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Erosion From All Terrain Vehicle (ATV) Trails on National Forest Lands

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Abstract. *The US Forest Service has identified unmanaged all terrain vehicle (ATV) use as a threat to forested lands and grasslands. Some undesirable impacts include severely eroded soils, user-created unplanned roads, disrupted wetland ecosystems, as well as general habitat destruction and degraded water quality throughout forested lands. A study was conducted by the Rocky Mountain Research Station and the San Dimas Technology Development Center to evaluate ATV impacts. Trails were classified into one of three disturbances classes of low, medium, and high, based on loss of litter and vegetation, trail width, and depth of wheel ruts. Following trail condition assessment, rainfall simulations were conducted to measure erosion parameters on each of the three disturbance classes. While infiltration parameters decreased with increased levels of ATV traffic, there was no statistically significant difference among the three classification levels. There was, however, generally a significant difference between undisturbed and the combined disturbed conditions. Similar significant differences existed for interrill erosion. In all cases sediment loss would be expected to increase due to ATV traffic. Information acquired from this study will be used to estimate ATV traffic induced erosion and assist in the managing of ATV use.*

Keywords. All Terrain Vehicles (ATV), recreation, hydraulic conductivity, interrill erodibility, rainfall simulation.

Introduction

The Chief of the US Forest Service, Dale Bosworth, has identified unmanaged recreation and especially impacts from Off Highway Vehicles (OHV) as one of the key concerns facing the nation's forests and grasslands (USDA, 2006). Unmanaged OHV use, which includes All Terrain Vehicles (ATVs), is creating a number of undesirable impacts on National Forest System Lands including 1) user-created, unplanned roads and trails, 2) severely eroded soils, 3) damaged wetlands and harm to wetland species, and 4) habitat destruction and degraded water quality due to trail generated sediment.

The soaring use of ATVs on public land has meant that even the small percentage of riders who travel off trails and roads create considerable impacts. Many existing trails are over used and abused to the extent that they too are significantly impacted (Personal communication, USFS Washington Office, Office of Communications, Jane Knowlton, 2003). Field managers are seeing more erosion, water degradation, and habitat destruction. The land may be able to rehabilitate itself after the impact from a few ATV passes across a meadow, but multiple passes across the same area often result in the loss of natural rehabilitation ability (Personal communication, USFS Washington Office, Office of Communications, Jane Knowlton, 2003). The agency is committed to effectively manage its system of designated ATV routes to ensure routes are in the best locations, provide an enjoyable experience for users, and protect the natural environment.

The Rocky Mountain Research Station and the San Dimas Technology and Development Center conducted a study to determine the impacts of ATVs on National Forest Lands. The objective of the study was to determine which types of ATVs and tire treads create an impact on the natural environment. For the purpose of the study an ATV was defined as any motorized off-highway vehicle, 1.27 m or less in overall width, designed to travel on four low pressure tires, having a seat designed to be straddled by the operator and handlebars for steering control, and intended for use by a single operator and no passengers.

At the completion of this project the goal was to be fully aware of 1) how ATV equipment affects trails and uncompacted areas, 2) what combination of ATV type and tire tread cause impacts to trails and uncompacted areas, and 3) what were the changes to infiltration and erosion as a result of ATV traffic. Information derived from this study was intended to provide managers with a scientific basis from which to make decisions about the management of ATVs on the National Forest Lands. This paper discusses the infiltration and sediment aspects of the larger study.

Methods

The study was conducted on six forests chosen to represent the range of forests from the Mississippi River and westward. The ecological provinces and states were 1) Sonoran desert in AZ, 2) Eastern broadleaf forest (continental) in KY, 3) outer coastal plain, mixed forest in LA, 4) Laurentian mixed forest in MN, 5) Middle Rocky Mountain steepe-coniferous forest-alpine meadow in MT, and 6) Cascade mixed forest-coniferous–alpine meadow in WA.

It was expected that ATV traffic would produce a continuum of disturbances from none to unacceptable disturbance. Rather than attempt to measure each structural characteristic of the natural environment along this continuum, three disturbance classes, low, medium, and high, were proposed. Disturbance classes were determined based on litter and vegetation, trail width, and ATV rut depth. At each location ATV traffic took place until each of the three classes was achieved. The low disturbance class was characterized by up to 75 mm deep ruts, up to 1.4 m wide trails, and up to 30% loss of ground cover. The medium condition class was characterized by 75 to 150 mm deep ruts, 1.4 to 1.8 m wide trails, and 30 to 70% loss of ground cover. The high condition class consisted of trail sections with ruts deeper than 150 mm, trail widths greater than 1.8 m, and greater than 70% loss of ground cover.

Erosion Determination Methods

Rainfall simulation on one meter square bordered plots was used to determine infiltration and rain drop splash parameters. Three replications of simulated rainfall were performed on trail sections with low, medium, and high disturbance plus an undisturbed section adjacent to the trails. 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 to a depth of 50 mm. The lower border consisted of a runoff apron flush with the soil surface that drained into a collection trough with a centrally located 25 mm opening. The runoff apron was placed on top of a 6 mm thick layer of bentonite to prevent any water from flowing under the apron. Dimensions of the exposed soil inside the plot were 1 m by 1 m.

Two rainstorms with an intensity of 100 mm/hr and a duration of 30 minutes were applied to each plot. The two rainstorms were applied 3 hours apart. Two soil moisture samples from each side of the plot were taken at a depth of 0 to 40 mm before and after each simulated storm. These soil samples were oven-dried overnight at 105°C.

The 100 mm/hr, 30 minute duration storm had a return period varying from 5 years at the LA site to 450 years at the AZ 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 all of the plot to contribute to runoff. Entire plot contribution to runoff is a requirement when determining infiltration and erosion parameters from simulated rainfall.

Once runoff began on a plot, timed grab samples in 500 ml bottles were taken each minute for the duration of runoff. 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.

Ground cover was measured by counting the number of grid points above vegetation, rocks, or duff in photographs of the simulation plots. The number of grid points used for each photograph varied from 100 to 120. Each plot photograph was counted twice using different grid orientations.

The Water Erosion Prediction Project (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 based on 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 rate of infiltration and, hence, less runoff. The parameter is also 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). This coefficient can be varied by the user. Interpretation of the interrill erodibility coefficient is also straightforward, although the units of kg s m^{-4} are not intuitive. Higher values indicate higher raindrop splash erosion.

The WEPP parameters of hydraulic conductivity and interrill erosion were determined from rainfall simulation on each plot. Pre-rain soil saturation, bulk density, and ground cover, as well as plot geometry were entered into the WEPP model. Repeated computer runs were performed varying an assumed hydraulic conductivity until an objective function was minimized. The objective function (Obj_{hc}) gave equal weight to matching the total rainfall simulation runoff volume and the peak flow and is shown below.

$$Obj_{hc} = (RO_{meas} - RO_{WEPP})^2 + (Peak_{meas} - Peak_{WEPP})^2 \qquad 1$$

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.

Results

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 AZ, LA, and WA, but not at KY, MN, and MT due to logistical conflicts between the ATV driving crew and the rainfall simulation crew. At KY, MN, and MT 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 intent of the study 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 MN there was no simulation on the high class because it was not achieved by the traffic crew in 1,000 passes. At MT there was no simulation on the high class because it was only achieved in curves where it was not possible to install rainfall simulation plots. At AZ there was no simulation on the medium class because of time constraints.

The soil texture and grain size measurements for each site are shown in Table 1. Soil textures ranged from loamy sand for LA to gravelly sand for AZ and MT. All sites had less than six percent clay, with the exception of LA which had more than 15% rock fragments. Mean grain size (d_{50}) ranged from 1.38 mm (AZ) to 0.19 mm (LA).

Average ground cover (plants, litter, and rock) for each site and disturbance class for the rainfall simulation plots is shown in Table 2. 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 loss of ground cover increases raindrop splash erosion because there are fewer plant leaves to absorb the raindrop impacts. Continued ATV use also inhibits plant re-growth in much the same manner as vehicle traffic inhibits plant re-growth 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 MT and WA for all disturbance classes. MT sites were on a high elevation forest with less rainfall and, hence, less cover. The WA site was on a compacted logging road, in a burned area, and also at high elevation, all of which contributed to the low ground cover. Cover at the AZ site appears unusually high, but was visited in the spring following a wet winter.

Inspection of Table 2 suggests that the ground covers for the disturbed classes were not consistent with the definitions of 0 to 30% removal, 30 to 60% removal, and greater than 60% removal. Values in Table 2 were taken from the rainfall simulation plots centered on the wheel tracks. These 1 meter square plots were samples taken from the entire 1.4 to 1.8 m 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 1 – "A" horizon soil characteristics at rainfall simulation sites.

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	Gravelly sand	3.26	1.38	0.49

Table 2 – Ground cover for rainfall simulations.

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
Med	31.0	6.8	14.7	15.0	3.0	ND
High	32.5	ND	1.3	ND	ND	21.4
ND is no data because no rainfall simulation on these plots						

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 plot ground cover, slope, and soil moisture have been taken into account. Additionally, these erosion parameters are need for the WEPP model to make erosion predictions.

Figures 1 and 2 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. Note the trend that hydraulic conductivity generally decreases with increasing level of disturbance class and that interrill erodibility generally increases with increasing level of disturbance. These trends will be tested for statistical significance.

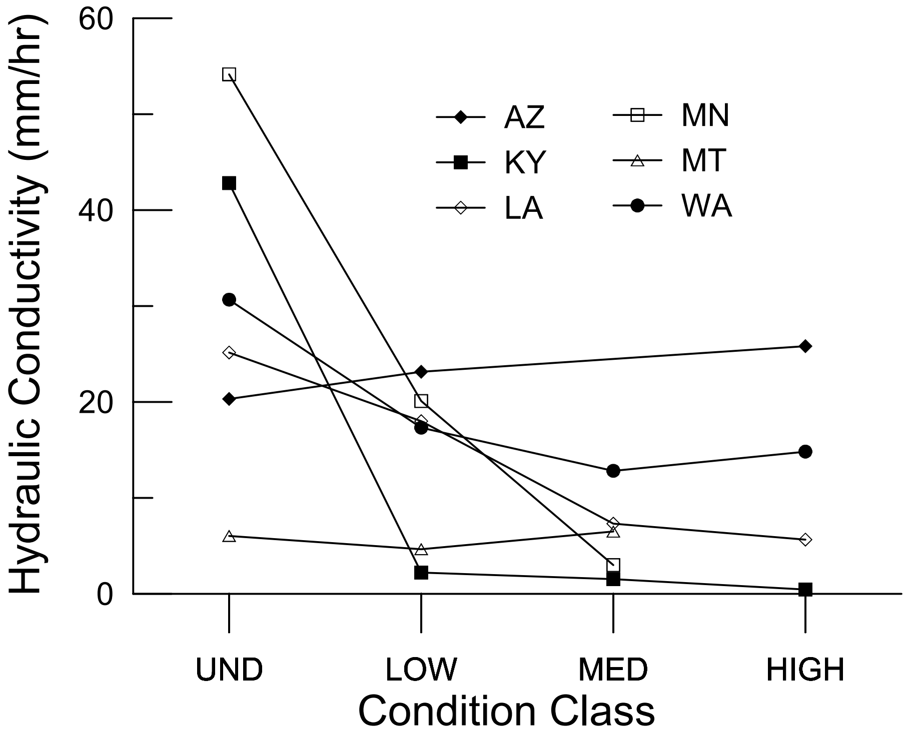

Figure 1 – Hydraulic conductivity (h_c) for each site and condition class.

Statistical Analysis of Erosion Parameters

A statistical analysis was performed to determine if condition class, site, and an interaction between condition class and site could explain the variability in both hydraulic conductivity and interrill erosion. 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 an interaction between the two explained 74% 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 were 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 an interaction between the two explained 63% (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.

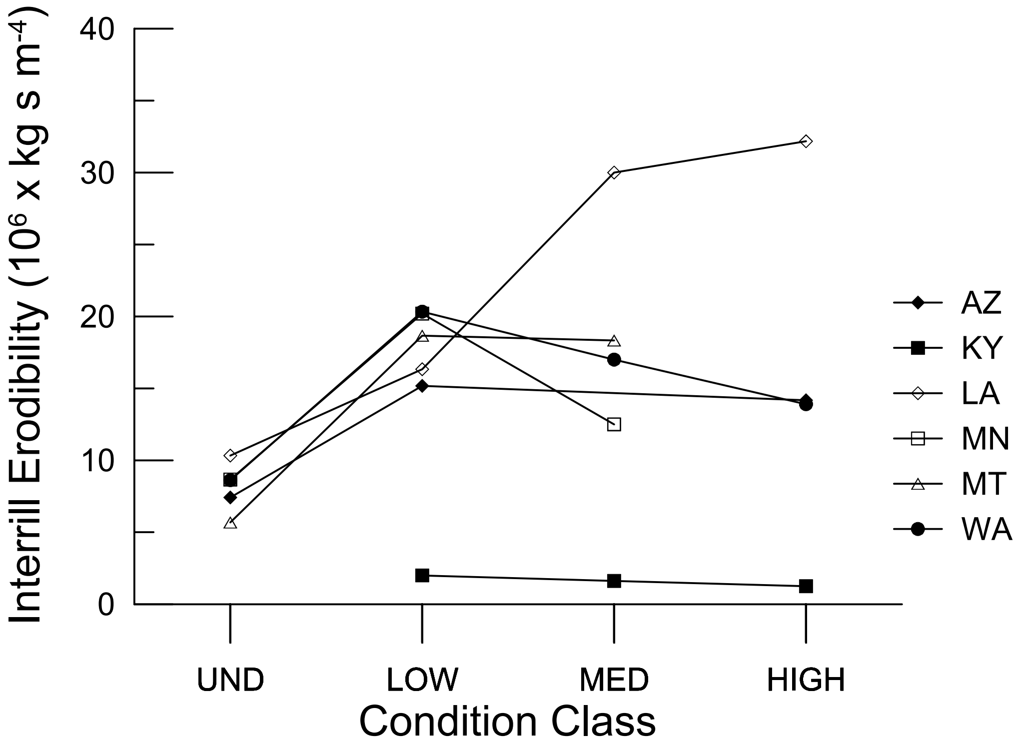

Figure 2 – Interrill erodibility (K_i) for each site and condition class.

Because there was an interaction between classes and sites, hydraulic conductivity and interrrill erodibility were further investigated. Those results suggested that the three condition classes of low, medium, and high plus the undisturbed could be reduced to two, i.e. undisturbed and disturbed, since there was often no statistical difference between the low, medium, and high classes. Table 3 displays the hydraulic conductivity and interrill erosion coefficient after reclassifying the condition class as either undisturbed or disturbed ($\alpha = 0.05$).

Table 3 – Hydraulic conductivity and interrill erosion coefficient from both rainfall simulations after reclassifying disturbance classes as either undisturbed or disturbed.

Site	Hydraulic Conductivity (mm/hr)		Interrill Erodibility (10^6 * kg s m^{-4})	
	Undisturbed	Disturbed	Undisturbed	Disturbed
LA	**25.17**	**10.33**	**10.33**	**25.94**
WA	**30.67**	**15.00**	**8.62**	**17.08**
KY	**42.83**	**1.42**	1.60	
MN	**54.17**	**17.25**	13.80	
MT	5.82		**5.68**	**18.50**
AZ	22.42		**7.42**	**14.67**
Values in **bold** indicate statistically significant differences at the 95% confidence level.				

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 higher sediment losses.

Interpretation of Hydraulic Conductivity and Raindrop Splash Parameters

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 due to 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 erodibility of the soil would decrease resulting in less sediment than before the ATV traffic.

In this ATV study there were only four of the possible nine combinations of changes in h_c and K_i. The sites with the largest potential increase in sediment loss were LA and WA where h_c decreased and K_i increased. Both of these sites had a rock-free soil texture of loamy sand. Note that WA 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 due to the 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 MN and KY. Soil texture for both of these sites was gravelly sandy loam. Here runoff would increase due to impacts of ATV traffic. At MN and KY post-traffic h_c's were 1/3 and 1/40 of their original values, respectively. Both of these sites would be expected to have large increases in runoff from ATV trails. The increased runoff would have the potential to 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 in proportion to that of the increased runoff when compared to undisturbed areas.

At the AZ and MT sites h_c was unchanged and K_i increased, indicating that runoff would be unchanged but sediment loss would have the potential to increase due to the increased erodibility of the soil. Both AZ and MT had soil textures of gravelly sand which did not compact during ATV traffic. Additionally, AZ had a soil crust on the undisturbed condition that ATV traffic destroyed. Since 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 AZ doubled, while at MT, 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 LA and WA which had decreased h_c and increased K_i, gravelly sandy loam at MN and KY which had decreased h_c and unchanged K_i, and gravelly sand at AZ and MT 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.

Comparison to Other Erosion Parameters

Table 4 compares values for hydraulic conductivity and interrill erodibiltity coefficient for forest, rangelands, and agricultural lands from the literature and values determined in this ATV study. The ATV undisturbed hydraulic conductivity values are similar to those reported for forest lands with the exception of the AZ site which was in a desert. The AZ hydraulic conductivity was similar to rangeland which does include desert habitats. The hydraulic conductivity due to ATV disturbance were below undisturbed forests, higher than forest roads, and similar to agricultural fields. The notable exception was KY where 30 years of ATV traffic resulted in h_c values approaching those of an unpaved forest road.

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.

Table 4 – Typical range of values for hydraulic conductivity (h_c) and interrill erodibility (K_i). Values are from WEPP Technical Documentation, WEPP User Summary, and Fangmeier et al (2006).

	Hydraulic Conductivity (h_c) ($mm*hr^{-1}$)	Interrill Erodibility (K_i) (10^6 $kg*s*m^{-4}$)
ATV – Undisturbed forest	25 – 55	5 - 10
ATV – Undisturbed desert	6	15
ATV – Disturbed	1 – 24	2 - 26
Forest	30 – 60	0.4
Forest roads	0.4 – 10	3
Forest skid trails	10	2
Range	3 – 30	0.01 - 2
Agricultural	5 – 30	5 – 6

Conclusion

This study on the impacts of ATV traffic on sediment production concluded for the levels of disturbance defined in this study, there was no statistical difference between the levels of disturbance, i.e., a trail section was either undisturbed or disturbed. Additionally, sediment loss would increase due to ATV trails by one of three mechanisms. Sites with loamy sand soils would experience an increase in runoff and an increase in sediment loss in excess of that due to the increase in runoff alone. Sites with gravelly sandy loam soils would experience an increase in runoff while sediment loss would increase in proportion to the increased runoff. Gravelly sand sites would experience unchanged runoff while sediment loss would increase due to the increased erodibility of the soil. Soil texture groupings were identical to the groupings based on changes in hydraulic conductivity and interrill erosion. Infiltration and interrill erosion parameters on ATV trails were similar to agricultural fields.

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