | 217 | 94 |

We installed the pre-treatment samplers during the first week of August 2001. At each site, samplers were installed along a transect that began at the road edge. The transects continued downslope until they reached an ephemeral or perennial channel. Three to five samplers, depending upon transect length, were spaced at equal intervals along each transect. We operated the samplers from mid-August 2001 through early January 2002 during the pre-treatment period, and from September 2002 through December 2002 during the post-treatment period. The samplers were checked on a weekly basis to insure that they were operating properly. They were also serviced immediately following each significant rainfall event. This consisted of thoroughly mixing the collected water in the 18 containers and extracting a one-liter sub sample of the sediment and water mixture. The samplers were then cleaned and prepared to collect samples from the next rain event. The sub samples were analyzed for total suspended solids to 1.5 μm in accordance with the American Public Health Association standard methods for wastewater analyses (Franson 1981).

## Model Research and Development

The modeling environment we employed is the Watershed Characterization System (WCS). WCS is an adaptation of the Environmental Protection Agency (EPA) ARCVIEW™ based watershed data management system known as BASINS (EPA 2001a). WCS was developed by Region 4 of the EPA to facilitate the development of total maximum daily loads (TMDLs) in the southeastern United States. Sediment is the primary pollutant for which TMDLs are established; consequently, the EPA developed a soil erosion and transport module for WCS called the Sediment Tool (Tetratech, Inc., and EPA 2000). The Sediment Tool is an Avenue™ extension that is called by ARCVIEW™ from within WCS. It is a spatially explicit, finite element, lumped parameter model that estimates soil erosion, sediment transport and sediment yield. Soil erosion is simulated on a grid cell basis with the USLE while one of four user specified transport equations is used to transport sediment from cell to cell. The development, scientific basis, and background research leading to the creation of the Sediment Tool have been reported by previous authors (Greenfield, et al. 2001; McNulty and Sun 1998; McNulty, et al. 1994).

To facilitate model development and application, we qualitatively calibrated WCS by "tuning" the USLE management factor, C, for each site. For the initial model runs, we used published USLE C factors for gravel roads to generate rough estimates of road erosion for each site (USDA 1976). We then ranked the predicted site erosion severity according to the number of standard deviations from the predicted average erosion rate for the entire road network (table 2). Next, we ranked the observed site erosion severity, as deviations from the observed average erosion rates (table 2). We then mapped the simulated results (e.g., figure 2) and compared them to observed. We adjusted the C factor for each site so that the predicted categories best matched those observed.

Table 2 .
Qualitative ranking of road erosion rates for qualitative model calibration.
Restoration Prioritization and Road reconstruction.

| Predicted site erosion: standard deviations from the predicted average erosion rate | Observed site erosion: site deviation from roads exhibiting average erosion. |
|---|---|
| Less than -1 | Below average |
| 1 to -1 | Average |
| 1 to 2 | Slightly above average |
| 2 to 3 | High |
| Greater than 4 | Extreme |

Through a series of public meetings and outreach activities, the Forest Service and Conasauga River Alliance identified numerous ecosystem restoration initiatives for the Conasauga River watershed. These initiatives were prioritized, and resources were allocated for implementation. An important aspect of prioritizing road restoration expenditures was locating reconstruction projects on roads that directly impacted streams. Because there are hundreds of miles of remote, National Forest System gravel roads in the Conasauga River watershed, we used WCS to identify highly erosive roads that had the potential to significantly degrade stream quality. We used the qualitatively-calibrated model to generate watershed maps that illustrated erosion and sediment yield potential from roads (figure 2).

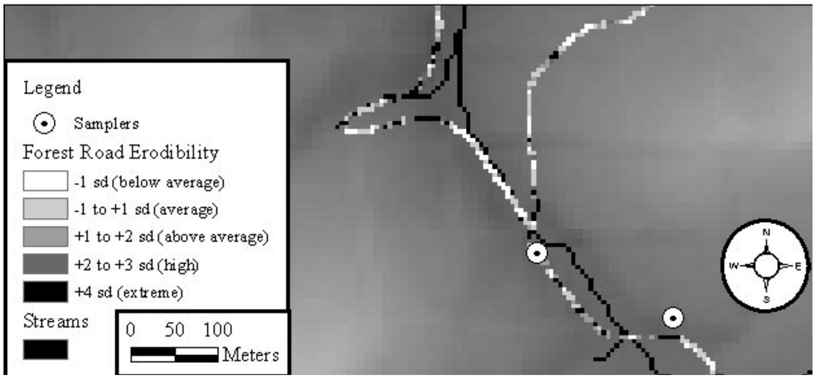

Fig. 2. Ranking of gravel roads by predicted severity of erosion to facilitate prioritization of road reconstruction projects. Ranks are based upon predicted deviation from average rate. Roads predicted to have greater than average erosion tend to be on steeper or longer slopes, as determined from digital elevation models (DEMs).

The largest road reconstruction project was on Three Forks Road. Large portions of this road were severely degraded. Three Forks Road serves numerous popular campgrounds; thus, it is subjected to intensive use. This road also runs along many ridgelines and through some of the steepest terrain in this part of the Blue Ridge Mountains. Rainfall in this area, up to 250cm (100 inches) per year, is among the highest in the nation. Consequently, Three Forks Road experiences greatly accelerated rates of wear and erosion. Approximately 12km (7.5 miles) of this road were reconstructed using a variety of best management practices (figure 3). The entire length of road was re-graded, dangerous turns were resurveyed and unstable roadbeds were relocated. During re-grading, slope was reduced and center crowns, ditches and culverts were removed in a process called out-sloping. This process fosters shallow, dispersed runoff of water as sheet-flow, rather than concentrating runoff with ditches and culverts, to reduce runoff energy and sediment transport capacity. The cut and fill slopes were vegetated and brush barriers were installed on fill slopes. These practices slow runoff, induce settling along the road edge, and minimize the transport of eroded sediments from the roadway to streams. In areas where roads ran down long grades, the grades were broken into small segments. This served to reduce the area contributing runoff and decrease runoff depth. The slopes were broken into smaller segments with the construction of features known as broad-based-dips. These are gentle, rolling humps that direct runoff from the roadbed to settling areas. The settling areas were contained with hay-bales, brush barriers and silt fences. Additionally, coarse run aggregate was added to the entire length of road, further reducing road surface erodibility. Complete descriptions of these road-building practices (Swift and Burns, 1999) and their effectiveness for protecting water quality (Sun, et al, 2003; Swift, 1988) have been widely published.

Fig. 3. A re-constructed forest road illustrating best management practices.

## Post-treatment Road Erosion and Runoff Monitoring

Following completion of the road reconstruction in July 2002, we conducted site surveys to determine the post-treatment monitoring locations. Due to the excessive site disturbance during road reconstruction, the pre-treatment samplers were removed. We could not install the post-treatment samplers in exactly the same locations as the pre-treatment samplers because the reconstruction also changed the surface drainage patterns of the roads. We instrumented five post-treatment sites using the same methods employed with the pre-treatment samplers (Table 3).

Table 3.
Post-treatment study sites and road characteristics. All roads were moderate usage and maintained twice annually. Pre-treatment roadbeds were supplemented with aggregate additions. Following reconstruction, roadbeds had three inches of aggregate. BMPs included: O.S. – outslope; D.O. – ditch obliteration; A.R. – area reduction; C.R. – culvert removal; S.A. – Settling area with hay bales and vegetative filter.

| Site | Samplers | Road Slope (%) | Best management Practices | Road Area ($m^2$) | RCN |
|---|---|---|---|---|---|
| 1 | 5 | 12 | O.S., D.O., A.R., S.A. | 119 | 91 |
| 2 | 4 | 10 | O.S., dip, A.R., S.A. | 124 | 91 |
| 3 | 4 | 8 | O.S., D.O., dip, S.A. | 218 | 91 |
| 4 | 5 | 5 | O.S., D.O., dip, C.R., S.A | 157 | 91 |
| 5 | 4 | 5 | O.S., D.O., dip, C.R., S.A. | 122 | 91 |

The reconstructed roads all had the same usage class, maintenance intervals and road surface type. At each site we surveyed roadbed slope, contributing surface area, distance between samplers, the slope along transects between samplers and roadbed characteristics. We also surveyed the best management practices that were implemented on each site (table 3).

### Data Analyses

The TSS data obtained with the overland flow samplers and the annual erosion estimates generated by WCS are not quantitatively similar. To make these data comparable, we adjusted their spatial and temporal scales to uniform dimensions. We multiplied TSS ($g*m^{-3}$) by runoff depth (m) and contributing surface area ($m^2$) to get sediment loading (kg) for each storm at each sampler and summed these to obtain total yield for the sampling period. We used the RCN method and the depth of rainfall from each storm to compute depth of runoff (USDA 1986).

We reduced the temporal scale of the soil erosion estimates from an annual soil loss to that of the pre- and post-treatment sampling periods. The pre-treatment period was August 15, 2001 – January 15, 2002, and the post-treatment period was September 1 - December 21, 2002. We reduced the annual values by using the bi-weekly erosivity factors (USDA 1997) to partition out the fraction of the annual erosivity corresponding to our sampling period (EPA 2001b). The bi-weekly erosivity factors represent the percentage of total, annual, cumulative rainfall erosivity for similar regions across the United States.

### Modeling

WCS is distributed on an 8-digit hydrologic unit basis by Region 4 of the EPA for the states of Alabama, Florida, Georgia, Kentucky, Mississippi, North Carolina, South Carolina, and Tennessee. The data are identical to those distributed with the EPA model, BASINS. These include USGS 90m DEMs, USGS 8 digit HUCs, EPA level 3 streams (1:24,000 scale), NRCS STATSGO soils data, and Tiger roads data. We replaced the default 90m DEM data with 10m DEM data because the accuracy of GIS-based soil erosion modeling is strongly dependent upon terrain data resolution and analytical resolution (figure 4, Riedel and Vose 2002).

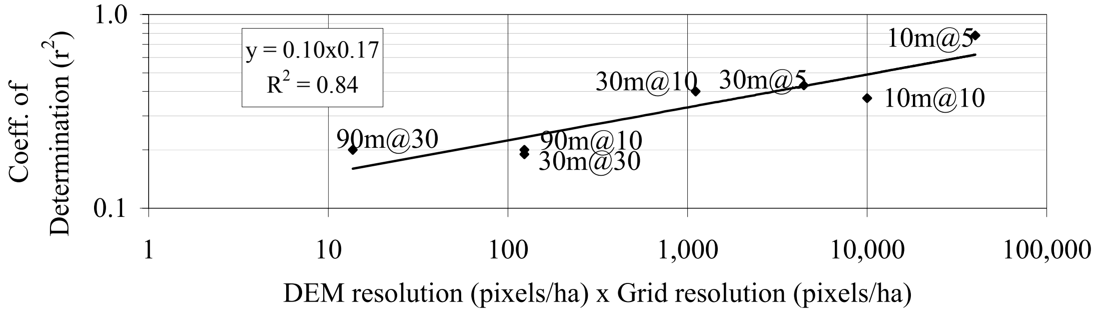

Fig. 4. Role of DEM and analytical (grid) resolutions on model accuracy. Coefficients of determination are from regressions of predicted versus observed sediment yields at pre-treatment sites (adapted from Riedel and Vose 2002).

We imported road data from the National Forest System database; these data have full attributes including length, usage, maintenance, road base type, vehicle type and jurisdiction. Higher resolution soils data (e.g. SSURGO) for the study area were not available; however, we updated the STATSGO data to reflect the existence of the forest roads by buffering the forest roads coverage to the road widths and intersecting the road buffers with the STATSGO soils database. Within the soils attribute table, we created new soil types for the improved and aggregate road bases. We determined the erodibility values for these types using RUSLE to compute the K factor for the observed road surface characteristics (USDA 1997).

## Results

### Model Validation

Predicted, pre-treatment sediment yields were highly correlated with observed sediment yield (figure 5). Sediment yields were generally underestimated for sites with low observed yields (large, negative intercept) and overestimated for sites with observed sediment yields (large, positive slope).

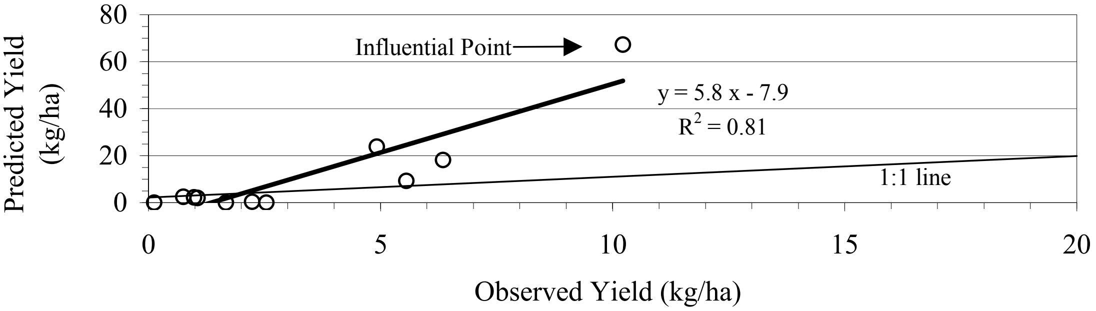

Fig. 5. Predicted, pre-treatment sediment yield versus observed, pre-treatment sediment yield (adapted from Riedel and Vose 2002).

Model error, defined as predicted minus observed yield, increased non-linearly with observed yield (figure 6). For relatively low observed yields, predicted yields were both over and under estimated. However, as observed yield increased beyond four kg/ha, yields were greatly over estimated.

On a site-specific basis, predicted sediment yields for the Doogan Mountain, Beach Bottom, Sina Branch and Double Branch sites were zero while predicted erosion varied from 12 to 250kg/ha (figure 7). This indicates that while WCS predicted that erosion would occur on these sites, it did not predict that the eroded sediments would be transported to the road edge, where the samplers were located. However, sediment yield was observed at these sites indicating that the sediment transport functions in WCS underestimated sediment transport. The model performed most poorly on the closed roads and the off-road vehicle trails. Predicted yields were greatly overestimated for the two closed roads and the off-road vehicle trail (figure 7).

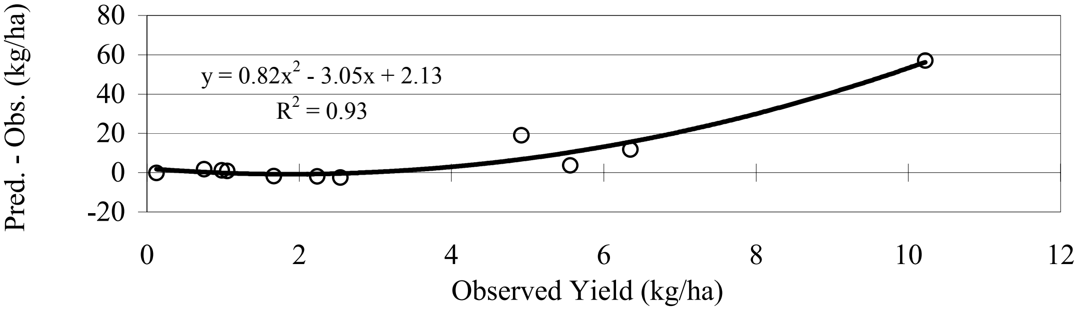

Fig. 6. Regression of model error (defined as predicted minus observed yield) vs. observed sediment yield. The curvature is significant (α=0.01).

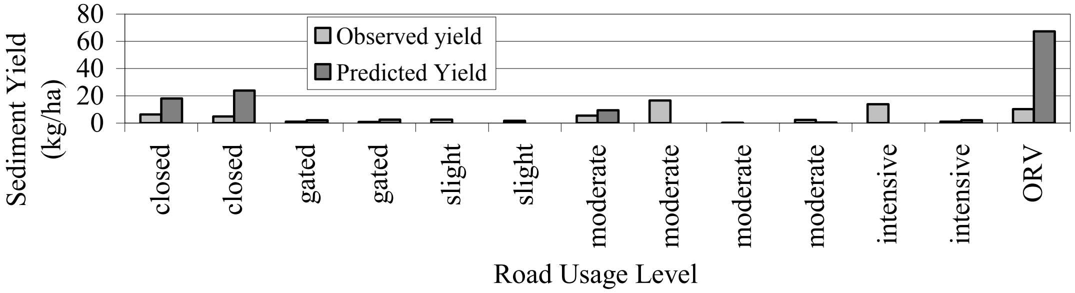

Fig. 7. Observed and Predicted pre-treatment sediment yield from forest roads by road usage intensity.

Model performance on the post-treatment sites was poor. For example, the predicted post-treatment sediment yields were not correlated with observed rates of sediment yield (figure 8), and for four of the five sites, the estimated post-treatment sediment yields were more than three times greater than observed.

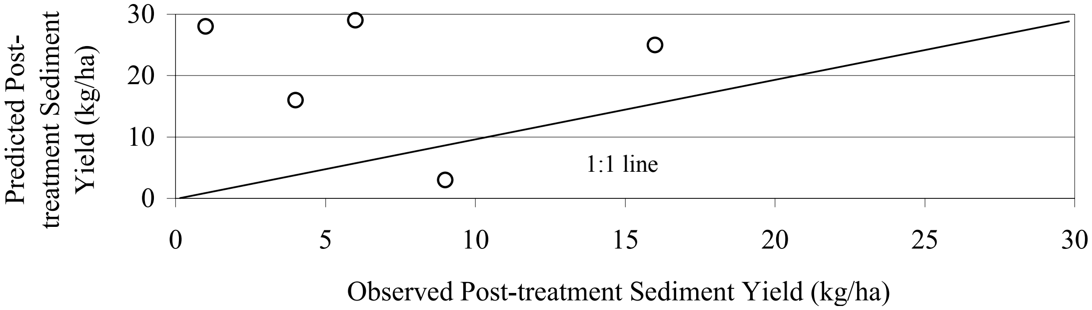

Fig. 8. Predicted, post-treatment sediment yield versus observed, post-treatment sediment yield. Predicted data are not correlated with observed.

Unlike the pre-treatment model results, the post-treatment errors (predicted minus observed) were independent of observed sediment yield. However, post-treatment errors were significantly dependent on road slope, where errors decreased as road slope increased (figure 9). Despite consistency in road reconstruction techniques and road reconstruction practices, predicted post-treatment sediment yields were two to three times greater on the flattest road segments (5 percent slope) as compared to the steepest road segments (8-12 percent slope).

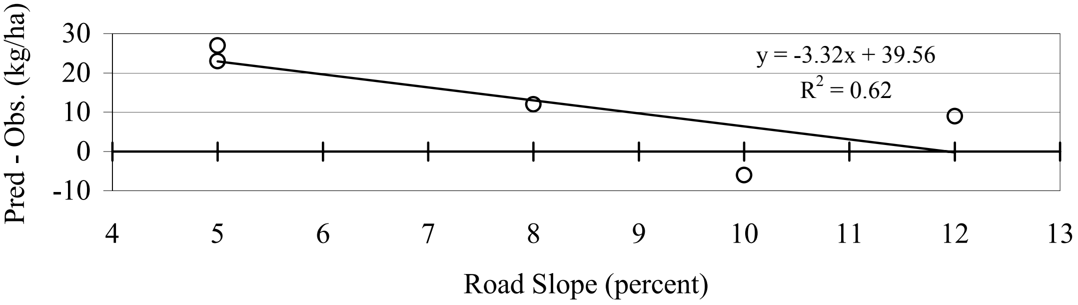

Fig. 9. Post-treatment model error (defined as the difference between predicted and observed yield) vs. road slope (α=0.01).

**Road Reconstruction**

Due to the significant roadbed disturbance caused by the road reconstruction, sediment yields immediately post-treatment were very high. In contrast, the pre-treatment samples were obtained from weathered roadbeds that had at least six months to recover from any road grading and maintenance activities. Consequently, we discarded the first two samples gathered immediately following road reconstruction so that the long-term stability of the newly constructed roads could be evaluated and properly compared to pre-treatment values. Observed sediment yields were initially high, though less than average pre-treatment, and rapidly declined to levels well below that of pre-treatment (figure 10).

The climatic regime changed dramatically between the pre- and post-treatment sampling period. During the pre-treatment sampling period, the region was experiencing its fifth year of record drought. Total precipitation during this period was approximately one half of average, and the average depth of precipitation for the monitored storm events was 4.8cm. Immediately following road reconstruction, Hurricane Isidore and Tropical Storm Kyle delivered over 50cm of precipitation to this region. Subsequent rainfalls during the post-treatment period were near average. The average storm depth during the post-treatment period was 7.0cm. Despite this substantial increase in rainfall, sediment yields decreased by 70 percent, from 0.71kg/ha per cm of rain pre-treatment to 0.2kg/ha per cm of rain post-treatment.

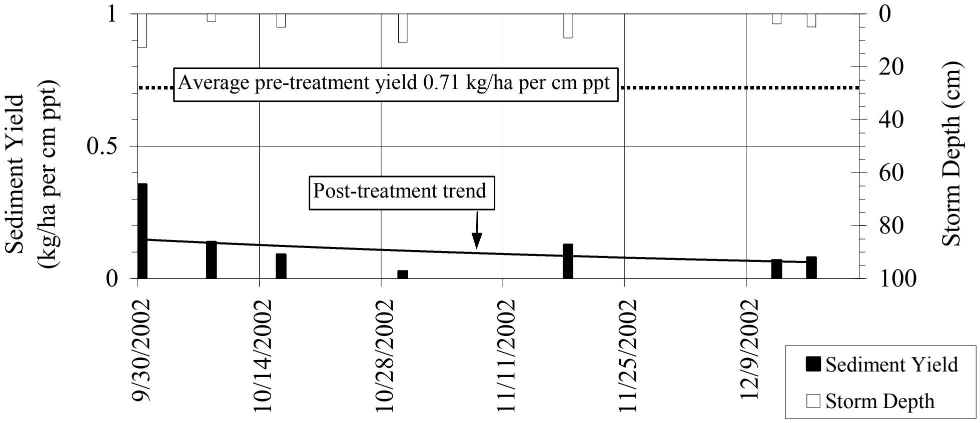

Fig. 10. Total sediment yield from post-treatment sampling period, following reconstruction of road and implementation of forest road best management practices.

## Conclusions

### Model Validation

We were able to qualitatively calibrate the model to observed erosion conditions. Thus, it was useful for characterizing sites based upon their inherent susceptibility to erosion. In contrast, quantitative estimates of forest road sediment yield were not accurate. Model accuracy declined rapidly as observed sediment yield increased. There are a number of factors that contribute to poor model performance. The modeling approach used in WCS, specifically the application of the Universal Soil Loss Equation (USLE), is based upon observed erosion rates from test plots and landscapes that are typically much larger than the road plots we monitored in this study. The USLE was developed for application at the field and forest stand scale. Our application of WCS implemented the USLE at a scale smaller than for which it was intended. Additionally, despite our use of high-resolution data and modeling environment (5m), our modeling scale was too coarse to accurately reflect the fine scale variations in terrain that control water flow and sediment transport on gravel roads. The USLE was also developed for use on natural soils; whereas, we applied it to gravel roads. While we attempted to account for this discrepancy in use by applying the methods in the Revised USLE for mines, application of the USLE to gravel roads remains beyond the intended scope of this tool. The erosion and transport algorithms within WCS were never intended for application on gravel roads; indeed, the results of our study seem to caution against such application.

In our pre-treatment application of WCS, the errors in simulated sediment yields were non-linearly dependent upon observed sediment yields. That is, model performance decreased rapidly as road sites became more prone to generating sediment. This was not the case for the post-treatment application where errors were independent of observed sediment yield. For the post-treatment model application, modeled sediment yield errors were negatively dependent upon road slope. For reconstructed roads having low slopes, the model tends to greatly underestimate the effectiveness of road reconstruction. However, as the roads became steeper, the errors in simulated sediment yields became smaller. This suggests that sediment yield predictions in WCS are very sensitive to slope. As the slope for each site was derived from the DEMs, this emphasizes the point raised previously. Our application of WCS (and inherently the USLE) to such a fine-scale process, in combination with relatively coarse data, pushes WCS beyond its limits. As gravel forest roads are a primary cause of stream sedimentation in the southern Appalachians, sediment yield modeling alternatives to WCS are necessary to address road and stream sediment interactions in the southern Appalachians.

### Road Reconstruction

The road reconstruction greatly reduced sediment yield from the moderate-use road we monitored. The best management practices included out-sloping of the road bed, ditch obliteration, rebuilding the road bed with coarse aggregate, reducing the length of roadbed that could concentrate surface runoff and culvert removal. These practices reduced sediment yield from 0.7kg/ha per cm of precipitation to 0.2kg/ha per cm of precipitation (a 71 percent reduction) within 4 months of completion of reconstruction activities. That such a reduction occurred despite a 46 percent increase in average storm depth emphasizes the importance of implementing forest road best management practices during road construction.

**Acknowledgements:** This research was made possible with the support and cooperation of the Conasauga River Watershed Restoration Project Board, the Cohutta Ranger District of the Chattahoochee National Forest and the Ocoee Ranger District of the Cherokee National Forest. Funding for this research was provided by the USDA Forest Service, Conasauga River Large Scale Watershed Restoration Project and the USDA Forest Service, Southern Research Station, Coweeta Hydrologic Laboratory. This research would not have been possible without the ongoing support of Larry Thomas, Chris Earnest and Alan Hughes of the Cohutta District and Jim Maxwell, Bo Reynolds, Charlie Patterson, and Mitch Loggins of the Ocoee District. Digital forest data were provided by Charlene Neihardt, Nan Schlatterer and Anita Bailey, USDA Forest Service. Thanks to Charles Marshall and Jason Love for construction and installation of samplers.

**Biographical Sketches:** Mark S. Riedel (mriedel@fs.fed.us) is a research hydrologist at the USDA Forest Service, Southern Research Station, Coweeta Hydrologic Laboratory. Dr. Riedel's research interests include land use legacy influences on water quality and fluvial processes, riparian land use impacts on stream stability, the cumulative effects of forest roads on erosion and sedimentation and the application and development of spatially explicit hydrologic and sedimentation models to explain the propagation of land use impacts on fluvial processes through time and space.

James M. Vose (jvose@fs.fed.us) is the project leader of the USDA Forest Service, Southern Research Station, Coweeta Hydrologic Laboratory. The mission of this laboratory is to evaluate, explain, and predict how water, soil, and forest resources respond to management practices, natural disturbances, and the atmospheric environment; and to identify practices which mitigate impacts on these watershed resources. Dr Vose's research interests include phytoremediation of groundwater pollutants, riparian zone restoration, forest carbon, nutrient, and water cycling, modeling of biological systems, fire ecology and restoration of fire dependent ecosystems, and old-growth structure and function.

USDA Forest Service Large Scale Watershed Restoration Projects: http://www.fs.fed.us/largewatershedprojects/
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