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Modeling Sediment Transport from an Off-Road Vehicle Trail Stream Crossing Using WEPP Model

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Abstract. There is a limited information available pertaining to the adverse effects of Off-Road-Vehicle (ORV) use and trail impacts. As a result, this study was initiated in 2003 to (a) quantify water quality impacts of an ORV trail stream crossing through monitoring of total suspended solids, and (b) conduct WEPP (Water Erosion Prediction Project) simulations to determine long-term sediment loads contributed by the ORV trail stream crossing. To collect suspended sediment samples from the ORV trail stream crossing, ISCO6 6700 water samplers were installed. Data was collected from November 2003 through July 2004. During this time suspended sediment samples were collected for three different operational conditions (open, closed, maintenance). When the study began the trail was open to traffic. The trail was then closed to traffic on January 1, 2004 and went through a two-week maintenance regime in early March. The trail was then opened to ORV traffic on April 1, 2004. The largest suspended sediment load contributed by the stream crossing during this study occurred during the trail closed condition. This storm event had a recorded rainfall of 49 mm, and contributed a suspended sediment load of 109 kg. Since there were no storm events sampled with return intervals of more than one year, the WEPP model was used to estimate the potential long term effects of ORV trail stream crossing. A thirty-year synthetic weather data (generated by CLIGEN) was used to predict sediment yield from the ORV trail stream crossing. The WEPP model suggested that average annual sediment load from the stream crossing is about 126.8 tons/ha, which is much higher than what is allowed by the USDA Forest Service-National Forests in Alabama for temporary roads. The model also suggested that most of the sediment load to the stream is contributed by a steep hillslope section that flows directly to the stream. Hence the modeling study suggests that a BMP needs to be implemented to control sediment loss from ORV trail section that contributes sediment directly to the stream. In addition, the ORV trail stream crossing should be located on as flat a slope as possible.

Keywords. Erosion, modeling, Off-Road Vehicles, ORV, runoff, stream crossing, suspended sediment, water quality, WEPP

Introduction

Water quality is a major concern for many countries around the world. Since fresh water is a finite resource, it needs to be protected to ensure its longevity. Research has been conducted in many areas to assess impairment of waterways by agriculture, urban development, wildlife, and recreational activities. In the United States, several federal acts have been enacted for the protection of water quality. In response to the Clean Water Act of 1972, and the Water Quality Act of 1987, improved guidelines and management practices have been implemented in each state. Sources of pollution to our waterways can be grouped as “point” and “nonpoint” sources. With the implementation of NPDES (National Pollutant Discharge Elimination System) permits, point sources of pollution, to a large extent, have been controlled. However, nonpoint sources of pollution continue to be a major concern. Among the chief nonpoint sources, sediment from construction activities, silvicultural operations, and stream bank erosion is currently responsible for the impairment of a number of stream segments.

Since Alabama has more that 70% forested areas and silviculture is a major industry, sediment from silvicultural operations is a major threat to water quality in Alabama. In fact, the Alabama Forestry

Commission lists sediment as “one of the most important considerations related to silvicultural activity” (Alabama, 1990). It also acknowledges that “many operations have the potential to increase sediment rates” (Alabama, 1990). In addition to silvicultural operations, sediment pollution created by Off-Road Vehicle (ORV) trails is a growing concern for many recreational areas including the National Forests. “The National Forest System is the single largest supplier of public outdoor recreation in the United States, [and] manages over 3,000 drinking water systems” (Dissmeyer, et al., 2000). Sediment from ORV trails can be a significant diffuse source of pollution reaching the surrounding waterways, but little research has been done to quantify the impacts on the surrounding environment. The trail systems set up for ORVs contain steep climbs, banked turns, and ruts or crevices that sustain high volumes of riders. The nature of ORV use for recreation includes quick stops, fast accelerations, and high speed turns. This type of activity leads to miles of exposed soil surfaces. During storm events, these trail systems become the primary contributor of sediment into the nearby streams. The sediment that enters streams from sources such as these have been shown to contribute to turbidity, transportation of harmful chemicals and microorganisms, and impairment of aquatic habitats.

Objective

The impact of ORV trails on nearby streams is a new area of research and limited scientific data are available to address sediment pollution created by ORV trails. The objectives of this study were to:

1. Quantify water quality impacts of an ORV trail stream crossing through the monitoring of total suspended solids, and

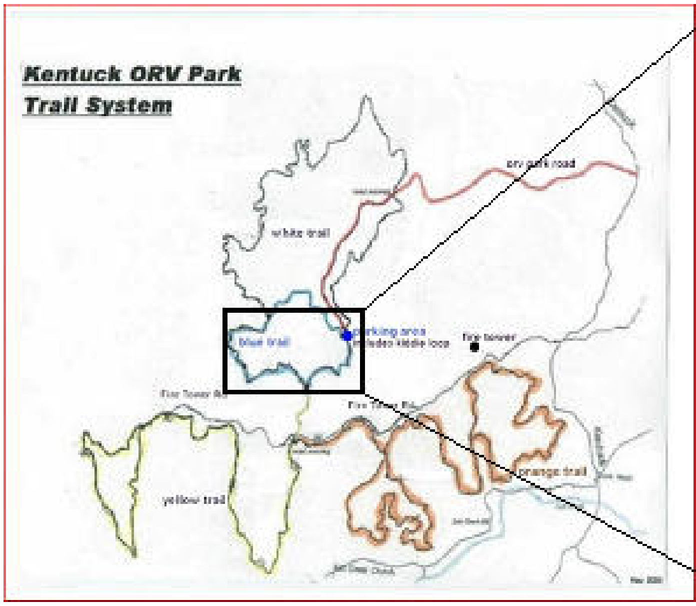
2. Determine potential long-term sediment loads contributed by the ORV trail stream crossing through sediment transport modeling using the WEPP (Water Erosion Prediction Project) model.

Methods

Site Description

This study was conducted on the Kentuck ORV trail located in the Talladega National Forest, Talladega County, Alabama. The study area was located in the Alabama Valley and Ridge Province, and is characterized by short, steep slopes, narrow ridgetops, and rock and shale outcrops. The elevation ranges between 300 and 580 m, and the soils belonging to the Fruithurst Chewacla series with 50% being Fruithurst and 30% being Chewacla. The Fruithurst soil consists of well drained upland soil with a 12 cm thick dark yellowish brown loam surface layer and a subsoil of red clay loam with a depth of about 86 cm. The average slopes are between 6 and 35%. The Chewacla soil is a poorly drained soil found on the flood plains with a brown surface silt loam layer about 20 cm thick. The subsoil is a yellowish brown silt loam and loam. Average slopes are between 0 and 2%. The average annual temperature ranges between 7.2 ^{0}C in January and 26 ^{0}C in August. The annual precipitation in this area is approximately 1330 mm (Cotton et al., 1974).

The Kentuck ORV trail system is comprised of approximately 48 km (30 mi) of trails that are divided into four sections, the white, yellow, blue, and orange trails (Figure 1). A small perennial stream with a wooden bridge crossing was selected for suspended sediment sampling and was located on the Blue Trail, which is a 3.2 km (2 mi) looped section. A Geographic Information System (GIS) was used to delineate the watershed area (113 ha) that encompassed the stream crossing (Figure 2). The trail ran down to the stream crossing with slopes that range from 1 to 18 percent on one side and 0.01 percent grade on the other side (Figure 3).



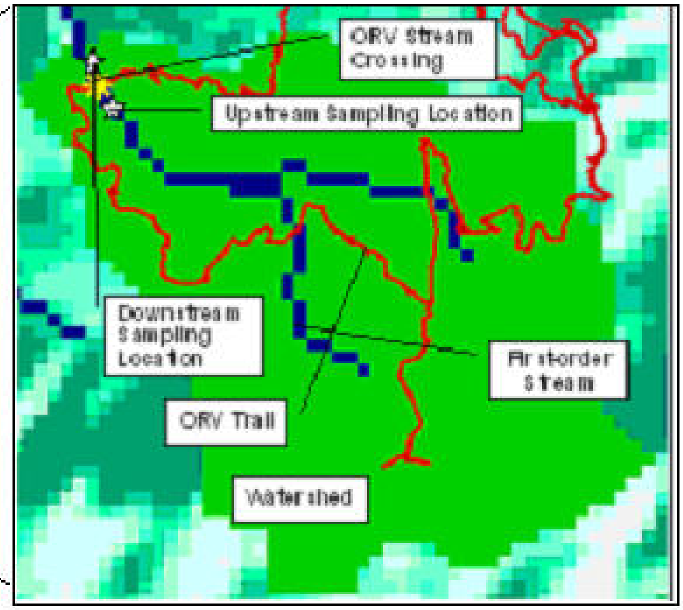


Figure 1. Kentucky ORV trail system Figure 2: Spatial representation of the **113 ha watershed and streams**

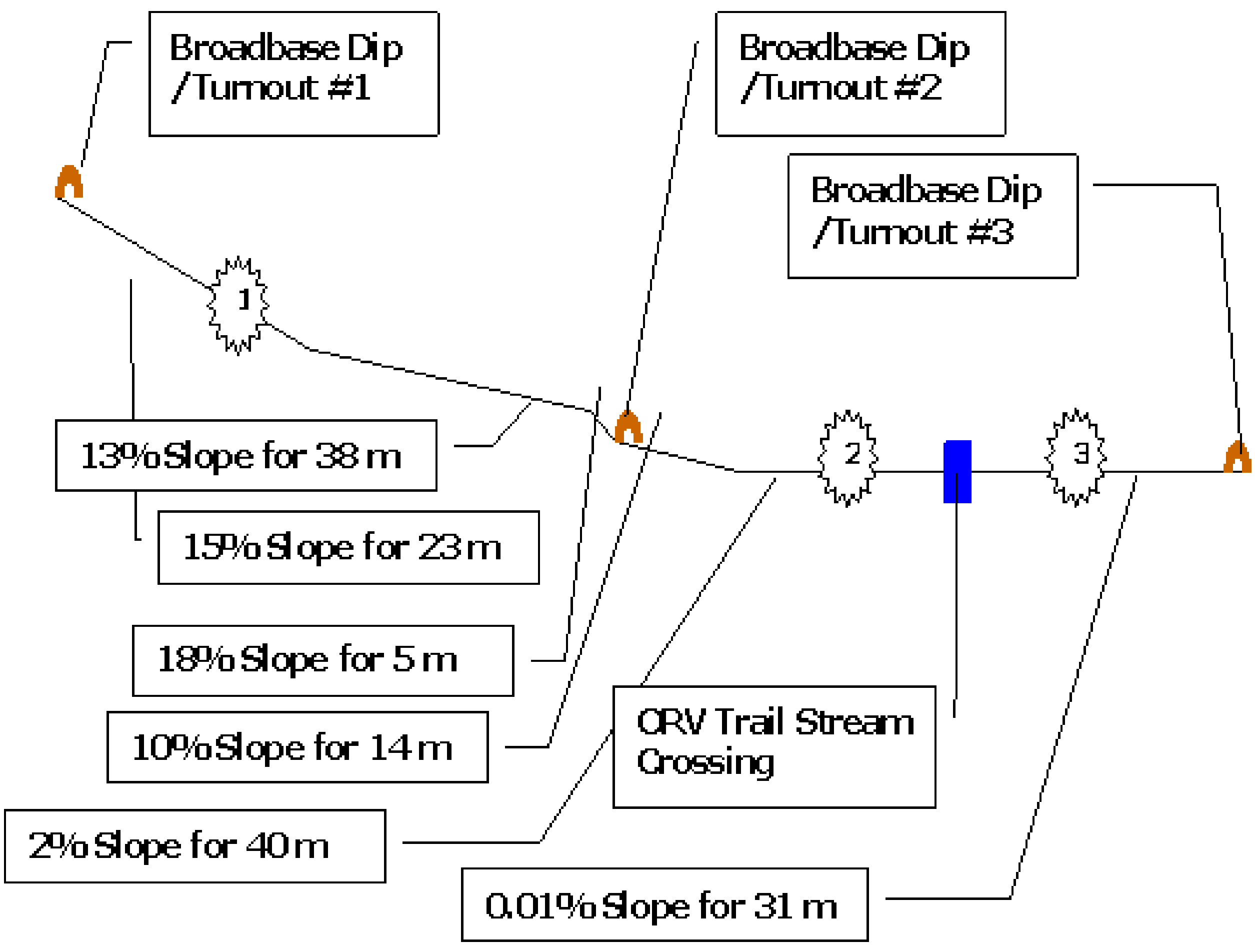


Figure 3. Profile view of the ORV trail stream crossing

Data Collection

Storm event suspended samples were collected over a 9-month period using two ISCO 6700 automated samplers (one upstream and one downstream of the ORV trail stream crossing); the stream flow data were collected using a StartFlow ultra doppler flow meter, while the rainfall data were collected using two ISCO tipping bucket raingauges. The ISCO samplers were installed on the streambanks. The intake hose of the upstream sampler was about 16 m from the stream crossing while the downstream sampler was 60 m from the stream crossing. These distances were determined by following the sediment plumes that were being deposited into the stream from the ORV trail turnouts. Each sampler was connected to its own tipping bucket rain gauge, which triggered the sampling when the rainfall intensity reached 2.6 mm/hr. Once the sampling began, the stream water was sampled at a rate of 250 ml every fifteen minutes for a continuous twenty-four hour period.

Laboratory analysis of the water samples was conducted to determine the amount of suspended sediment (SS) in each 1000-mL collection bottle. These measurements were obtained by following standardized procedures (APHA – AWWA – WPCF, 1995), and the SS loads were calculated.

WEPP Modeling

To address the second objective of this study, the hillslope version of WEPP (Water Erosion Prediction Project) model was used to determine the long-term pollution potential of the ORV stream crossing. The erosion and sediment transport model, WEPP was created by the USDA-ARS laboratory located at West Lafayette, IN for use by the USDA-Natural Resources Conservation Service, USDA-Forest Service, USDI Bureau of Land Management, and others to predict erosion and sediment transport from cropland, rangeland, and forested areas. Recently, WEPP has been applied to assess sediment pollution created by forest roads, site preparation, and timber harvest operations. WEPP was designed to replace the universal and modified soil loss equations (USLE & MUSLE) for areas that are dominated by Hortonian overland flows. The model is most accurate when site characteristics and field data have been collected and input into the model. WEPP has approximately 400 variables that can be modified to model most site conditions. “The WEPP model includes components for weather generation, frozen soils, snow accumulation and melt, irrigation, infiltration, overland flow hydraulics, water balance, plant growth, residue decomposition, soil disturbance by tillage, consolidation, and erosion and deposition” (USDA, 1995).

The model uses CLIGEN, a climate generation program, to create climate files based on the information available from weather stations across the nation. Several models have been included in WEPP to create climate files that “[generate] mean daily precipitation, daily maximum and minimum temperature, mean daily solar radiation, and mean daily wind direction,” as well as time-rainfall intensity, and winter processes (USDA, 1995). A user can also choose to input known weather data into climate files for weather simulation.

The slope file allows the user to create a hillslope that simulates the variability in conditions of the actual site. This is accomplished by creating an overland flow element (OFE) for each condition. The length, width, slope, and trail conditions can be entered into the slope file through an easy to use pop-up window. The WEPP model displays the input values on a two-dimensional plane that models the changes in slope and conditions. The maximum number of OFEs for the WEPP model is 10. The user must also ensure that the same numbers of OFEs are created for the slope and soil files.

The model utilizes a soil file that allows the user to adjust several soil parameters to accurately represent the known soil characteristics. They “include: random roughness, oriented roughness, bulk density, wetting-front suction, hydraulic conductivity, interrill erodibility, rill erodibility, and critical shear stress” (USDA, 1995).

The management file allows the user to account for most conditions and management applications that have been implemented over time. This information is input through several parameters: plant growth, tillage, OFE conditions, channel conditions, surface-disturbing implements, contouring, drainage, and management information. The WEPP model will assess the amount of erosion for each scenario that has been programmed into the file.

Model Set up

To estimate the long-term sediment yield from the ORV trail stream crossing, three hillslopes were modeled, two on the left side of the stream crossing and one on the right side of the stream crossing (Figure 3). On the left side of the stream, it was assumed that the broadbase dip/turnout #1 diverted all the runoff and sediment from the trail upslope of the first hillslope to the adjacent forested area which does not reach the stream. This assumption is based on the observation at the site, and also based on the model runs that suggested that sediment from ORV trail sections upslope from the broadbase dip/turnout #1 does not reach to the stream. The runoff and sediment from the first hillslope is diverted by the broadbase dip/turnout #2 and flows through 75 m of 20 year old forested area (first 25 m at 14% slope and rest at 1% slope). The slope of the first hillslope varies from 13 to 18%. The second hillslope on the left side of the stream crossing contributes sediment directly to the stream. The slope ranges from 10% to 2% (Figure 3). The hillslope on the right side of the stream (hillslope 3) is flat with about 0.01% slope and is 31 m long. The broadbase dip/turnout #3 on the upslope side of the third hillslope diverts the runoff and sediment to adjacent forested area and does not reach the stream. The trail is about 3 to 3.5 m wide and was modeled as low-volume insloped forest road with a maintenance rotation that occurred on March 1 of each year of a 30 year simulation. The maintenance on the trail is currently done using a crawler tractor with a rear mounted blade that disturbs the soils to a depth of 20 cm. The goal of this maintenance operation is to move the loose soil on the trail to fill the ruts and ensure proper functioning of the broadbase dips and turnouts.

Model Parameters

The soil on the ORV trail was modeled as Chewacla series. However, several soil parameters specific to the ORV trail segments used for this modeling study were adjusted using data from soil analyses of samples collected from the surface layer of the ORV trail. More specifically, road surface interrill erodibility, rill erodibility, critical shear, and effective hydraulic conductivity were estimated (from the equations listed in the WEPP user document) using the soil properties (textural and other) determined using the soil samples collected from the ORV trail surface. The equations listed in WEPP user document are applicable for croplands as a baseline value. Since these values will be a lot different for the ORV trails and low volume roads, critical shear and effective hydraulic conductivity values suggested by the WEPP model for the low volume forest roads were used. These two parameters were found to be the two most sensitive soil parameters for determining sediment yield. Table 1 shows the road surface soil parameters used in the WEPP model. The management file for this trail was represented by the insloped forest road with, a bare ditch, and no vegetation. The climate file was created using CLIGEN. The climate station selected was the Alabama Anniston WB AP AL station which was about 15 miles from the stream crossing. A 30-year climate data simulated by CLIGEN was used for model simulations.

Table 1. ORV trail surface soil parameters used for the WEPP modeling

Parameter	Value
Interrill Erodibility (kg*s/m ^{4})	4.5E +006
Rill Erodibility (s/m)	0.0074
Critical Shear (N/m ^{2})	0.04
Effective Hydraulic Conductivity (mm/h)	0.18
Soil Texture	SIL
Depth (mm)	200
Sand (%)	27.5
Clay (%)	28.2
Organic (%)	0.8
Rock (%)	2.0
CEC (meq/10)	12.0

Results and Discussion

Observed Suspended Sediment Loads from ORV Trail Stream Crossing

Data was collected for three different operational conditions: trail closed, trail maintenance, and trail open (Table 2). When the sampling process began in November of 2003 the trail was in a highly degraded state. There were areas of exposed soil that had accumulated over the months of use. The ORV trails were closed to traffic from January 1, 2004 through April 1, 2004. The maintenance occurred between March 6 and 16, 2004. During the maintenance period, a crawler tractor was brought in to break up any areas that contained standing water. The trail was then allowed to dry, and after a few days the tractor was brought back to scrape the trail. During the scraping process the excess soil was pushed to the center of the trail and compacted down with repeated passes of the equipment. This process allowed for the accumulation of loose soil on the trails surface. During the maintenance period, the broadbase dips/turnouts were repaired to ensure their proper functioning. The trail was opened again on April 1, 2004.

During the 9-month study period, flow and suspended sediment data were collected from 15 different storm events (Table 2). It should be noted that a number of other storm events also occurred during the study period, but because of the malfunctioning of the ISCO samplers data for only 15 storm events were captured. Among the storm events for which the data were collected, only the 49 mm storm that occurred on February 6, 2004 produced appreciable suspended sediment load. The other storm events, which were smaller than this event, did not contribute to a lot of suspended sediment load. The return period of the storm that occurred on February 6, 2004 is less than one year. The ORV trail did not contribute big sediment loads during other smaller events. Hence, this study suggests that ORV trail stream crossings have potential to contribute large sediment loads from storm events that have higher return intervals. However, since data was collected for only one such event, a modeling study was needed to better assess potential loads contributed by the ORV trail stream crossing. Hence, to quantify long-term sediment loads (and hence pollution potential) from the ORV trail stream crossing, WEPP modeling was done.

Table 2. Individual storm events and the suspended sediment (SS) loads contributed by the ORV trail stream crossing

Trail Condition	**Date**	**Cumulative Rainfall**	**SS Upstream**	**SS Downstream**	**SS Load Contributed by Stream Crossing**	**% of Load Contributed by Stream Crossing**
		(mm)	(kg)	(kg)	(kg)	(kg)
Trail Open	12/16/2003	10	0.4	0.6	0.2	33.3
Trail Closed	01/25/2004	22	0.8	0.9	0.1	11.1
	02/06/2004	49	171.3	280.3	109.0	38.9
	02/12/2004	20	4.8	4.9	0.1	2.0
	02/25/2004	11	0.7	0.8	0.1	12.5
Maintenance	03/06/2004	20	26.7	30.7	4.0	13.0
	03/16/2004	5	0.1	0.2	0.1	50.0
Trail Closed	03/20/2004	9	1.3	1.7	0.4	23.5
	03/29/2004	20	2.1	2.2	0.1	4.5
Trail Open	04/11/2004	13	1.2	1.7	0.5	29.4
	04/26/2004	18	0.5	0.8	0.3	37.5
	04/30/2004	22	18.2	20.4	2.2	10.8
	05/16/2004	36	7.3	9.3	2.0	21.5
	06/22/2004	10	0.3	0.9	0.6	66.7
	07/02/2004	16	1.6	1.8	0.2	11.1

WEPP estimated Suspended Sediment Loads from OVR Trail Stream Crossing

As discussed previously, three hillslope segments leading to the stream crossing were modeled using WEPP. A 30-year synthetic climate data generated by CLIGEN was used for this simulation. Based on the slope and soils parameters and management operations described previously, the model estimated that the three hillslope segments (that make up the stream crossing) contributed about 5744 kg (at the rate of 126 tons/ha) of sediment annually. This sediment contribution is much higher than the sediment yield allowed by the USDA Forest Service-National Forests in Alabama for temporary roads. The National Forests in Alabama considers more than 44.5 tons/ha/yr (or 18 tons/ac/yr) of sediment yield temporary roads and disturbed areas as unacceptable (Personal Communication with Jay Edwards, Forest Hydrologist, USDA Forest Service-National Forests in Alabama, Montgomery, AL). The annual rate of sediment loads contributed by the hillslopes 1, 2, and 3 were 22.9, 243.2, and 1.6 tons/ha, respectively. This suggests that most of the sediment contribution to the stream is from the hillslope that contributes sediment directly to the stream. It should be noted that on a long term basis about 50% of sediment load from this ORV trail stream crossing is in the form of clay and silt particles and about 50% is in the form of sand particles.

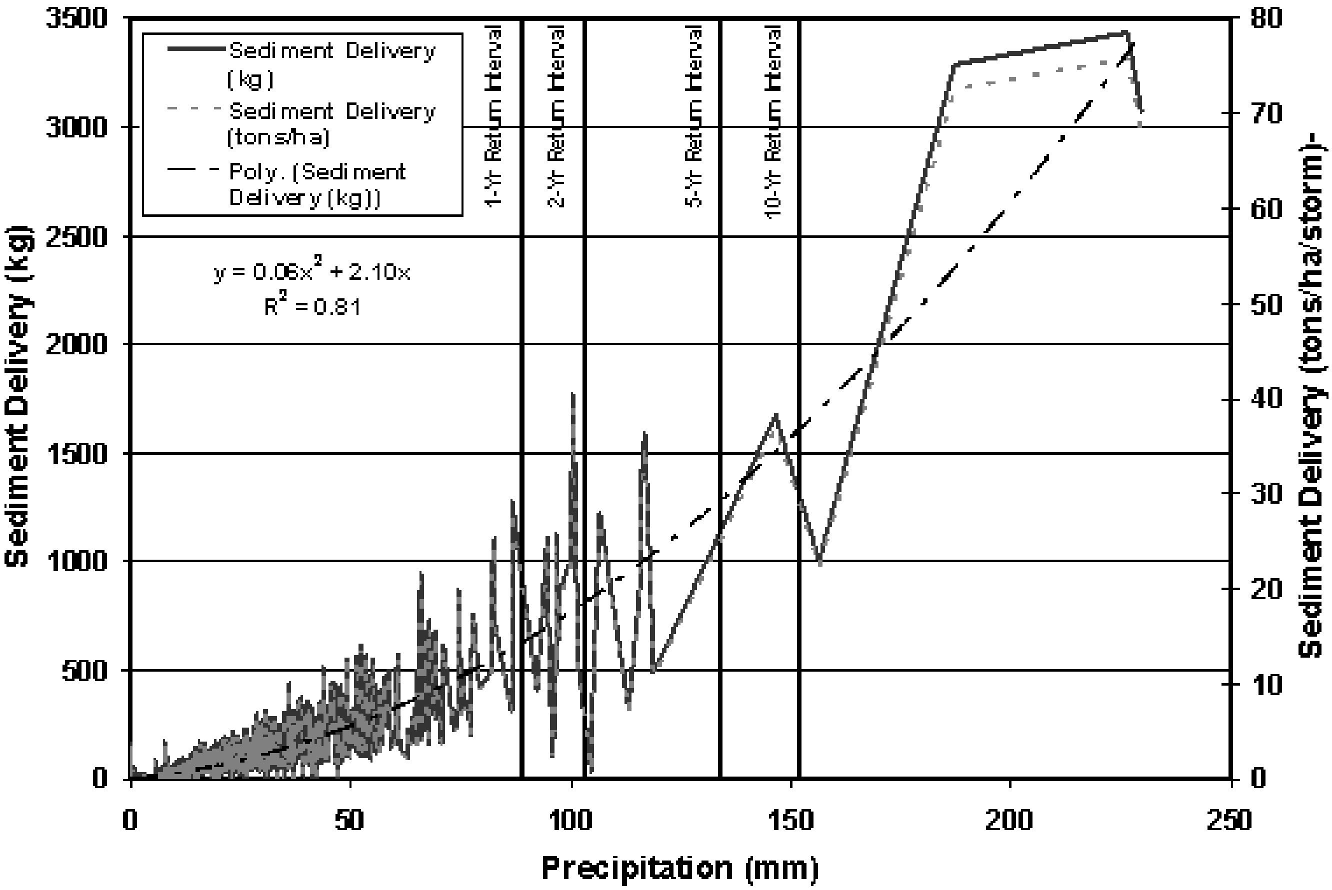


Figure 4. WEPP predicted sediment delivery in kg and tons/ha during various precipitation events that occurred during the 30 year simulation period.

Figure 4 shows sediment loads (in kg) and sediment loading rate (in tons/ha) produced by the ORV trail stream crossing during various storm events that occurred over a 30 year period. The figure also shows a best fit polynomial of degree 2. This polynomial is used to show the trend line and not to suggest a relationship between precipitation events and sediment delivery. This figure also suggest that single storm events of 1, 2, 5, and 10 year return intervals have potential to contribute large sediment loads from the stream crossing. A 50 mm storm event will contribute about 250 kg of total sediment, which will result in about 125 kg of suspended sediment (assuming that 50% of the total sediment load is in the form of suspended sediment (clay and silt particles); see above). The WEPP predicted sediment load is similar to the one observed for the 49 mm storm event that occurred on February 2, 2004. Based on this modeling study, it can be suggested that the last section of the ORV trail stream crossing should be as small as possible and should be as flat as possible. If a broadbase dip/turnout is constructed very close to the stream crossing (to reduce the length of the ORV trail section that directly contributes sediment to the stream), the plume itself might directly contribute sediment to the stream and buffering potential of the forested area might by underutilized. Hence, we suggest that there is a need to develop either a BMP that can reduce direct contribution to the stream or build ORV trail stream crossing on flat slopes.

Conclusion

The use of ORVs on a trail results in ruts, crevices, and the accumulation of loose soil that is spun off of the tires during fast accelerations and turns. This sediment is transported to nearby streams during storm events that occur throughout the year. In this study, sediment loads contributed by an ORV trail stream crossing was measured using automated samplers. The most significant sediment contribution into the stream occurred during an intense storm that lasted for several hours. This rainfall event had a return interval of less than 1 year. The ORV trail did not contribute big sediment loads during other smaller events. Hence, this study suggests that ORV trail stream crossings have potential to contribute large sediment loads from storm events that have return interval 0.5 year or higher. However, since the data was collected for only one such event, either more long-term data was needed to better quantify sediment loads contributed by ORV trail stream crossings or a modeling study was needed to better assess long term potential loads contributed by the ORV trail stream crossing. The long term pollution potential of ORV trail stream crossing was determined using the WEPP model. The model suggested that the storm events as small as 0.5 year return interval (about 50 mm cumulative rainfall) has potential to contribute significant sediment loads. Since the model suggests that most of the sediment load to the stream is contributed by the steep hillslope that directly contributes sediment to the stream, a BMP needs to be developed and implemented to reduce load from this approaching section. Also, the modeling study suggests that the ORV sections adjacent to the stream should be on as flat a slope as possible. Future plan for this study include properly calibrating the WEPP model using total sediment load data collected at the downslope end of three different slopes and then using the calibrated model to evaluate ORV trail BMPs, appropriate slope for the ORV trail stream crossing, and maintenance schedule. The goal of the future study will be to reduce the maintenance cost as well as the water quality impacts of the ORV trails.

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