A CASE STUDY OF AN EROSION CONTROL PRACTICE: THE BROAD-BASED DIP

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Abstract: In 2006, 19 gravel haul roads with broad-based dips within the Monongahela National Forest were examined to determine if those dips adhered to Forest specifications for cut depth and dip outslope. Data on the azimuth, contributing road lengths, slopes of the contributing lengths, landscape position of the dip, and soil texture of the road bed materials also were recorded to identify variables that explained variation in cut depth and dip outslope. Only about 22 percent of the dips met allowable cut depth specifications, and just over half of the dip slopes met the 2-5 percent outslope specifications. Cut depth was explained primarily by road geometry variables, suggesting that proper construction is important to ensure the dip impedes longitudinal drainage down the road while remaining traversable. Dip slope was affected by environmental and use variables, so maintenance during and following use is critical to ensuring proper short- and long-term drainage.

Introduction

The construction and use of forest roads can alter natural forest hydrologic processes primarily through destruction of the forest floor, including soil compaction (Stuart and Edwards, 2006; Greacen and Sands, 1980; Packer, 1967). Forests roads can generate significant overland flow resulting in erosion and sedimentation (Jones and Grant 1996; Elliot, 1999). As a result many best management practices (BMPs) are implemented to control water on roads and road runoff. One such BMP is the construction of cross drainage structures designed to efficiently drain water off the road prism in order to control the erosion potential of water collecting on the road surface (Packer 1967). Culverts and broad-based dips are the primary cross drains constructed on cut-and-fill haul roads (Copstead et al. 1998). Broad-based dips originally were designed for eastern forests because they provide water drainage while providing vehicular traffic a smooth, traversable route (Swift, 1985; Cook and Hewlett, 1979; Hewlett and Douglass, 1968).

Visual observations during and after rain events on a limited number of roads within the Monongahela National Forest, however, indicated that many broad-based dips were not functioning properly. Water was either ponding in the dip or moving longitudinally down the road. Consequently, the objective of this paper was to determine how commonly broad-based dips on roads in the Monongahela National Forest maintained original designed specifications, after use and road closure, and to identify the factors that significantly explain the variation in broad-based dip geometry.

Methods

Study Site

Broad-based dips examined in this study were from cut-and-fill haul roads on the Monongahela National Forest, West Virginia. A sample of roads across the entire Forest was desired, but there were fewer roads with dips in the southern and southwestern portions of the Forest. Thus, the majority of sampled roads were in the northern and east-central part of the Forest. An average of 8 dips per road were sampled on the 19 roads included in the study.

Field Methods

In each dip, points of interest were surveyed in 2006 by a two-person crew using a total station. The parts of the dip that were surveyed included the base of dip, defined as the transect across the dip where water should concentrate and drainage should occur (Fig. 1), and the upper and lower dip boundaries, which were the longitudinal limits of each dip (Fig. 1). The points measured in the transect across the base of the dip were: the bottom of the cutbank, the outside edges of both wheel tracks, the center of each wheel track, the approximate center of the road, and the outside edge of the road (Fig. 2). The outside edge of the road, which at times was the same point as the outside tire track (Fig. 2), was identified as the approximate point where the road surface substrate noticeably changed in size or material. A point was surveyed in each wheel track in both the upper and lower boundaries of each dip (Fig. 1).

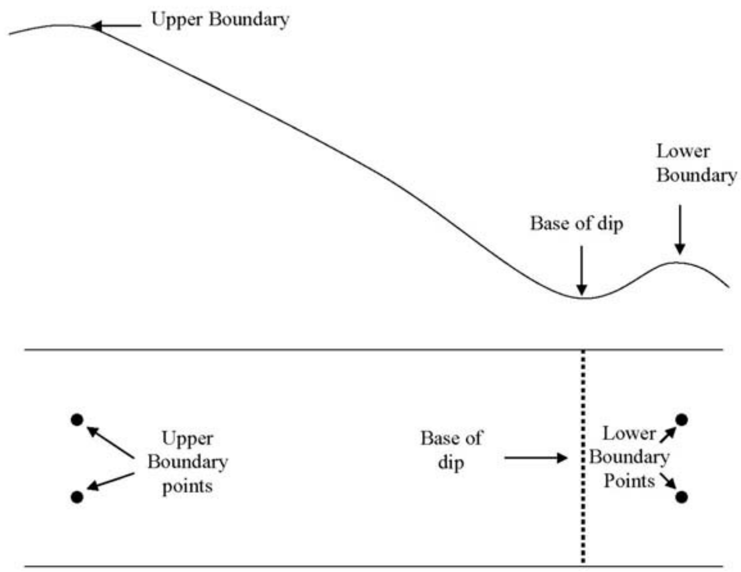

Figure 1. (Top) Exaggerated schematic of a road profile displaying upper and lower boundaries and the base of a broad-based dip. (Bottom) Plan view schematic of a broad-based dip showing the surveyed transect at the base of the dip and the two points in the wheel tracks in the upper and lower boundaries of the dip.

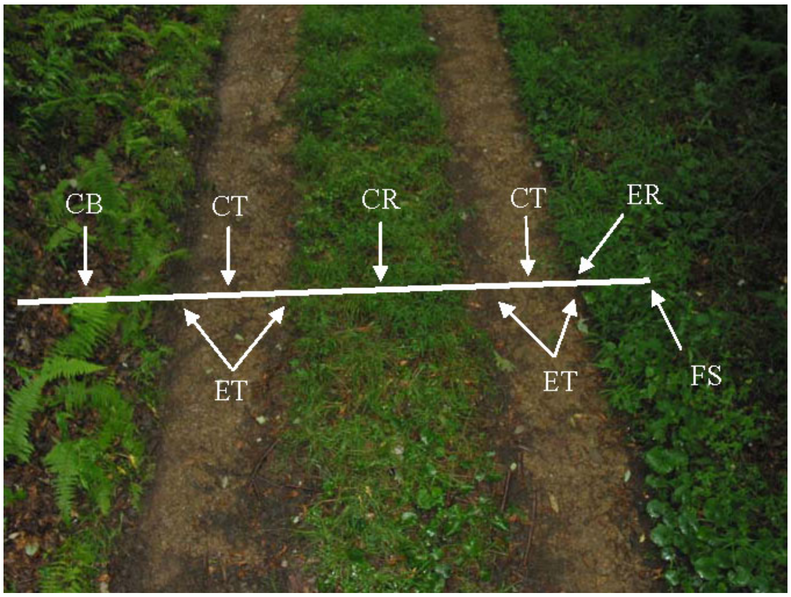

Figure 2. Points were measured in a transect across the base of the dip from the bottom of the cutbank (CB) to the top of the fillslope (FS). Points included CB, edge of track (ET), center of track (CT), center of road (CR), and edge of road (ER), which is the same as edge of track in this example.

Data on other variables also were collected. These variables were position of the dip on the road, azimuth, presence/absence of seeps, and soil texture. Three possible dip positions were identified in the field: nose of ridge (nose), cove, and other, which included all positions that were not classified as nose or cove. Azimuth was measured using a compass at the dip outlet, facing the fillslope in the direction water would flow through the dip. The number of dips in each of the road positions by aspect (determined from azimuths) is presented in Table 1.

Presence/absence of seeps within the boundaries of each dip was recorded; however, seeps were present in only 9 of studied dips so this variable was not used in further analyses.

Table 1. Number of dips in each road position by aspect in the Monongahela National Forest.

		Position on road			
Aspect	Azimuth range	Cove	Nose	Other	Total
North	>337.5° to 22.5°	8	13	11	32
Northeast	>22.5° to 67.5°	2	7	9	18
East	>67.5° to 112.5°	6	1	4	11
Southeast	>112.5° to 157.5°	4	1	4	9
South	>157.5° to 202.5°	3	5	5	13
Southwest	>202.5° to 247.5°	5	8	18	31
West	>247.5° to 292.5°	3	3	7	13
Northwest	>292.5° to 337.5°	1	7	11	19
Total		32	45	69	146

Samples for soil textural analysis (i.e., percents sand, silt, and clay) were collected from the bottom of the cutbank near the base of the dip using a spade. This location represents the soil from which most of the road surface is composed. Approximately 2 kg of soil was collected and placed into a bag containing the Forest Service road number, the dip identification number, and position on the road. Generally one soil sample was collected from each dip, but occasionally, one sample was used to represent the texture for two or three adjacent dips located in the same position on the road. Soil texture then was determined on the <2-mm material using the hydrometer method (Gee and Bauer 1986). Several of the dips did not have textures associated with them because some of the identification numbers became smeared and were not readable. Five dips were missing soil textures because one road could not be accessed at the time of soil sample collection because of a locked gate for which a key was not available.

Forest Broad-Based Dip Specifications

The Monongahela National Forest requires broad-based dip construction to meet two primary engineering specifications to ensure that they function properly. First, the dip must be sufficiently deep to impede water from draining down the road (USDA Forest Service 1996); this specified cut depth, herein called Forest cut depth, is the vertical distance from the Forest profile grade to the center of the base of the dip (Figs. 3 and 4). The Forest profile grade is the original grade of the road extending from where dip excavation began to the lower boundary of the dip (Fig. 3). The Forest cut depth is related to the Forest profile grade in that as the grade increases so does the specified depth (Table 2). The second Forest specification is that the base of the dip should be out-sloped 3 percent toward the fillslope (Fig. 4), though a range of 2-5 percent is allowed. Dips with too little of an outslope (<2%) are not steep enough to drain water, and dips with outslopes that are too extreme (>5) are too steep to accommodate vehicular traffic (W. Church, Monongahela National Forest, pers. comm.).

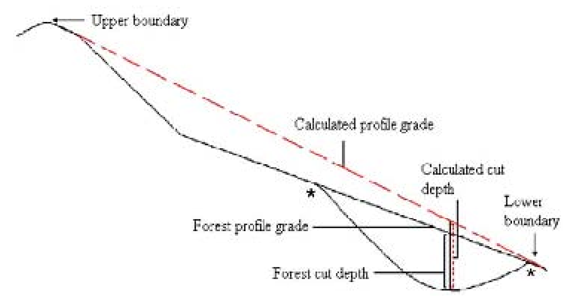

Figure 3. Exaggerated schematic of a broad-based dip showing the upper and lower boundaries, Forest profile grade, Forest cut depth, calculated profile grade, and calculated cut depth. The * symbols mark the beginning and end of dip excavation.

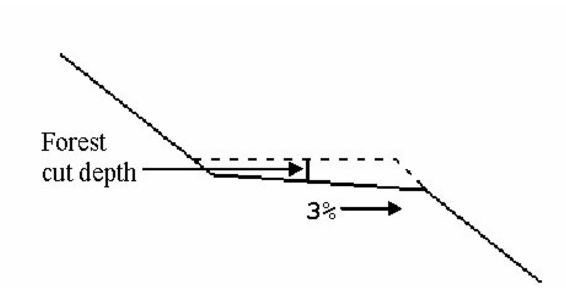

Figure 4. Schematic of a dip cross section displaying the Forest cut depth and 3% outslope (toward the fillslope).

Table 2. Forest profile grades and corresponding Forest cut depths allowed for dips constructed on the Monongahela National Forest. Road segments exceeding 9 percent grade may not be drained by broad-based dips in the Monongahela National Forest.

Forest profile grade range	Cut depth range
(%)	(cm)
<1	2 to <22
1 to <3	22 to <37
3 to <5	37 to <46
5 to <7	46 to <58
7 to <9	58 to <76

Data Processing and Statistical Analyses

The Forest profile grade was estimated by a calculated profile grade. Although the lower boundary point approximates the lower end of dip excavation, the upper point where dip excavation began could not be identified with certainty in the field, so the profile grade had to be estimated. Consequently, the calculated profile grade was measured from wheel track point in the upper boundary to the wheel track in the lower boundary (Fig. 3). Because two wheel tracks measurements were available, for consistency the upper/lower pair that comprised the longest length was used to define the calculated profile grade. By this method, calculated profile grade generally is higher than the Forest profile grade, but as long as there were no major grade breaks in the upper contributing length of the road it was a good estimate of the Forest profile grade.

Likewise a calculated cut depth was used to estimate the Forest cut depth. Calculated cut depth was the vertical distance from the wheel track in the base of the dip used for the calculated profile grade to the calculated profile grade (Fig. 3). The calculated cut depth was not determined in the center of the road because no center of the road measurement was made in the upper or lower dip boundaries, so no calculated profile grade could be calculated for the center of the road position.

The percent slope of the base of the dip also was determined from the bottom of the cutbank to the edge of the road (Fig. 2). Positive values indicate outsloping dips, and negative values indicate dips that are in-sloped toward the cutbank.

Because the total station results represent only X, Y, and Z (elevation) values relative to the location and elevation of the instrument height, ArcMap™ 9.1 and Microsoft™ Excel were used to calculate additional slope length and distance measurements. These included the upper and lower contributing lengths, measured from the upper and lower boundary points, respectively, to the base of dip (Fig. 5), and the percent slope of both of those components, termed the upper and lower contributing slopes (Fig. 5).

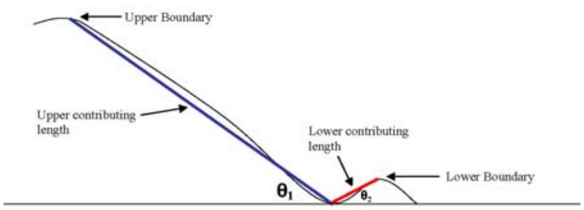

Figure 5. Schematic showing upper and lower contributing lengths and upper (θ_1) and lower (θ_2) contributing slopes.

Mean calculated cut depths and dip slopes were examined for differences among the three positions on the road using SAS at α=0.05 (SAS Institute 1988). Stepwise regression also was run in SAS to identify variables that explained a significant portion of the variation in calculated cut depth and dip slope. The explanatory variables were azimuth, upper and lower contributing lengths, upper and lower contributing slopes, and soil texture. An alpha value of 0.15 was used so the analysis would not be too stringent to exclude variables with predictive power (SAS Institute 1988).

Results and Discussion

Cut Depth

Mean calculated cut depths were not significantly different among road positions (Table 3), so all data were pooled for further analyses. The distribution of dips in each profile grade by calculated cut depth is shown in Table 4. Twelve dips had calculated profile grades that exceeded the allowable Forest profile grade (>9%) for road segments with broad-based dips. No more than 30% of the dips in any single calculated profile road grade category met Forest cut depth specifications, and overall only 28 of the 130 total dips met Forest cut depth specifications. Of the dips that did not meet cut depth specifications, the majority of them had cut depths that were shallower than allowed, though most of those were at least 22 cm deep.

Table 3. Means and standard deviations of calculated cut depths and dip slopes on roads in the Monongahela National Forest. None of the calculated cut depths or dip slopes were statistically different among positions on the road at α=0.05.

Position on the road	Calculated cut depth	Dip slope
	(cm)	(%)
Cove	53.6 ± 21.4	3.35 ± 1.64
Nose	50.6 ± 32.6	3.89 ± 2.66
Other	42.9 ± 22.3	3.65 ± 1.95
All Positions	47.4 ± 25.6	3.67 ± 2.14

As noted previously, calculated cut depth was measured in the center of one of the wheel tracks rather than in the center of the road. One implication of using the wheel track positions for the calculated profile grades and the calculated cut depths is that the calculated cut depths probably were slightly greater than the actual Forest cut depth. Thus, some dips, especially those that were near the upper or lower limit of a specific cut depth category, may be assigned to incorrect cells in Table 4. Additionally, the wide distribution of values across all of the calculated profile road grades suggests that there were many dips that would not have met Forest cut depth specifications even if actual Forest profile grades and Forest cut depths had been used.

Four variables explained a total of 48.7 percent of the variation in the calculated cut depth (Table 5). Lower and upper contributing slopes were positively related to calculated cut depth, so as the road grade and reverse grade of the broad-based dip increased, so did the cut depth. This is logical since dip construction on steeper roads necessarily requires a deeper cut for the dip to adequately impede longitudinal drainage down the road. The specifications shown in Table 2 illustrate this need. Likewise, based on the geometrical relationships of a right triangle, the lower contributing length (i.e., the hypotenuse) must increase as the lower contributing slope (Fig. 5) increases, assuming a constant horizontal distance from the base of the dip to the lower boundary of the dip. Thus, the relationships between the cut depth and other significant road geometry measurements appear to be attributable largely to the initial construction characteristics and subsequent maintenance.

The percentage of silt in the soil composing the base of the dip explains less than 2 percent of the variation in calculated cut depth. There is no clear explanation of why silt was a significant variable.

Table 4. Number and percentage of dips (in parentheses) for calculated cut depths. Values in grey cells indicate those that meet Monongahela National Forest specifications for the corresponding profile grade range.

	Calculated cut depth (cm)							
Road grade (%)	< 2	2 to <22	22 to <37	37 to <46	46 to <58	58 to <76	>76	Total
<1	0	0 (0%)	0	1	0	0	1	2
1 to <3	0	2	3 (16.7%)	5	5	1	2	18
3 to <5	0	4	6	8 (25.8%)	8	4	1	31
5 to <7	0	3	11	8	11 (28.2%)	4	0	37
7 to <9	0	0	5	8	7	6 (15.4%)	4	30
> 9	1	1	0	1	3	4	2	12
Total	1	10	25	31	34	19	10	130

Table 5. Independent variables with accompanied P-value and partial r^2 that significantly explain the variance of dependant variables measured on broad-based dips on roads in the Monongahela National Forest. Plus or negative signs indicates a positive or negative relationship between the dependent and independent variables. α=0.15

Dependent variable	Independent variable	P value	Partial R^2
Calculated cut depth	Lower contributing length (+)	<0.0001	0.165
	Upper contributing slope (+)	<0.0001	0.154
	Lower contributing slope (+)	<0.0001	0.15
	Silt (-)	0.0727	0.018
Dip outslope	Azimuth (+)	0.0020	0.0936
	Lower contributing slope (-)	0.0744	0.0294
	Clay (-)	0.1472	0.0191

Dip Slopes

Mean slopes of the dips also were not significantly different across the three road positions (Table 3). Average dip outslope for each of the road positions was between 3 and 4 percent, which is within the 2-5 percent allowable range defined by the Forest engineers. The average dip outslope for all positions was 3.67 percent, but the high standard deviation (2.14 percent) indicates that many dips were outside of the allowable 2-5 percent range. In fact, almost half of the dips (42 percent) had slopes < 2 percent or >5 percent. Approximately 24 percent had dip slopes < 2 percent, and 18 percent were > 5 percent.

Dip slope variation was explained by three variables that collectively accounted for just over 14 percent of the variation. Azimuth explained the greatest amount of variability, about 9 percent. As azimuth increased from 0° to 359°, so did the percent of outslope (Fig. 6), indicating that the dominant control was whether the dip had an east-facing or west-facing component. Aspect has a strong influence on temperature and evapotranspiration (Haase, 1970), and the greater outsloping on western aspects probably exists because it is easier for dips to retain their designed ~3 percent outslope in drier conditions. During periods of use, higher evaporation rates would help keep west-facing soils and road surfaces dry and less apt to deformation by trafficking effects.

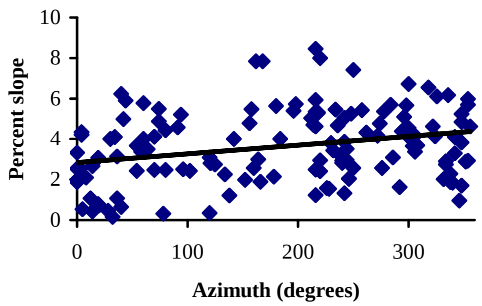

Figure 6. Linear regression relationship between azimuth and dip slope on roads in the Monongahela National Forest.

The inverse relationship between dip slope and lower contributing slopes may be partly a function of dip construction, because proper dip outslopes are easier to construct on gentler slopes, which also typically would require less steep lower contributing slopes. However, heavy equipment use on these haul roads also is believed to contribute to the inverse relationship between dip slope and lower contributing slopes. Log trucks and other heavy equipment tend to favor traveling toward the inside of the road because it is made of more stable residual soil material compared to less consolidated soils on the fillslope side of the road. It is not uncommon to see evidence of log truck tires running immediately along the bottom of the cutbank. As a result, the bottom of the cutbank receives repeated heavy travel that tends to compact the soil more than at the outside edge of the road. This problem may be exacerbated more in the base of the dip than anywhere else because of the effect that the reverse grade of the dip (i.e., the lower contributing slope) has on how vehicles move through the base of the dip. Trucks typically slow down as they approach the reverse grade, regardless of the direction they travel. Then as they travel through the base of the dip they must accelerate to go up the subsequent incline (either the lower or upper contributing lengths). The steeper those inclines become, the greater the potential for wheel slip and/or friction in the dip base, which can result in increased soil displacement and contribute to compaction and possibly rutting. The result of soil displacement and compaction is a reduction in the elevation of the inside of the base of the dip, while the edge of the road is less affected because it bears much less trafficking. Thus, since the slope of the dip was measured from the bottom of the cutbank to the outside edge of the road (Fig. 2), greater changes to the elevation at the base of the cutbank will reduce the dip slope.

Dip slope also was inversely related to the percent clay, though the amount of variation explained was less than 2 percent. The significance of clay content in the soil can be explained by the relationship of soil moisture, pore volume, and soil strength. Compared to sand and silt, clay generally has greater pore volume (Fisher and Binkley, 2000). When the soil is wet and vehicular traffic drives over it, soil strength is decreased and the susceptibility to compaction is increased (Greacen and Sands, 1980). Consequently, dips containing higher percentages of clay will be susceptible to changes in their constructed geometry, especially in the inside of the dip under the conditions of heavy equipment traffic described above.

Conclusions and Implications

Overall, 20 out of 130 total dips met Forestry cut depth specifications, and of those that did not, the majority had cut depths that were shallower than allowed. Just over half of the total dips met outslope specifications, with the majority being <2 percent. Cut depth was explained primarily by road geometry variables including upper and lower contributing slopes and upper contributing length. Dip slope was affected primarily by azimuth and soil clay content.

While much more variation in cut depth was explainable by the available independent variables compared to the slope of the dip, in both cases less than 50 percent of the variation was accounted for. This is not necessarily surprising since there were many factors that were not considered in this analysis, including road age, information on the types and frequencies of trafficking, and maintenance histories. However, the results of both the cut depths and dip slopes indicate the importance of proper initial construction and subsequent maintenance of dips. Cut depth was largely dependent upon road geometry variables, suggesting that it was less affected by environmental conditions than dip slope. Consequently, if proper attention is paid to the cut depth during construction, it will likely remain at an adequate depth for the long term. By contrast, dip slope was primarily affected by environmental variables and also probably road use related variables. Thus, retention of proper dip slope will require adequate maintenance during road use and before road closure.

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