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Modeling Erosion from Insloping Forest Roads With the WEPP Watershed Model

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Abstract-Roads can be a major source of sediment in sensitive forest watersheds. In order to economically mitigate soil erosion from roads, we need to be able to understand the processes that cause erosion. The Water Erosion Prediction Project (WEPP) has been shown to be valid for predicting erosion from some forest roads (1)(2) that can be described as hillslopes. Watershed applications of WEPP can predict erosion and sedimentation values for small watersheds (3). This paper discusses how well WEPP models insloping roads through a sensitivity analysis and validation process using two ongoing studies in the Oregon Coast Range.

Introduction

Forest roads are generally designed to be either outsloped, where water flows across the road prism and down the hillslope without concentrating, or insloped, where water flows into a ditch and then across the road in a waterbar or through a culvert as concentrated flow. The complex topography of an insloped road is better described as a watershed than as a simple hillslope. WEPP's hillslope model is able to model the outsloped road (4), but the watershed version must be employed when modeling the insloped road for complete analysis of cutslope, ditch, and channel erosion processes. WEPP incorporates land characteristics and topography with physical activities such as precipitation or road maintenance in a model to simulate erosion processes. Input files describe management, soil, slope, channel, and climate. A variety of output information is available, including runoff amounts and sediment detachment and delivery.

A segment of an insloping forest road with a cutslope and ditch may be modeled as a small watershed which drains through a culvert and filters down a forested waterway. The purposes of this paper are to discuss how well WEPP models insloping roads, to improve our understanding of insloping road erosion processes, and to determine whether or not the WEPP-predicted values are a good approximation of observed runoff and erosion from forest roads. This paper describes the insloped road structure as modeled in WEPP, presents the sensitivity to the input parameters, and provides validation. This information may contribute to design or maintenance of forest roads to meet erosion and soil loss goals.

Validation

Field data from studies with similar roadcut characteristics were used to assess the validity of the WEPP watershed roadcut scenario. In an ongoing study, we are monitoring 75 plots in the Oregon Coast Range Resource Area, west of Eugene, to assess the effects of cutslope height and cover, road length and grade, and ditch management (5).

Table 1 illustrates that sediment volume measurements in western Oregon vary naturally by a significant amount and that WEPP's predictions fall in this range. The road and ditch lengths, road gradients, and cutslope heights were measured in the field for two different road segments with similar topography, soil, and management characteristics. The climate data was from a station near the sites. The cutslopes did not appear to be a source of sediment to the ditch in any of the runs in either the field study or the WEPP simulations. Observations show that longer, steeper roads produce more sediment and that grading in the ditch increases sediment yield by a substantial amount.

Figure 1 shows the distribution of the field data in comparison to the trends that WEPP predicts for a 60-meter road at various gradients for the sites in western Oregon (5). It illustrates, for both the predicted and measured roads, the marked effect of grading the ditches. This suggests that bare ditches (new construction or a vegetation removal treatment) will cause more sediment production from these roads.

A study by Brake and Molnau (6) investigating sediment plume length was conducted in the Oregon Coast Range near our sites. WEPP does not directly predict the sediment plume length, but rather the sediment yield for a given set of conditions. In order to estimate plume length using WEPP, the forested waterway element below the culvert was divided into several sections of variable length and the sediment leaving each section was recorded. The length where most of the sediment was deposited on the waterway was compared to the site observations. The plume length is sensitive to both the hydraulic conductivity and the amount of vegetation on the forested waterway channel, as well as the different obstructions that are present in the path of the runoff. The vegetation was set at a fairly dense level to correspond to the Coast Range characteristics and the conductivity on the waterway was set at 80 mm/hr, which corresponds to some field measurements. The sediment plume validation was also performed using the WEPP Hillslope model with a similar configuration as that described by Morfin et al (7).

Table 2 shows that WEPP overestimates the measured plume lengths in most cases. The most significant factors in plume length is the road's contributing area and gradient and the presence and type of obstructions in the flow path. Unlike WEPP, the field observations in Table 2 do not show any relationship between plume length and road gradient or road area**.** It is difficult to predict where, at what orientation, and how large obstructions are and therefore modeling such occurrences is difficult. WEPP currently does not provide such a scenario, although with further work some of the impoundment options may be capable of modeling the effects of some of these obstructions. Also, the presence of a sediment plume does not necessarily mean that there is no sediment carried beyond the plume. There is currently a field study underway to determine the amount of sediment carried beyond the observed plume (6).

Another factor not considered in this validation is the fact that these waterways may not act like grassed waterway channels, which concentrate road runoff. One or more of the channels may be better represented by a hillslope waterway element with a dispersed flow pattern (Figure 2), in which case the current WEPP Watershed Version cannot be used for this scenario. Different flow patterns result in different sedimentation properties, such as in a wide flat channel best represented as a hillslope below the culvert, or as a rill forming below the culvert, which is best represented as a channel.

The validation studies indicate that the current version WEPP can model the effects of different road topographies and treatment conditions on the erosion processes for insloping forest roads, but does not readily model sediment plume length in channels.

Sensitivity

Having determined that WEPP predicts reasonable results for road erosion, we performed a sensitivity study to determine the most important processes in insloped road erosion. The elements of an insloping forest road are the cutslope, a ditch, the road, culverts spaced at desired intervals, and the hillslope or gully below the culvert where sediment follows an ephemeral vegetated channel toward a perennial stream. To model this scenario in WEPP, each element was developed individually and then linked together in a watershed structure.

The road traveled was modeled with an inslope of 3 percent, diverting all runoff to an inside ditch rather than onto the hillslope below. Road gradients of 2, 4, 8, and 16 percent were combined with road lengths of 10, 20, 40, 60, and 100 meters for a total of 20 road-length combinations. These 20 combinations, each simulated for five different soil types, produced 100 different runs. The soils represented a range of typical soil types observed on forest roads and included a silt loam, clay loam, sandy loam, loam with gravel, and sandy loam with gravel (Table 3).

Of the 20 road-length combinations for the silt loam soil, several were chosen and combined further in the watershed scenario with a cutslope, ditch, culvert, and waterway. These combinations were analyzed in WEPP to establish trends for future scenarios and validation.

Forest Travelways

Because a forest road has little or no vegetation, the management file in WEPP describes a fallow system with seasonal blading. The runoff flow path on an insloping and downsloping road follows a diagonal pattern across the road toward the ditch and is dependent on both the inslope gradient and the downslope gradient. This configuration neglects any rutting in the road and assumes a planar travel surface. A rutted road would increase the flow path by diverting the runoff down the ruts for a distance, thus increasing the erosion from the road surface.

WEPP performed the 100 runs for a North Bend, Oregon climate for one year, and output values for average sediment loss and average runoff were recorded. These results are summarized in Figures 3 and 4. Other climates had similar trends. Using generally the same variable inputs, Burroughs and King (8) developed an empirical equation to predict sediment yield based on road grade, surface density, and the D_{50} of the loose soil for the road element of the roadcut scenario. This equation produces a curve with similar trends to Figure 4. For more erosive soil properties and higher road gradients, soil losses were higher and increased in an exponential manner with road length.

The increased runoff is likely due to the reduced surface storage capacity, while increased erosion results from deeper runoff and greater erosivity of the runoff water because of higher water energy. There was more erosion on the longer roadslopes due to a larger area contributing. Changes in road length did not affect the runoff depth. Erosion and runoff were greatest for the silt loam and clay loam soils, respectively. Soil loss and runoff were both the least for the sandy loam with gravel.

Ditch Characteristics

The next element to be incorporated into the watershed was the ditch, which WEPP models as a seasonal channel. These runs were performed using the same climates as the single-element road, and a silt loam soil. Four different length and slope combinations were selected for the runs. The ditch experienced the same seasonal grading as the travelway. In all cases, the road ditch was eroding. Table 4 shows some typical results.

Cutslope Characteristics

The cutslope was modeled with three different amounts of vegetation, which were named Much, Some, and None for simplicity. Vegetation characteristics are described in the management file and include a number of variables such as stem diameter, plant height and spacing, and rill and interrill cover. In order to reduce repetitive runs, the road length was fixed at 60 meters and the soil type as the silt loam. Cutslopes in the Oregon Coast Range generally have steep slopes, so the slope was fixed at 100 percent and the height was varied at one, two, and three meters. This made a total of 36 runs: four different road slopes, three different vegetation covers, and three different cutslope heights.

The soil characteristics are different for each element because of compaction and disturbance. Table 5 shows the modeled soil properties in the WEPP soil file for the silt loam soil.

Figure 5 summarizes what portion of the sediment eroding comes from the road, channel, and cutslope for the four percent road gradient. Regardless of cutslope characteristics, the soil loss from the road is the same for a given road slope and, in this case, erosion from the graded ditch dominates. It is apparent from Figure 5 that erosion from the cutslope decreases slightly with more vegetation and increases with height. Greater cutslope height also causes more channel erosion due to greater runoff. Dependent upon soil characteristics and road and ditch management, other scenarios may show erosion being driven primarily by the road, but the general relationship between cutslope vegetation and height, and road gradient and length to erosion holds.

Below the Culvert: Forested Waterways

A corrugated metal or high density polyethylene pipe culvert or a surface waterbar is usually used to divert runoff from an insloped road to the waterway below, where water infiltration and sediment deposition occur in a concentrated channel or in a plume formation. This portion of the study investigates the complex interaction of discharge and infiltration below the road (7). We assume in this section that the portion of the forest floor where the runoff infiltrates has formed an ephemeral V-shaped channel (Figure 2).

The structure of the watershed as perceived by WEPP is a series of hillslopes and channels. The importance of the waterway below the culvert can be quantified by comparing incoming sediment amounts and water volumes to outgoing sediment amounts and water volumes. These may vary with road length and gradient, as well as waterway length, gradient, side-slope and roughness. In this study, we have developed sets of WEPP runs to examine volumes and sediment amounts with these waterway variables, holding other variables constant.

To illustrate the effect of waterway length and road length for attenuating discharge, the gradient of the waterway was fixed at 8 percent and the road gradient at 3 percent. Waterway discharge increased as road length increases and/or waterway length decreases. This occurs because the larger surface area of the road produces more runoff, but a longer waterway results in more infiltration, or less runoff.

The effect of waterway length on sediment yield shows a different initial trend than for the runoff discharge. Sediment yield is generally less for roads which have longer waterways. For short road segment lengths, longer waterways produce the least amount of sediment. As road length increases, however, runoff increases sufficiently to erode the entire length of the waterway, and longer waterways result in more sediment production, as shown in Table 6. Erosion occurs in the waterway channel for a certain distance before deposition begins to occur. At this point, Sediment delivery is limited by the length of the waterway and is transport-limited in that the energy of the runoff is too low to transport all of the sediment previously eroded. Results from this study suggest that a short waterway is better for controlling sedimentation than a waterway of “medium” length in some cases, while a waterway of extreme length is preferred in all cases.

The relationships between waterway length and sediment yield were similar to those presented by Morfin et al. (7), who modeled the flow downstream from the road as dispersed flow rather than channelized flow. The results from that study indicated sediment plume lengths shorter than those predicted with the WEPP watershed model, presumably because of the difference in channel geometry (Figure 2).

An analysis of the effect of differing waterway gradient indicated that neither sediment yield or runoff are sensitive to changes in the gradient of the waterway. A similar set of runs showed that waterway channel side slope had no effect on sediment yield or runoff and that the roughness in the channel as quantified by Manning’s n showed some effect on channel erosion events (9).

Discussion

The road portion of this study points to road length, road gradient and soil type as the driving factors in erosion. Erosion from the cutslope element is relatively small compared to that from the road element. This study examined cutslopes with heights up to three meters. Cutslopes found in mountainous areas may be much higher than this, and therefore contribute more significantly to the runoff and sediment yield. Depending on the soil and management characteristics of the ditch, erosion from the ditch may or may not be of significance. A graded ditch allows more erosion than an undisturbed ditch.

The waterway study demonstrates that the most significant variable driving erosion on a waterway is downslope waterway length. The amount and density of vegetation are important, as well as the hydraulic conductivity. Factors such as waterway gradient, channel sideslope, and roughness are of not as important when modeling with WEPP. The presence and orientation of obstructions drives where and how much sediment is deposited in the waterway, as well. Also important is the geometry of the outlet channel or plume. The recommended practice is to generally discharge on concave slopes, rather than into channelized waterways.

The large variability in sediment yield patterns shows the high complexity of modeling a roadcut watershed scenario. Even with a model such as WEPP, it is difficult to account for all the variables and their boundary conditions, but WEPP allows many of these type of variables to be accounted for that past studies have “lumped” into “factors” in simpler models. For example, we found soil erodibility to be an important parameter when validating field measurements. Without knowledge of soil erodibility and conductivity, WEPP runs can be useful for comparison relative to other WEPP scenarios in establishing trends, but may not approach values that one may observe in the field.

Applications of WEPP to roads in other settings such as developed rural areas or agricultural areas is possible using this model. These areas often have a ditch on either side of the road and smaller cutslopes (or none at all). This scenario can be modeled by dividing the road in two at the crown and modeling each side separately. This would decrease the contributing surface area for each ditch, reducing the erosion potential in those channels.

Conclusions

We developed a set of insloped road scenarios with different topographies, soils, and management practices. These scenarios can be modified for site specific roadcuts in different climates for practical application by forest engineers and managers. They can also be adapted to other areas. A validation study reflected that WEPP's predictions were reasonable approximations for the sediment yields at plots in the Oregon Coast Range and the ditch conditions greatly impacted the sediment yield. This yield also varies with topography, soil type, and climate. WEPP appeared to overestimate sediment plume formation in waterways. It appears that factors such as obstructions and runoff dispersion are critical in plume formation, and modeling these features requires further investigation. A sensitivity analysis was performed and the applicability of these templates was tested using the field validation. The most important variables in terms of sediment production that can be controlled to some degree are, in order:

- Road segment length
- Road slope
- Ditch management practices
- Waterway properties
- Cutslope topography and management

When used correctly, the WEPP Watershed Model can be useful in predicting runoff and sediment yields for insloped forest roads. WEPP can account for such variations as topography, soil properties, management practices, and climate, all of which cause substantial differences in the forest road erosion process. Because WEPP is sensitive to numerous input variables, it is important to have site specific details for comparison or calibration for the areas of interest.

References

1. Elliot, W. J., R. B. Foltz, and M. D. Remboldt. 1994. Predicting sedimentation from roads at stream crossings with the WEPP model. Presented at the 1994 ASAE International Winter Meeting, Paper No. 947511. ASAE, St. Joseph, MI.

2. Elliot, W. J., R. B. Foltz, and C. H. Luce. 1995. Validation of the Water Erosion Prediction Project (WEPP) model for low-volume forest roads. Proceedings of the Sixth International Conference on Low-Volume Roads. Washington D.C.: Transportation Research Board. 178-186.

3. Flanagan, Dennis C., and Stanley J. Livingston. 1995. *WEPP User Summary*. NSERL Report No. 11, W. Lafayette, IN: National Soil Erosion Research Laboratory.

4. Elliot, W. J., and D. Hall. 1997. Water Erosion Prediction Project (WEPP) Forest Applications. General Technical Report INT-GTR-365. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Research Station. 11 p.

5. Luce, Charles H., and Thomas A. Black. 1998. Under review. Rocky Mountain Research Station, 316 E. Myrtle Street, Boise, ID.

6. Brake, Diana, Myron Molnau, and John G. King. 1997. Sediment Transport Distances and Culvert Spacings on Logging Roads Within the Oregon Coast Mountain Range. Presented at the 1997 ASAE Annual International Meeting, Paper No. IM-975018. ASAE, St. Joseph, MI.

7. Morfin, S., W. Elliot, R. Foltz, and S. Miller. 1996. Predicting Effects of Climate, Soil, and Topography on Road Erosion with WEPP. Presented at 1996 ASAE Annual International Meeting, Paper No. 965016, ASAE, St. Joseph, MI.

8. Burroughs, Edward R., and John G. King. 1985. Surface Erosion Control in Roads in Granitic Soils. Proceedings of Symposium Sponsored by Committee on Watershed Management/Irrigation and Drainage Div., ASCE, ASCE Convention, April 30 - May 1, Denver, CO.

9. Tysdal, Laurie, William Elliot, Charles Luce, and Thomas Black. 1997. Modeling Insloping Road Erosion Processes With the WEPP Watershed Model. Presented at the 1997 ASAE Annual International Meeting, Paper No. 975014, ASAE, St. Joseph, MI.

Tables

Table 1. *Comparison of some field observations to simulated WEPP outputs (5)*

	Run 1	Run 2	Run 3	Run 4	Run 5
Road Length (m)	87	33-40	60	59	60
Ditch Length (m)	88	34-41	60	60-62	58-60
Road Gradient	12-13%	3-5%	10%	5-7%	7%
Cutslope Height	1.2-4.9	0.6-2.0	1.2-3.0	6.1-7.0	2.3-5.5
Ditch Management	none	none	graded	none	graded
Total Sediment Production (kg)	163-234	5-67	503-1197	39-167	154-696
WEPP Erosion from Road (kg)	166.8	18.3	52.7	36.3	40.5
WEPP Erosion from Culvert Outlet (kg)	172.3	18.8	829.6	39.8	338.5

Table 2. *Comparison of some of Brake and Molnau's (7) measurements to simulated WEPP outputs.*

	Road 53	Road 9	Road 94	Road 120	Road 106
Road Length (m)	366	223	177	248	213
Contributing Road Area (m^2)	125	645	81	889	290
Road Gradient	7.6%	6.0%	16.6%	9.6%	17.2%
Ditch Management	none	none	graded	none	graded
Measured Plume Length (m)	15	7	5	13	33
WEPP Predicted Plume Length (m)	21	33	11	45	21
WEPP Predicted Plume Length, Hillslope Model (m)	24	16	15	18	16

Table 3. *General Road Input Parameters*

Gradient	Length	Soil Type
2%	10 m	Silt Loam
4%	20 m	Clay Loam
8%	40 m	Sandy Loam
16%	60 m	Loam with Gravel
	100 m	Sandy Loam with Gravel

Table 4. *Sediment yields from the travelway and the travelway with ditch in one year for several silt loam roads predicted by WEPP for a North Bend, OR climate*

Gradient	Road Length (m)	Sediment Yield from Travelway (kg)	Total Sediment Yield (kg)
2%	60	523	830
4%	60	651	1554
8%	60	1326	2775
4%	30	326	1045
4%	90	977	2027

Table 5. *Soil Erodibility Characteristics of Watershed Elements for Silt Loam Soil*

Element	**Interrill Erodibility** $kg*s/m^4$	**Rill Erodibility** s/m	**Critical Shear** N/m^2	**Hydraulic Conductivity** mm/hr
Travelway	3000000	.0006	1.8	0.3
Ungraded Ditch	2000000	.0003	4	10
Graded Ditch	3000000	.0100	1.8	10
Cutslope	2000000	.0003	2	10
Waterway	3000000	.0006	1.8	80

Table 6. *Discharge and Sediment Yield data at different distances down the waterway. Waterway gradient is 8% while road is 60m long at 3% in Medford, OR for one year.*

Distance (m)	**Sediment Yield** (tonnes)	**Runoff** (mm)
1	0.3	157
3	0.4	144
9	0.5	113
20	0.8	72
40	1.0	40
80	1.2	14
120	1.1	7
160	0.2	1
180	0.0	0

Figures

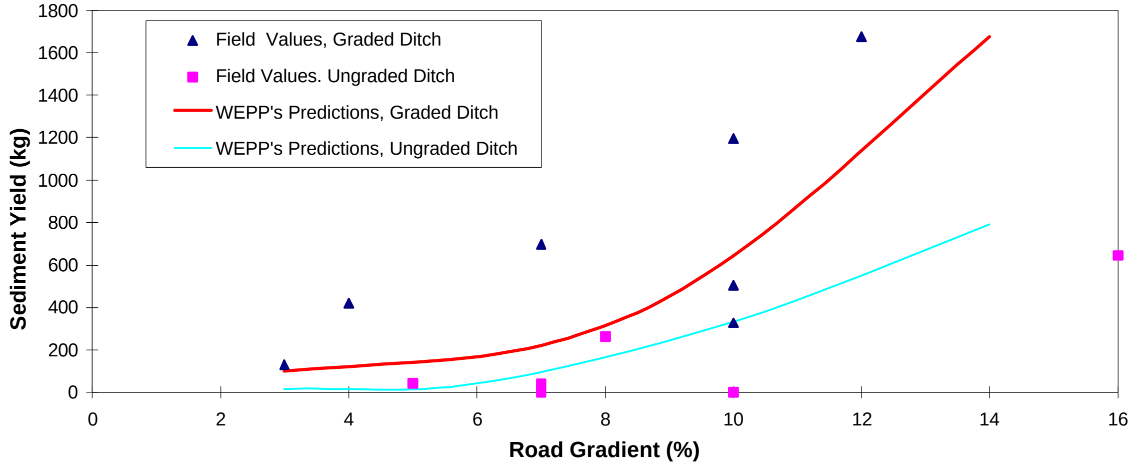

Figure 1. *Measured and Predicted sediment yields for a 60-m road at Low Pass in western Oregon (5).*

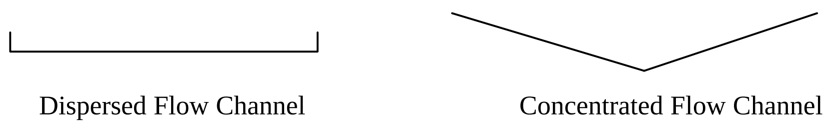

Figure 2. *Channel Structure used in the WEPP Hillslope and Watershed Models*

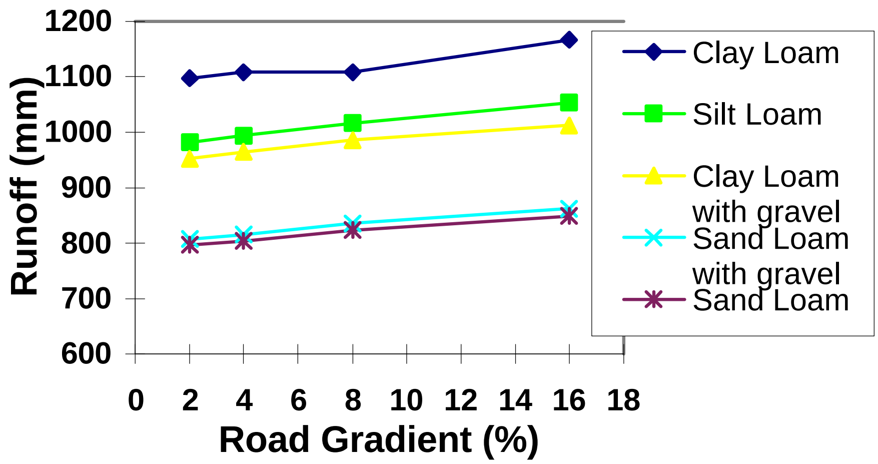

Figure 3. *Average Annual Runoff values predicted by WEPP for one year in North Bend, OR*

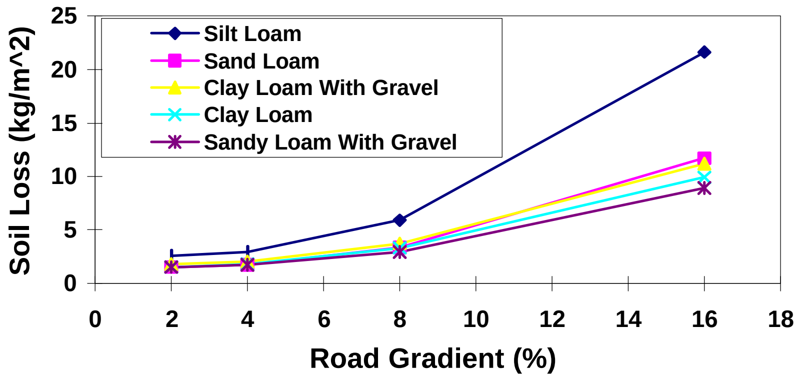

Figure 4. *Average Annual Erosion values for one year predicted by WEPP for a 60-m road segment in North Bend, OR*

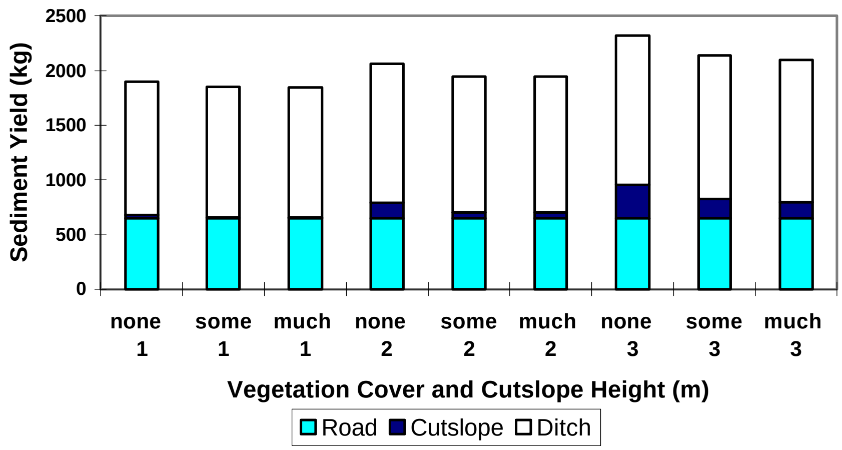

Figure 5. *WEPP's predicted sediment yield for different cutslope heights and vegetation amounts for a watershed consisting of a 4% silt loam road 60-m long, with a channel and a cutslope for one year in North Bend, OR*

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