United States
Department of
Agriculture

Forest Service

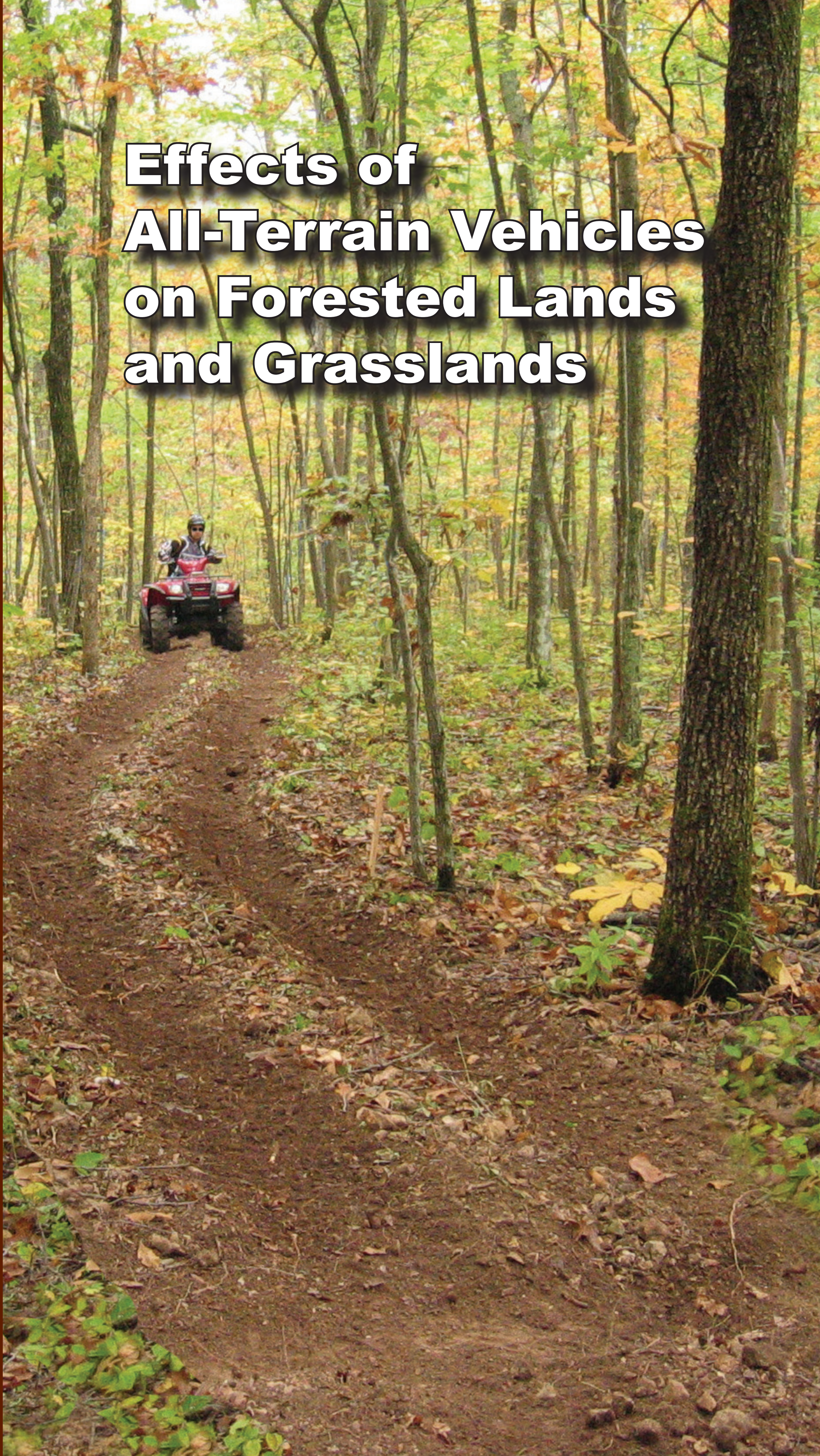
**National Technology &
Development Program**

**Recreation
Management**

0823 1811—SDTDC
December 2008

U.S. Department
of Transportation
**Federal Highway
Administration**

Effects of All-Terrain Vehicles on Forested Lands and Grasslands



Acknowledgments

Without the spirited cooperation and volunteer contributions from many forests, other Federal agencies, industry, and volunteer organizations this project woud have been impossible to complete. We offer a special thanks to: The Minnesota Department of Natural Resources, The Federal Highway Administration, The Specialty Vehicle Institute Of America, The National Off-Highway Vehicle Conservation Council, and all of the participating forests.

Effects of All-Terrain Vehicles on Forested Lands and Grasslands

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December 2008

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EXECUTIVE SUMMARY

One goal of the Forest Service, U.S. Department of Agriculture, is to provide outdoor recreation opportunities with minimized impacts to natural resources (USDA Forest Service 2006). All-terrain-vehicle (ATV) use on public lands is a rapidly expanding recreational activity. An estimated 11 million visits to national forests involve ATV use. This constitutes about 5 percent of all recreation visits to national forests (English 2003). When repeated ATV use occurs on undesignated trails, the impacts can exceed the land's ability to rehabilitate itself. The challenge for recreation managers is to address the needs—and conflicting expectations—of millions of people who use and enjoy the national forests while protecting the land's health and integrity.

In addition to a new travel management policy that restricts travel on undesignated trails, the Forest Service studied previously unused trails to determine the effects of ATV traffic on the natural resource. The study's three main questions were: Are natural resources being affected by ATV use; to what degree are natural resources being affected; and does the ATV's design make a difference in the effects? To answer these questions on a nationwide scale, the study was performed at seven locations within representative ecoregions. The ecoregions included Desert, High-elevation Western Mountains, Gulf Coastal Plains, and Eastern Broadleaf.

Yes, natural resources were affected by ATV traffic. At all seven locations, some portion of the previously unused trail transitioned from a low to medium disturbance class in 20 to 40 passes. Medium-disturbance occurred when two of the following three conditions were present: sixty-percent loss of original ground cover, trail-width expansion to 72 inches, or wheel ruts up to 6 inches deep. At each location some portion of the trail transitioned from medium to high disturbance in 40 to 120 passes. High disturbance occurred when two of the following three conditions were present: more than 60-percent loss of original ground cover, trail width exceeding 72 inches, or wheel ruts deeper than 6 inches.

Disturbance levels were caused by three independent variables: sites, trail features, and vehicles and tires. There was a statistically significant difference between the number of passes required to transition from the low to medium disturbance class for the seven sites. Desert and Eastern-broadleaf ecoregions were the most susceptible to ATV traffic, and the Gulf Coastal Plain ecoregion was the least susceptible. Each ecoregion trail section that required wheel-spin or slip moved quickly to increasing levels of disturbance. Compared to tight-radius curves, nearly eight times as many passes were required to produce equal impacts on straight sections, and nearly five times as many passes were required for uphill or downhill sections.

There were no statistically significant differences for the sport and utility ATVs equipped with either original equipment manufacturer tires or after market tires with ¾-inch lugs. The study concluded that the impacts from the four combinations of vehicles and tires were indistinguishable.

Following any level of disturbance, runoff and sediment generated on the ATV trails increased by 56 percent and 625 percent, respectively, compared to the undisturbed forest floor. ATV trails are high-runoff, high-sediment producing strips on a low-

runoff, low-sediment producing landscape. Frequent diversions of the trail runoff onto the forest floor will reduce the amount of sediment and runoff as it infiltrates into the forest floor.

The study demonstrated that ATV traffic does have an impact on natural resources. The levels of disturbance can be reduced by proper trail design and maintenance and by focusing efforts on trail sections that require extra attention. Application of this study should assist managers in planning, designing, and implementing decisions related to ATV management.

INTRODUCTION

As the United States population has grown, so has all-terrain-vehicle (ATV) use on national forests and grasslands and other public lands. Annual sales of ATVs have increased over 272 percent since 1994 to an estimated 876,000 units in 2005 (Specialty Vehicle Institute of America - Special Report Summer 2006). ATVs are a popular choice for outdoor recreation. According to a national survey on recreation and the environment, about 36.3 million people participate in off-highway driving or ATV or motorcycle use (Cordell et al. 2001). An estimated 11 million visits to national forests involve off-highway-vehicle (OHV) use—or about 5 percent of all recreation visits (English 2003).

Unauthorized trails from motorized use cause much of the natural resource [impacts] and some of the public safety concerns on national forests. Unauthorized trails are a major problem for forest managers. For example, Lewis and Clark National Forest personnel in Montana currently estimate that the forest has 1,348 unauthorized roads and trails extending for 646 miles (Robertson 2003). The increased use of ATVs on public land has meant that even the small percentage of riders who desire to travel off trails and roads can have considerable effects on the natural resources around them. Paterson 2003 states that equipment modifications designed to enhance vehicle performance have caused many of these effects. A disproportionate effect from irresponsible OHV—particularly ATV—use is possible because motorized vehicles are powerful, can travel many miles quickly, and can damage sensitive resources easily.

The magnitude of effects varies depending on local characteristics of the landscape including slope, aspect, soil susceptibility to erosion, and vegetation type (Stokowski and LaPointe 2000). The land may be able to rehabilitate itself after the effects from a few ATV rides across a meadow, but multiple passes across the same area often result in a reduced or complete loss in the capacity for natural rehabilitation.

Sustaining and enhancing outdoor recreation opportunities with minimized impacts to natural resources is Goal 4 in the FY 2007-2012 USDA Forest Service Strategic Plan. The expected outcome is a variety of high-quality outdoor recreational opportunities on the Nation's forests and grasslands that are available to the public. (USDA Forest Service 2007).

Recreation visitors expect a great deal from their national forests and other public lands in terms of settings, experiences, facilities, and services. The challenge for recreation managers is to address the needs and conflicting expectations of millions of people who use and enjoy national forests while protecting the health and integrity of the land. Increased pressure from growing populations, coupled with advances in recreation technology, will continue to challenge public land-management agencies, State and local governments, and private landowners (USDA Forest Service position paper 2003).

The Forest Service has responded to these pressures by establishing a new travel management policy. The Forest Service also conducted a study to determine the effects of ATVs on the natural resources. This publication documents that study and provides field managers with information and tools to make good, science-based decisions in managing the effects of ATVs, as they implement policies and plans related to travel management in the national forests and grasslands.

Chapter 1 discusses the methodology behind the study, as well as, its design and implementation. It also discusses the assessment tool used to measure the effects on natural resources.

Chapter 2 includes an analysis of the data collected during the test period and answers the three questions that framed the study:

1. Are natural resources being affected by ATV use? In other words, is change occurring?
2. If change is occurring, to what degree are natural resources affected?
3. If natural resources are affected, does the design of the ATV (or the way that it is equipped) make a difference?

Chapter 2 also contains a discussion of ATV performance, rider behavior, and their effects.

Chapter 3 includes descriptions of the settings and habitats for the seven study sites. The changes to natural resources as a result of repetitive ATV traffic also are included.

Chapter 4 contains recommendations to assist managers in planning, designing, and implementing decisions related to ATV management.

CHAPTER 1. METHODOLOGY

Experimental Approach

The experimental approach was to make repeated passes over the same landscape and measure the effects on the natural resources. More specifically, at each forest location, four loop trails were set up with uphill climbs, downhill slopes, turns, and straight sections.

Sport and utility ATVs were tested with original equipment manufacturer (OEM) tires and a non-OEM (aftermarket) tires. Only one vehicle and tire combination was used on each test section. Trail section condition was assessed prior to traffic using several soil and vegetation condition indices. Table 1 identifies the information collected and when the measurements were taken.

Riders made a fixed number of passes over the test loops. Test-loop condition was assessed and classified into three disturbance classes: low, medium, and high. The low disturbance class was characterized by litter and vegetation largely unchanged from initial conditions, with loose material less than 3 inches deep and shallow wheel ruts. Loss of litter and vegetation up to 50 percent and wheel ruts up to 6 inches deep defined the medium disturbance class. Large tree-root exposure and wheel ruts deeper than 6 inches defined the high disturbance class. When each of the test loops reached one of the defined disturbance classes, traffic ceased on that loop.

Disturbance Classes

One expectation was that wheel slip and vehicle weight would produce a continuum of disturbances from none to unacceptable. Rather than attempt to measure each structural characteristic of the natural resources along this continuum, three disturbance classes were used as defined in tables 4 and 5. The four structural characteristics within the disturbance classes are defined as:

Vegetation and Cover Conditions—Litter, vegetation, tree roots, and rocks dominate. As roots and rocks are exposed, and litter and vegetation is reduced, the disturbance condition

Table 1—Timing of trail measurements.

Measurement	Before Any Traffic Begins	Continuously	Beginning of Each Day's Traffic	During Each Day's Traffic	After Completion of Traffic
Soil relative strength			✓		✓
Soil texture					✓
Air temperature	✓	✓			✓
Precipitation	✓	✓			✓
Soil moisture					✓
Rut depth			✓		✓
Trail width			✓		✓
Vehicle speed				✓	

moves toward high. The high disturbance class is characterized by greater than 60 percent bare soil and exposed roots and rocks.

Trail Conditions—Depth of rutting and trail width are the key indicators in the trail conditions. A trail width greater than 54 inches and ruts greater than 6 inches deep are indicative of a high disturbance class.

Erosion Conditions—Rill networks and dust are used as indicators of erosion conditions. Rills on more than one-third of the trail length, sediment movement off the trail, and a dust cloud more than 6 feet high are used to indicate a high disturbance class.

Soil Conditions—The depth of the A-horizon is the soil indicator for disturbance classes. A loss of more than 50 percent of the A-horizon is cause for classifying a trail section in the high disturbance class.

Disturbance Class Matrix

The idea behind a trail-condition class matrix is well established. The Forest Service (1975) used a Stream Reach Inventory and Channel Stability Evaluation matrix with stability indicators of excellent, good, fair, and poor. There are 15 descriptions for these conditions that correspond to the proposed 9 descriptions in table 2. Using this classification matrix, the verbal description most closely matching the actual conditions on the

Table 2—Trail disturbance class matrix for trails.

Trail Disturbance Class Matrix For New Trail			
	Low Disturbance	*Medium Disturbance*	*High Disturbance*
Vegetation and Cover Conditions			
Litter and vegetation	0-30% bare soil.	30-60% bare soil.	Greater than 60% bare soil.
Tree roots	Small roots exposed.	Small roots exposed and broken.	Large roots exposed and damaged.
Rocks	No more exposed or fractured rocks than natural conditions.	Exposed and fractured rocks.	Large rocks worn around or displaced.
Trail Conditions			
Trail width (both tread and displaced material)	54 inches or less.	Between 54 and 72 inches. Some trail braiding. Evidence of width increasing.	72 inches or greater. Braided trails evident. Trail width is growing.
Trail tread/surface	Loose material up to 3 inches deep and wide.	Loose material 3 to 6 inches deep.	Loose material deeper than 6 inches.
ATV rut depth	Ruts less than 3 inches deep.	Ruts 3 to 6 inches deep.	Ruts greater than 6 inches deep.
Erosion Conditions			
Rill networks	Little or no rilling, less than 1/3 of trail between water breaks has rills.	More than 1/3 of trail between water breaks has rills.	Rills evident on more than 1/3 of trail between water breaks.
Dust	Less than 3 feet high. Traffic does not slow down. Does not obstruct visibility.	3- to 6-foot cloud. Causes traffic to slow down. Partially obstructs visibility.	Greater than 6 feet. Causes traffic to slow or stop. Very thick cloud that obstructs visibility.
Soil Conditions			
Depth of A horizon	Greater than 70% of natural.	70 to 50% of natural.	Less than 50% of natural.
TOTALS			

ground was checked, the number of checks in each class added together, and the condition class rating was determined by the total score. This procedure is illustrated in table 3.

Application of the Disturbance Class Matrix

Table 3 illustrates how the disturbance class matrix was used. An observer walks along a trail section and makes a qualitative judgment, or in a few cases a quantitative measurement, for each entry in the matrix by circling the appropriate description. After all the descriptors have been rated, the circles (disturbance class) are totaled at the bottom of each column. The disturbance class corresponding to the column with the highest total is deemed the condition of that trail section. Ties are rounded down.

In table 3 the total of the factors in the low disturbance class was five, in the medium class was three, and in the high class was one. Since the class receiving the highest total was low, the section was classified as low disturbance.

Two techniques were used for assessing changes to the natural resources as ATVs made repeated passes over the loops. The first assessment was made using the condition-class matrix described

Table 3—Example of trail disturbance class matrix for trails.

Trail Disturbance Class Matrix For New Trails			
	Low Disturbance	*Medium Disturbance*	*High Disturbance*
Vegetation & Cover Conditions			
Litter and vegetation	0-30% bare soil.	30-60% bare soil.	Greater than 60% bare soil.
Tree roots	Small roots exposed.	Small roots exposed and broken.	Large roots exposed and damaged.
Rocks	No more exposed or fractured rocks than natural conditions.	Exposed and fractured rocks.	Large rocks worn around or displaced.
Trail Conditions			
Trail width (both tread and displaced material)	54 inches or less.	Between 54 and 72 inches. Some trail braiding. Evidence of width increasing.	72 inches or greater. Braided trails evident. Trail width is growing.
Trail tread/surface	Loose material up to 3 inches deep and wide.	Loose material to depth of 3 to 6 inches.	Loose material deeper than 6 inches.
ATV rut depth	Ruts less than 3 inches deep.	Ruts 3 to 6 inches deep.	Ruts greater than 6 inches deep.
Erosion Conditions			
Rill networks	Little or no rilling, less than 1/3 of trail between water breaks has rills.	More than 1/3 of trail between water breaks has rills.	Rills evident on more than 1/3 of trail between water breaks.
Dust	Less than 3 feet high. Traffic does not slow down. Does not obstruct visibility.	3- to 6-foot cloud. Causes traffic to slow down. Partially obstructs visibility	Greater than 6 feet. Causes traffic to slow or stop. Very thick cloud that obstructs visibility.
Soil Conditions			
Depth of A horizon	Greater than 70% of natural.	70 to 50% of natural.	Less than 50% of natural.
TOTALS	*5*	*3*	*1*

above. The second assessment was made using cross-section transects. The cross-section transects were designed to measure changes to the trail tread as vehicles made passes over the loops. These measurements were taken each day at the end of the riding period. See figures 1 and 2. Three transects were placed at each of the four transect areas.

Figure 1—Transect and measurement process.

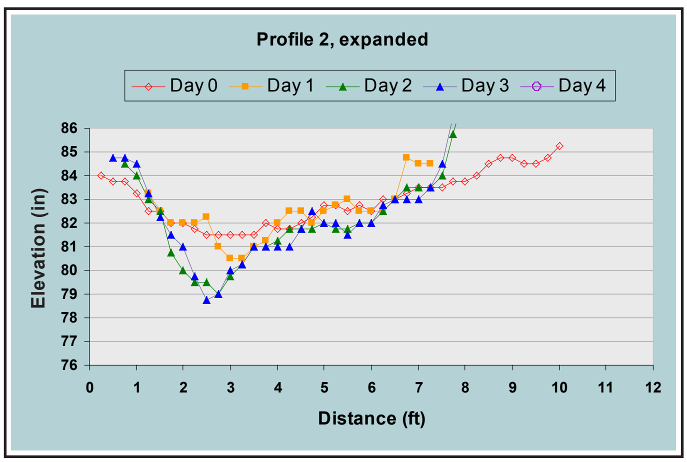


Figure 2—Example of how the information for the transect profiles was recorded on each loop at each transect.

Changes to the trail tread's vertical profile were measured by deploying a fiberglass measuring rod across the trail onto two previously leveled stakes, or plastic jacks, in rocky areas. The stakes or jacks maintained the same elevation throughout the study. It was assumed that as ATV traffic continued, the trail tread could widen. The width of the transect was set at 14 feet, and the measuring rod was placed to measure not only the vertical changes to the trail tread but also changes that occurred in the shoulder areas.

Rainfall simulation to measure erosion-prediction parameters was performed on the undisturbed class and each of the three ATV-disturbance classes. It was not important whether the disturbance class came from an uphill, downhill, straight, or turn segment. What was important was that the soil condition within the erosion test plot was determined by the vegetation cover, trail conditions, erosion conditions, and soil conditions.

The simulation consisted of measuring the runoff and sediment production from a 4-inch-per-hour, 30-minute rainstorm. This rate and duration was selected based on previous rainfall simulations on forest roads, undisturbed forest soils, timber harvest areas, and burned forest areas. The 4-inch-per-hour rate was the minimum that produced runoff on the undisturbed class. This rate also produced runoff on both the medium and high disturbance classes.

Analysis of the runoff and sediment-production data allowed calculation of erosion parameters for use in the soil-erosion prediction model known as Water Erosion Prediction Project (WEPP). This model allowed erosion prediction from each disturbance class at the test locations.

Soils Characterization

Soil samples were taken at each location. The samples, characterized using the USDA Soil-Texture Class and the Unified Soil Classification System, were typically A-horizon soils.

The characterization tests included moisture content and bulk dry density, soil texture (classification) requiring gradation analyses (sieve and hydrometer analysis) and Atterberg Limits, and shear strength testing (using a direct-shear device) to evaluate soil strength parameters cohesion and internal-friction angle. The testing provided uniform sets of results that can be compared to results from other locations.

Relatively undisturbed samples were obtained using a hand-drive sampler (2.0 or 2.5 inches in diameter) in areas generally free of coarse gravel, cobble, and shale fragments. In areas of coarse materials, grab samples were collected. All testing was performed using standardized methods in accordance with Forest Service specifications established by the American Association of State Highway and Transportation Officials (AASHTO) and the American Society for Testing and Materials (ASTM).

ATV Equipment

Two ATV types (sport and utility) and two tire tread types (OEM and a more aggressive aftermarket tire) were selected for this study. The ATVs appear to be the most popular. Table 4 lists the ATV characteristics used in the study.

The tire pressure, rim size, and tire width were according to ATV-manufacturers' specifications. The OEM was a general-purpose tire with lug height not to exceed ½ inch and lug width not to exceed 1½ inches. The aftermarket tire for each location was the non-OEM tire most often used by local riders and accepted by the local regulatory authorities. Consequently, different aggressive-tread tires were tested at each site.

The ATVs' speed in the test loops was defined by the 85-percent speed standard in the Manual for Uniform Traffic Control Devices. This speed standard generally equates to 10 to 17 miles per hour. Radar measured vehicle speed.

Measurement Parameters and Data-Collection Devices

Each vehicle was equipped with a data collection and recording device. Sport vehicles were equipped with AIM MyChron 3 XG Log dataloggers. This datalogger measured front- and rear-wheel speeds, lap times, lap distance, and lateral acceleration. Longitudinal acceleration was calculated from vehicle speed and distance.

Utility vehicles were equipped with AIM MyChron 3 Gold dataloggers. This datalogger measured vehicle speed based on the rear wheel. Lap times, engine speed (revolutions per minute [rpm]), and loop distances were also measured. Like the XG Log datalogger, longitudinal acceleration also was calculated. The riders viewed vehicle speed and lap times on a liquid crystal display mounted on the handlebar. See figure 3.

Table 4—ATV Characteristics

	Sport Type	**Utility Type**
Weight (pounds)	350 – 450	540 – 610
Stroke cycle	4	4
Transmission/drive	Manual or automatic	Automatic
Number of drive wheels	2	4
Final drive	Chain drive, solid axle	Shaft drive, rear differential
Front suspension type	Double A-arm	Double A-arm
Rear suspension type	Swing arm	Double wishbone

Figure 3—Datalogger.

A Hall-effect sensor measured vehicle speed. The sensor uses a magnet and a pickup that senses a small voltage each time the magnet passes the sensor. The wheel circumferences were measured and entered into the datalogger, which provided an accurate distance measurement. See figure 4.

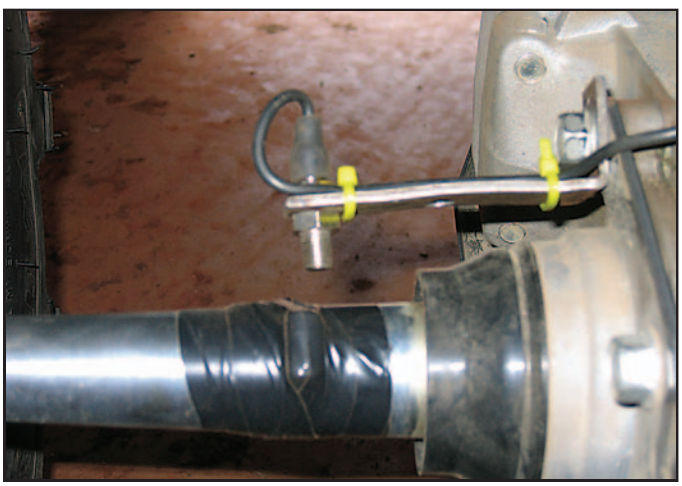


Figure 4—Hall-effect sensor.

Accelerometers, mounted behind the riders along the vehicle's centerline, measured acceleration. The accelerometers were calibrated at the start of each day. See figure 5.

Lap timers started when the datalogger received an rpm or speed signal. An infrared receptor sensed a signal from a trail beacon. A lap was complete when the sensor *saw* the beacon.

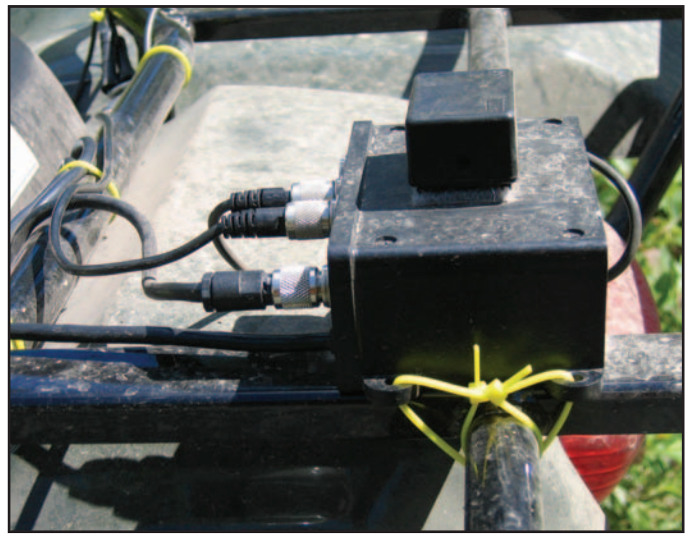


Figure 5—Datalogger instrumentation.

Datalogger data are downloaded to a laptop computer every 40 laps. Riders' names are recorded with the download data. See appendix B for additional ATV and rider information.

Test Locations

The study was conducted on seven forested areas throughout the United States representing a diverse group of ecological provinces. The locations and ecological provinces are shown in table 5.

Table 5—National forests and ecological provinces study sites.

Location	State	Ecological Province
Beaverhead/Deerlodge NF	MT	Middle Rocky Mountain Steppe-Coniferous Forest-Alpine Meadow
Kisatchie NF	LA	Outer Coastal Plain-Mixed Forest
Land Between the Lakes, NRA	KY	Ozark Broadleaf Forest-Meadow
Mark Twain NF	MO	Eastern Broadleaf Forest (Continental)
Minnesota State Forest	MN	Laurentian Mixed (Power) Forest
Tonto NF	AZ	Arizona-New Mexico Mountains Semi-Desert-Open
Wenatchee NF	WA	Marine Regime Mountains-Cascade Mixed Forest Coniferous/ Meadow

CHAPTER 2. ANALYSIS OF FINDINGS

The ATV study was effectively designed to answer three questions.

1. On a continuum from undisturbed to highly disturbed, are the natural resources being affected by ATV use? Is change occurring?

2. To what degree are they affected. Is the disturbance level low, moderate, or high?

3. Do vehicle designs and/or the manner in which the vehicles (sport and utility models) are equipped make a difference?

This chapter explores ATV disturbance levels to soil and vegetation in response to these three questions. Two analytical tools were uses to collect the results from ATV traffic, the trail disturbance class matrix and rainfall simulation. Analyzing information from both sources provided conclusive information about how ATVs affect soil and vegetation.

Another expectation was that dust generated by ATV activity may have an affect on vegetation and the soil migration (through the air) that was occurring contributes to soil erosion.

A dust study was conducted at Land Between the Lakes, Kentucky, to quantify soil loss caused by the effects of ATV trafficking. This study is included in the appendix C.

Disturbance Classes

An expectation was that wheel slip and vehicle weight would produce a continuum of disturbances from none to unacceptable. Rather than attempt to measure each structural characteristic of the natural environment along this continuum, three disturbance classes, low, medium, and high, were proposed. The three determining characteristics were litter and vegetation, trail width, and ATV rut depth.

Removal of litter and vegetation causes visual impacts and increases soil erosion. The low disturbance class had 0- to 30-percent ground cover loss with few exposed roots or rocks. The medium disturbance class was characterized by 30- to 60-percent ground cover loss; small roots exposed; and broken, fractured, and exposed rocks. As roots and rocks were increasingly exposed and litter and vegetation were reduced, the disturbance condition moved toward high. The high disturbance class was characterized by greater than 60-percent ground cover loss and exposed roots and rocks. As noted before the descriptors in table 6 are adapted from McMahon (1995), Page-Dumroese et al. (2000), and Meyer (2002). Generally these

Table 6—Trail disturbance class matrix.

	Low Disturbance	**Medium Disturbance**	**High Disturbance**
Litter and vegetation	0- to 30-percent ground cover loss, small roots exposed, rocks no more exposed than natural conditions.	30- to 60-percent ground cover loss, small roots exposed and broken, rocks exposed and fractured.	Greater than 60-percent ground cover loss, large roots exposed and damaged, large rocks worn around or displaced.
Trail width (both tread and displaced material)	54 inches or less.	Between 54 and 72 inches. Some trail braiding. Evidence of width increasing.	72 inches or greater. Braided trails evident. Trail width is growing.
ATV rut depth	Ruts less than 3 inches deep.	Ruts 3 to 6 inches deep.	Ruts greater than 6 inches deep.
TOTALS			

references used either a set of descriptions for unacceptable conditions or had four to six classes of disturbance. The present study chose three classes.

Trail width was a key indicator of trail conditions. A trail width of 54 inches or less was rated as a low disturbance class. As the width increased from 54 to 72 inches, the condition was rated a medium disturbance class, and a width greater than 72 inches was rated a high disturbance class.

ATV rut depth was the final indicator of trail conditions. A low rating was from no ruts up to 3-inch-deep ruts; a medium rating was 3- to 6-inch-deep ruts; and a high rating was greater than 6-inch-deep ruts.

To use the disturbance class matrix, an observer walked along a trail section and made a qualitative judgment, or in a few cases a quantitative measurement, for each entry in the matrix by circling the appropriate description. After all of the descriptors had been rated, the number of circles in each column (disturbance class) was totaled. The disturbance class corresponding to the column with the highest total was deemed the condition of that trail section. Ties between low and medium or between medium and high were rounded down. Any observation of high resulted in a condition classification of at least medium.

Analysis of Disturbance Classes

The experimental design for the ATV traffic was one loop for each combination of vehicle and tire type, for a total of four loops at each site. Each loop had four trail features, and each feature was rated with the condition class matrix after approximately every 40 passes. While this results in a large number of observations, there are no replications in the experimental design. Further, the number of ATV passes was not the same on each loop, and the goal of reaching the high condition was not achieved at all sites.

Frequently, the data say only that riding stopped after 500 passes and the trail condition was medium. From this information one can conclude only that it would have taken more than 500 passes to reach the high condition. There are instances where a similar statement has to be made for the medium class, as well. It is not possible to average an observation of 150 passes and one of greater than 500 passes.

Data that measure lifetime—or the length of time until the occurrence of an event—are called lifetime, failure time, or survival data. Classic examples are the lifetime of diesel engines, the length of time a person stays on a job, or the survival time for heart-transplant patients. An intrinsic characteristic of survival data is the possibility for censoring observations, that is, the actual number of passes until leaving a class was not observed. A large percentage of censored values results in a low statistical validity. In the ATV study, the corresponding variable of interest is the number of passes before leaving the low or medium condition class. There were occasional censored values for leaving the low condition and a large number of censored ones for leaving the medium condition.

The first step in the analysis of survival data is an estimation of the distribution of survival times, which are often called failure times. Uncensored survival times (i.e., times at which the event actually occurs) are called event times. The survival-distribution function (SDF) is used to describe the lifetimes of the population of interest. The SDF evaluated at *t* is the probability that an experimental unit from the population will have a lifetime exceeding *t*, or

$$S(t) = \Pr(T > t)$$

where *S(t)* denotes the SDF and *T* is the lifetime of a randomly selected experimental unit. For the ATV study, times were synonymous with passes.

To make an SDF, two of the three independent variables (i.e., trail feature, vehicle and tire combination, and sites) have to be combined in order to investigate changes in the third variable. The condition-class-matrix results were used to determine the survival distribution function for (1) sites where trail feature and vehicle type were combined, (2) trail feature where sites and vehicle type were combined, and (3) vehicle type where trail feature and sites were combined. There was an insufficient number of uncensored passes to make a statistical analysis of the transition from medium to high condition class, so only the transition from low to medium is presented.

The median number of passes required to transition from low to medium condition class will be considered to be that corresponding to the 0.50 value of the SDF. When comparing one SDF to another, a lower number of passes for the same value of the SDF is indicative of fewer passes to achieve the same disturbance and, hence, a greater sensitivity to ATV traffic.

Rut-Depth Analysis

Each trail feature had three cross sections measured at the end of each driving day, resulting in replicated rut depth data. The wheel rut depth was measured from top of the berm to bottom of the rut. The depth of any initial rills or ruts was subtracted from that caused by ATV traffic. The three replications were averaged to determine a representative rut depth.

Erosion Determination Methods

Rainfall simulation on 1-meter-square bordered plots was used to determine infiltration and raindrop-splash parameters. The rainfall simulator used a Spraying Systems Veejet 80100 nozzle to approximate the raindrop distribution of natural rainfall.

Rainfall-simulation plots consisted of an upper border and two side borders of 16-gauge sheet metal driven into the soil 2 inches deep. The lower border consisted of a runoff apron flush with the soil surface that drained into a collection trough with a centrally located 1-inch opening. The runoff apron was placed on top of a 1/4-inch-thick layer of bentonite to prevent any water from flowing under the apron. Dimensions of the exposed soil inside the plot were 1 meter by 1 meter.

Two rainstorms with an intensity of 4 inches per hour with 30-minute duration were applied to each plot. The two rainstorms were applied 3 hours apart. The 4 inches per hour, 30-minute-duration storm had a return period varying from 5 years at the Louisiana site to 450 years at the Arizona site. This rainfall intensity and duration were chosen not to represent a specific design storm, but to exceed the expected infiltration rate at each site, thus allowing the entire plot to contribute to runoff. Entire-plot contribution to runoff is a requirement when determining infiltration and erosion parameters from simulated rainfall.

Two soil-moisture samples from each side of the plot were taken at a depth of 0 to 1½ inches before and after each simulated storm. These soil samples were oven-dried overnight at 105 degrees Celsius (°C).

Once runoff began on a plot, timed grab-samples in 500-milliliter bottles were taken each minute for the runoff's duration. These runoff samples were oven-dried overnight at 105 °C to determine sediment concentrations. Water-runoff rates, sediment concentrations, and sediment-flux rates were calculated based on these samples. There were three repetitions of each soil-disturbance class at each site.

Ground cover was measured by counting the number of grid points above vegetation, rocks, or duff in simulation-plot photographs. Each plot photograph was counted twice using different grid orientations.

The WEPP model was used to determine the infiltration and erosion characteristics from the ATV study. The WEPP model (Flanagan and Livingston 1995) is a physically based soil erosion model that provides estimates of runoff, infiltration, soil erosion, and sediment yield considering the specific soil, climate, ground cover, and topographic conditions.

The WEPP model uses the Green-Ampt Mein-Larson model for unsteady intermittent rainfall to represent infiltration (Stone et al. 1995). The primary user-defined parameter is hydraulic conductivity. Interpretation of this parameter is straightforward. Higher values indicate a more rapid infiltration rate and hence, less runoff. The parameter also is an indication of the maximum-rainfall rate that a soil can absorb without producing runoff.

Raindrop splash in the WEPP model is characterized by an interrill-erodibility coefficient, which is a function of rainfall intensity and runoff rate (Alberts et al. 1995). Interpretation of the interrill-erodibility coefficient is also straightforward, although the units of $kg \cdot s \cdot m^{-4}$ are not intuitive. Higher values indicate higher raindrop-splash erosion.

From the rainfall-simulation data, the WEPP parameters of hydraulic conductivity and interrill erosion were determined for each run. The resulting six values (first and second rain for each of the three repetitions) were averaged to determine values for each treatment class at each site. Prerain soil saturation, bulk density, and ground cover as well as plot geometry were entered into the WEPP model. Hydraulic conductivity was determined by minimizing the objective function in equation 1. The objective function (Obj_{hc}) gave equal weight to matching the total rainfall-simulation runoff volume and the peak flow and is shown below.

Equation 1.

$$Obj_{hc} = (RO_{meas} - RO_{WEPP})^2 + (Peak_{meas} - Peak_{WEPP})^2$$

where RO_{meas} was the measured runoff, RO_{WEPP} was the WEPP-predicted runoff, $Peak_{meas}$ was the measured-peak runoff, and $Peak_{WEPP}$ was the WEPP-predicted peak flow. When the appropriate value of hydraulic conductivity was determined, the interrill-erosion parameter was found in a similar iterative manner until the WEPP-predicted soil loss matched the measured-sediment loss. Calculated hydraulic conductivity and interrill-erosion parameters were averaged to represent values for each treatment class at each site.

Weather Measurements

Hourly air temperature and breakpoint precipitation were taken during and after traffic. National Weather Service records from nearby stations were used to supplement locally measured values.

Results

Weather Measurements

Table 7 shows the 5-day antecedent precipitation, total rainfall, and average temperatures for both the ATV traffic and the rainfall-simulation periods. The 5-day antecedent precipitation served as an indicator of soil-moisture content. Noteworthy were the precipitation values in Louisiana, where both traffic and simulation were performed during a very wet period. At least 3 days were lost due to natural rainfall during the rainfall-simulation period. None of the other sites had lost days due to natural rainfall.

Table 7—Precipitation and temperatures during ATV traffic and rainfall-simulation activities for all sites.

Site	ATV-traffic period			Rainfall-simulation period		
	5-day antecedent precipitation (in)	Total precipitation (in)	Average temperature (°F)	5-day antecedent precipitation (in)	Total precipitation (in)	Average temperature (°F)
AZ	0	0	91	0	0	86
KY	0.34	0	59	0.4	2.84	76
LA	3.36	0.95	78	2.09	10.59	79
MN	0.10	0.38	56	0	2.98	60
MO	0	0.72	64	no rainfall simulation		
MT	0.34	0	61	0	0.67	63
WA	0	0	64	0	0.28	67

Disturbance Class Results

The number of passes required to leave the low and medium condition for each site and each trail feature is shown in appendix A. The transition from low to medium and from medium to high was not achieved on some loop-treatment combinations. In these cases, the final number of passes is preceded by a “greater than” symbol (e.g., >160).

Question 1 – Are the natural resources being affected by ATV use?

One of the goals of the study was to answer the question “Are the natural resources being affected by ATV use?” An inspection of the disturbance-class results will be used to answer this question. Table 8 contains data showing the minimum number of passes required to remain in both low and medium classes and the range of passes to achieve medium and high condition classes. For table 8, vehicle and tire combinations were combined as were trail features with only the sites displayed separately. For this level of analysis, these combinations are appropriate. On real trails, there would be a mix of vehicle types and tires. No trail could exist without a mix of curves, straights, uphill, and downhill, so this combination is also appropriate. The minimum number of passes to remain in low represents how quickly some portion of the trail transitioned from the low disturbance class to the medium class. Similarly, the minimum number of passes to remain in medium represents how quickly some portion of the trail transitioned from the medium class to the high-disturbance class. The range of passes to remain in low and medium classes is included.

At all seven sites, some portion of the trail transitioned from low to medium disturbance class in 20 to 40 passes. While the number of days required to achieve this number of passes varies from location to location, this level of ATV traffic could be achieved in one weekend from a moderate-sized ATV group. Not all of the trail had left the low disturbance class, but some combination of vehicle and tire and trail feature was no longer in the low class. Similarly, all seven sites had some portion of the trail transition from the medium to high disturbance class in 40 to 120 passes. This level of ATV traffic could be achieved in less than a month, depending upon trail usage.

Our conclusion is that the natural resources are being affected by ATV use as exhibited by the impacts achieved during the study. It is also reasonable to expect that similar impacts would result to similar natural resources on any national forest and grasslands where similar ATV riding occurs.

Table 8—Minimum and range of ATV passes to remain in low and medium condition classes for all trail features and all vehicle and tire combinations.

Site	Minimum number of passes to		Range of passes to	
	Remain in Low	Remain in Medium	Remain in Low	Remain in Medium
AZ	40	60	40 to >160	60 to > 160
KY	40	40	40 to >320	40 to > 800
LA	30	70	30 to >630	70 to > 730
MN	40	120	40 to >600	120 to > 700
MO	40	80	40 to >560	80 to > 560
MT	40	120	40 to >640	120 to >1,000
WA	20	80	20 to >480	80 to > 960

Question 2 – To what degree are the natural resources being impacted?

The second goal of the study was to answer the question “To what degree are the natural resources being impacted?” This study uses the condition-class matrix to quantify the degree of natural resource impacts. The impacts were caused by three independent variables, namely, sites, trail features, and vehicles and tires. Vehicles and tires will be considered separately in question 3. Combinations of the remaining two impacts, sites and trail features, and the causative agents will be discussed by considering the number of passes required to remain in the low disturbance class.

By site: The survival distribution function for number of passes required to remain in the low disturbance class is shown in figure 6. Visual inspection of this figure suggests that there are differences among the sites, and statistics validates this observation. The p-value for a difference among the sites was 0.067, indicating that one can be 93 percent confident that there is a difference among the sites. The range of median values for the remain-in-low condition class was 80 at Kentucky to 270 at Louisiana. Sites in Arizona, Kentucky, and Minnesota were the most susceptible to ATV traffic; Missouri, Montana, and Washington were intermediate; and Louisiana was the least susceptible for remaining in the low condition class.

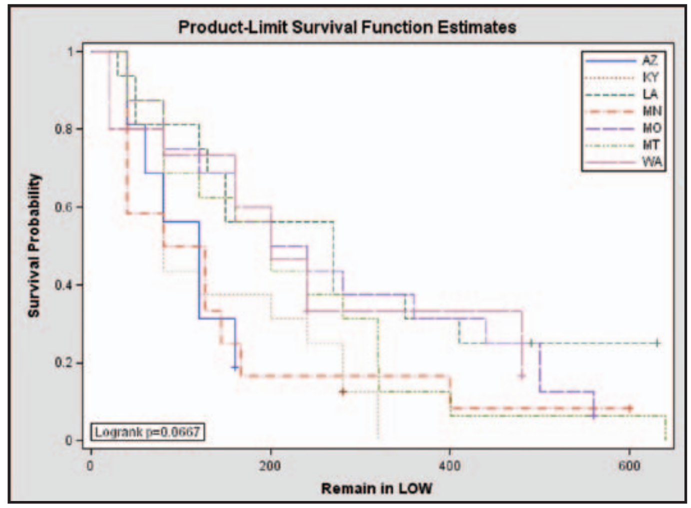


Figure 6—Survival-distribution function for number of passes to remain in low condition class for each site.

Rut depths were measured at three locations in each trail feature at each site, allowing average values to be calculated. ATV passes and average rut depths for each combination of vehicle and tire type as well as each trail feature at each location are shown in figures 7 through 10.

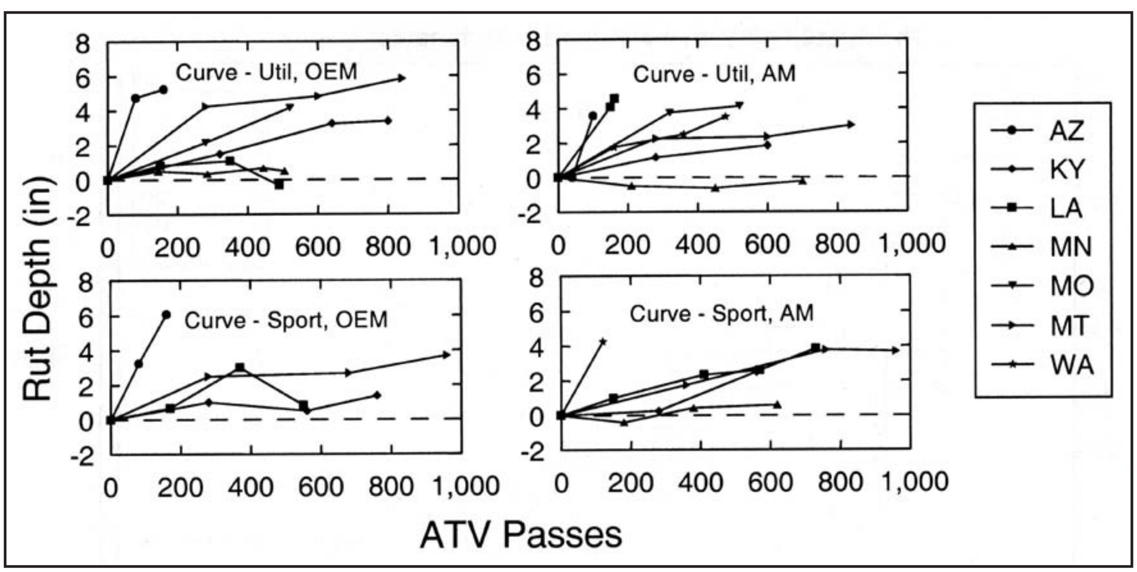


Figure 7—Rut depth and ATV passes for curve trail feature.

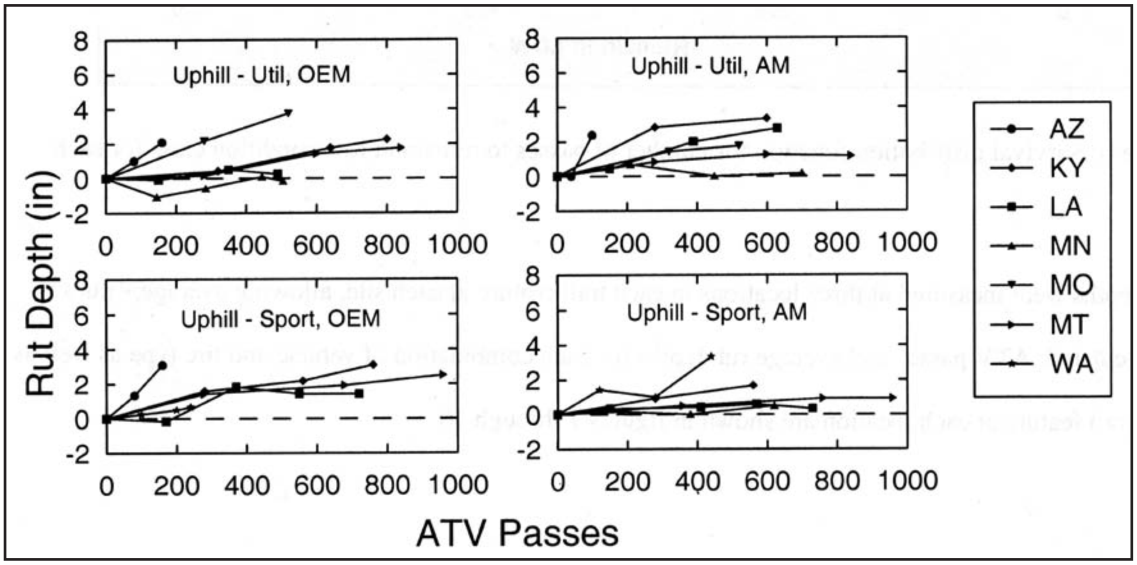


Figure 8—Rut depth and ATV passes for uphill trail feature.

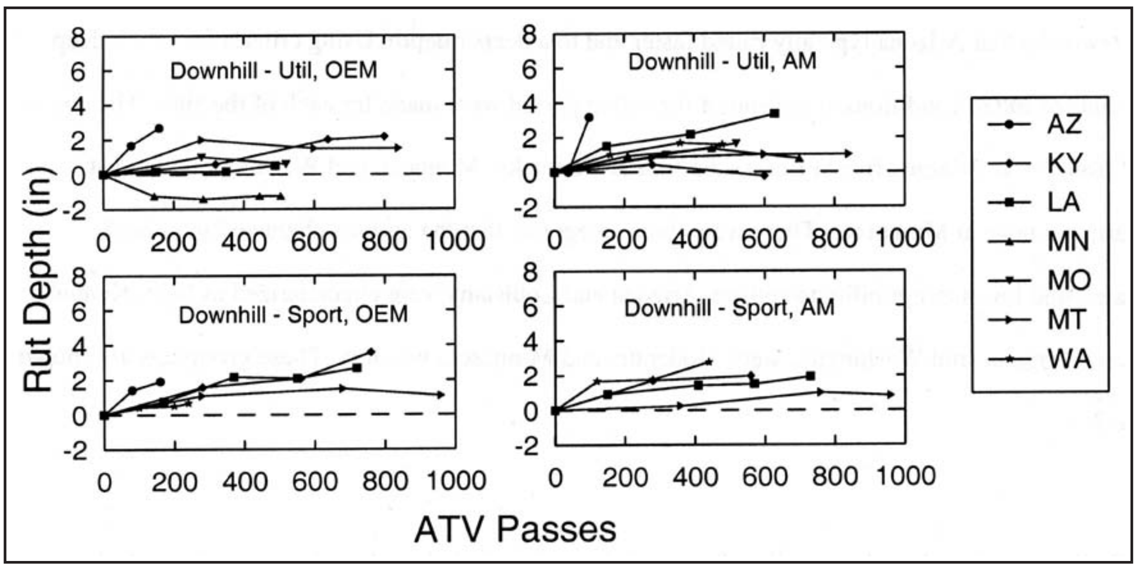


Figure 9—Rut depth and ATV passes for downhill trail feature.

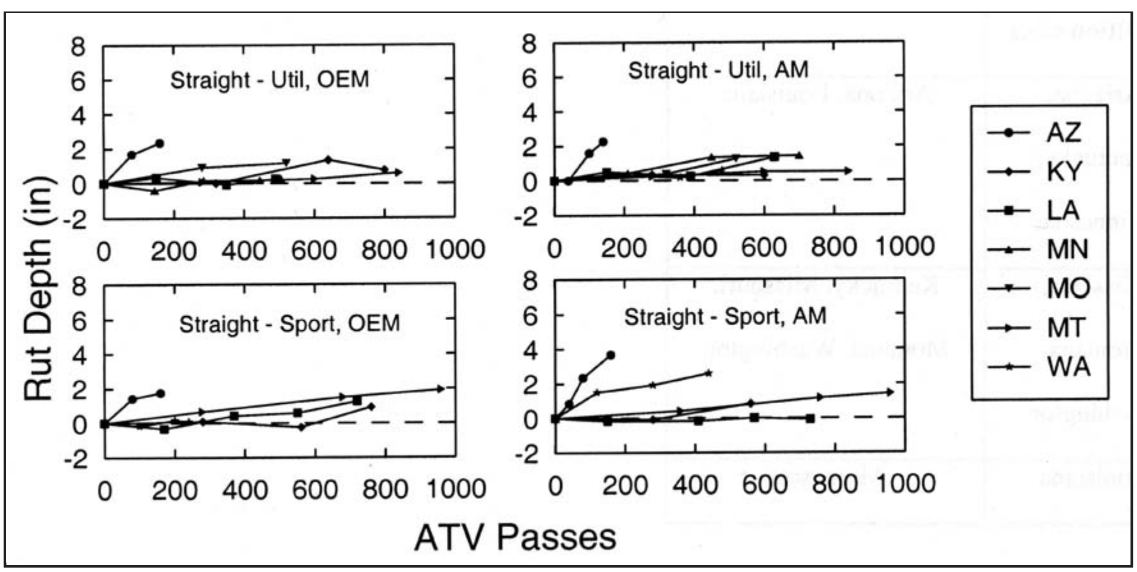


Figure 10—Rut depth and ATV passes for straight trail feature.

It is noteworthy that Arizona typically rutted faster and to a deeper depth. Using criteria of 3-inch-deep ruts, counts of rutted conditions at the end of the riding period were made for each of the sites. The counts ranged from six at Arizona; five at Louisiana; four at Kentucky, Montana, and Washington; three at Missouri; and none at Minnesota. There were three categories that the authors characterize as high-, moderate-, and low-susceptibility to rutting. Arizona and Louisiana were characterized as high; Kentucky, Missouri, Montana, and Washington were moderate; and Minnesota was low. These groupings are shown in table 9.

Table 9—Site groupings based on similar characteristics to remain in low disturbance condition and susceptibility to rutting. Order is highest to lowest.

Remain in low condition class	Susceptibility to rutting
Arizona, Kentucky, Minnesota	Arizona, Louisiana
Missouri, Montana, Washington	Kentucky, Missouri, Montana, Washington
Louisiana	Minnesota

By trail features: The four trail features tested were curves, downhill, straight, and uphill. Figure 11 presents the survival-distribution function for number of passes to remain in the low-condition class. It is clear that the curve feature required fewer passes before it was no longer in the "remain in low condition." Results of the statistical analysis were that one could be +99 percent confident that there was a difference among the trail features (p-value of >0.0001). The curve was no longer in the low condition in nearly 5 times fewer passes than in the next highest impacted trail feature (40 for the curve compared to 200 for the uphill). The range of median passes to remain in the low-condition class was 40 for the curve to 320 for the straight. Both the uphill and the downhill had median values of 200 passes.

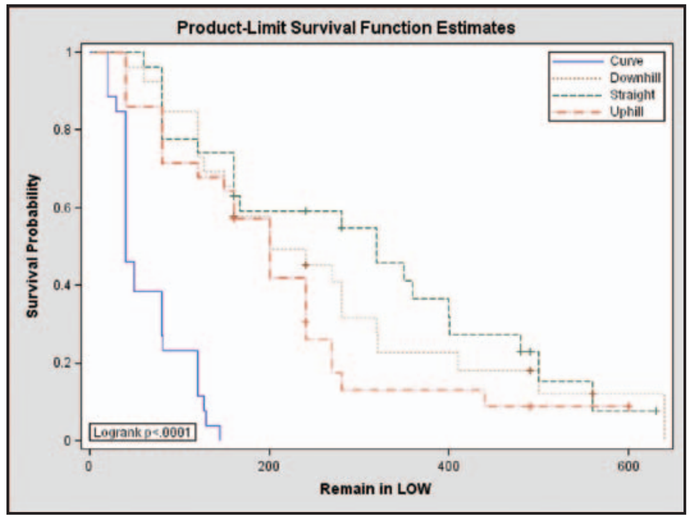


Figure 11—Survival-distribution function for number of passes to remain in low condition for each trail feature.

Using figures 7 through 10, the number of instances of 3-inch-deep or greater ruts was 14 for the curve, 6 for the downhill, 4 for the uphill, and 1 for the straight trail features. The groupings for trail features based on rut depths were (1) curve, (2) downhill and uphill, and (3) straight.

Table 10 displays the rutted condition groups for the overall condition class and the rut depth. The authors conclude that the trail features, in decreasing order of impact, are curves, uphill, downhill, and straight.

Table 10—Trail feature groupings based on similar characteristics to remain in low disturbance condition and susceptibility to rutting. Order is highest to lowest.

Remain in low condition class	Susceptibility to rutting
Curve	Curve
Uphill, Downhill	Uphill, Downhill
Straight	Straight

Question 3 – Do the vehicle and tire combinations tested make a difference in impacts to the natural resources?

The impacts considered are trail condition class and rut generation.

Trail condition class: The survival-distribution function for number of passes to remain in low condition class for combinations of vehicle and tires is shown in figure 12. The range of median passes required to remain in low condition class ranged from 127 for the utility vehicle with aftermarket tires to 200 for the sport vehicle with original equipment manufacturer tire. There was no statistically significant difference between the vehicle and tire combinations tested (p-value = 0.56).

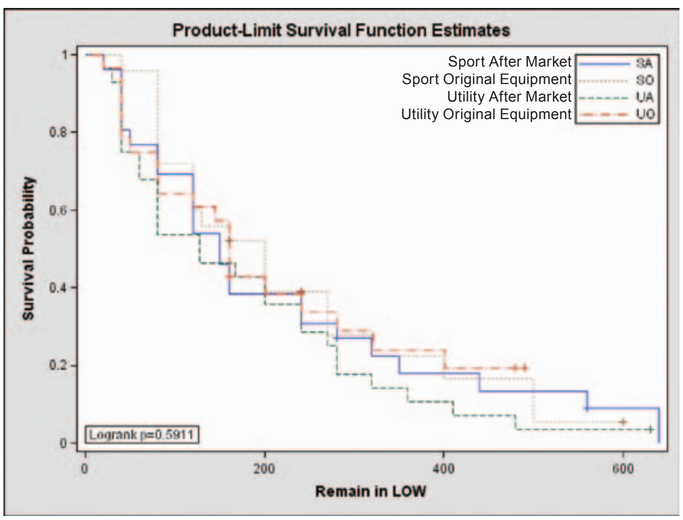


Figure 12—Survival-distribution function for number of passes to remain in low condition class for each ATV and tire combination.

Rut generation: The rut-depth figures are shown in figures 7 through 10. The number of ruts with depths greater than 3 inches—caused by vehicle type and tire combinations—were nine for the utility vehicle with aftermarket tires, six for the sport vehicle with original equipment tires, and five for both the utility and sport vehicles with aftermarket tires. Only two groups resulted from the rut-depth measurements. There does not appear to be a clear order to the vehicle type (see table 11). Therefore, the authors conclude that while ATV traffic does have an impact on the natural resources, we were not able to distinguish differences in impacts among the four vehicle and tire combinations tested.

Table 11—ATV vehicle and tire groupings based on similar characteristics to remain in low disturbance condition and susceptibility to rutting. Order is highest to lowest.

Remain in low condition class	Susceptibility to rutting
SA, SO, UA, UO	UA
	UO, SO, SA

Rainfall Simulations

In order to have each site representative of conditions immediately following traffic, rainfall simulation was intended to immediately follow the ATV traffic. This was achieved at Arizona, Louisiana, and Washington, but not at Kentucky, Minnesota, and Montana due to logistical conflicts between the ATV driving crew and the rainfall simulation crew. At Kentucky, Minnesota, and Montana, the rainfall crew made up to 100 additional ATV passes to reduce natural compaction and remove surface sealing that occurred between the end of traffic and beginning of rainfall simulation.

The study's intent was to attain each condition class at each site and then to perform rainfall simulation on each condition class; however, rainfall simulation on the high-condition class was not always performed. At Minnesota there was no simulation on the high class because it was not achieved by the traffic crew in 1,000 passes. At Montana there was no simulation on the high class because it was achieved only in curves, where it was not possible to install rainfall simulation plots. At Arizona there was no simulation on the medium class because of time constraints. Table 12 summarizes the dates of traffic and rainfall simulation as well as condition classes with rainfall simulation.

The soil texture and grain size measurements for each site are shown in table 13. Textures ranged from loamy sand for Louisiana to gravelly sand for Arizona and Montana. All sites had less than 6-percent clay and, with the exception of Louisiana, had more than 15-percent rock fragments. Mean grain size (d_{50}) ranged from 1.38 millimeters (Arizona) to 0.19 millimeter (Louisiana).

Average ground cover (plants, litter, and rock) for each site and disturbance class for the rainfall simulation plots is shown in table 14. Changes in ground cover with ATV traffic were a major impact. Visually, the reduction of cover distinguishes an ATV trail from the undisturbed forest. Additionally, the ground cover loss increases raindrop-splash erosion because there are fewer plant leaves to absorb the raindrop impacts.

Table 12—Date of traffic, rainfall simulation, and condition classes with simulation.

Site	Traffic Dates	Rainfall Simulation Dates	Und	Low	Med	High
AZ	May 24-26, 2005	May 25-June 7, 2005	✓	✓		✓
KY	Oct. 3-5, 2004	May 21-June 3, 2004	✓	✓	✓	✓
LA	June 4-6, 2004	June 7-July 2, 2004	✓	✓	✓	✓
MN	June 20-23, 2004	July 20-Aug 2, 2004	✓	✓	✓	
MO	Oct. 7-10, 2004	no rainfall simulation				
MT	July 22-24, 2004	Aug 11-21, 2004	✓	✓	✓	
WA	June 14-16, 2005	June 16-July 2, 2005	✓	✓	✓	✓

Table 13—A horizon soil characteristics at rainfall simulation sites sorted by soil texture.

Site	Soil texture	d_{84} (mm)	d_{50} (mm)	d_{16} (mm)
LA	Loamy sand	0.35	0.19	0.05
WA	Gravelly loamy sand	2.86	0.50	0.05
KY	Gravelly sandy loam	3.24	0.48	0.02
MN	Gravelly sandy loam	3.22	0.96	0.02
MT	Gravelly sand	2.40	0.89	0.27
AZ crust	Gravelly sand	2.97	0.95	0.15
AZ	Gravelly sand	3.26	1.38	0.49

Continued ATV use also inhibits plant regrowth in much the same manner as vehicle traffic inhibits plant regrowth on unpaved forest roads. Noteworthy were (1) the decrease in cover from undisturbed to low, (2) the continuing decrease in cover from low through high, and (3) the lower covers at Montana and Washington for all disturbance classes. Montana sites were on a high-elevation forest with less rainfall and, hence, less cover. The Washington site was in a burned area, on a compacted logging road, and at high elevation. Cover at the Arizona site appears unusually high, but was visited in the spring following a wet winter.

Inspection of table 14 suggests that the ground covers for the disturbed classes were not consistent with the definitions of 0- to 30-percent removal, 30- to 60-percent removal, and greater than 60-percent removal. Values in table 13 were taken from the rainfall simulation plots centered on the wheel tracks. These 1-meter-square plots were samples taken from the entire 54- to 72-inch-wide trail where the trail condition assessment was performed. When the area outside the wheel tracks was included, the reduction in cover was consistent with the definitions.

Table 14—Ground cover for rainfall simulations sorted by soil texture.

Class	LA	WA	KY	MN	MT	AZ
Undisturbed	99.9	47.9	99.6	90.8	69.9	96.1
Low	49.5	25.3	42.1	33.5	17.6	42.6
Medium	31.0	6.8	14.7	15.0	3.0	ND
High	32.5	ND	1.3			21.4
ND indicates no data because no rainfall simulation was performed on these plots						

Hydrographs and sediment concentrations for each initial run on the undisturbed, low, medium, and high condition classes are shown in figures 13 through 18. The hydrographs and sediment concentrations represent the average of the three repetitions for each disturbance class.

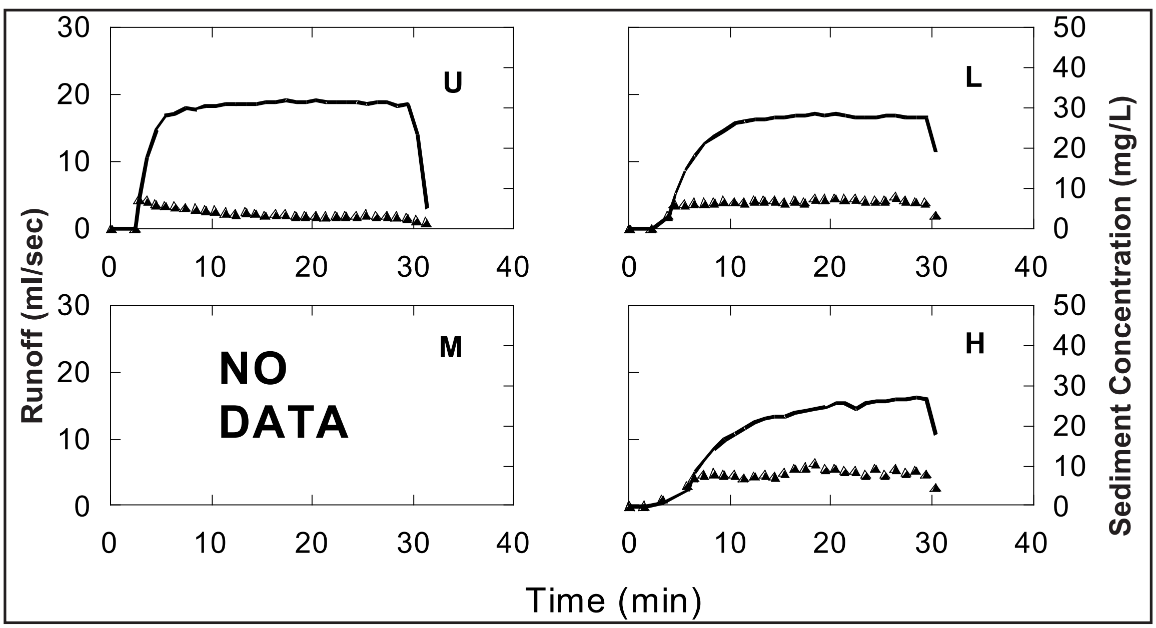


Figure 13—Hydrograph and sediment concentrations for initial run at Arizona.

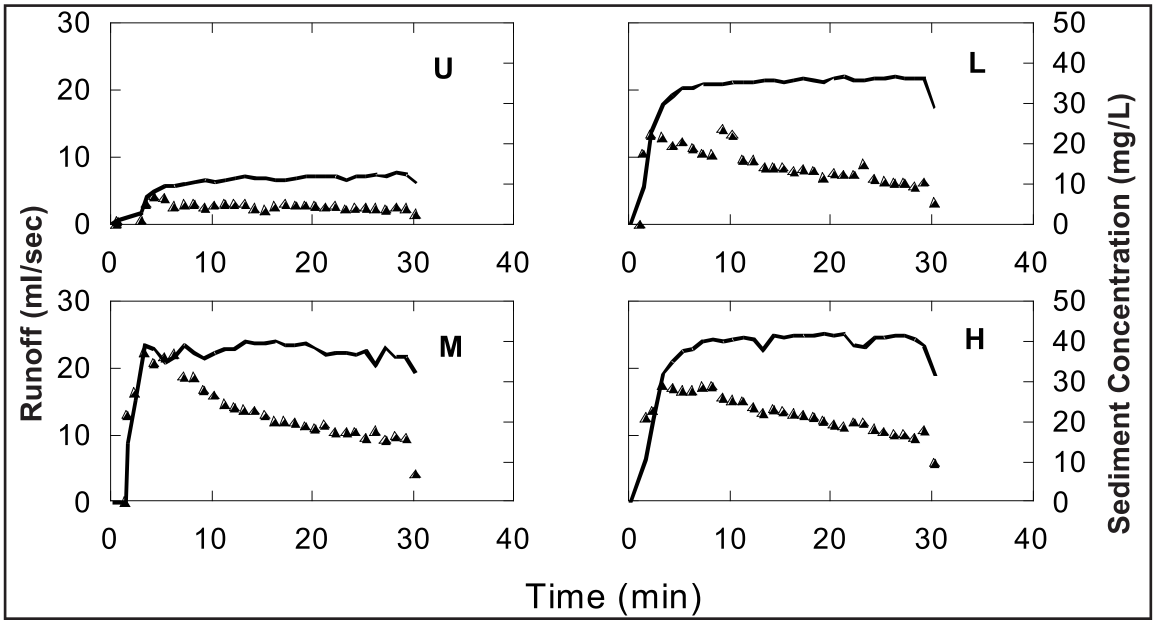


Figure 14—Hydrograph and sediment concentrations for initial runs at Kentucky.

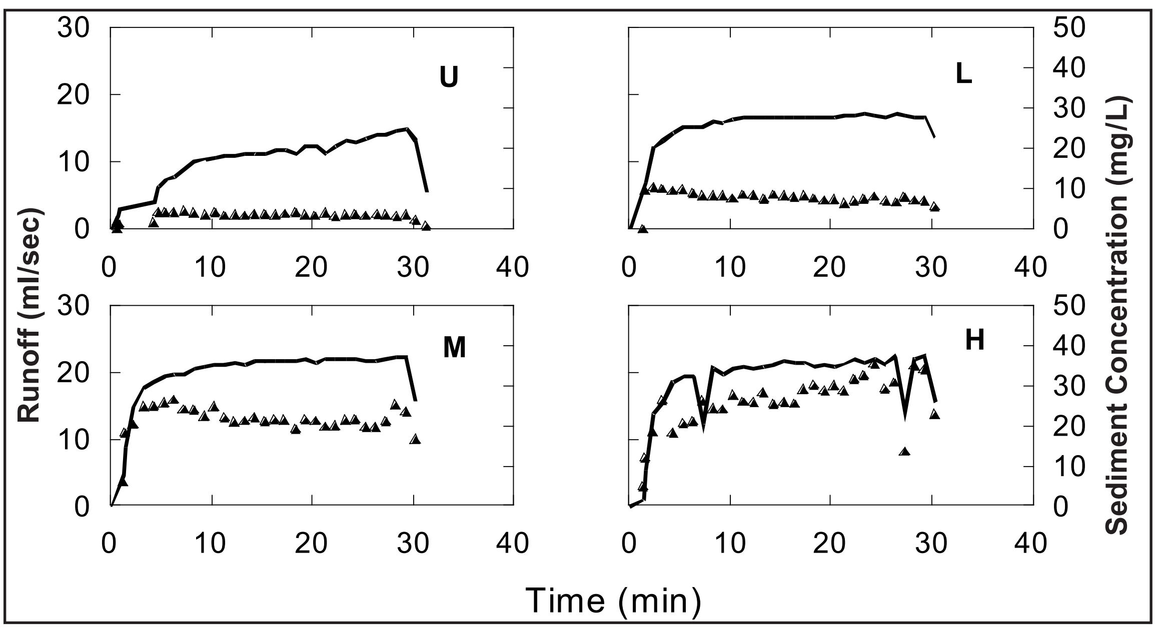


Figure 15—Hydrograph and sediment concentrations for initial runs at Louisiana.

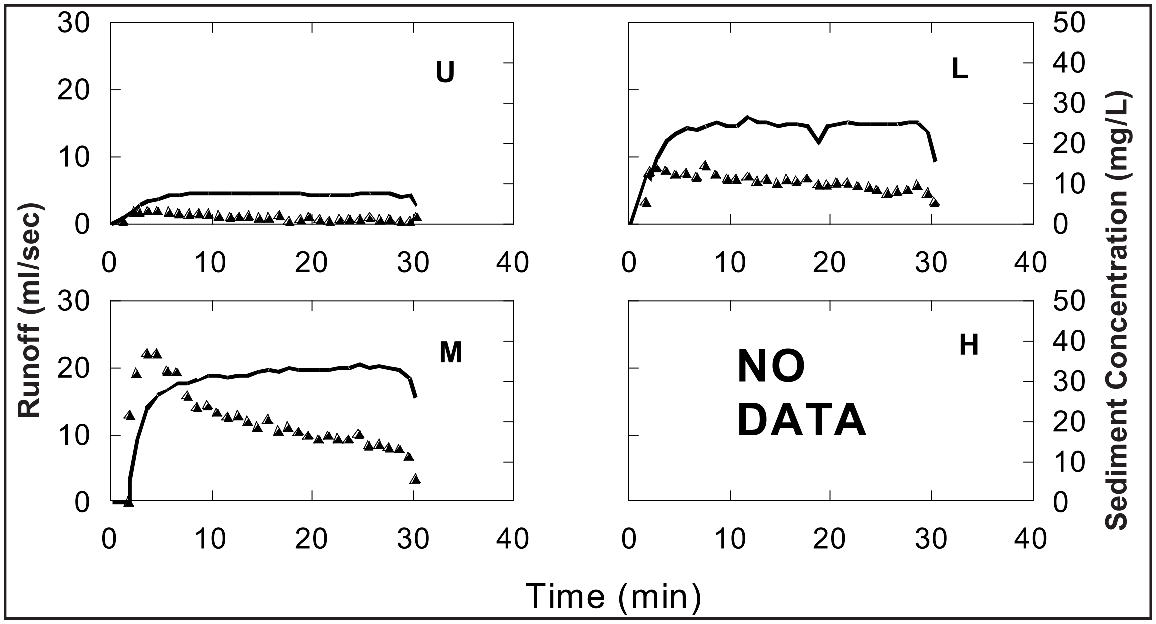


Figure 16—Hydrograph and sediment concentrations for initial runs at Minnesota

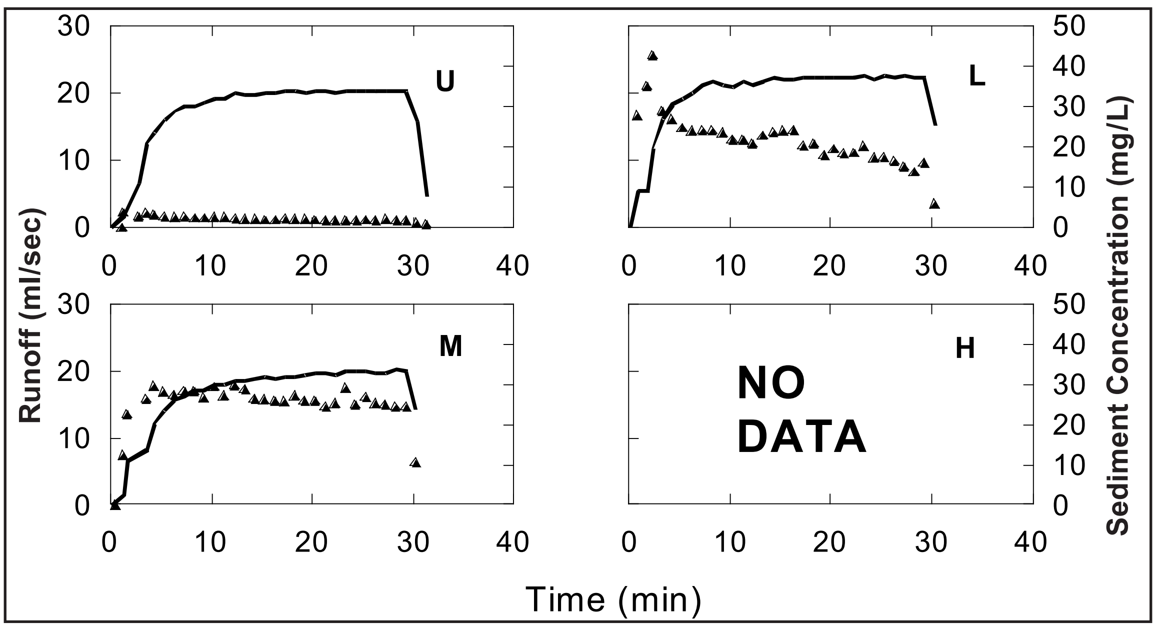


Figure 17—Hydrograph and sediment concentrations for initial runs at Montana.

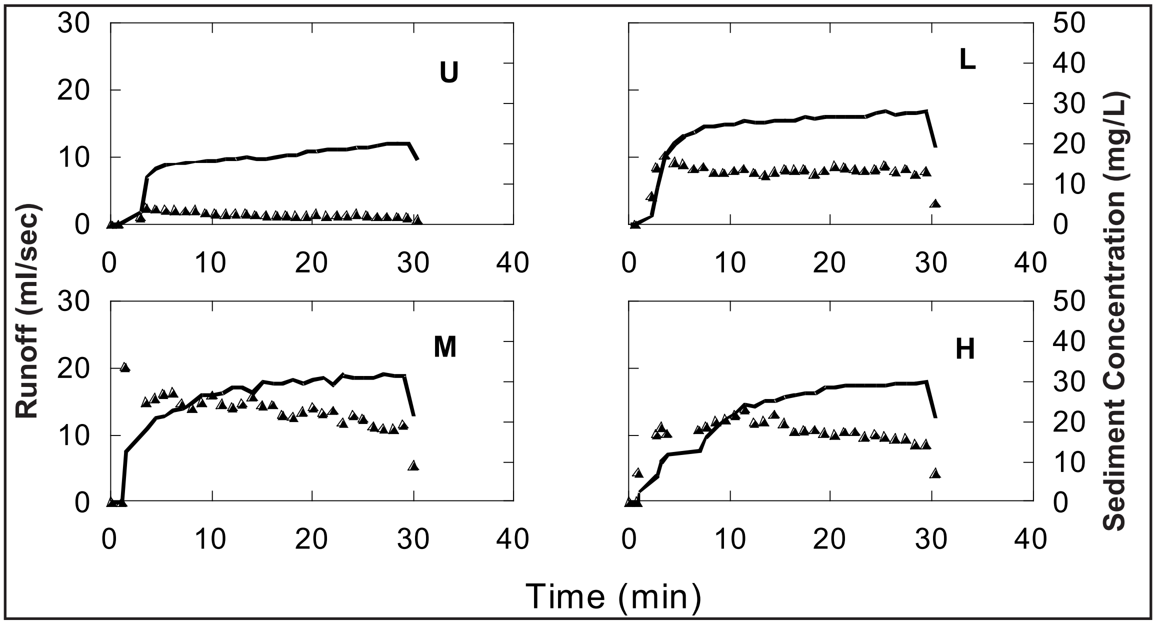


Figure 18—Hydrograph and sediment concentrations for initial runs at Washington.

From the hydrographs and sediment-concentration graphs, the runoff volume and sediment mass were determined. Figure 19 shows the runoff volume for both rainfall simulations for each site and condition class. Noteworthy in this figure are (1) the range of runoff volume for the undisturbed condition, (2) the reduced range for each of the condition classes, and (3) trends with increasing condition class.

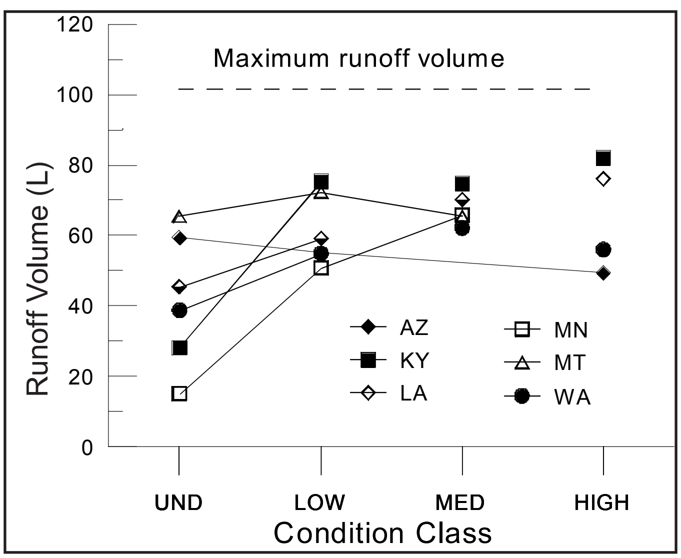


Figure 19—Runoff from both rainfall simulations with all trail features combined for all locations.

Runoff volume in the undisturbed condition varied from 15 to 65 liters, a ratio of 4.3:1. This ratio decreased to 1.5:1 for the low, 1.2:1 for the medium, and 1.7:1 for the high. These ratios represent the variation between sites for the four condition classes. The authors expect that these ratios would apply nationwide for similar soils.

Sediment loss for each site and condition class is shown in figure 20. These values represented the total sediment loss for both rainfall simulations. Notable are (1) apparent clustering of sediment-loss values for the undisturbed class, and (2) the increase in sediment values with increasing disturbance levels.

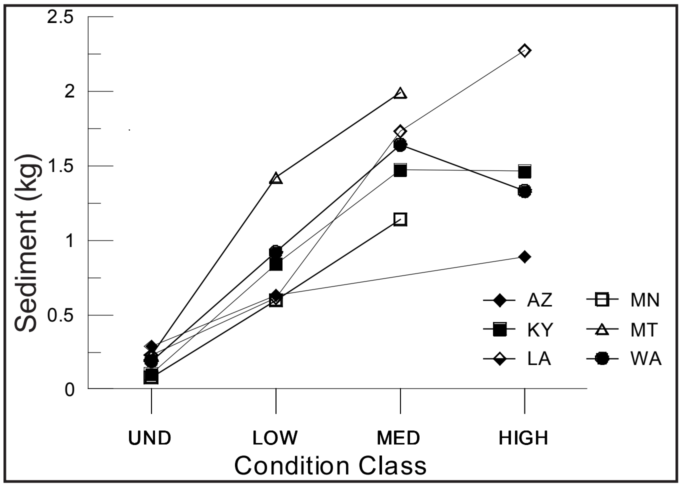


Figure 20—Sediment loss from both rainfall simulations with all trail features combined for all locations.

The ratio of sediment-loss values for the undisturbed class was 3.6:1, for the low class 2.4:1, for the medium class 1.7:1, and for the high disturbance class 2.6:1. These ratios represent the variation between sites for the four conditions classes and would be expected to be similar nationwide for similar soils.

Discussion of Rainfall Results

There were three types of hydrographs. The first, and most common, was characterized by runoff from the undisturbed class being notably lower than any of the disturbed classes. In this group were Kentucky, Louisiana, Minnesota, and Washington. The second group was characterized by runoff from the undisturbed class being comparable to the disturbed classes. Montana was in this group. The final group was characterized by the runoff from the undisturbed class being greater than from the disturbed classes. Arizona fell in this group.

The group characterized by runoff from the undisturbed class being notably lower than the disturbed class was expected. The ATV traffic compacted the soil, reducing infiltration and increasing runoff. This is the phenomenon that occurs on unsurfaced forest roads. Vehicle weights and number of passes are different, but the mechanism of traffic causing compaction and increased runoff appears to be similar.

Runoff from the undisturbed and the disturbed classes were comparable only on the Montana site. This site was characterized by a soil texture of gravelly sand, mean diameter of 0.89 millimeters, and one of the lowest ground covers. The geologic parent material was decomposed granite, and the soil-moisture contents were low. In unpublished studies at the Forest Service's Rocky Mountain Research Station, Robichaud (2006) found that similar undisturbed decomposed granite soils exhibited high runoff rates. Bone-dry soil, bone-dry organic matter, and a volcanic ash layer were believed to be responsible for this runoff response. In the ATV study performed in August 2004, the prerain soil moisture saturation for all nine plots was 14 percent, the organic matter was quite dry, and there was a volcanic ash layer.

The final group was characterized by high runoff from the undisturbed plot and lower runoff from the disturbed plots. The sole member of this group was Arizona. Prior to ATV traffic, there was a soil crust, which subsequent traffic destroyed and exposed the underlying sand-texture soil. Table 13 shows that the crust soil layer had a smaller d_{84} and d_{50} which would tend to reduce infiltration compared to the underlying soil. As the soil crust was destroyed, higher infiltration rates and less runoff would occur.

Sediment concentrations tended to increase with increasing disturbance levels. The Montana site (figure 17) was a good example of this trend. Sediment concentrations during the rainfall simulation predominantly decreased (see figures 14, 16, 17, and 18 for Kentucky, Minnesota, Montana, and Washington, respectively). The Arizona site (figure 13) had sediment concentrations that remained relatively constant during the simulation. At Louisiana (figure 15) the undisturbed, low, and medium classes decreased during the simulation, while the high class had increasing sediment concentrations.

A decreasing sediment concentration was indicative of the flow removing sediment faster than it could be generated by raindrop splash, concentrated flow, or small-bank sluffing. This is the condition usually encountered on native-surface roads and is often called armoring. A constant sediment concentration rate was caused by either of two mechanisms. One was a balance between sediment removal by flow and generation by splash, concentrated flow, or bank sluffing. The other was by sediment being generated more rapidly than it could be removed. Due to the higher slopes of the ATV trails, generation likely exceeded the removal rate. The increasing sediment concentration found on the high disturbance class at Louisiana was caused by needle-dams breaking and releasing their dammed up water and sediment into the overland flow.

A trend of increasing runoff with increasing disturbance class was exhibited by four of the six sites, namely Kentucky, Louisiana, Minnesota, and Washington. These are the same four that were grouped together by hydrograph appearance and can be explained by increased compaction and reduced infiltration caused by ATV traffic. The Montana site showed an increase from undisturbed to low followed by a decrease from low to medium. These changes are attributable to removal of the water-repellent duff layer and breakup of the water repellent conditions of the dry soil by ATV traffic. The Arizona site showed a continuing decrease in runoff from undisturbed to low to high due to the breaking of the soil crust by ATV traffic.

All six sites had increasing sediment loss with increasing condition class from undisturbed through low to medium. Only Washington had less sediment loss on the high condition class than the medium, with the remaining five sites continuing to have increasing sediment loss as the condition class increased.

Erosion Parameters

Erosion parameters of hydraulic conductivity and interrill erosion were determined for each set of rainfall-simulation tests. The purpose was to eliminate differences in runoff and sediment loss due to differences in plot slope and antecedent moisture condition. Comparison of hydraulic conductivity and interrill-erosion coefficients between sites is an improvement over comparing runoff and sediment loss because differences in plots have been taken into account. Additionally, these erosion parameters are needed for the WEPP model to make erosion predictions.

Figures 21 and 22 display the hydraulic conductivity (h_c) and interrill-erodibility coefficient (K_i) for each site and each condition class. Smaller values of hydraulic conductivity (h_c) result in less infiltration and more runoff, while larger values of K_i result in more sediment loss.

There were three hydraulic conductivity responses to increasing condition classes. The most prevalent one was a continuing decrease in h_c as the condition class went from undisturbed to low to medium to high. Sites in this category were Kentucky, Louisiana, Minnesota, and Washington.

This indicates that ATV traffic compacted the soil, increased the runoff, and decreased the hydraulic conductivity. The second type was characterized by Montana, where the condition class appeared to have little impact on the hydraulic conductivity or the runoff. The final type was an increase in hydraulic conductivity with increasing condition class. Arizona was the sole member of this group. Groupings by h_c were the same as previous ones.

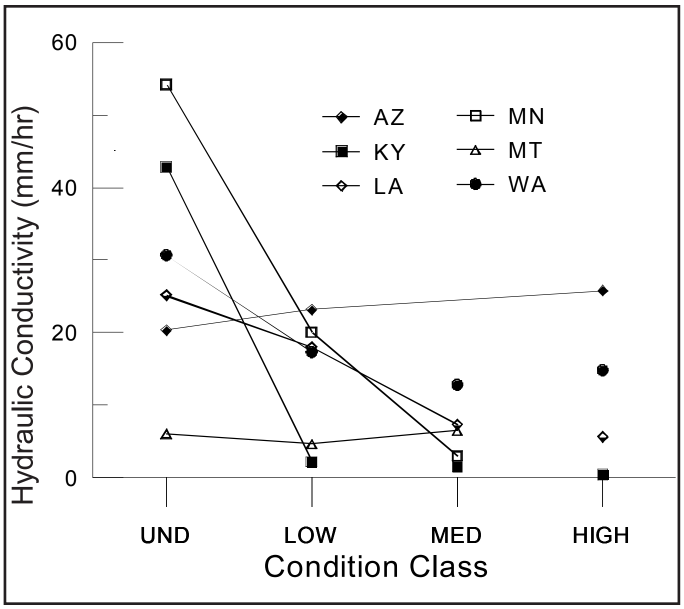


Figure 21—Hydraulic conductivity.

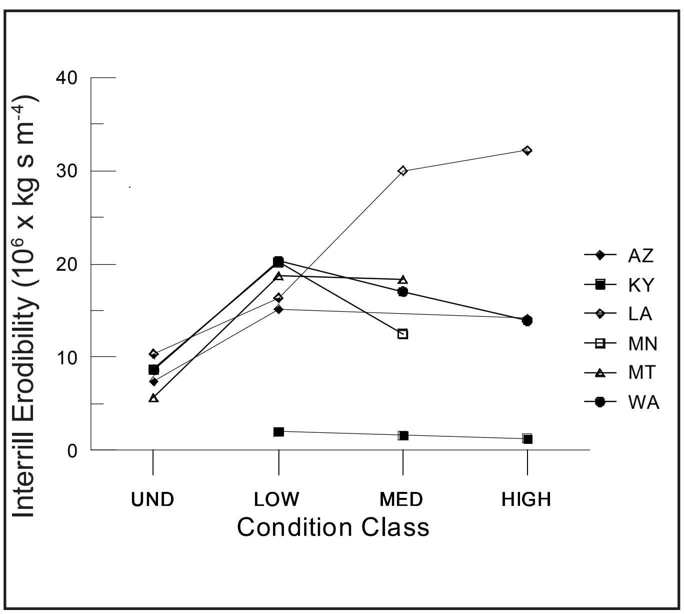


Figure 22—Interrill erodibility.

Statistical Analysis

A statistical analysis was performed to determine if condition class, site, and interaction between condition class and site could explain the variability in both hydraulic conductivity and interrill erosion. The results are shown in tables 15 and 16.

For hydraulic conductivity, the analysis showed that some linear function of the model parameters was significantly different from zero (p-value of < 0.0001). This p-value and the model r^2 means that some combination of condition class, site, and interaction between the two explained 74 percent of the variation in the hydraulic conductivity values. The condition-class variable had a p-value of < 0.0001, indicating that there was a significant difference among the undisturbed, low, medium, and high conditions. The site variable had a p-value of < 0.0001, indicating that there was a significant difference among the locations where the study was performed. The interaction (condition by site with p-value of < 0.0001) indicated that trends in condition class were not the same at all the sites visited.

The analysis for interrill erosion indicated similar results, namely that some linear function of the model parameters was significantly different from zero (p-value of < 0.0001) and the combination of condition class, site, and interaction between the two explained 63 percent (value of model r^2) of the variation in the interrill-erodibility parameter. Results indicated that there were significant differences among the disturbance classes (p-value of < 0.0001) and among the sites (p-value of 0.0001). The interaction was also significant (p-value of 0.008) with interrill erodibility trends among condition classes not being the same at all the sites.

Table 15—Statistical analysis of hydraulic conductivity equals condition class, site, and interaction between condition class and site.

Source	Degrees of Freedom	Mean Square	F	p-value
Model	20	1160	15.1	< 0.0001
Error	105	77		
Condition class	3	2968	38.6	< 0.0001
Site	5	811	10.6	< 0.0001
Cond * site	12	668	8.7	< 0.0001

Table 16—Statistical analysis of interrill-erosion parameter equals condition class, site, and interaction between condition class and site.

Source	Degrees of Freedom	Mean Square	F	p-value
Model	19	393	8.6	< 0.0001
Error	95	46		
Condition class	3	741	16.27	< 0.0001
Site	5	915	20.11	< 0.0001
Cond * site	11	115	2.53	0.008

Because there was interaction between classes and sites, the analysis for both hydraulic conductivity and interrrill-erosion parameter was investigated further. Those results (appendix A) suggested that the four condition classes could be reduced to two; undisturbed and disturbed, because there was often no statistical difference between the low, medium, and high classes. Table 17 displays the hydraulic conductivity and interrill-erosion coefficient after reclassifying the condition class into either undisturbed or disturbed ($\alpha = 0.05$).

Table 17—Hydraulic conductivity and interrill-erodibility coefficient from both rainfall simulations after reclassifying disturbance classes into either undisturbed or disturbed.

Site	Hydraulic Conductivity (h_c) (mm/hr)		Interrill-Erodibility Coefficient (K_i) (10^6 * kg s m^{-4})	
	Undisturbed	**Disturbed**	**Undisturbed**	**Disturbed**
AZ	20.33	24.50	**7.42**	**14.67**
KY	**42.83**	**1.42**		1.60
LA	**25.17**	**10.33**	**10.33**	**25.94**
MN	**54.17**	**17.25**	8.67	18.92
MT	6.05	5.58	**5.68**	**18.50**
WA	**30.67**	**15.00**	**8.62**	**17.08**
Values in **bold** indicate statistically significant differences at the 95-percent confidence				

One can conclude that a site is either undisturbed or it is disturbed, and attempting to quantify levels of disturbance from a hydraulic conductivity and raindrop splash viewpoint are unlikely to be successful. Robichaud (2000) observed a similar result when measuring sediment loss from three levels of burn severity. He concluded that there was either low sediment loss from the unburned or high sediment loss from the low-, medium-, or high-burn severity. In the ATV case, a site is either disturbed or it is not, with the undisturbed producing low sediment loss and the disturbed producing high sediment loss.

Sediment loss is a combination of runoff and raindrop-splash erosion. Investigation of changes in both hydraulic conductivity (h_c) and raindrop splash (K_i) can indicate how erosion changes as a result of ATV traffic. It is possible for h_c and K_i to independently increase, decrease, or remain the same, resulting in a total of nine combinations. A decrease in h_c results in an increase in runoff. This additional runoff has the potential to increase sediment loss solely due to the increased runoff. In combinations where the K_i also increases, sediment loss has the potential to increase in excess of that from just the increase in runoff alone. Actual erosion increases would, however, depend on the transport capacity of the runoff, which is primarily a function of the slope steepness.

The combination that results in the greatest increase in erosion would be a decrease in h_c and an increase in K_i. Runoff would increase and the erodibility of the soil would increase, resulting in an increase in sediment loss due to both the runoff and the more erosive soil. The least impact, and in fact a reduction in sediment loss, would result from h_c increasing and K_i decreasing. In this case, runoff would decrease and the soil's erodibility would decrease, resulting in less sediment than before the ATV traffic.

In this study there were only four of nine possible combinations of changes in h_c and K_i. The sites with the largest potential increase in sediment loss were Louisiana and Washington, where h_c decreased and K_i increased. Both of these sites had a rock-free soil texture of loamy sand. Note that Washington had a sufficiently high fraction of rock fragments to make its classification a gravelly loamy sand. At these locations, ATV traffic would be expected to increase runoff and increase sediment loss in excess of that caused by increased runoff. At both of these sites, hydraulic conductivity was approximately halved after traffic, and K_i was approximately doubled after traffic. These sites and ones with similar soils would be expected to have increased runoff and increased sediment loss in excess of that due to the increased runoff when compared to undisturbed areas.

Hydraulic conductivity decreased and interrill erosion remained unchanged at Minnesota and Kentucky. Soil texture for both of these sites was gravelly sandy loam. Here, runoff would increase due to impacts of ATV traffic. At Minnesota and Kentucky, post-traffic h_c's were 1/3 and 1/40 of their original values, respectively. Both sites would be expected to have large increases in runoff from ATV trails. The increased runoff would potentially increase erosion in proportion to the increase in runoff. These sites—and ones with similar soils—would be expected to have increased runoff and increased sediment loss proportional to the increased runoff when compared to undisturbed areas.

At the Arizona and Montana sites, h_c was unchanged and K_i increased, indicating that runoff would be unchanged but sediment loss would potentially increase due to the soil's increased erodibility. Both Arizona and Montana had soil textures of gravelly sand that did not compact during ATV traffic. Additionally, Arizona had a soil crust on the undisturbed condition, which ATV-traffic destroyed. Because the sand was not compacted, there was no statistically significant change in h_c from the undisturbed to the disturbed condition. The soil erodibility at Arizona doubled, while at Montana, it tripled. These sites—and ones with similar soils—would be expected to have similar runoff and increased sediment loss in excess of the runoff when compared to undisturbed areas.

Groupings of the sites based on soil texture were identical to groupings based on changes in h_c and K_i (i.e., loamy sands at Louisiana and Washington, which had decreased h_c and increased K_i; gravelly sandy loam at Minnesota and Kentucky, which had decreased h_c and unchanged K_i; and gravelly sand at Arizona and Montana, which had unchanged h_c and increased K_i). The soil texture with the highest potential for increased soil loss was loamy sand. The lowest potential for increased soil loss was from the gravelly sand with the gravelly sandy loam as the intermediate.

Recommended Erosion Parameters

Table 18 compares values for hydraulic conductivity, interrill-erodibility coefficient, rill erodibility (K_r), and critical shear (T_c) for forest, range, and agricultural lands from the literature and values determined in this study. The ATV undisturbed hydraulic conductivity values are similar to those reported for forest lands with the exception of the Arizona site, which was in a desert. The Arizona hydraulic conductivity was similar to rangeland, which does include desert habitats. The hydraulic conductivity caused by ATV disturbance was below undisturbed forests, higher than forest roads, and similar to agricultural fields. The notable exception was Kentucky, where 30 years of ATV traffic resulted in h_c values approaching those of an unpaved forest road.

Table 18—Typical range of values for hydraulic conductivity (h_c), interrill erodibility (K_i), rill erodibility (K_r), and critical shear (T_c). Values are from WEPP Technical Documentation, WEPP User Summary, and Fangmeier et al.

	h_c ($mm*hr^{-1}$)	**K_i (10^6 $kg*s*m^{-4}$)**	**K_r ($s*m^{-1}$)**	**T_c (Pa)**
Forest	30 – 60	0.4	0.0005	1
Range	3 – 30	0.01 – 2	0.0001 – 0.0006	1.5 – 6
Agricultural	5 – 30	5 – 6	0.001 – 0.025	2 – 2.5
Forest roads	0.4 – 10	3	0.0003 – 0.002	1– 3
Forest skid trails	10	2	0.003	2
ATV – Undis	6 – 55	5 – 10		
ATV – Dist	1 – 24	2 – 26		

Undisturbed interrill-erodibility values from the undisturbed condition were higher than those reported for forest conditions and similar to agricultural conditions. In the ATV disturbed category K_i values were among the highest reported and exceeded those for agricultural fields.

Rainfall simulation on 1-meter-square plots allows determination of infiltration and raindrop splash parameters, but not interrill erosion (concentrated flow) parameters. On an ATV trail with ruts, concentrated-flow erosion would likely be a major contribution to soil erosion. The length of ruts and the distance that concentrated flow occurs is of major concern. The rainfall simulation found no statistically significant difference between the low, medium, and high condition classes. The typical rut depths for the low were up to 3 inches, 3 to 6 inches for the medium, and greater than 6 inches for the high.

Observations by the authors on native surface forest roads are that deeper ruts tend to be longer than shallow ones. This would also be expected on ATV trails and would likely increase the sediment loss on the medium and high disturbance classes. Such an increase could result in a statistically significant difference between the low, medium, and high disturbance classes. Determination of concentrated-flow-erosion parameters is straight forward and should be performed.

CHAPTER 3. STUDY SITES

This chapter summarizes the data collected at each of the seven sites. The discussion includes a general discussion of the location's landscape character, soil properties, the type of vehicles, and the number of passes made by each. The locations are: the Tonto National Forest, Arizona; Land Between the Lakes, Kentucky; Kisatchie National Forest, Louisiana; Minnesota State Forest, Minnesota; Mark Twain National Forest, Missouri; Beaverhead-Deerlodge, Montana; Wenatchee National Forest, Washington.

Arizona

Tonto National Forest

The ATV testing was conducted on the Mesa Ranger District of the Tonto National Forest in the Southwest Region (R-3). Because of the close proximity of Phoenix, Arizona, this ranger district receives an estimated 5,000 ATV users per week. The topography is flat to gently rolling and is defined by hills and numerous alluvial washes. The area's vegetation consists of numerous grasses, shrubs, and trees. These include rabbit brush, saltbush, mesquite, and ocotillo, cholla, and saguaro cactus.

In preparation for ATV testing, four loop trails were laid out that ranged in length from 900 to 1,500 feet. Slopes through the transects for all loops ranged from 17 to 24 percent. The distance between transects ranged from 12 to 30 feet. The downhill and curve segments for loops C and D were combined or partially combined.

Prior to riding, trail segments, including the uphill, downhill, turns, and straight sections, were identified on the ground for all loops. The trails were brushed and cleared of any hazards, and transects were placed for each trail segment. All four loops were located on undisturbed ground.

Soil Properties

Representative soil samples from the four loop trails were taken for analysis. These soils were classified as poorly graded sand. They are characterized as medium strength and have a medium-to-high susceptibility to surface erosion. Other soil properties are shown in table 19.

Table 19—Soil properties for Tonto NF study site.

Forest	USCS Group Symbol-Description	Surface Erosion	Dry Strength	Saturated Strength	Rutting (Saturated)	Raveling	Dust
TNF	SP-poorly-graded sand	Medium-high	Medium	Medium-high	Low	High	Low-medium

Vehicle Types

Table 20 provides the model, ATV type, and total number of passes for each loop.

Table 20—Loops, vehicle characteristics, and total number of passes.

Loop	Vehicle Model/ Type	OEM/ AM	Total Passes
A	Honda Sport	OEM	160
B	Kawasaki Prairie Utility	OEM	160
C	Kawasaki Prairie Utility	AM	60
D	Honda Sport	AM	160

Condition Class Summary

One study objective was to determine if ATVs affect the natural resources and, if so, to what degree. Table 21 provides a summary of the condition-class assessments and, specifically, how condition classes changed over time with subsequent passes.

Table 21—Summary of condition classes.

Tonto National Forest ATV TEST Summary of Condition Classes							
				Summary of Condition			
Equipment Type	**Tire Type**	**Loop**	**Number of Passes**	**Uphill**	**Curve**	**Downhill**	**Straight**
Sport	OEM	A	40	Low	Low	Low	Low
			80	Med	Low	Low	Low
			120	Low	Med	Low	Low
			160	Med	Med	Low	Med
Utility	OEM	B	40	Low	Med	Low	Low
			80	Low	Med	Low	Low
			120	Low	Med	Low	Low
			160	Low	Med	Med	Low
Utility	AM	C	40	Med	Med	Low	Low
			60	High	High	Med	Med
Sport	AM	D	40	Low	Low	Low	Low
			80	Low	Low	Low	Med
			120	Med	Med	Med	Med
			160	Med	Med	Med	Med

Summary of Effects

The area's soils are classified as poorly graded sand. On some of the loops, the sand was quickly dispersed to the sides, exposing the bedrock underneath. Riding was halted after 160 passes on loops A, B, and D, and after only 60 passes on loop C.

Figure 24—Loop B uphill, rated medium.

Figure 25—Loop A straight, rated low.

Figure 26—Loop C straight, rated medium.

Loop C reached a high disturbance class in two of the four transect areas and a medium disturbance class in the other two transects. Thirteen of 16 transect areas reached medium or high after only 80 passes. Three had reached bedrock or highly compacted soils after only 40 passes, and condition classes did not change further.

Figure 27—Loop A uphill, rated medium.

Loops A and D showed similar effects moving from low- to medium-disturbance levels between 120 and 160 passes for uphill, downhill, and straight segments of trail.

Figure 28—Loop A straight, rated low.

The effects of ATV traffic showed the greatest disturbance in the curves for all loops. Loop C showed the most dramatic change moving from medium to high after 20 additional passes. Riding through the downhill and curve transects was rerouted after 60 passes, and data collection for these transect areas was discontinued. The rerouted section was rated medium after 40 passes.

Figure 29—Loop C curve after 60 passes, rated high.

The curves in loops B and C, as well as the uphill for loop C, were all rated at medium levels of disturbance within the first 40 passes.

Figure 30—Loop A turn, rated high.

Vegetation cover was reduced by 20 to 25 percent on all loops and, conversely, bare soil was increased by 20 to 25 percent on all loops. In the curves on all loops, bare soil increased from a before-riding level of 42 percent to an after-riding level of 50 percent (figures 31 and 32). Vegetation cover was reduced from 58 percent before riding to 44 percent after riding, with a proportional increase in rock and root exposure of 6 percent.

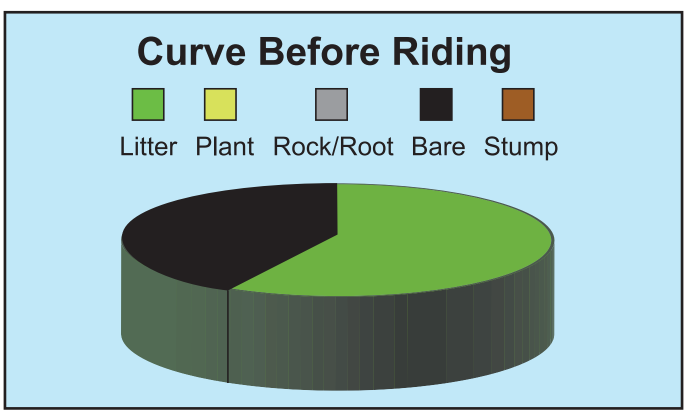


Figure 31—Illustration of proportional amounts of litter and bare soil on the curve segment before riding began.

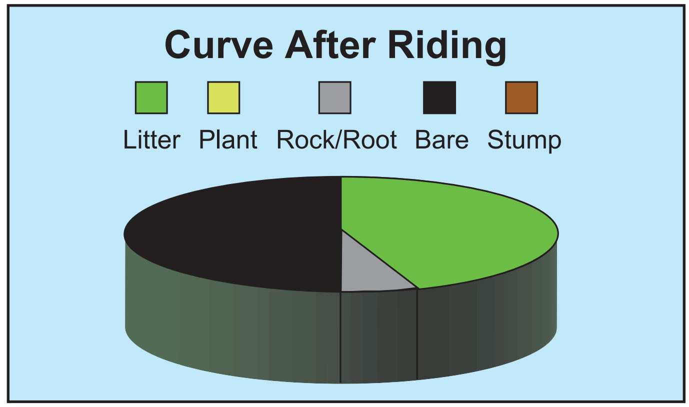


Figure 32—Illustration of proportional amounts of vegetation and litter removed, bare soil, rock/root exposure, and stump exposure on the curve segment at completion of total passes.

Figure 33—Loop C curve, rated high.

Rut depths up to 16 inches were recorded in the curves and some uphill segments. Shallower (2- to 4-inch) depths were recorded on straight and downhill sections.

Kentucky

Land Between the Lakes

Land Between the Lakes (LBL) National Recreational Area site is located near Cadiz, Kentucky, at Turkey Bay, a 2,200-acre, off-highway vehicle (OHV) area open to trail and cross-country riding. The OHV area is centrally located within the LBL and consists of three seventh-level watersheds that contribute 3,166 acres to Turkey Bay. The watershed consists of the North Forks of Turkey and Turner Creeks. The streams of these main channels are intermittent, and the headwaters are ephemeral.

The topography of the area is moderately dissected because of the nearby Tennessee and Cumberland Rivers. The slopes range from 6 to 50 percent and, due to steep slopes and narrow, closely spaced drainage valleys, surface-water runoff has contributed to the erosion process. Streambeds are filled with chert gravels transported from upper slopes. Annual rainfall for LBL averages 46 inches.

Cretaceous gravels, sands, and clays are overlain by a thin layer of brown Tertiary-Quaternary-age cherty gravels. The gravels have a matrix of reddish sandy clay and are interbedded with reddish-brown argillaceous sand. The upland is veneered with tan-to-buff colored Quaternary-age loess. The loess is generally believed to have a wind-blown origin and is probably related to past glaciations.

The study area was located in a 90-percent wooded area with a predominant cover of oak or hickory with little understory. The terrain is characterized as hilly with shallow to deep soils with a limestone-chert base. The soils are well drained with depths ranging from shallow to deep.

The selected study sites were similar in topography and tree cover to the Turkey Bay ATV open-riding areas. Loops A and B were adjacent to each other with steep uphill and downhill sections. Loops C and D were slightly gentler than loops A and B. The topography was hilly with slopes ranging from 17 to 24 percent on all loops.

Figure 35—Loop D downhill.

The area had been without rainfall for over 2 months, which was considered an unusually long dry spell. This resulted in very dusty, dry conditions and soils medium to high in strength.

Prior to riding, trail segments for all loops, including the uphill, downhill, turns, and straight sections, were identified on the ground. Because the testing occurred in the autumn, many trees had dropped their leaves and ground cover (duff) was abundant. The trails were brushed and cleared of any hazards and transects for each trail segment were placed. The downhill, uphill, and straight sections for all four loops were on newly cleared areas.

Soil Properties

Representative soil samples from the four loop trails were taken for analysis. These soils were classified as silt and silty sand. They are characterized as medium strength and have a medium to high susceptibility to surface erosion. Other soil properties are shown in table 22.

Table 22—Soil properties for LBL study site.

Forest	USCS Group Symbol-Description	Surface Erosion	Dry Strength	Saturated Strength	Rutting (Saturated)	Raveling	Dust
LBL	SM-silty sand	Medium-high	Low-medium	Low-medium	Low-medium	Medium-high	Medium-high
LBL	ML-silt	High	Low-medium	Low	High	Low	High

Vehicle Types

Table 23 provides the model, ATV type, and total number of passes for each loop.

Table 23—Loops, vehicle characteristics, and total number of passes.

Loop	Vehicle Model /Type	OEM/ AM	Total Passes
A	Kawasaki Prairie Utility	OEM	800
B	Kawasaki Prairie Utility	AM	800
C	Honda Recon Sport	OEM	760
D	Honda Recon Sport	AM	280

Condition-Class Summary

One study objective was to determine if ATVs affect the natural resources and, if so, to what degree. Table 24 provides a summary of the condition-class assessments and specifically how condition classes changed over time with subsequent passes.

Table 24—Summary of condition classes.

Land Between The Lakes ATV Test Summary of Condition Classes							
				Summary of Conditions			
Equipment Type	**Tire Type**	**Loop**	**No of Passes**	**Uphill**	**Curve**	**Downhill**	**Straight**
Utility	OEM	A	40	Low	High	High	Low
			80	Low	High	High	Low
			160	Low	High	High	Low
			200	Med	High	High	Low
			240	Med	High	High	Low
			280	High	High	High	Med
			480	High	High	High	Med
			520	High	High	High	Med
			560	High	High	High	Med
			600	High	High	High	Med
			800	High	High	High	Med
Utility	Aftermarket	B	40	Low	Med	Low	Low
			80	Med	Med	Med	Med
			120	Med	Med	Med	Med
			160	Med	Med	Med	Med
			200	Med	Med	Med	Med
			280	Med	Med	Med	Med
			320	High	High	Med	Med
			360	High	Med	Med	Med
			400	High	High	Med	Med
			440	High	Med	Med	Med
			480	High	High	Med	Med
			520	High	Med	Med	Med
			560	High	Med	Med	Med
			600	High	High	Med	Med
			640	High	Med	High	Med
			680	High	High	High	High
			800	High	High	High	High
Sport	OEM	C	40	Low	Low	Low	Low
			80	Med	High	Med	Med
			160	Med	High	Low	Med
			200	High	High	Med	Med
			240	Med	High	Med	Med
			280	Med	High	Low	Med
			320	Med	High	Low	High
			360	High	High	Med	High
			440	High	High	Med	High
			480	High	High	Med	High
			560	High	High	Med	High
			600	High	High	Med	High
			640	High	High	Med	High
			720	High	High	Med	High
			760	High	High	Med	High
Sport	Aftermarket	D	40	Low	Med	Low	Low
			120	Low	Med	Low	Low
			160	Low	Med	Low	Low
			240	Med	Med	Low	Low
			280	Med	Med	Med	Low

Summary of Effects

Between 280 and 800 passes were made on each of the transect areas of uphill, downhill, curves, and straight sections of trail. All trail sections were rated medium or high for all four loops with the exception of loop C's straight section, where a low rating was sustained from 40 to 280 passes (figures 36 through 41).

In the straight sections of loop A, the rating changed from low to medium at 280 passes and remained at medium through the 800 passes of the test.

Figure 36—Loop C straight, rated medium.

Loops B and C showed a change from low to medium at 80 passes. Loop C showed a change from medium to high at 320 and remained high to the end of the test, 760 passes. Loop B showed a high rating on the straight section of trail at 680 passes and remained high to the end of the test at 800 passes.

Uphill and downhill sections on loop D remained low from the start to completion of 240 and 280 passes, respectively.

Figure 37—Loop A uphill, rated high.

For all sections on loop D, no condition-class rating ever exceeded medium. However, this was not the case on loops A, B, and C. On loop A, the rating for the uphill section changed from medium to high at 280 passes. Notably, the downhill section on loop A was rated high from 40 passes through 800 passes.

For uphill and downhill section on loop B, a high rating was indicated at 320 and 640 passes, respectively, and remained high for the test's 800 passes.

Figure 38—Loop B downhill, rated medium.

Figure 39—Loop A downhill, rated high.

Figure 40—Loop D turn, rated high.

On loop C, a high rating was achieved on the uphill section at 360 passes and remained high through the total of 760 passes made on the loop. On this section, a medium rating was indicated at 360 passes and this rating was sustained through test's full 760 passes.

ATV use in curves appeared to show the greatest effects on loops A and C. On loop A, the rating was high after only 40 passes, and on loop C, a high rating was indicated after only 80 passes. Riding through this transect was rerouted after 162 passes, and data collection was discontinued. The curve for loop B indicated a high rating at 320 passes, but fluctuated between medium and high until 680 passes, when a high rating was continued through the test's 800 passes. On loop D, the condition-class rating of medium was indicated from 40 through the test's 280 passes.

Vegetation cover was reduced from 41 to 99 percent on all loops. Conversely, on all loops, bare soil was increased by 43 percent on straight sections and up to 58 percent on curves. In the curves on all loops, bare soil increased from a before-riding level of 5 percent to an after-riding level of 58 percent (figures 42 and 43). Vegetation cover was conversely reduced from 95 percent before riding to 42 percent after riding.

Figure 41—Vegetation/cover completely removed on loop D turn.

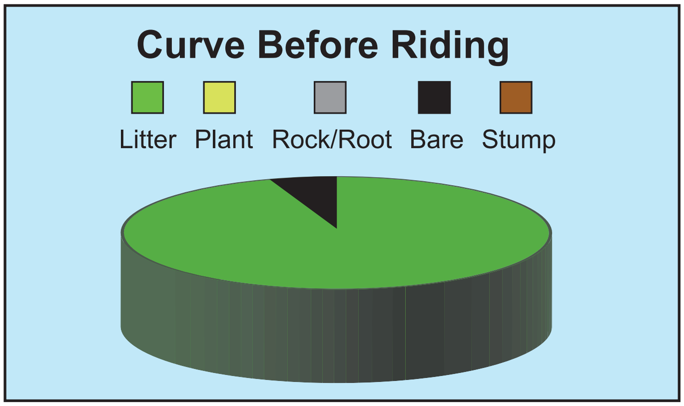


Figure 42—Illustration of proportionate amounts of litter and bare soil on the curve segment before riding began.

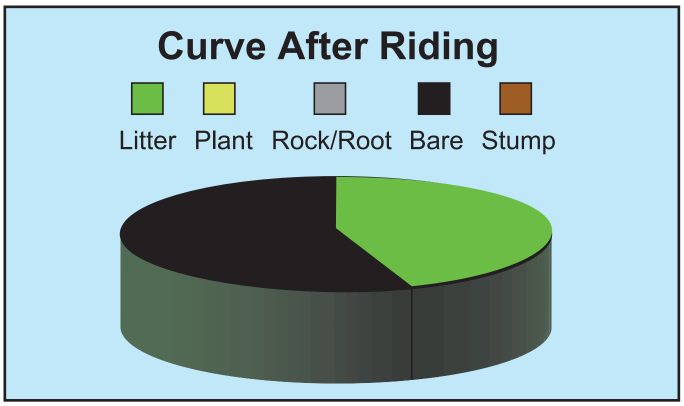


Figure 43—Illustration of proportionate amounts of vegetation and litter removed, bare soil, rock/root exposure, stump exposure on the curve segment at completion of total passes.

Rut depths to 4 inches were recorded in the turns, with the trail widening up to 6 feet. Rut depths to 3 inches were measured in uphill segments, with the trail widening to 3 feet in these segments. Rut depths of 1 to 4 inches were recorded on straight and downhill sections (figure 44).

Figure 44—Rut depths of 1 to 4 inches were recorded.

ATVs for loops B and D were fitted with aftermarket tires that appear to have influenced ratings in all sections on loop D. ATVs for loops A and C were fitted with OEM tires and showed much higher condition-class ratings overall (figures 45 and 46).

Figure 45—Loop C turn, rated high.

Figure 46—Loop A downhill, rated low.

Louisiana

Kisatchie National Forest

The Kisatchie National Forest encompasses 603,769 acres. All of Louisiana is considered typical coastal plain. The forest's topography ranges from hilly to undulating on the uplands to level on stream terraces and flood plains. Elevations range from 80 feet above sea level in flood plains to 425 feet above sea level in the Kisatchie hills. The area's general slope is southward to the Gulf of Mexico.

Most soils in the forest area are highly weathered and acidic, with low nutrients. Their productivity, however, is generally high because they are generally deep with abundant plant-available moisture. The area's climate is subtropical.

Weather is highly variable. Annual rainfall averages 59 inches. Summer temperatures range from 85 to 95 °F in the afternoons and 65 to 75 °F in the early morning hours. Winter temperatures range from 55 to 65 °F in the afternoons and 40 to 50 °F in the early morning hours. The average temperature is 68 °F, and the average humidity is 74 percent.

Located within the forest boundaries today are four, broad, historically present plant or vegetation communities: longleaf pine, shortleaf pine/oak-hickory, mixed hardwood-loblolly pine, and riparian.

The study area was located on an old military base on the Kisatchie National Forest's Calcasieu Ranger District. Much of the area was roaded and covered with mature pines and a tall grass understory. Prior to riding, four trail loops were identified that ranged in length from 900 to 1,500 feet. Loops were selected that had similar characteristics: uphill and downhill of approximately 10 percent, a sharp hairpin turn, and a straight section to allow for acceleration and higher speed.

Soil Properties

Representative soil samples from the four loop trails were taken for analysis. These soils were classified as silt and silty sand. They are characterized as medium strength and have a medium-to-high susceptibility to surface erosion. Other soil properties are shown in table 25.

Table 25—Soil properties for Kisatchie NF study site.

Forest	USCS Group Symbol-Description	Surface Erosion	Dry Strength	Saturated Strength	Rutting (Saturated)	Raveling	Dust
KNF	SM-silty sand	Medium-high	Low-medium	Low-medium	Low-medium	Medium-high	Medium-high
KNF	ML-silt	High	Low-medium	Low	High	Low	High

Vehicle Types

Table 26 provides the model, ATV type, and total number of passes for each loop.

Table 26—Loops, vehicle characteristics, and total number of passes.

Loop	Vehicle Model /Type	OEM/ AM	Total Passes
A	Suzuki Vinson 4 by 4 500 Utility	OEM	480
B	Honda Foreman Rubicon 500 Utility	AM	640
C	Suzuki Ozark Sport	OEM	720
D	Suzuki Ozark Sport	AM	600

Condition Class Summary

One study objective was to determine if ATVs affect the natural resources and, if so, to what degree. Table 27 provides a summary of the condition-class assessments and specifically how condition classes changed over time with subsequent passes.

Table 27—Summary of condition classes.

Kisatchie National Forest ATV Test Summary of Condition Classes							
				Summary of Condition			
Equipment Type	**Tire Type**	**Loop**	**No. of Passes**	**Uphill**	**Curve**	**Downhill**	**Straight**
Utility	OEM	A	40	Low	Low	Low	Low
			80	Med	High	Low	Low
			120	Low	Med	Low	Low
			160	Low	Med	Low	Low
			200	Low	Low	Low	Low
			240	Low	Med	Low	Low
			360	Low	Med	Low	Low
			400	Med	Med	Low	Low
			480	Low	Med	Low	Low
Utility	Aftermarket	B	40	Low	Med	Low	Low
			80	Low	Med	Low	Low
	* Stopped riding at 162 passes in Curve		160	Low	High*	Low	Low
			240	Low		Low	Low
			280	Med		Low	Low
			360	Med		Low	Low
			400	Low		Med	Low
			440	Med		Med	Low
			520	Med		Med	Low
			500	Med		Med	Low
			560	Med		Med	Low
			640	Med		Med	Low
Sport	OEM	C	40	Low	Low	Low	Low
			80	Low	Low	Med	Low
			120	Med	Med	Low	Low
			200	Med	Low	Med	Med
			240	Med		Med	Med
			580	Low		Low	Low
			640	Low		Low	Low
			720	Low		Low	Low
Sport	Aftermarket	D	40	Low	Low	Low	Low
			120	Low	Med	Low	Low
			200	Med	High	Med	Low
			240	Med	High	Med	Low
			280	Med	High	Med	Low
			320	Med	High	Low	Low
			360	Low	High	Med	Med
			400	Med	High	Med	Med
			560	Med	High	Med	Low
			600	Med	High	Med	Med
			640	Med	High	Med	Med
			680	Med	High	Med	Med
			720	Med	High	Med	Med
			740	High	High	Med	Med

Summary of Effects

For loops A and B, riding was stopped after 480 and 640 passes respectively, because very little change was observed and documented in the test segments. Loops C and D showed some change in condition classes over time; however, they both remained in a condition class for a long period of time.

Between 480 and 740 passes were made over the four transect areas of uphill, downhill, curve, and straight segments. Downhill and straight trail segments were rated low for all four loops, with two exceptions. Loop B indicated a change from low to medium at 640 passes and loop D indicated a change from low to medium at 720 passes.

Figure 48—Loop C downhill, rated low.

Figure 49—Loop C straight, rated low.

Figure 50—Loop A straight, rated low.

ATVs appeared to have the greatest effects in curves. On loop B, the condition-class rating changed from low to high after only 160 passes. Riding through this transect was rerouted after 162 passes and data collection was discontinued. The curve in loop C demonstrated a similar dynamic. The condition class changed from low to medium at 80 passes and riding was terminated after 200 passes out of concern for rider safety.

Figure 51—Loop B turn, rated high.

The condition-class rating for the curve segment on loop D changed at 120 passes from low to medium and remained so until changing to high at 720 passes.

In the uphill section, loop B changed from low to medium at 560 passes and loop D changed from low to medium at 680 passes. Loops A and C indicated a low condition class throughout the study.

The condition class summary (table 27) shows the different condition classes found during the test runs. In some cases, the test segment was excluded after a number of passes due to either a condition class being obtained or to safety concerns with continued riding. Loop B attained a high-condition class on the turn at approximately 150 passes. With additional loops, it was determined that rut depths could no longer increase because of the vehicle's clearance limitation.

Vegetation cover was reduced by a range of 41 percent to 62 percent in the downhill and straight sections of all loops. Vegetation cover was reduced by as much as 99 percent in the curve of loop B. Bare soil was increased to 30 percent early in the number of passes and remained the same on straight sections. Bare soil increased to up to 73 percent on curves on all loops (figures 52 and 53).

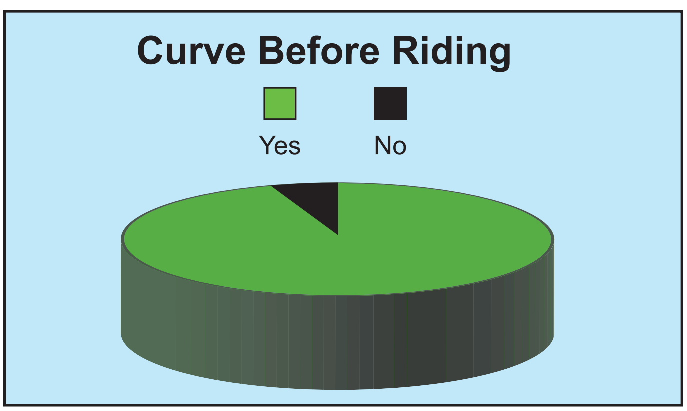


Figure 52—Illustration of proportionate amounts of litter and bare soil on the curve segment before riding began.

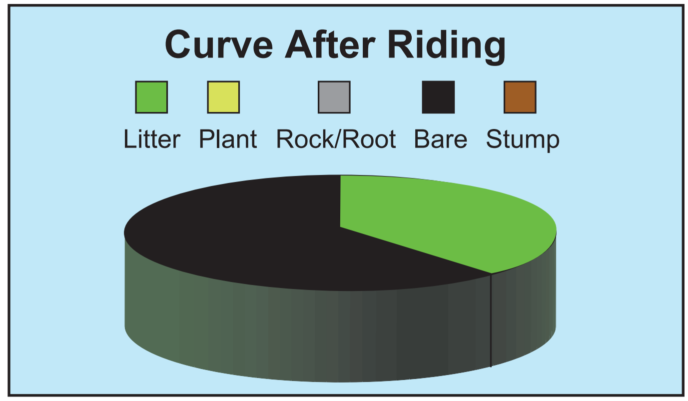


Figure 53—Illustration of proportionate amounts of vegetation and litter removed, bare soil, rock/root exposure, stump exposure on the curve segment at completion of total passes.

Rut depths up to 8 inches were recorded in the curves with trail-shoulder mounding up to 9 inches in curve segments (figure 54). Rut depths up to 4 inches were measured in uphill segments with the trail-shoulder mounding up to 6 inches in these segments. Shallower depths, 0.5 to 3 inches, were recorded on straight and downhill sections.

Figure 54—Loop B, 8-inch rut on the turn.

Vehicles for loops B and D were fitted with aftermarket tires that achieved a high condition class in the curve, uphill, and downhill segments. They achieved a medium rating on the uphill segments of loop B.

Vehicles for loops A and C used OEM tires. They achieved a low rating for the entire test for all trail segments except the curve on loop A. The turn for loop A indicated a medium condition class.

Minnesota

Department of Natual Resource Lands

The Minnesota test site was located on Minnesota Department of Natural Resources (DNR) land adjacent to the Superior National Forest and the Big Aspen Trail loop. The test included portions of existing trails, as well as new or uncompacted trail segments. The trails varied in length from 600 to 1,100 feet.

Sites were selected that followed the natural topography and included slopes typically encountered on existing trails. Uphill and downhill slopes ranged from 16 to 30 percent. On two loops (B and D) tight, hairpin turns were included in the design and layout. On loop A, a more gentle sweeping turn was incorporated as a test segment.

Once the four trails were identified, the trails were cut-in to remove the dominant vegetation, including young aspen saplings 1 to 2 inches in diameter. Stumps, roots, low branches, and other obstacles to riding were removed. In test segments, the trails were widened slightly to aid in the measurement process. Surface rocks and decaying logs were left in place.

Prior to riding, trail segments including the uphill, downhill, turns, and straight sections were identified on the ground for loops A and B. Loop A had the downhill, uphill, and straight section totally on uncompacted soils or newly cleared trails. The sweeping turn was on both new and existing trails.

The uphill and part of the hairpin turn on loop B were on existing trails. The downhill and straight sections on loop B were located on uncompacted or newly cleared trails.

At each segment, three cross sections were placed to record changes to the natural resources that included changes to vegetative cover and soil profile. The three cross sections were extended to approximately 30 feet to reflect the lessons learned in Louisiana. A pretest soil core sample was taken at each of the four trail sections on loops A and B, and at two sections on loops C and D (figures 56 and 57).

One of the few times we had the opportunity to observe ATV effects on an existing trail was on loop C. Loop C was located on an existing road that was primarily used as a snowmobile route and for logging access. An uphill segment was set up in the shoulder of the road using a bypass on the return trip to prevent double counting. The straight segment was set up in the roadbed itself. A bypass was not setup for the return trip, and double counting was allowed. Data collection for the downhill and turn segments were omitted but observed.

Figure 56—Loop C uphill, rated low.

Loop D was located on an existing cross-country ski trail and thought to be used previously as a skid trail for logging. An uphill area and a sharp hairpin curve were cleared of vegetation for use as test sections. These test sections were on predominantly uncompacted soils. Data collection for the downhill and turn segments were omitted but observed.

Figure 57—Loop D, rated medium.

Soil Properties

Representative soil samples from the four loop trails were taken for analysis. These soils were classified as predominately organic silt/clays. They are characterized as low in strength and medium in susceptibility to surface erosion. Other soil properties are shown in table 28.

Table 28—Soil properties for Minnesota DNR study site.

Forest	USCS Group Symbol-Description	Surface Erosion	Dry Strength	Saturated Strength	Rutting (Saturated)	Raveling	Dust
MDNR	PT,OL/OH-peat, organic silt/clays	Medium	Low	Low	High	Low	Medium-high

Vehicle Types

Table 29 provides the model, ATV type, and total number of passes for each loop.

Table 29—Loops, vehicle characteristics, and total number of passes.

Loop	Vehicle Model /Type	OEM/ AM	Total Passes
A	Kawasaki Prairie Utility	OEM	500
B	Kawasaki Prairie Utility	AM	700
C	Suzuki Ozark Sport	OEM	1,200
D	Suzuki Ozark Sport	AM	620

Condition-Class Summary

One study objective was to determine if ATVs affect the natural resources and, if so, to what degree. Table 30 provides a summary of the condition-class assessments and, specifically, how condition classes changed over time with subsequent passes.

Table 30—Summary of condition classes.

Minnesota-DNR ATV Test Summary of Condition Classes							
				Summary of Condition			
Equipment Type	**Tire Type**	**Loop**	**No of Passes**	**Uphill**	**Curve**	**Downhill**	**Straight**
Utility	OEM	A	40	Med	Low	Med	Low
	Cumulative daily passes		80	Med	Low	Med	Med
			120	Med	Low	High	Med
			160	Med	Med	High	Med
			280	Med	Med	High	Med
			320	Med	Med	High	Low
			440	High	Med	High	Med
			500	Med	High	High	Med
Utility	Aftermarket	B	40	Med	Low	Low	Low
			80	Med	Low	Low	Low
			120	Med	Med	Med	Low
			200	Med	Med	Med	Med
			320	Med	Med	Med	Med
			360	Med	Med	Med	Med
			440	Med	Med	Med	Med
			700	Med	Med	Med	Med
Sport	OEM	C	40	Low**	All	All	Low**
	** Uphill and		160	Low	passes	passes	Low
	straight sections		320	Low	in	in	Low
	of trail located where vegetation present in roadbed		400	Low	roadbed	roadbed	Low
			640	Low	NA	NA	Low
			1,040	NA	NA	NA	Low
			1,200	NA	NA	NA	Low
Sport	Aftermarket	D	40	Med	Med	Bypass	Low
			80	Med	Med	(see	Low
			220	Med	High	summary	Med
			260	Med	High	of	High
			300	High	High	findings)	High
			420	High	High		High
			500	High	High		High
			620	High	High		High

Summary of Effects

Between 500 and 1,200 passes were made on each of the transect areas of uphill, downhill, curves, and straight sections of trail. All trail segments were at some point rated medium or high, except loop C. In the straight section of loops A, the rating changed from low to medium at 80 passes and remained generally at medium through the test's 500 passes. Straight sections of loops B and D indicated a change from low to medium at 200 and 220 passes, respectively.

The straight segment of loop C remained low through the 1,200 passes completed. The straight segment has a higher number of passes recorded because of the double counting as the vehicle passed back and forth over the same area as it completed each lap.

The uphill sections on loop C remained low from the start to completion of 640 passes. Loop D indicated a high rating on the straight section of trail at 260 passes and remained high through the end of the test at 620 passes. Uphill sections on loops A, B, and D indicated a medium condition class at 40 passes. Loop B remained at medium throughout the test of 700 passes on the uphill section.

Loop A indicated a medium condition class in the uphill section of trail until 440 passes, when a high condition class was indicated. This condition class changed back to medium at the end of the test, 500 passes. Loop D indicated a change from medium to high at 300 passes and remained at this condition class until the end of the test, 620 passes.

On the downhill section of loop A, a medium condition class was indicated at 40 and 80 passes. At 120 passes, a high was indicated and remained the condition class for the downhill section of loop A through the end of the test, 500 passes. On loop B, the condition class was low at 40 and 80 passes and then indicated medium at 120 passes, remaining the same throughout the test, 700 passes.

On loop C, the downhill section was conducted in an existing roadbed and on loop D, a bypass for the downhill section was used that replicated the conditions on the uphill section of trail on this loop.

Only the curves on loop A and loop D reached a high condition class. On loop A, a low was indicated from 40 through 120 passes. Then, at 160 passes through 440 passes, a medium was indicated. At 500 passes and to the end of the test on this loop, the condition class was high. This gradual change in condition class was not the case in the curve section of loop D. A medium rating was indicated from 40 through 220 passes. However, at 220 passes through the end of the test at 620 passes, a high condition class was indicated.

On loop B, a low was indicated at 40 through 80 passes in the curve. The condition class changed to medium at 120 passes and remained the same through the test's 700 passes on this loop. Loop C was located in a roadbed where vegetation was present.

Overall, the effects of ATV use on loop B were never rated high on any one of the trail sections. This result is most striking in comparison to the straight sections of loops C and D where high condition class was indicated at 400 and 260 passes, respectively.

The percentage of ground cover disturbed ranged from a low of 47 percent on the straight section of loop D, to 96 to 100 percent on all other sections of all loops. As an example, vegetation cover was reduced from 37 to 14 percent in the curve on loop D. Bare soil was increased from none before riding to 10 percent after riding.

Root/rock exposure changed from a before-riding level of 1 percent to an after-riding 3 percent. Litter increased from 62 percent prior to riding to 73 percent after riding in the curve on loop D. This increase in litter was due to ground disturbance, exposure, and loose vegetation from the effects of riding (figures 58 and 59).

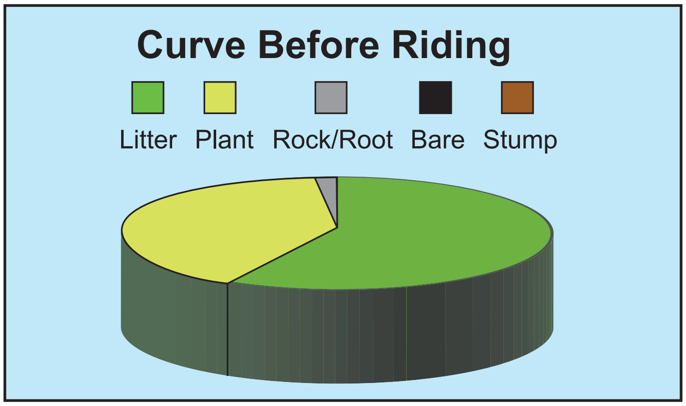


Figure 58—Illustration of proportionate amounts of litter and bare soil on the curve segment before riding began.

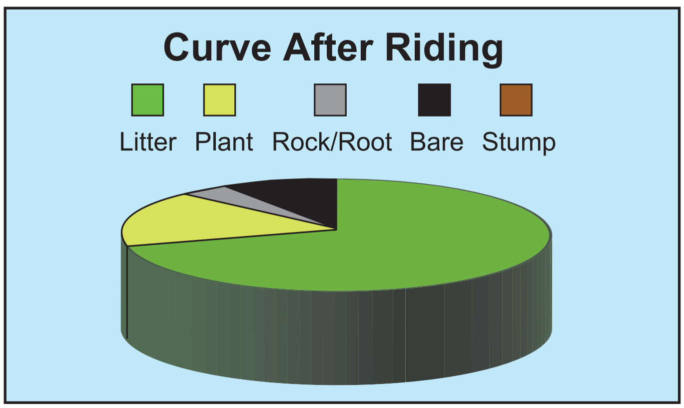


Figure 59—Illustration of proportionate amounts of vegetation and litter removed, bare soil, rock/root exposure, and stump exposure on the curve segment at completion of total passes.

Rut depths up to 5 inches were recorded in the curves, with shoulder mounding up to 4 inches. Rut depths up to 2 inches were measured in uphill segments, with shoulder mounding up to 3 inches in these segments. Rut depths of 1 to 2 inches were recorded on straight and downhill sections.

Vehicles for loops B and D used aftermarket tires, and vehicles for loops A and C used OEM tires. It is difficult to discern any differences due to tire type alone as to the effects of ATV use on all loops. This is especially highlighted on the downhill section of loop A, where a high condition class was reached after only 80 passes with the OEM-tire-equipped vehicle. Conversely, on loop D, with aftermarket tires on the sport vehicle, a high condition class was indicated in the curve at 220 passes, the uphill section at 300 passes, and the straight section at 260 passes.

Missouri

Mark Twain National Forest

The Mark Twain National Forest encompasses roughly 1.5 million acres, mostly within the Ozark Highlands. Located across southern and central Missouri, the Mark Twain National Forest has the largest base of public land open for a variety of uses.

The Mark Twain is characterized by large permanent springs, caves, rocky barren glades, old volcanic mountains, and nationally recognized streams. A trademark of the forest is plant and animal diversity. The eastern upland oak hardwood and southern pine forests converge with the drier western bluestem prairie of the Great Plains, creating a distinctive array of open, grassy woodlands and savannas. These diverse and ecologically complex vegetative communities provide a home for nearly 750 species of native vertebrate animals and over 2,000 plant species. The study area was located in the Sutton Bluff ATV trail area, about 40 miles southeast of Salem, Missouri. The watershed consists of the West and Middle Forks of the Black River. This is an area of well developed karst terrain that is characterized by the presence of caves, springs, and sinkholes. Soils are developed from cherty limestone and are both stony and acidic. Slopes (10 to 35 percent) are gently rolling to steep near the bigger drainages. The major landform in this area is the Salem Plateau, which is part of the Ozark Plateau. Elevation is about 1,200 feet. The dominant vegetation type is oak and shortleaf pine. Average annual rainfall is 38 inches.

The ATV study was conducted on October 9 and 10, 2004. Riding was to begin on October 8, but was postponed 1 day due to rain and slick riding conditions. The test trail site was located on slopes adjacent to existing trails.

Test trails were laid out on September 29, and the forest conducted subsequent brushing and clearing of small diameter deciduous hardwood trees to accommodate rider safety (figures 61 and 62).

Loops A and B were located next to each other on similar soils and slopes suitable for 4-wheel-drive vehicle use.

Figure 61—Figure 8 Loop D uphill, rated low.

Figure 62—Figure 8 Loop D downhill, rated low.

Loop C was the shortest and loop A was the slowest due both to length and drivability. Approximately 500 passes were completed on each loop.

Prior to riding, trail segments, including the uphill, downhill, turns, and straight segments, were identified on the ground for all loops. In early October many of the trees had dropped their leaves, and ground cover (duff) was abundant. The study area was predominantly an oak hickory forest with little understory.

The trails were brushed and cleared of any hazards, and transects for each of the trail segments were placed. The downhill, uphill, and straight sections for all four loops were located in undisturbed areas.

Soil Properties

Representative soil samples found at the four loop trails were taken for analysis. The results of the analysis concluded that the soils were predominately silty sand. These soils are low to medium in strength and are medium-high to highly susceptible to surface erosion. Other soil properties are shown in table 31.

Table 31—Soil properties for Mark Twain NF study site.

Forest	USCS Group Symbol-Description	Surface Erosion	Dry Strength	Saturated Strength	Rutting (Saturated)	Raveling	Dust
MTNF	SM-silty sand	Medium-high	Low-medium	Low-medium	Low-medium	Medium-high	Medium-high

Vehicle Types

Table 32 provides the model, ATV type, and total number of passes for each loop.

Table 32—Loops, vehicle characteristics, and total number of passes.

Loop	Vehicle Model /Type	OEM/ AM	Total Passes
A	Kawasaki Prairie Utility	OEM	480
B	Kawasaki Prairie Utility	AM	520
C	Honda Recon Sport	OEM	500
D	Honda Recon Sport	AM	500

Condition-Class Summary

One study objective was to determine if ATVs affect the natural resources and, if so, to what degree. Table 33 provides a summary of the condition-class assessments and, specifically, how condition classes changed over time with subsequent passes.

Table 33—Summary of condition classes.

Mark Twain National Forest ATV Test Summary of Condition Classes							
				Summary of Condition			
Equipment Type	**Tire Type**	**Loop**	**No of Passes**	**Uphill**	**Curve**	**Downhill**	**Straight**
Utility	OEM	A	40	Low	Med	Low	Low
			80	Med	High	Low	Low
			120	Med	High	Low	Low
			160	Med	High	Med	Med
			320	Med	High	Med	Med
			360	High	High	Med	Med
			480	High	High	Med	Med
Utility	Aftermarket	B	40	Low	Med	Low	Low
			80	Low	High	Low	Low
			120	Low	Med	Low	Low
			280	Med	High	Med	Low
			320	Low	High	Med	Low
			360	Med	High	Med	Med
			400	Med	High	Low	Med
			440	Med	High	Med	Med
			520	Med	High	Med	Med
Sport	OEM	C	40	Low	Low	Low	Low
			120	Low	Med	Low	Low
			200	Med	Med	Low	Low
			240	Low	Med	Low	Low
			320	Med	Med	Low	Med
			360	Low	Med	Low	Low
			440	Med	Med	Low	Low
			480	Med	High	Low	Low
			500	Med	High	Med	Med
Sport	Aftermarket	D	40	Low	Low	Low	Low
			80	Low	Low	Low	Low
			280	Low	Med	Low	Low
			400	Low	Low	Low	Low
			440	Med	Med	Low	Low
			520	Med	Med	Low	Low
			560	Med	Med	Low	Med

Summary of Effects

Between 480 and 560 passes were made over the transect areas on each of the uphill, downhill, curves, and straight sections of trail (figures 63-69). The downhill section of trail was rated low for loop D and low for loop C until after 500 passes, when the rating changed to medium.

Figure 63—Loop D downhill, rated medium.

Loop A changed from low to medium at 160 passes in the downhill section of the trail, and loop B changed from low to medium at 280 passes in the downhill section as well.

Figure 64—Loop A downhill, rated low.

The straight sections of trail on all loops indicated very similar condition-class ratings as those in the downhill sections.

ATV use in curves on loops A and B indicated the greatest effects early in the number of passes. On loop A, the condition-class rating changed from medium to high after only 80 passes. The curve for loop B demonstrated a similar dynamic. Its condition-class rating changed from medium to high at 80 passes, fluctuated back to medium at 120 passes, and then back to high for the remainder of the test's 520 passes.

Figure 65—Loop A, rated medium.

Figure 66—Loop B, rated high.

Figure 67—Loop A turn, rated high.

Figure 68—Loop C turn, rated high.

The effect rating for the curve section on loop C changed at 120 passes from low to medium and changed at 480 passes from medium to high and remained at high for the remaining passes. Loop D changed from low to medium at 280 passes.

In the uphill section, loop B changed from low to medium at 280 passes, and loop C changed from low to medium at 200 passes. On loop C, however, the rating fluctuated from medium to low and then back to medium between 240 and 440 passes. At 440 passes, the condition-class rating on loop C remained at medium until the end of the test at 500 passes.

Figure 69—Loop D uphill, rated high.

Loop A changed from low to medium at only 80 passes on the trail's uphill section. The condition-class rating changed again on loop A from medium to high at 360 passes on the uphill section of trail. The uphill section of trail on loop D did not change from low to medium ratings until 440 passes and remained at medium through the end of the test, 560 passes.

Vegetation cover was reduced from 41 percent to 62 percent in the downhill and straight sections of all loops to as much as 99 percent in the curve of loop B and 98 percent in the curve on loop A. In the curve section of loop A, bare soil was increased to 57 percent at 80 passes. Bare soil increased up to 58 percent on curves on all loops (see figures 70 and 71). Bare soil increased to 51 percent on the uphill section of loop A.

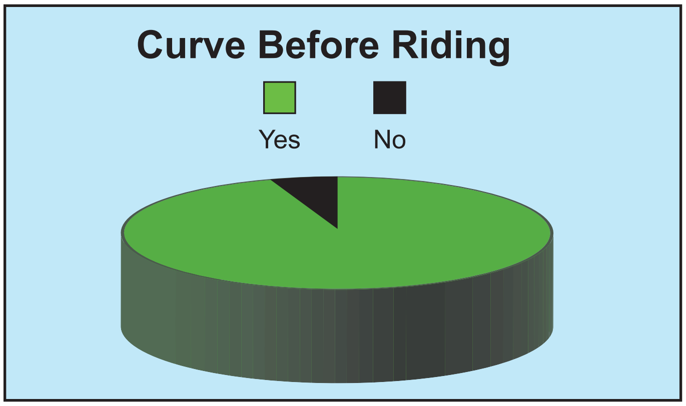


Figure 70—Illustration of proportionate amounts of litter and bare soil on the curve segment before riding began.

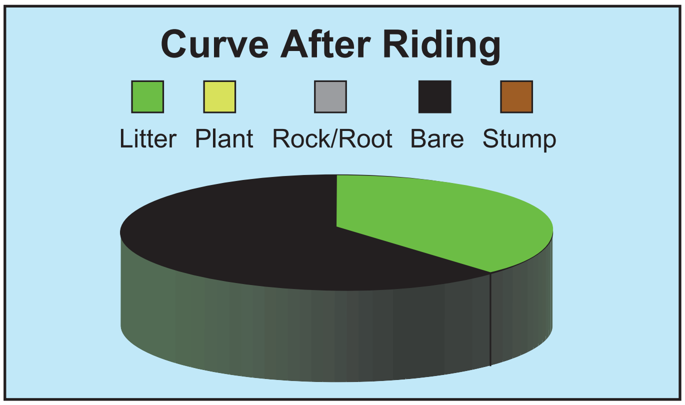


Figure 71—Illustration of proportionate amounts of vegetation and litter removed, bare soil, rock/root exposure, stump exposure on the curve segment at completion of total passes.

Rut depths up to 7 inches were recorded in the curves, with the trail widening up to 6 feet in curve segments on all loops and in the uphill section of loop D. Rut depths up to 6 inches were measured in uphill segments, with the trail shoulder mounding up to 10 inches in these segments. Shallower depths—1 to 2 inches—were recorded on straight and downhill sections.

ATV use in turns appeared to show the greatest effects on loops B and D. On loop B, the rating was high after only 80 passes and, on loop D, a high rating was achieved after only 40 passes. Riding through this section was discontinued after 80 passes, as a high-condition class was reached and sustained. The turn for loop A indicated a high rating at 240 passes, after a medium rating was sustained from 40 through 200 passes.

Montana

Beaverhead-Deerlodge National Forest

The Beaverhead-Deerlodge National Forest (BDNF) is located in the Middle Rocky Mountain steppe-coniferous forest/alpine meadow ecological province. It is the largest national forest in Montana, covering 3.32 million acres in 8 counties. The forest is in 11 separate landscapes spread across a number of island mountain ranges and accounts for approximately 42 percent of the lands within those counties.

The unique pattern of forest and meadow in southwest Montana makes the land more physically and visually accessible than the more heavily timbered forests of northern Montana. This characteristic of the landscape is also more visually diverse than the open rangelands of eastern Montana. An array of vegetation types characterize the forest, including lodgepole pine, Douglas fir, spruce, sub-alpine fir, whitebark pine, aspen, and juniper, along with great expanses of sagebrush and grasslands.

Four loop trails were laid out for the ATV test. Loops A and B had slopes up to 25 percent for the uphill and downhill sections. Uphill and downhill sections on loops C and D had slopes of 23 percent and 16 percent, respectively. Overall, loops C and D were gentler in slope than loops A and B and were used for the sport ATVs.

Soil Properties

Representative soil samples from the four loop trails were taken for analysis. These soils were classified as silty sand, clayey sand, and silt. They are characterized as low-medium strength and have a medium to high susceptibility to surface erosion. Other soil properties are shown in table 34.

Table 34—Soil properties for Beaverhead-Deerlodge NF study site.

Forest	USCS Group Symbol-Description	Surface Erosion	Dry Strength	Saturated Strength	Rutting (Saturated)	Raveling	Dust
BDNF	SM-silty sand	Medium-high	Low-medium	Low-medium	Low-medium	Medium-high	Medium-high
BDNF	SC-clayey sand	Medium	Medium-high	Low	Low-medium	Low-medium	Medium
BDNF	ML-silt	High	Low-medium	Low	High	Low	High

Vehicle Types

Table 35 provides the model, ATV type, and total number of passes for each loop.

Table 35—Loops, vehicle characteristics, and total number of passes.

Loop	Vehicle Model /Type	OEM/ AM	Total Passes
A	Kawasaki Prairie Utility	OEM	840
B	Arctic Cat Utility	AM	840
C	Yamaha Bearcat Sport	OEM	960
D	Honda Sport Trax 250 Ex Sport	AM	960

Condition-Class Summary

One study objective was to determine if ATVs affect the natural resources and, if so, to what degree. Table 36 provides a summary of the changes in condition class and, specifically, how they illustrate change over time with subsequent passes.

Table 36—Summary of condition classes.

Beaverhead-Deerlodge National Forest ATV Test Summary of Condition Classes							
				Summary of Condition			
Equipment Type	**Tire Type**	**Loop**	**No of Passes**	**Uphill**	**Curve**	**Downhill**	**Straight**
Utility	OEM	A	40	Low	Low	Low	Low
			80	Low	Med	Low	Low
			120	Low	Med	Low	Low
			240	Med	Med	Low	Low
			320	Med	Med	Med	Low
			360	High	Med	Med	Low
			400	High	Med	Med	Med
			520	High	Med	Med	Med
			640	High	High	Med	Med
			840	High	High	Med	Med
Utility	Aftermarket	B	40	Low	Low	Low	Low
			80	Low	Med	Low	Low
			120	Low	Med	Low	Low
			200	Med	Med	Low	Low
			280	Med	Med	Med	Low
			320	Med	Med	Med	Med
			360	Med	Med	Med	Low
			400	Med	Med	Low	Med
			440	Med	High	Med	Med
			520	Med	Med	Med	Med
			560	Med	Med	Med	Med
			640	Low	Low	Low	Low
			680	Med	Med	Low	Low
			720	Med	Med	Low	Low
			760	Med	Med	Med	Med
			840	Med	Med	Med	Med
Sport	OEM	C	40	Low	Med	Low	Low
			120	Low	High	High	Med
			200	High	High	High	Low
			320	High	High	High	Med
			400	High	High	High	Med
			560	Low	High	High	Med
			720	High	High	High	Med
			960	High	High	High	Med
Sport	Aftermarket	D	40	Low	Med	Low	Low
			120	Low	High	Low	Low
			160	Med	High	Low	Low
			240	Med	High	Low	Low
			320	Med	High	Low	Med
			360	Med	High	Low	Low
			400	Med	High	Low	Low
			560	Med	High	Low	Med
			640	Med	High	Med	Med
			800	Med	High	Med	Med
			960	Med	High	Med	Med

Summary of Findings

Between 840 and 960 passes were made over the transect areas on the trail's uphill, downhill, curves, and straight sections. Downhill and straight sections of all four trail loops were rated high, with one exception. Loop C changed from low to high at 120 passes on the downhill section of the trail and remained at a high condition class to the end of the test, 960 passes. Loop D changed from low to medium at 640 passes on the downhill section of the trail and remained the same to the end of test, 960 passes (figures 73 through 76).

Figure 73—Loop C turn, rated high.

The greatest effects of ATV passes were documented in the curves on loops C and D. The effects of ATVs on the curve of both loops C and D were significant, and a condition-class of high was achieved quite early in the number of passes. In both cases, the condition class was medium at only 40 passes and changed to high at 120 passes, remaining high for the remainder of the test, 960 passes.

The condition class for the curve section on loop A changed from low to medium at 80 passes and from medium to high at 640 passes. Loop B changed from low to medium at 80 passes and remained at medium with two exceptions, a low rating at 640 passes and a high rating at 440 passes.

The uphill sections on loop C were low from the start to 200 passes, when the condition class changed to high. The condition class remained high with the exception of one change to low from 560 passes to 720 passes. A high was indicated through the remainder of the test, 960 passes.

Uphill sections on loops A, B, and D indicated a medium condition class at 240, 200, and 160 passes, respectively. Loop B remained at a medium throughout the test, 840 passes, with the brief exception of a low condition class rating from 640 to 680 passes. Loop A indicated a medium condition class in the uphill section of trail from 240 through 360 passes, when a high was indicated. The condition class remained high through the 840 passes of the test. Loop D indicated a medium from 160 passes through the end of the test, 960 passes.

On the downhill section of loop A, a medium condition class was indicated at 340 passes and remained medium through the rest of the test, 960 passes. On the downhill section of loop D, the condition class was low until 640 passes and then medium for the remaining test, 960 passes. On loop B, the downhill section indicated a low from the start of the test through 280 passes, at which time a medium was indicated generally through to the end of the test, 840 passes. At 400 passes—and from 640 to 720 passes—a low was indicated briefly.

Vegetation cover was reduced by 100 percent on all loops, and bare soil was increased to 36 percent on straight sections and up to 78 percent on curves on all loops (figures 77 and 78).

Figure 74—Loop B downhill, 640 passes rated medium.

Figure 75—Loop A downhill, rated low.

Figure 76—Typical vegetation and ground cover.

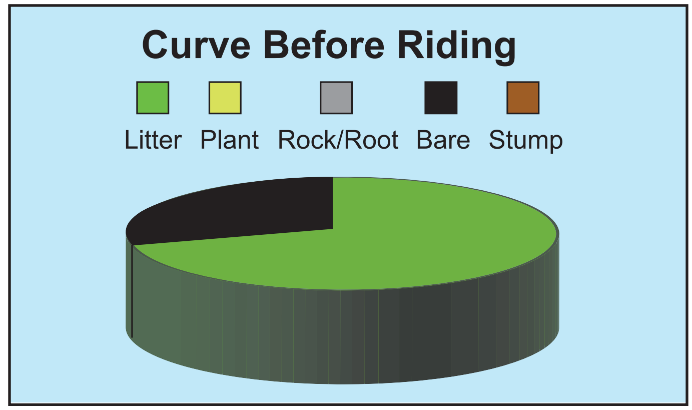


Figure 77—Illustration of proportionate amounts of litter and bare soil on the curve segment before riding began.

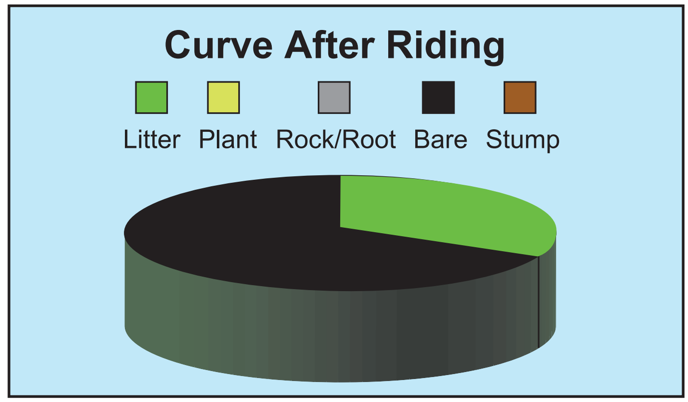


Figure 78—Illustration of proportionate amounts of vegetation and litter removed, bare soil, rock/root exposure, stump exposure on the curve segment at completion of total passes.

Rut depths to 7 inches were recorded in the curves. Rut depths to 4 inches were measured in uphill segments, with the trail widening to 6 feet in these segments. Shallower depths—0.5 to 3 inches—were recorded on straight and downhill sections of trail.

A Honda Sporttrax 260 Ex, with a more aggressive aftermarket tire, was used for loop D. The effects of ATV passes—regardless of tire or vehicle type—are significant in curves where shallow soils and rapidly diminished vegetative cover are inherent.

Washington

Wenatchee National Forest

The Wenatchee National Forest has a net area of 2,164,180 acres. Elevations on the forest range from 800 feet to more than 9,500 feet, encompassing three major landforms and more than 30 different geologic formations. This geologic variety—and a wide difference in precipitation across the forest—leads in turn to an unusual diversity in vegetation and an associated richness of wildlife species. The vegetation changes with elevation and moisture as the forest rises from grass, sage, and bitterbrush in the low-lying eastern areas, through open stands of orange-barked ponderosa pine, and into mixed forests of pine, Douglas fir, and larch. Next, it rises into subalpine areas with true firs and lodgepole pine, and finally reaches lush alpine meadows fringed with hardy stands of alpine firs, larch, and whitebark pine.

Areas near the Cascade crest receive up to 140 inches of precipitation and as much as 25 feet of snow accumulation each year. Moisture declines markedly to the east, resulting in near-desert conditions with less than 10 inches of precipitation on the eastern fringes of the forest. However, the generous precipitation and snowpack in the high mountain areas supply hundreds of sparkling alpine lakes and dozens of tumbling streams and rivers.

The study area was located in the planned—and yet to be developed—Preston Creek OHV on the Entiat

Ranger District. Most of the planning area was severely burned in the 1970 Entiat Fire. Vegetation consists predominately of stands of young trees with a shrub/grass understory. The study was on an abandoned logging road that was identified for conversion to trails for the Preston Creek OHV area.

The primary bedrock unit in the area is quartz and granodiorite of the Duncan Hill Pluton. This light-colored granitic rock weathers to a very well-drained, relatively coarse-textured sandy soil with rounded rock fragments. Glaciation was the primary land-forming process on the mid and lower slopes. Soils are derived primarily from volcanic ash and pumice, overlying or mixed with residuum and/or colluvium from granodiorite and, locally, glacial till.

Precipitation within the study area ranges from approximately 27 to 45 inches (35-inch average) annually, generally increasing with elevation. The majority of the precipitation falls in October to March, mostly as snow; however, periodic high-intensity convective storms in the summer months also account for a small percentage of the total precipitation.

The study was conducted on roads that had been closed to vehicle access for about 20 to 30 years. The road segments were selected because the Wenatchee National Forest administration was considering reopening some of the road segments to ATV use. To enable the forest personnel to better understand the potential effects of ATV use on the roads, minimal clearing was done. The road prism was a cut-and-fill and easily identified. Heavy vegetation and waterbars were within the trail.

Due to the width of the road segments, loops were constructed that shared the road and had some road segments in which traffic was combined. Downhill and uphill test segments had narrow adjacent areas. Riders had to carefully skirt the test section on their return trip (either uphill or downhill) so they would not be double-counted. Other areas, including the straight sections, had traffic in both directions.

For each loop, uphill and downhill test segments were located on the steepest segments. These loops, however, showed little adverse effect, because riders had to slow down for vegetation or waterbars before or after the test segment.

Encroaching vegetation was purposefully left in the trail to encourage slower speeds and to challenge riders. The road section for loop B had trees and shrubs, with some trees as tall as 15 feet. The other loops had manzanita and grasses growing within the road prism.

Soils Properties

Representative soil samples from the four loop trails were taken for analysis. The results showed that the soils were predominately poorly graded sand and silty sand. These soils tested low-medium to medium-high in strength and medium-high in susceptibility to surface erosion. Other attributes of these soils are indicated in table 37.

Table 37—Soil properties for Wenatchee NF study site.

Forest	USCS Group Symbol-Description	Surface Erosion	Dry Strength	Saturated Strength	Rutting (Saturated)	Raveling	Dust
OW	SP-poorly-graded sand	Medium-high	Medium	Medium-high	Low	High	Low-medium
OW	SM-silty sand	Medium-high	Low-medium	Low-medium	Low-medium	Medium-high	Medium-high

Vehicle Types

Table 38 provides the model, ATV type, and total number of passes for all loops.

Table 38—Loops, vehicle characteristics, and total number of passes.

Loop	Vehicle Model /Type	OEM/ AM	Total Passes
A	Arctic Cat Utility	OEM	240
B	Honda 2 WD Sport	AM	960
C	Honda 2 WD Sport	OEM	240
D	Kawasaki 650 Utility	AM	440

Condition-Class Summary

One study objective was to determine if ATVs affect the natural resources and, if so, to what degree. Table 39 provides a summary of the condition-class assessments and, specifically, how condition classes changed over time with subsequent passes.

Table 39—Summary of condition classes

Wenatchee National Forest ATV Test Summary of Condition Classes							
				Summary of Condition			
Equipment Type	**Tire Type**	**Loop**	**No of Passes**	**Uphill**	**Curve**	**Downhill**	**Straight**
Utility	OEM	A	40	Low	Med	Low	Low
			80	Low	Med	Low	Low
			200	Med	Med	Low	Low
			240	Med	High	Low	Low
Utility	Aftermarket	B	40	Low	Med	Low	Low
			80	Low	High	Low	Low
			120	Low	High	Low	Low
			200	Low	High	Med	Low
			240	Med	High	Med	Low
			360	Med	High	Med	Low
			480	Med	High	Med	Med
			960	N/A	N/A	N/A	Med
Sport	OEM	C	40	Low	*	Low	Low
			80	Low	*	Low	Low
	*Curve abandoned for this loop.		120	Low	*	Low	Low
			160	Low	*	Low	Low
			200	Low	*	Med	Low
			240	Low	*	Low	Low
Sport	Aftermarket	D	40	Low	High	Low	Low
			80	Low	High*	Med	Low
	*Riding stopped after 80 passes after reaching High on curve segment.		160	Low		Med	Med
			240	Med		Med	Med
			360	Med		Med	Med
			440	Med		Med	Med

Summary of Effects

Between 240 and 960 passes were made on each of the transect areas of uphill, downhill, curves, and straight sections of trail. All curve sections of trail were rated medium or high, with the exception of loop C. This exception was due to the fact that the curve was abandoned on this loop (figures 80 through 86).

Figure 80—Loop A straight.

The straight section of loop A also remained at a low condition class throughout the 240 passes.

On loop B, the straight section indicated a low rating until 480 passes, when the condition class rose to medium. The rating remained medium to the end of the test, 960 passes.

Figure 81—Loop B straight after 960 passes.

Figure 82—Loop D after 440 passes.

On loop D, the condition class was low from 40 through 120 passes. At 160 passes, it switched to medium and remained the same to the end of the test, 440 passes.

On the straight and uphill sections of loop C, the condition-class rating remained low from 40 passes through the end of the test, 240 passes.

Figure 83—Loop C downhill, rated low.

The downhill section of loop C remained low until 200 passes, when it increased to medium. The condition class reverted to low again on the downhill section at 240 passes.

The downhill section on loop A remained low from the start to completion, 240 passes.

Figure 84—Loop C uphill, rated low.

On the uphill, downhill, and straight sections of trail on all loops, no condition-class rating exceeded medium. On loop A, the rating for the uphill section changed from low to medium at 200 passes and remained at medium to the end of the test, 240 passes.

Figure 85—Loop B downhill, rated medium.

On loop B, on uphill and downhill sections, a medium rating was indicated at 240 passes and 480 passes, respectively, and remained medium to the end of the test, 480 passes. On loop D, a medium rating was achieved on the uphill section at 240 passes and through the end of the test, 440 passes. Again on loop D, a medium rating was achieved on the downhill section at 80 passes. On this section, a medium rating was sustained to the end of the test, 440 passes.

Figure 86—Loop D, rated high after 80 passes.

The percentage of ground cover disturbed increased from 41 percent to 98 percent on all loops. Bare soil on the curve segment of loop B was decreased from 96 to 91 percent. In the curve on loop B, litter increased from a before-riding level of 1 percent to an after-riding level of 3 percent (see figures 87 and 88). Vegetation cover remained at 3 percent before and after riding, while root and rock exposure increased from none to 3 percent after riding in the curve segment of loop B.

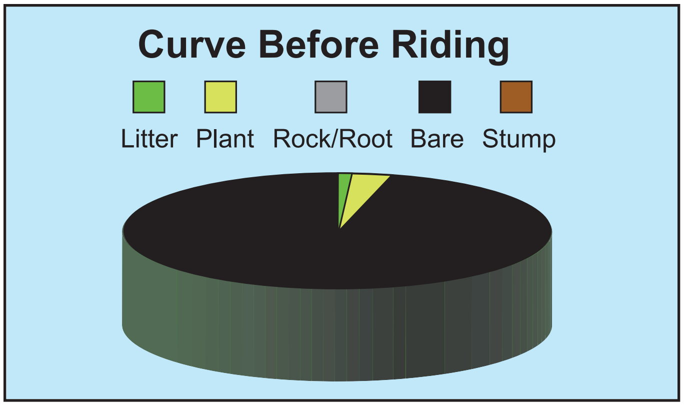


Figure 87—Illustration of proportionate amounts of litter and bare soil on the curve segment before riding began on loop B.

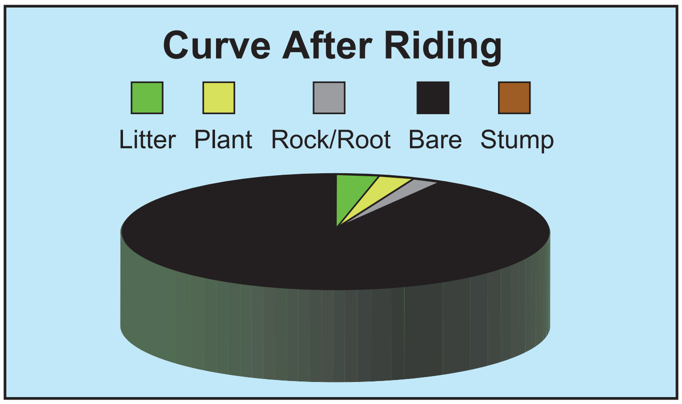


Figure 88—Illustration of proportionate amounts of vegetation and litter removed, bare soil, rock/root exposure, stump exposure on the curve segment at completion of total passes on loop B.

Figure 89—Loop B turn, rut depth 10 inches, trail widening to 6 feet.

Figure 90—Loop D turn, rut depth 10 inches.

Rut depths up to 10 inches were recorded in the turns, with the trail widening to 6 feet. Rut depths up to 3 inches were measured in uphill segments, with the trail widening to 4 feet in these segments. Rut depths of 1 to 4 inches were recorded on straight and downhill sections (figures 89 and 90).

CHAPTER 4. CONCLUSIONS AND MANAGEMENT IMPLICATIONS

At the study's outset we asked three defining questions: Are natural resources being affected by ATV traffic on forested lands; if so, by how much; and does the way an ATV is equipped make a difference?

In short, this study concludes that ATV traffic can adversely affect natural resources and the way the vehicle is equipped does not make a statistically significant difference. The study further concludes that—of the vehicles tested—all ATVs contribute to the effects regardless of type and equipment.

The effects are considered adverse when the natural resources (vegetation, soil, water, and air) have been reduced or changed in a manner that prevents them from maintaining and performing their ecological functions. The ramifications of the effects are manifested in the removal or destruction of vegetation, including forest-floor litter, the exposure and destruction of plant-root networks, the exposure of bare soil, soil erosion, and dust migration as a result of bare-soil exposure.

Vegetation was reduced by a minimum of 40 percent and more often was completely eliminated as a result of ATV traffic at the test sites. Soils were compacted (except sands and gravels), displaced, or loosened, making it available for transport (erosion) by water. Of the soils tested, the hydraulic conductivity (soil's ability to absorb rainfall) was reduced by more than one-half, while the interrill-erosion coefficient (soil erosion) increased by more than one-half as a result of ATV traffic. Results from the high-intensity rainfall-simulation test concluded that freshly disturbed soils on an ATV trail produce, on average, 10 times more sediment than undisturbed soils.

The dust study (conducted only at the LBL site) was designed to measure the soil displaced by aerial erosion caused by ATV traffic. The goal was to understand the relationship among soil types, vehicle traffic, and dust creation. A secondary objective was to evaluate the effects dust had on native human health and vegetation.

The results of the study (see appendix C) concluded that ATVs can cause significant amounts of soil migration by aerial displacement. Dust particles were captured 200 feet from the trail. Spikes in average-particulate loads greater than 150 micrograms per cubic meter were common as vehicles passed the active monitors positioned 3 to 6 feet off the trail. ATV traffic was relatively light during the experiment. When the numbers of riders are substantially higher, air concentrations would be expected to be well into the unhealthful range where the forested edges of the trails inhibit air circulation. Where trails are open with adequate air circulation, the particulate loads have lower impacts on human health. The passive samplers deployed at head-height confirm a substantial atmospheric loading that could affect the riders' respiratory systems.

The evaluation of dust effects on vegetation suggests that ATVs cause only minor perturbations (disturbances). Some stomatal (pore) blockage was observed, as were surface accumulations of dust that may periodically inhibit photosynthesis and respiration, but little superficial damage to the cuticle was evident in the images captured by a scanning electronic microscope. Because of frequent rainfall at the test site, it is unlikely that the effects are long lasting or a cause for serious concern (Padgett 2006).

There are two surprising results from the study. First, sport-model vehicles (lighter weight ATVs) cause as much disturbance as the heavier utility-model vehicles. There were no significant differences between the level of disturbance caused by sport- or utility-model vehicles. The heavier, more powerful utility vehicles reached the targeted disturbance levels in fewer passes than the sport two-wheel-drive models; but, when the number of passes was the same, the levels of disturbance were the same for each vehicle type.

Second, there were no distinguishable differences between the level of disturbance caused by a vehicle with standard manufacturer-issued tires or a vehicle equipped with more aggressive after-market tires. Ultimately, all tire and vehicle combinations tested caused the same levels of disturbance.

Four trail features were tested: a curve, downhill, uphill, and straight runs. For all soil types, curves were most susceptible to soil displacement, followed by uphill and downhill runs regardless of soil type. Straight runs showed the least amount of soil displacement. The difference in soil displacement for an uphill or downhill section was five to eight times greater than on level-straight sections. Therefore, trail managers should make monitoring and maintaining curves and turns a high priority, followed by uphill and downhill sections of trail. Curves require extra attention to ensure that they are designed and constructed for proper armoring and drainage.

The data also imply that straight sections of trail will require less maintenance, especially if these sections are located away from weaker soils. This is an important distinction to manage as forests involve and work with volunteer groups to make their contributions meaningful and effective.

Perhaps the most important management implication of this study is that ATV traffic should be limited to trails. The data gathered in this study overwhelmingly support this direction. Areas that continue to allow cross-country travel can only expect to see a further reduction in the ability of natural resources to maintain their composition and structure and perform their natural functions. Other studies related to soil and vegetation disturbance indicated that the rehabilitation of these areas will take many years, especially those in arid climate zones (Cole 1986). Some may never recover without assistance.

The study also suggests that limiting ATV traffic to trails is not enough to protect the natural resources. Trail planning and design, particularly the trail's location, are key considerations for limiting natural-resource disturbances. The primary objective of a well-designed ATV trail is to protect and conserve the natural resources while providing an enjoyable and challenging experience. The experience is the purpose of the trip! The design phase should identify destinations as well as areas to avoid, such as soils that are easily disturbed, wet areas (riparian zones), ridge tops, and sensitive wildlife habitats and archeological sites.

Trail alignments should be curvilinear with short sight distances. Avoid tight turns and steep climbs, as these trail features are susceptible to high levels of soil disturbance and erosion. Use contours and the vertical alignment to facilitate drainage across and away from the trail. Avoid constructing trails on the fall line. Use water diversions as often as necessary to move water off the trail and onto the forest floor. These practices will significantly reduce erosion and sedimentation.

The data also suggest setting limits or developing natural-resource tolerance levels as a way to manage and reduce the effects of ATV traffic on the natural resources. Consider for example the hydraulic conductivity, interrill coefficient, and dust-migration data. The hydraulic conductivity of soil (soil's ability to absorb rainfall) is a way of estimating soil saturation and when overland flow begins. This information is very useful for establishing natural-resource tolerances and developing trail-closure parameters based on scientific principles (i.e., the rainfall rate at which soils begin to experience runoff, and the magnitude of rainfall events). The Kisatchie National Forest sets a rainfall limit of 2 inches before closing its ATV trails, and they remain closed until the soil regains its absorption capacity. Similar parameters have been developed for other forests.

Information that describes the effects of dust migration as a result of ATV traffic could also prove to be an effective tool for monitoring trail use and keeping natural resources in balance. Managers could use such information to establish seasonal closures, employ dust abatement techniques, and design better trails to reduce soil migration.

Casual observations made during the study also suggest a need to develop sustainable riding practices to assist riders to improve their riding habits and information to enhance their knowledge about the affects of ATV traffic on natural resources. Riding practices would include: slower speeds through curves, avoiding wheel spins and fish tailing, and avoiding travel through wet areas. Information should also be provided about why it is important to avoid these sensitive areas.

Appendix A. Tables A1 through A7

Table A1—Number of passes required to remain in low and medium-condition classes at Arizona. The entry ">160" means that in 160 passes the condition was not achieved.

Site	Vehicle and Tire	Trail Feature	Passes to Remain in Low	Passes to Remain in Medium
AZ	Util, OEM	Uphill	80	>160
AZ	Util, OEM	Downhill	>160	>160
AZ	Util, OEM	Straight	160	>160
AZ	Util, OEM	Curve	120	>120
AZ	Util, AM	Uphill	>160	>160
AZ	Util, AM	Downhill	160	>160
AZ	Util, AM	Straight	>160	>160
AZ	Util, AM	Curve	40	>160
AZ	Sport, OEM	Uphill	40	60
AZ	Sport, OEM	Downhill	60	>60
AZ	Sport, OEM	Straight	60	>100
AZ	Sport, OEM	Curve	40	60
AZ	Sport, AM	Uphill	120	>160
AZ	Sport, AM	Downhill	120	>160
AZ	Sport, AM	Straight	80	>160
AZ	Sport, AM	Curve	120	>160

Table A2—Number of passes required to remain in low and medium condition classes at Kentucky.

Site	Vehicle and Tire	Trail Feature	Passes to Remain in Low	Passes to Remain in Medium
KY	Util, OEM	Uphill	200	280
KY	Util, OEM	Downhill	120	160
KY	Util, OEM	Straight	280	>800
KY	Util, OEM	Curve	40	40
KY	Util, AM	Uphill	80	320
KY	Util, AM	Downhill	80	680
KY	Util, AM	Straight	80	680
KY	Util, AM	Curve	40	320
KY	Sport, OEM	Uphill	80	360
KY	Sport, OEM	Downhill	320	>760
KY	Sport, OEM	Straight	80	320
KY	Sport, OEM	Curve	80	80
KY	Sport, AM	Uphill	240	>280
KY	Sport, AM	Downhill	280	>280
KY	Sport, AM	Straight	>280	>280
KY	Sport, AM	Curve	40	>280

Table A3—Number of passes required to remain in low and medium condition classes at Louisiana.

Site	Vehicle and Tire	Trail Feature	Passes to Remain in Low	Passes to Remain in Medium
LA	Util, OEM	Uphill	>490	>490
LA	Util, OEM	Downhill	>490	>490
LA	Util, OEM	Straight	>490	>490
LA	Util, OEM	Curve	50	70
LA	Util, AM	Uphill	270	>630
LA	Util, AM	Downhill	410	>630
LA	Util, AM	Straight	>630	>630
LA	Util, AM	Curve	30	130
LA	Sport, OEM	Uphill	270	>720
LA	Sport, OEM	Downhill	270	>720
LA	Sport, OEM	Straight	120	>720
LA	Sport, OEM	Curve	130	>720
LA	Sport, AM	Uphill	150	730
LA	Sport, AM	Downhill	150	>730
LA	Sport, AM	Straight	350	>730
LA	Sport, AM	Curve	50	150

Table A4—Number of passes required to remain in low and medium condition classes at Minnesota.

Site	Vehicle and Tire	Trail Feature	Passes to Remain in Low	Passes to Remain in Medium
MN	Util, OEM	Uphill	40	145
MN	Util, OEM	Downhill	40	120
MN	Util, OEM	Straight	80	>505
MN	Util, OEM	Curve	145	505
MN	Util, AM	Uphill	40	>700
MN	Util, AM	Downhill	127	>700
MN	Util, AM	Straight	167	>700
MN	Util, AM	Curve	127	>700
MN	Sport, OEM	Uphill	>600	>600
MN	Sport, OEM	Downhill	ND	ND
MN	Sport, OEM	Straight	400	400
MN	Sport, OEM	Curve	ND	ND
MN	Sport, AM	Uphill	40	300
MN	Sport, AM	Downhill	ND	ND
MN	Sport, AM	Straight	ND	ND
MN	Sport, AM	Curve	40	160

Table A5—Number of passes required to remain in low and medium condition classes at Missouri.

Site	Vehicle and Tire	Trail Feature	Passes to Remain in Low	Passes to Remain in Medium
MO	Util, OEM	Uphill	80	360
MO	Util, OEM	Downhill	160	>480
MO	Util, OEM	Straight	160	>520
MO	Util, OEM	Curve	40	80
MO	Util, AM	Uphill	280	>520
MO	Util, AM	Downhill	240	>520
MO	Util, AM	Straight	360	>520
MO	Util, AM	Curve	40	80
MO	Sport, OEM	Uphill	200	>500
MO	Sport, OEM	Downhill	500	>500
MO	Sport, OEM	Straight	500	>500
MO	Sport, OEM	Curve	80	480
MO	Sport, AM	Uphill	440	>560
MO	Sport, AM	Downhill	>560	>560
MO	Sport, AM	Straight	560	>560
MO	Sport, AM	Curve	120	>560

Table A6—Number of passes required to remain in low and medium condition classes at Montana.

Site	Vehicle and Tire	Trail Feature	Passes to Remain in Low	Passes to Remain in Medium
MT	Util, OEM	Uphill	241	361
MT	Util, OEM	Downhill	321	>841
MT	Util, OEM	Straight	401	>841
MT	Util, OEM	Curve	81	641
MT	Util, AM	Uphill	200	>840
MT	Util, AM	Downhill	280	>840
MT	Util, AM	Straight	320	>840
MT	Util, AM	Curve	80	440
MT	Sport, OEM	Uphill	200	200
MT	Sport, OEM	Downhill	120	120
MT	Sport, OEM	Straight	80	>960
MT	Sport, OEM	Curve	40	120
MT	Sport, AM	Uphill	160	>960
MT	Sport, AM	Downhill	640	>1,000
MT	Sport, AM	Straight	320	>1,000
MT	Sport, AM	Curve	40	80

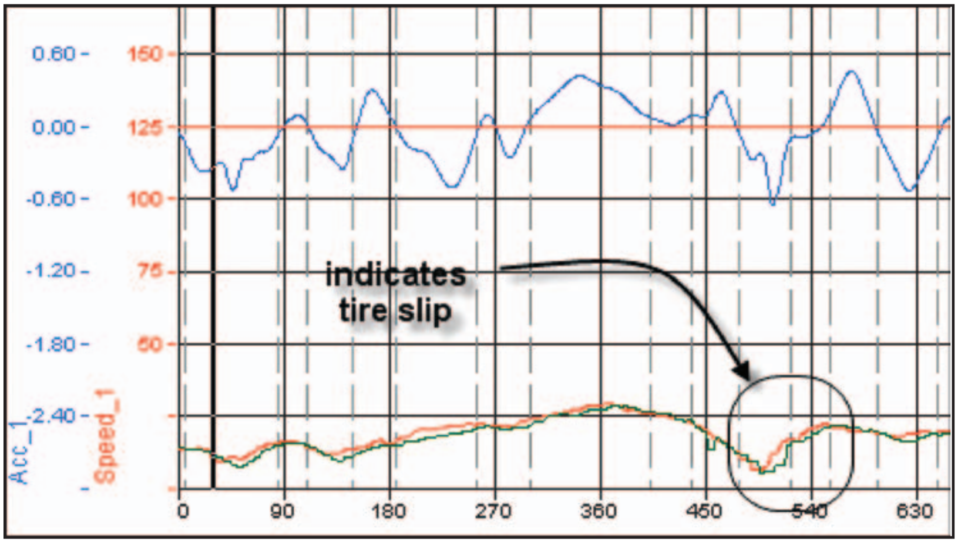
Table A7—Number of passes required to remain in low and medium condition classes at Washington.

Site	Vehicle and Tire	Trail Feature	Passes to Remain in Low	Passes to Remain in Medium
WA	Util, OEM	Uphill	160	>240
WA	Util, OEM	Downhill	>240	>240
WA	Util, OEM	Straight	>480	>480
WA	Util, OEM	Curve	20	240
WA	Util, AM	Uphill	240	>480
WA	Util, AM	Downhill	200	>480
WA	Util, AM	Straight	480	>960
WA	Util, AM	Curve	20	80
WA	Sport, OEM	Uphill	>240	>240
WA	Sport, OEM	Downhill	200	>240
WA	Sport, OEM	Straight	>240	>240
WA	Sport, OEM	Curve	ND	ND
WA	Sport, AM	Uphill	240	>400
WA	Sport, AM	Downhill	80	>440
WA	Sport, AM	Straight	160	>880
WA	Sport, AM	Curve	20	20

APPENDIX B. ATV and Rider Effects

Table B1 is a graphical representation of the speed and acceleration data collected from the AIM MYCHRON XGLOG data recorder. The graphs indicate a difference in speed between the front (orange) and rear (green) tire. A high rear tire speed, as shown, is an indication of tire slip. The dip in the speed graph (blue) occurs at a turn.

Table B1—Speed and acceleration.



Riders and Riding Style

American Safety Institute (ASI) instructors and volunteer riders from different ATV clubs were used as test riders. All of the riders had been through an ATV safety course. The majority of the riders had completed the safety course provided through ASI.

The riders were instructed to maintain the established lap times for each loop (table B2). The riders were also instructed not to modify their riding style. For example, riders were allowed to ride on top of the ruts instead of following the groove if that is their normal practice.

Riders were rotated every 20 laps within the loops. This rotation time varied depending on rider fatigue. Riders on test-loop A were rotated every 10 laps rather than at 20 laps because of rider fatigue. Riders were moved to different loops throughout the day. The rotations were necessary to control speeds and even-out riding styles. As a rider becomes familiar with the course, the rider tends to ride faster. Rotating riders—along with monitoring the lap times—reduced this tendency.

Table B2—Average speeds.

Loop	Loop Length (feet)	Average			Test Section Average Speed (mph)			
		Lap Time (sec)	Max. Speed (mph)	Min. Speed (mph)	Straight	Uphill	Downhill	Turn
A	987.5	135	10.9	3.9	10	9	8	8
B	633.2	53.5	11.9	3.5	11	9	6.6	5
C	1,755	106	23.8	6.5	22	19	18	7
D	856.3	104	15.9	4.6	~	12	~	6

Trail Layouts for Each Loop

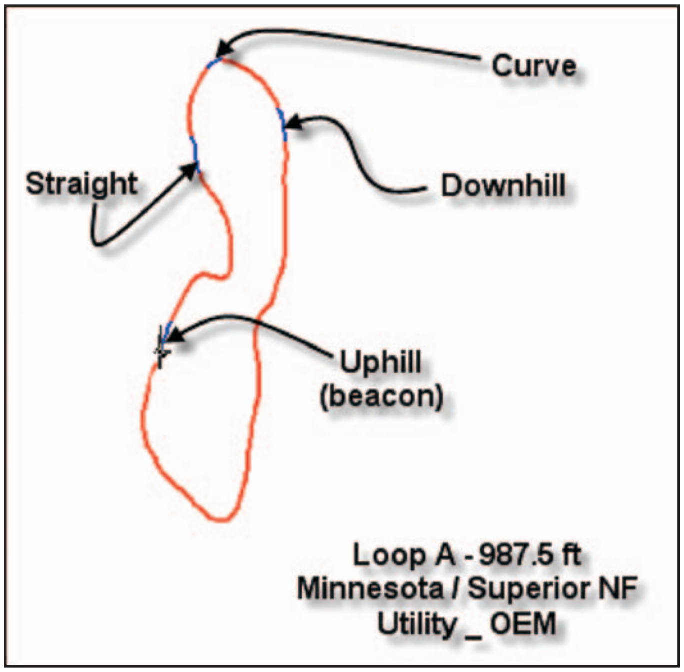


Figure B1—Loop A, 987.5 feet, on the Minnesota DLR and Superior NF. Utility ATV with original equipment tires.

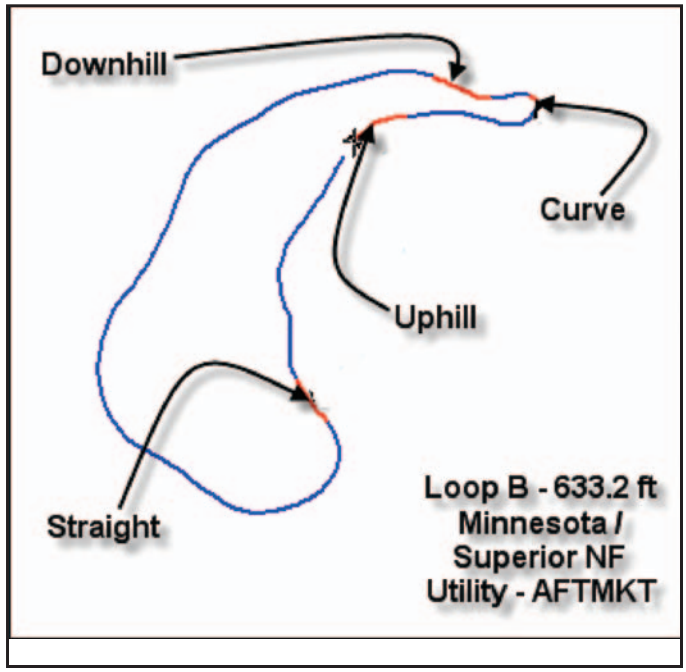


Figure B2—Loop B, 633.2 feet, on the Minnesota DLR and Superior NF. Utility ATV with aftermarket tires.

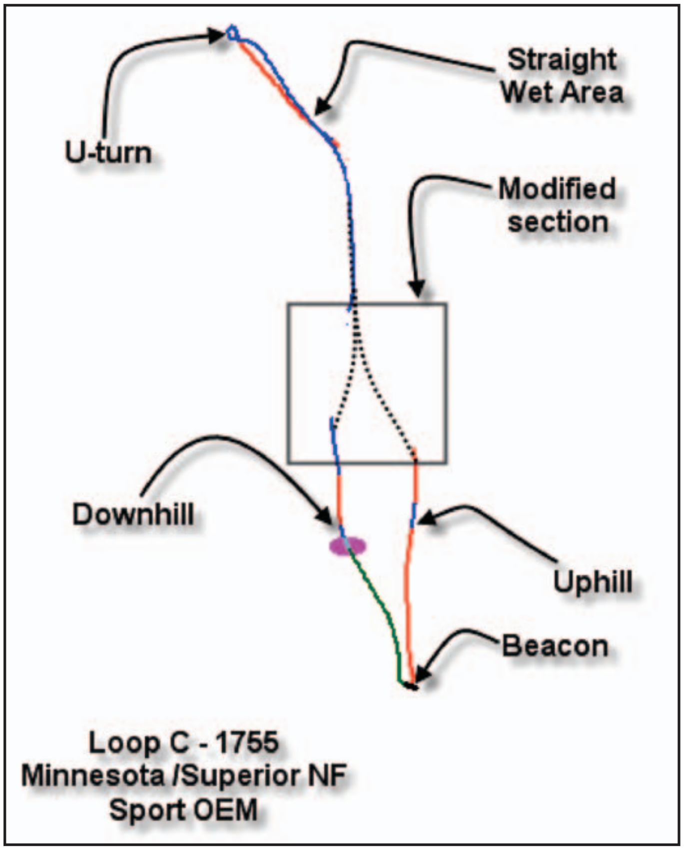


Figure B3—Loop C, 1,755 feet, on the Minnesota DLR and Superior NF. Sport ATV with original equipment tires.

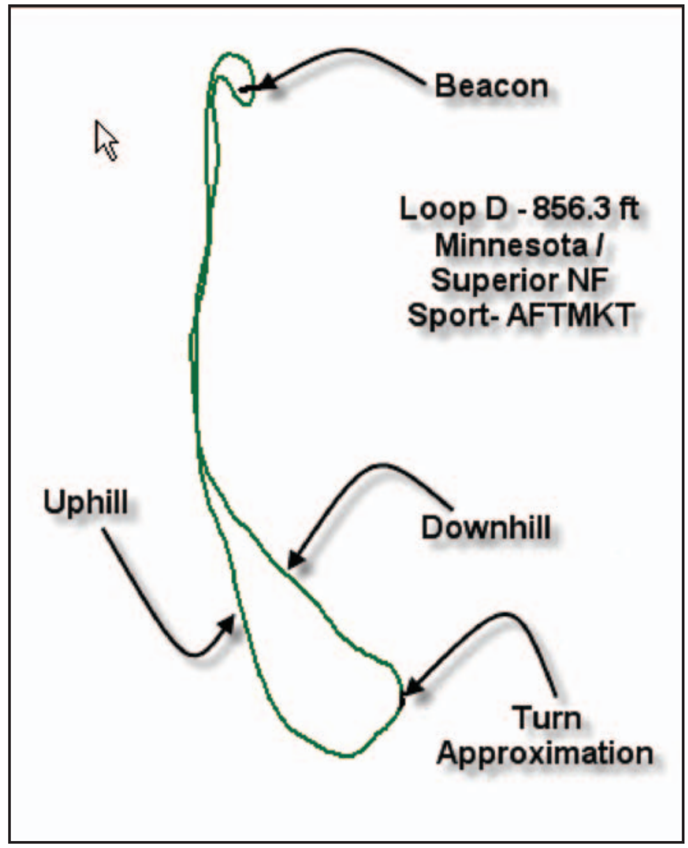


Figure B4—Loop D, 856.3 feet, on the Minnesota DLR and Superior NF. Sport ATV with aftermarket tires.

Observations

1. Rider behavior and riding style make a significant change to the ground. A more aggressive riding style with higher speeds into and out of a turn displaces more soil. Data recorders (persons) reported more visible change on the test loop after an aggressive rider rode the course for 20 laps. Table B3 shows a significant increase in speeds. Riders reduced speed more rapidly going into the turn and accelerated more quickly out of the turn.

2. Rut depth is dependent on the ATV's clearance. The ATV's undercarriage will scrape the top of the rut, preventing it from getting deeper. However, a rider can "knock down" the ruts by straddling the berm and moving the soil back into the groove. This tends to increase the track width because the rider has to take a different path.

APPENDIX C

Monitoring fugitive dust emissions from off highway vehicles traveling on unpaved roads: a quantitative technique

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Final Report To the Recreation Unit – San Dimas Technology Center
August 2, 2006

Land between the Lakes dust monitoring project

Objectives

Roughly 1,700 acres have been set-aside in the Turkey Bay Off Highway Vehicle (OHV) area for use by any operator of an OHV. The area was originally designated by the Tennessee Valley Authority around 1975 and has been operated as an open riding (that is, no requirement to stay on trails) area ever since. The Forest Service acquired the property in 1999. Under National Forest System guidelines, the area must be managed for preservation of the resource in addition to recreation opportunities. Changes in, and increases in usage have left the area severely scared and impacted. Impacts include severely denuded and eroded hillsides, loss of leaf litter and topsoil, compacted soils, heavily disturbed and dead flora, and dust everywhere. Off trail dust deposition is an indication of soil migration. This study was designed to quantify soil migrating, and determine far away from trail it was moving. The study also investigated the effects of dust on the local ecology and provided insight on visibility and health effects for riders and national forest employees.

National forest management is trying to develop both short-and-long term management plans that will rehabilitate and protect the land. Information that describes the quantities and effects of soil migration as a result of OHV traffic could prove to be an effective tool for monitoring trail use, keeping natural resources in balance, while providing a healthy, pleasant recreation experience for the user. Such information could suggest to managers when to use seasonal closures, dust abatement techniques and how to design trails to reduce soil migration.

Experimental approach:

This study was designed to measure the amount of soil displaced by aerial erosion due to vehicle movement along established trails. The goal is to understand the relationship among soil types, vehicle use intensity, and dust creation. The amount of dust generated was determined by weight using sticky-traps, the particle sizes generated were determined using electronic instruments for PM2.5, and visualization of particles was conducted using scanning electron microscopy (SEM). Trips past the collectors were determined using automated counters. Portable weather stations were used to measure wind speed and direction, temperature and relative humidity at the test sites.

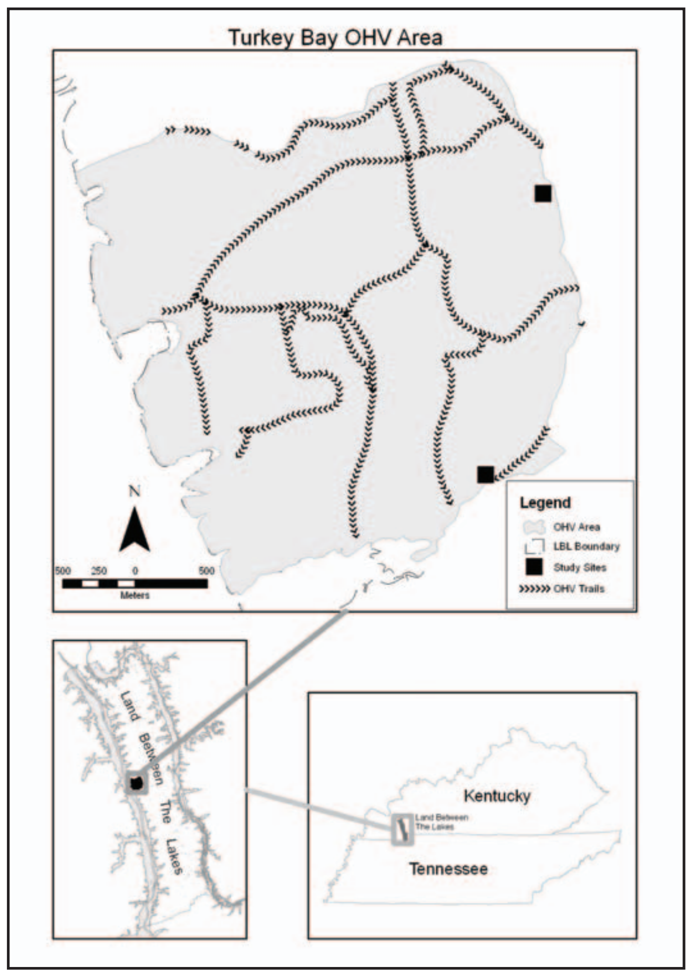

Figure 1—Turkey Bay off highway vehicle riding area, Land Between the Lakes National Recreation Area, Golden Pond, Kentucky.

Secondary objectives were to evaluate the effect dust has on native vegetation and human health. Leaf samples were be collected and viewed by SEM to determine damage to cuticle surface and interference with stomata opening. Portable electronic particulate monitors were deployed along the two test sites in order to quantify atmospheric concentrations of particles less than 2.5μm – the EPA standard for damage to respiratory tissues.

Experimental design

Two test sites were chosen. The first site was along a broad main trail close to the entrance station. The trail was bordered on the north side with forest, and on the south side with an open field. The second site was further into the trail network where the trails are narrower. The second site (referred to as the "tunnel") was bordered by dense forest vegetation on both sides and a nearly enclosed canopy. The trail ran north-south therefore the sampling grids were on the east and west sides of the trail. The sampling transects were established along the edges of the trails with points 50m intervals along the trail and in 3 rows 50 and 100 meters away from the trail, for a total of 20 sampling points along the main trail and 30 sampling points along the tunnel trail. Adjustments to the grid were made to accommodate terrain and rider safety.

The study employed three techniques for assessing dust production and characteristics, two portable active particulate monitors, SEM, and passive dust collectors. The portable monitors were MEI DataRam 2000, which calculate atmospheric concentrations by light scattering techniques. The monitors were loaned to the study by Andy Trent at Missoula Technology and Development Center. They were outfitted with critical cut point nozzles so that only particles smaller than 2.5μm were measured. The monitors were deployed continuously during the exposure period.

The JEOL-T-330 scanning electron microscope is housed at the Hancock Biological Station research facility, part of Murray State University, near the Turkey Bay OHV Area. The microscope was used to assess damage to leaf surface, accumulation patterns of dust on leaves, and to determine the physical characteristics of the dust particles. Leaves were harvested from along the trails and from trees 25m or more away from the trails to evaluate the effects of high and low deposition. Four common species were chosen: autumn olive (*Eleaganus umbellata*), staghorn sumac (*Rhus typhina*), sycamore (*Platanus occidentalis*), and wild grape (*Virtis spp*). Discs of leaves were prepared using a single hole punch, and each disc cut in half so that the upper and lower surfaces of the same sample could be viewed. Leaf discs were mounted on aluminum stubs with double-stick tape and sputter coated with a gold/palladium mix. Polaroid micrographs were taken of representative samples to catalog dust and cuticle features. The micrographs were subsequently scanned into Photoshop for electronic duplication and presentation.

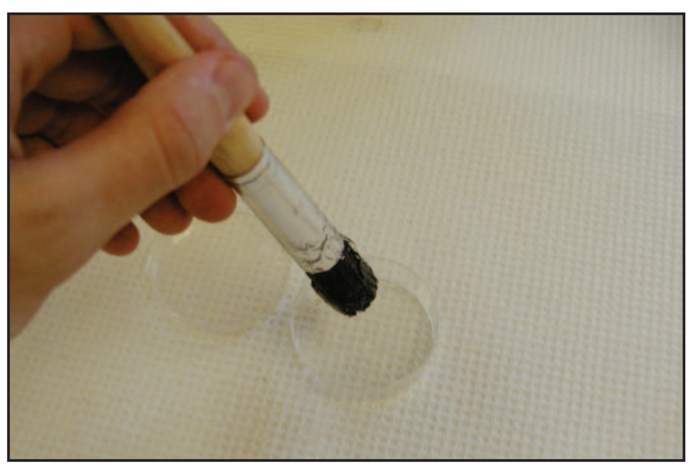

Figure 2—Preparation of "sticky-trap" dust collector.

The passive dust collectors were constructed from 5.5 cm disposable Petri dishes. Each dish was coated with a thin layer of environmentally stable Tangle-Trap® brush-on insect trap. A 1-cm^2 strip of heavy duty Velcro was glued to the back before each collector was weighed for the pre-exposure (“before”) weight. The dust collectors were mounted on 15-foot aluminum conduit using Velcro at 4, 6, 10, and 15 feet above the ground. The poles were held in place by sliding the hollow conduit over 3 foot length of rebar pounded into the ground. A grid pattern consisting of 3 rows, 50m apart, with 4 or 5 poles in each row, also 50m apart, was established at the 2 test sites. One grid was on the north side of the main trail (woods side) and another grid was established on the south side of the same trail in the front field. A second pair of grids were established roughly ½ mile from the entrance station along a trail nearly completely enclosed by vegetation (the tunnel site). In addition to the 4 grid locations a series of 18 passive collectors (9 on each side of the trail) were deployed along the tunnel site within 1m of the trail at roughly head height for the riders. These collectors were mounted on trees and were designed to get a measure of the dust load at mouth height.

All passive dust collectors were deployed within 30 minutes of one another beginning at 8:00 am and taken down at 6:00 pm. Following exposure, the collectors were covered and sealed for transport to Riverside, CA, for reweighing. The difference between the weights before and after deployment was assumed to be accumulated dust. Both laboratory control collectors, those that did not leave Riverside, and field control collectors, those that traveled to the site and back but were not open were used to evaluate environmental effects of weight. Ten percent of the collectors were controls. Data was calculated as mg dust per cm^2, and adjusted to m^2 where appropriate.

In addition to the dust monitoring techniques, weather data and the number of vehicles passing the sites were recorded. A portable weather station (HOBO, Onset computers) was deployed in the front field to measure wind speed and direction, temperature, and relative humidity. Small HOBO temperature and relative humidity sensors were used at the tunnel site to check for differences between the two test sites. Trip counters were installed across the trails at both locations.

Experimental results

Particulate PM 2.5 load

Two DataRam real time particulate monitors were deployed to determine ambient dust concentrations of particle less that 2.5μm. Particles smaller than 2.5μm are considered deleterious to human health by damaging respiratory tissues. One DataRam was deployed in the front field, on the south side of the main trail across from the entrance station. A second instrument was deployed in the tunnel-sampling site in a heavily vegetated location. The front field site maintained a consistent low ambient concentration of particles smaller than 2.5μm of approximately 2-μg m^{-3} (micrograms per cubic meter) throughout the day (fig. 3). Spikes in concentrations occurred as vehicles passed. The average concentration for most of the spikes was less than 6μg m^{-3}. Wind conditions had a significant effect on the monitoring data (fig. 4).

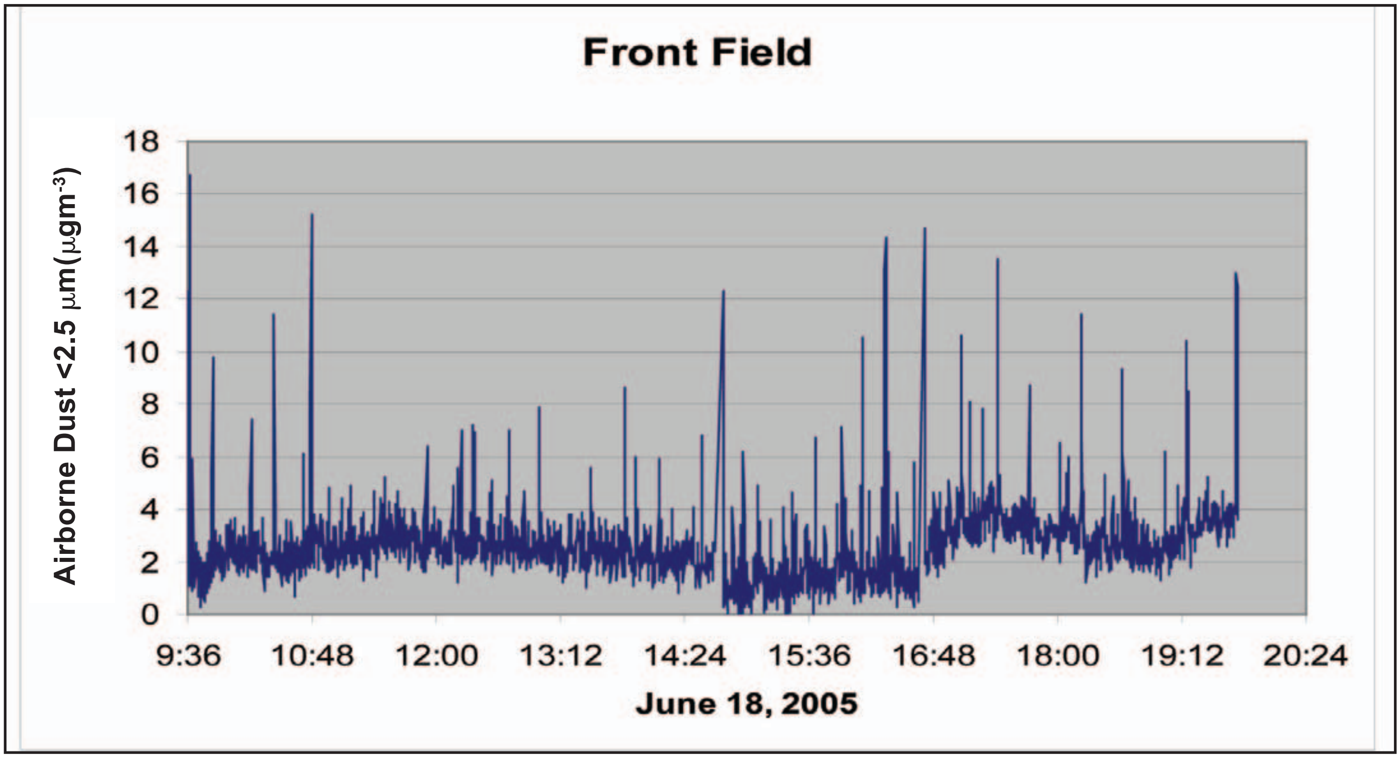

*Figure 3—Active monitoring data for ambient concentrations of particle measuring less than 2.5μm***.**

Overall wind speeds were light, averaging between 2 and 4 miles per hour. Gust speeds up to 13 mph were observed with average gust speeds of 8.27 mph (fig. 4). The direction was predominately toward the west with gust tending to be northwest. Both the wind direction and speed tended to blow dust away from the active monitor contributing to low ambient concentrations. This was confirmed by the passive monitors described below (fig. 9).

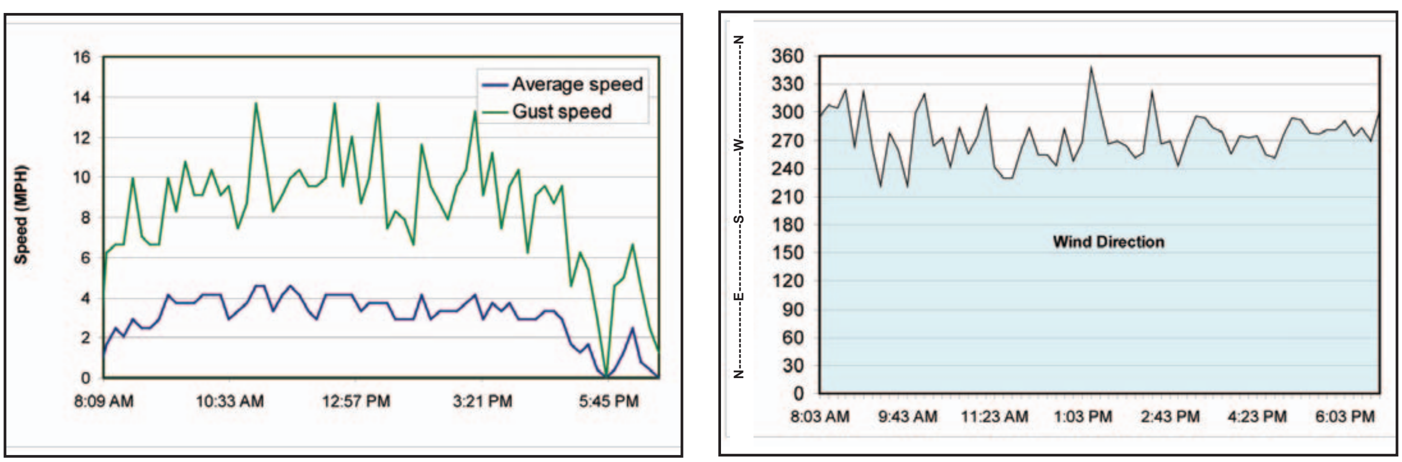

Figure 4—Wind speed (left) and wind direction (right) measured in the front field.

The DataRam set-up in the tunnel site was a meter off the trail, ½ meter off the ground and surrounded by dense vegetation. The location was chosen partially to keep the instrument hidden when not attended, and partially to evaluate the effect of vegetation on dust movement. Ambient concentrations were negligible until a vehicle passed (fig. 5). Average concentrations due to vehicle traffic ranged from 50 to 300μg m^{-3} (top panel) with maximum concentrations 1.5 to 2 times higher (bottom panel). The day the study was conducted rider numbers were quite low as compared to many weekends. Each one of the spikes corresponds to a single passage by an individual or group. If one passing generates average ambient loads of 150 to 250μg m^{-3}, on days where rider numbers are much higher, the ambient concentration would be well into the unhealthful range for continuous exposure at this test site.

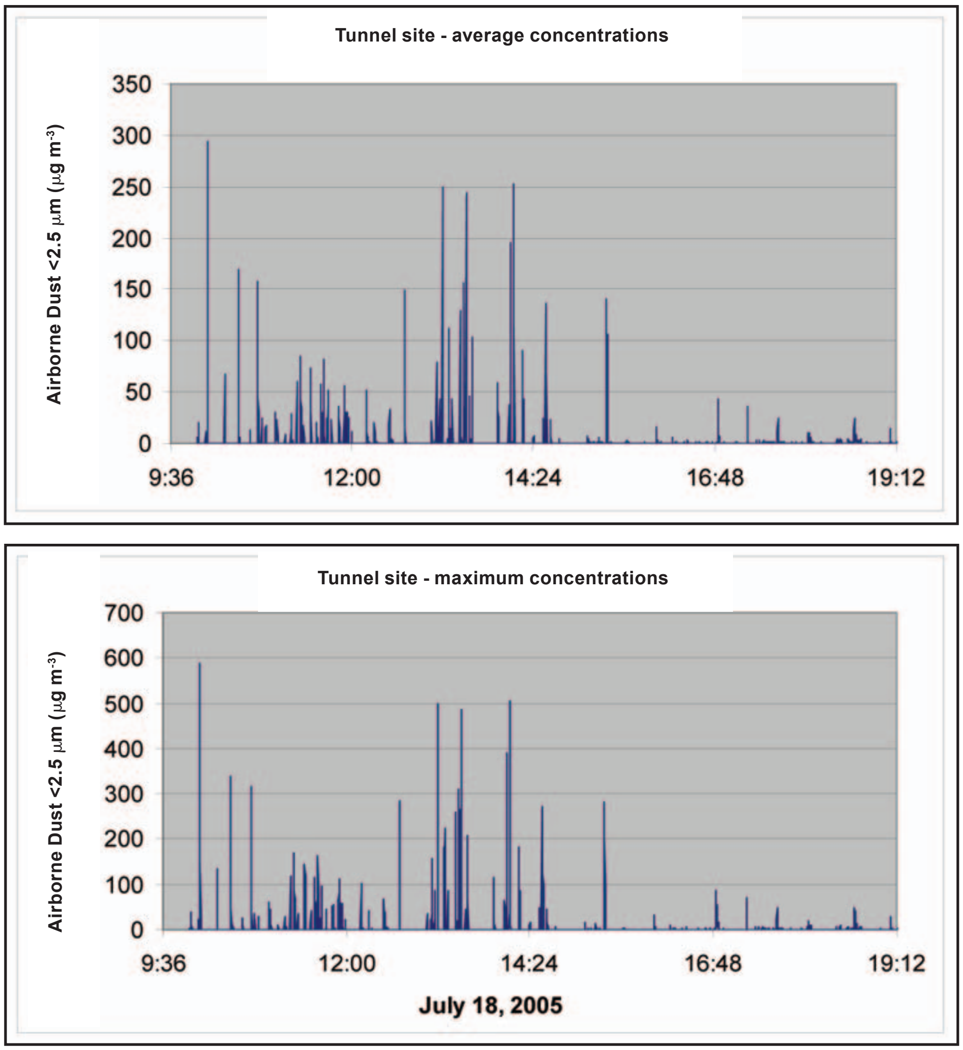

Figure 5—Ambient concentrations of particle measuring less than 2.5μm.

Total particulate loads estimated by the passive monitors deployed at the riders' head height (about 4 feet off the ground) was 0.433 mg cm^2, or roughly 4.33 g of dust per meter of trail over the 10 hour sampling period.

Ambient particulate loading and human health

The EPA has shifted from an absolute concentration metric for determining concern levels for human health to an index system. The index is based on a 24-hour average concentration and has a scale of 0 to 500 for all criteria pollutants (those that EPA has established health risks for). Above 100 is considered unhealthy for sensitive groups. An index of 100 is equivalent to 40-μg m^{-3} PM 2.5. An index of 150 is unhealthy for all individuals and corresponds to 65.4-μg m^{-3}. A calculator to converting concentration to index and visa-a-versa can be found at:
http://cfpub.epa.gov/airnow/index.cfm?action=aqi.aqi_conc_calc

The current EPA method does not account for very high, but short acute exposures. On the day of the experiment the air quality at both sites was good with short episodes of very unhealthful air.

Although dust was visible for longer periods than were recorded by the particulate monitors, based on images of particulates accumulating on leaf surfaces, most of the dust particles generated by OHVs are larger than 2.5μm (fig. 6). Based on this limited information and the current EPA interpretation, particles sent airborne by OHV traffic do not pose any long-term health concerns at the rider densities encountered on June 18, 2005.

Vegetation

Leaf samples from autumn olive (*Eleaganus umbellata*), staghorn sumac (*Rhus typhina*), sycamore (*Platanus occidentalis*), and wild grape (*Virtis spp*) were collected next to the main trail and 25 meters away from the trail. The sampling day followed several days of heavy rain so only small amounts or dust was visible to the naked eye. Dust deposition assessments were made using a JEOL-T-330 scanning electron microscope. Images were assessed for:

1. Physical damage such as abrasions, broken trichomes and punctures.
2. Percent surface area occupied by dust particles.
3. Blocked stomata.
4. Estimated size of particles.

In comparing samples on and off the trail, the leaves collected along the trail did have a higher number of particles on the surface, but there was no observed difference in lesions or superficial damage. Particles were observed on both sides of the leaves (fig. 6). All four of the species examined had stomata on the underside of the leaves exclusively, which is common for temperate zone plants, and important for dust interference with leaf respiration. A few examples of particles blocking stomata were observed and captured in images, but there were no consistent patterns of stomatal blockage due to dust deposition (figs. 6 and 7).

Based on a visual assessment, it does not appear that plants growing along the roads and trails are severely impacted by dust generated by OHVs, as long as heavy traffic is followed by rain. We did not do a physiological assessment where photosynthesis and respiration were measured, but outside of a biochemical assimilation of nutrient elements from dust, it seems unlikely that a physiological assessment would change the conclusion.

The scanning electron microscope images also allow an estimate of typical dust size – at least particles that remained after rain. For the most part, particles were larger that 2.5μm, but examples of fine particles were captured at higher magnification (figs 6,7,8).

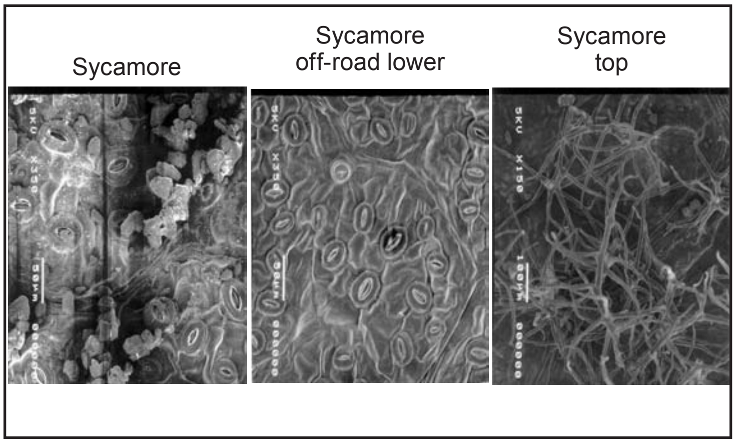

Figure 6—Sycamore

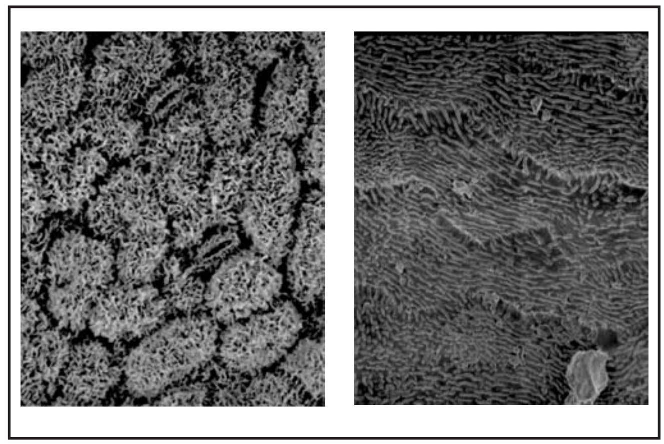

Figure 7—Grape lower and top.

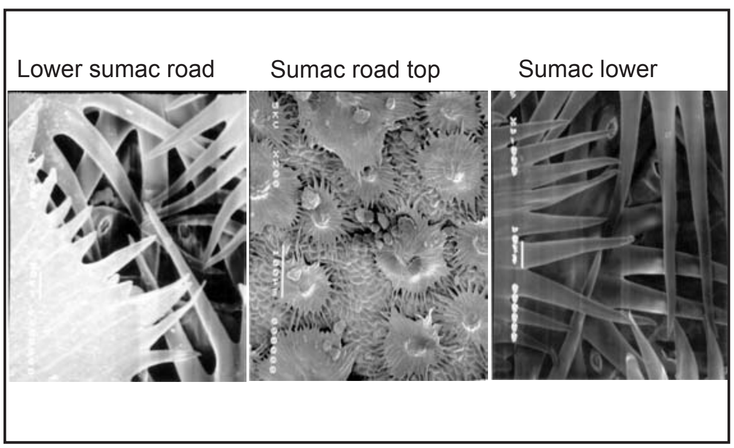

Figure 8—Sumac lower road, road top, lower.

Passive dust collectors

Both the “laboratory controls” and the “field controls” indicated a small but consistent loss of mass from the initial weights to the final weights. The weights of the collectors deployed were adjusted to compensate for losses. The collectors deployed closest to the dust source at the edges of the trails captured the majority of the dust in the lower 6 feet (fig. 9). The mass collected was variable along the transects, as expected, with variances up to ± 50 percent. In all cases, accumulation of dust in the 4-foot and 6-foot samplers was significantly greater than accumulation in the upper 10-foot and 15-foot collectors for samplers in the front row.

Wind direction had a significant effect on dust collection in the front field and woods sites. Wind direction was generally to the west-northwest, and the collectors on the north side (fig 9B) of the road accumulated nearly 10 times more mass than did the southside collectors (fig 9A). Along the tunnel site, winds were generally calmer because of dense vegetation. This probably contributed to the reduced variability along sampling points of the transect and no significant differences between the two sides of the trail (fig. 9 C and D).

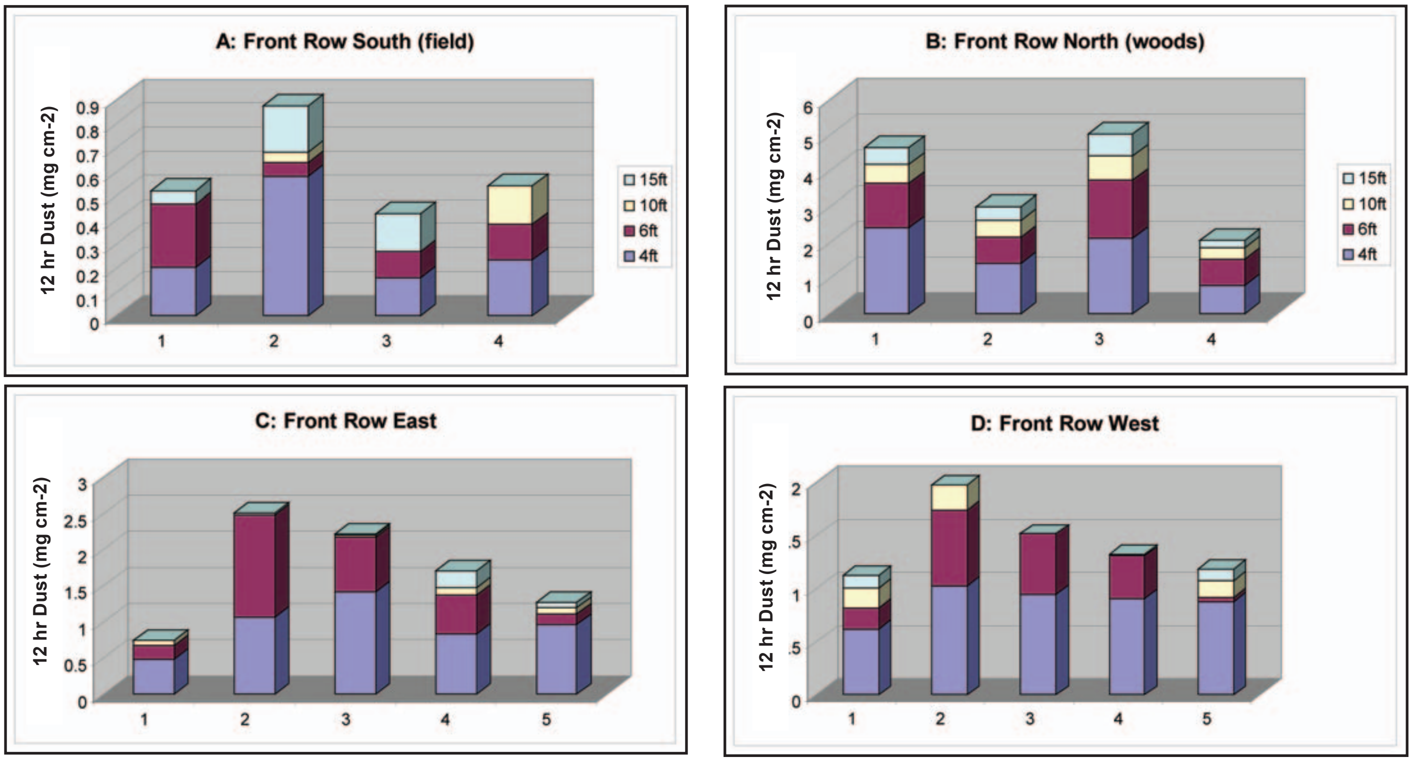

Figure 9—Dust accumulation on passive samplers after 10 hours. Each bar indicates one sampling pole and the divisions indicate the quantity of dust collected at each sampling height.

At 50 m (row B) and 100 m (row C) away from the trails, a higher percentage of particulates was captured at the 10-foot and 15-foot heights (figs. 10 and 11). Although particle sizes on the collectors were not determined, the pattern of capture is consistent with larger particles traveling shorter distances and at lower elevation while smaller particles were launched higher and tended to travel further. Along the tunnel transects, dust movement back into the woods was inhibited by the dense vegetation along the trail, particularly on the west side of the trail where collection rates were very close to zero (fig 12). On the east side, where the boundary vegetation was slightly thinner, a small, but significant, amounts of dust moved horizontally over the landscape.

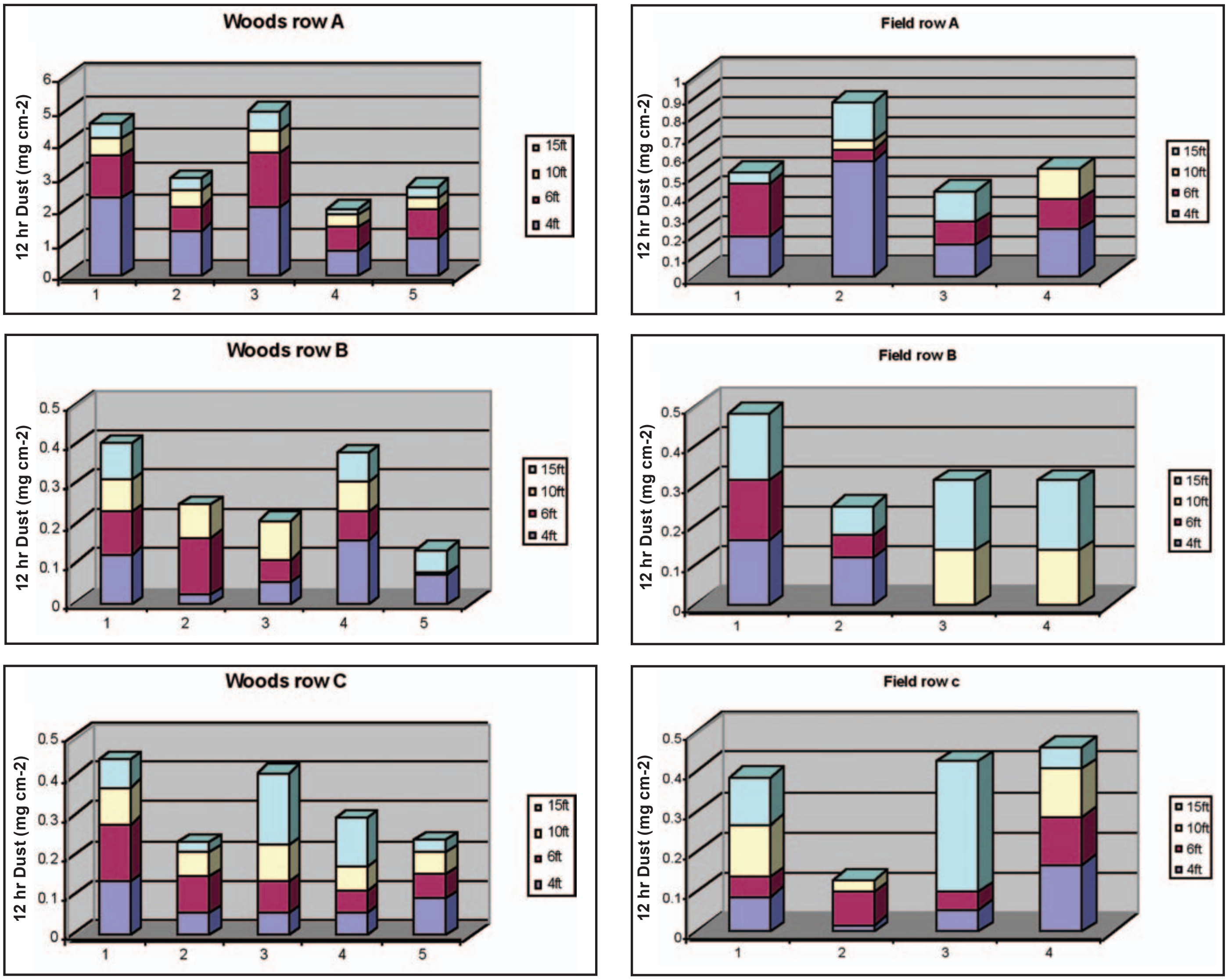

Figure 10 (left – woods) Figure 11 (right – field)—Accumulation of dust particles along a 200m transect and at 50m and 100m away from the source. Note the differences in y-axis scales.

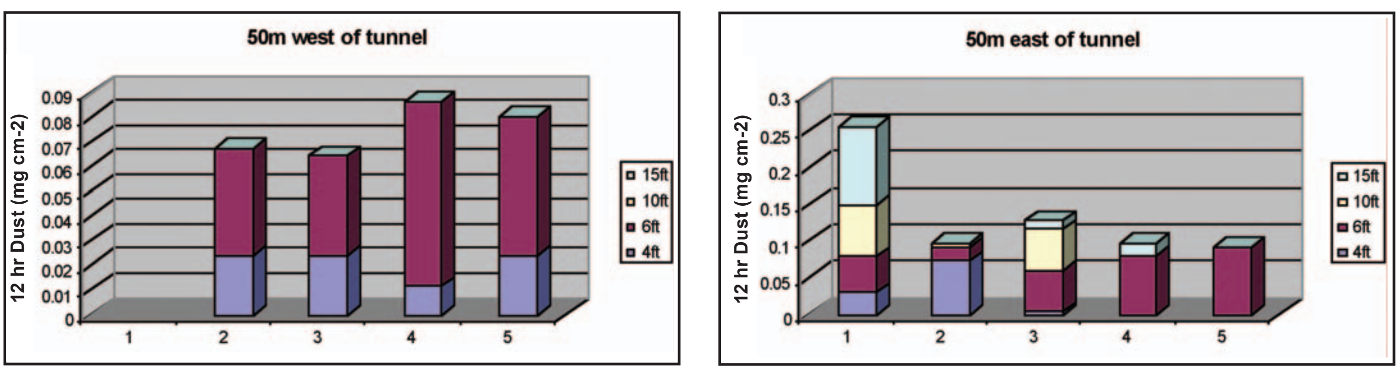

Figure 12—Dust movement off the trail into the forest along the tunnel trail. Note the differences in y-axis.

Estimating aerial displacement

Soil displacement was calculated by integration of the average dust mass for each height over the 15-foot collection pole. The underlying assumption is that the samples taken at four heights are representative of the gradient in dust concentration moving past the poles. An average vertical value of 0.244 grams of particles per square meter was calculated for the woods transect (north of the road) in comparison to 0.125 gram per square meter for the Field transect (south side of the road). The two tunnel transects indicated similar displacement at 0.098 (west side) and 0.113 (east side) grams of dust per vertical square meter. When this value is converted to a linear distance, total displacement for the front field was 1,844 grams of soil per km of trail under a very light riding day, and 1,058 grams of soil per kilometer in the tunnel area. These data only account for dust collected in the first 10 meters. A small percent of the displaced dust was collected 50 meters further away from the road in 3 out of the 4 transects, suggesting that the calculations slightly underestimate the quantity displaced.

Table 1—Displacement of soils particles due to vehicle traffic

		Woods	***Field***	***Tunnel West***	***Tunnel East***
	Collector Height (ft)	**Average dust collected (mg per cm²)**			
	4	1.575	1.595	0.875	0.949
	6	1.027	0.146	0.383	0.611
	10	0.484	0.045	0.117	0.057
	15	0.398	0.076	0.049	0.067
Displacement	**Unit**	**Integration**			
Particle mass per pole	mg per 450 cm²	10.979	5.618	4.420	5.106
Particle mass crossing front row	g per m²	0.244	0.125	0.098	0.113
Soil displacement along transect	g per 5m x 200m	243.98	124.85	98.22	113.47
Linear soil displacement	g per km trail	1219	624	497	567
Soil displaced per trip in 1km	g per trip number	8.19	4.19	3.90	4.50

Summary:

Off highway vehicles cause a significant amount of soil migration by aerial displacement. Most of the soil particles launched during the study period were in size classes greater than 2.5μm and tended to travel less than 50 meters away from the trails.

However, spikes in average particulate loads greater than 150μg per cubic meters were common as vehicles passed the active monitor in the tunnel test site. Given the relatively light ridership during the experiment, when the numbers of riders are substantially higher, air concentrations would be expected well into the unhealthful range where the forested edges of the trails inhibit air circulation. Where the trails are open with adequate air circulation, such as along the main trail by the entrance station, the particulate loads have lower impacts on human health. The passive samplers deployed at head-height confirm a substantial atmospheric loading that could have effects on the rider's respiratory systems.

The evaluation of dust effects on vegetation suggests that OHVs cause only minor perturbations. Some stomatal blockage was observed, and surface accumulations of dust that may periodically inhibit photosynthesis and respiration, but little superficial damage to the cuticle was evident in the images captured by SEM. Because of frequent rainfall, it is unlikely that the effects are long lasting or a cause for serious concern. Vegetation naturally tends to be thickest along the sides trails because of reduced competition for nutrients and water in the trails (this is typically called an edge effect). This density tends to shelter understory plants off the trail from large deposits of dust and any subsequent deleterious effects, and therefore should be maintained or encouraged.

Overall, the results of this study demonstrate the success of using a low-tech particulate trap for determining soil migration and atmospheric loading due to vehicle traffic on unpaved roads.

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Forest Service and U.S. Department of the Interior Bureau of Land Management employees also can view videos, CDs, and SDTDC's individual project pages on their internal computer network at: http://fsweb.sdtdc.wo.fs.fed.us/

For additional information on the ATV study, contact Dexter Meadows at SDTDC. Phone: 909–599–1267 ext 276. E-mail: dmeadows@fs.fed.us