Describing Insloping Forest Roads With WEPP

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Introduction

Watershed applications of WEPP can predict erosion and sedimentation values for small watersheds (Flanagan and Livingston 1995). A segment of forest road with a cutslope and ditch may be modeled as a small watershed which drains through a culvert and filters down a forested hillslope. The purpose of this paper is to discuss how well WEPP models this type of scenario and whether or not the output values are a good approximation of real runoff and erosion from forest roads. With this information, recommendations can be made when designing or maintaining forest roads to best control erosion and soil loss.

The area developed for an insloping forest road consists of the cutslope, a ditch, the road, culverts spaced at certain intervals, and the hillslope below the culvert where sediment is carried down toward a perennial stream. To develop this scenario in WEPP, each element must be developed individually and then linked together in the watershed structure.

Parameters

The road was modeled with an inslope of 3 percent, causing all runoff to go directly into the 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 100m 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 and included a silt loam, clay loam, sand loam, loam with gravel, and sandy loam with gravel (Table 1).

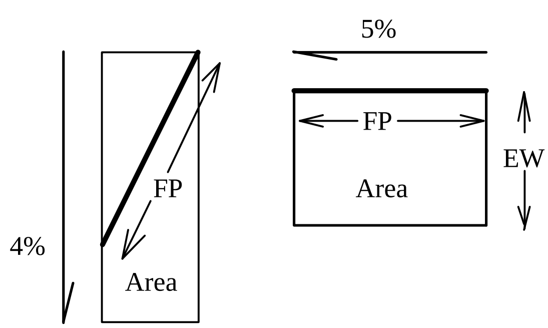
Table 1. *General Input Parameters*

Climate	Gradient	Length	Soil Type
North Bend, OR	2%	10 m	Silt Loam
Medford, OR	4%	20 m	Clay Loam
Deadwood Dam, ID	8%	40 m	Sand Loam
Charleston, WV	16%	60 m	Loam with Gravel
Tucson, AZ		100 m	Sandy Loam with Gravel

Five climates were used for different parts of the study including North Bend, OR, Deadwood Dam, ID, Charleston, WV, and Tucson, AZ. The climates for North Bend and Medford were most similar to those of field sites in and near the Coast Range Resource Area where sediment and erosion samples were measured for validation of the WEPP predicted values. Deadwood Dam, Charleston, and Tucson each represent climates that are snow-driven, rain-driven, and dry, respectively.

Foreset Roads

Because a forest road has little or no vegetation and is not harvested, the management file in WEPP describes a fallow system with blading at certain time intervals. The runoff flow pattern (FP) on an insloping and downsloping road occurs in a diagonal pattern across the road toward the ditch and is dependent on both the inslope gradient and the downslope gradient (Figure 1). In order to accurately model this as a hillslope element in WEPP, we have described the road segment with a length of the flow pattern, rather than the physical road width. Subsequently, in order to maintain the same surface area for precipitation and evapotranspiration, the road segment width was acquired by dividing the physical road area by the flow pattern length to get an effective width (EW).



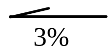


Figure 1. *Flow Pattern Description of Road Element*

WEPP performed the 100 runs using the North Bend climate for one year, and output values for average sediment loss and average runoff were recorded. These results are summarized in Figures 2 and 3. They illustrate that as slope gets larger, runoff and erosion increases, as expected due to the energy of the water. The increase in slope from 8 to 16 percent showed an extreme jump in soil loss. More erosion is also evident for the longer roadslopes due to a larger area contributing. Changes in road length did not affect the runoff depth. As for variation between soil types, erosion and runoff were greatest for the silt loam and clay loam, respectively. Soil loss and runoff were both the least for the sandy loam with gravel.

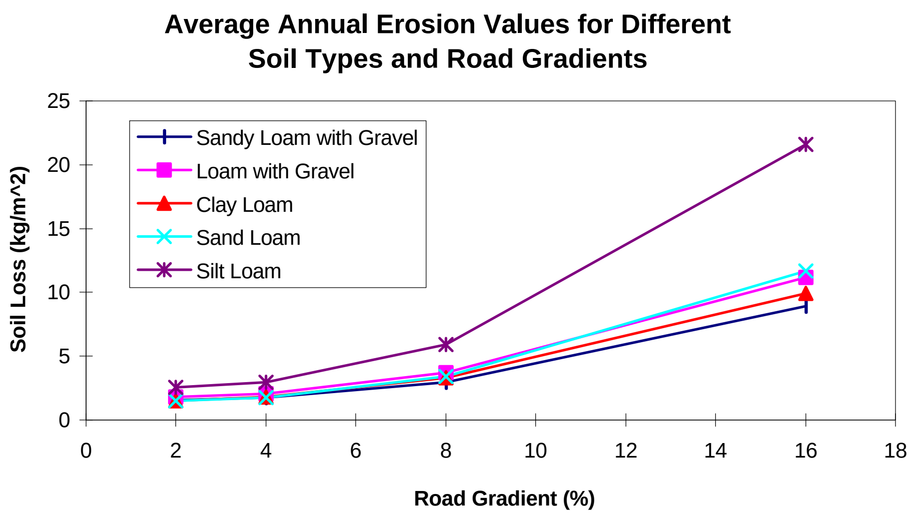


Figure 2. *Average Annual Erosion values for one year predicted by WEPP for a 60m road segment in North Bend, OR*

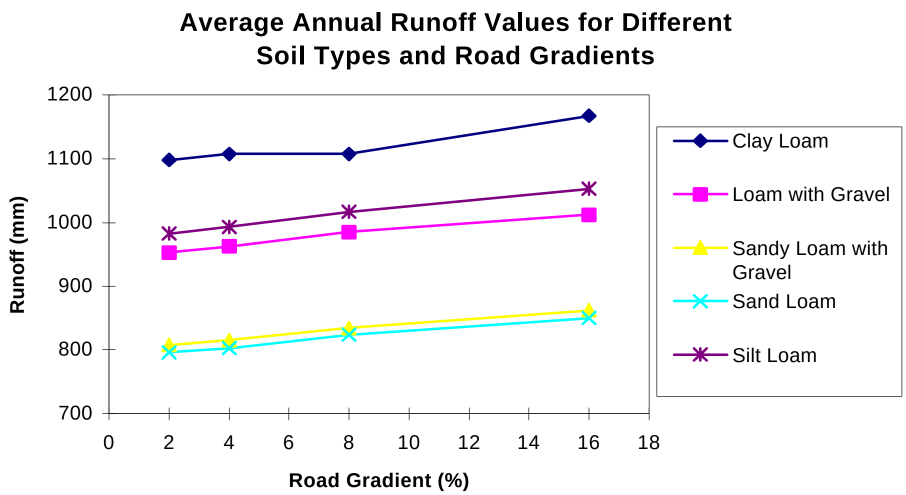


Figure 3. *Average Annual Runoff values predicted by WEPP for one year in North Bend, OR*

Ditch

The next element to be incorporated into the watershed was the ditch, which WEPP models as a seasonal channel. The soil of a roadside ditch is different from the road itself because of compaction on the road. For this reason, the properties for the soil in the ditch and cutslope are slightly altered from that of the road.

Since the road shape was changed to accommodate the flow pattern, the question arose as to where along the ditch to place the road element. WEPP uses structure elements and places them side by side or above or below one another. Several different configurations were simulated and the results suggested that the best way to configure the road and channel was to center the modified road segment along the midpoint of the channel (Figure 4). This configuration was not only easy to build, but gave more consistent outputs.

These runs were performed using the same climate as the single-element road, and two soils rather than all five. Four different length and slope combinations were sampled for the runs and the output sediment yields turned out expected results. In all cases, the road ditch was eroding. Table 2 shows some example results for one soil type.

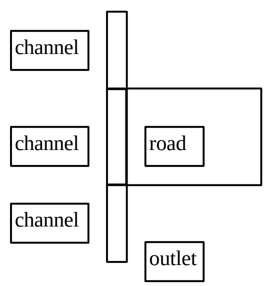


Figure 4. *Channel and Road Configuration*

Table 2. *Sediment Yields in one yearfor several Clay Loam Roads predicted by WEPP for North Bend climate*

Gradient	Road Length (m)	Sediment Yield from Road (kg)	Total Sediment Yield (kg)
2%	10	29.2	138.05
4%	20	48.0	173.80
8%	40	151.8	640.20
16%	100	863.0	4554.00

Cutslope

The cutslope was modeled with three different amounts of vegetation, which we have named Much, Some, and None for simplicity. Vegetation characteristics are stored in the management file and include a number of variables such as stem diameter, plant height, and rill and interrill cover. Also, in order to reduce repetitive runs, we fixed the road length at 60 meters and the soil type as the silt loam. Cutslopes generally have steep slopes, so we fixed it at 100 percent and varied the height 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 sample bar graph summarizes what portion of the sediment eroding comes from the road, channel, and cutslope. Regardless of cutslope characteristics, the soil loss from the road is the same for a certain road slope and length and is much greater than the erosion from the channel and cutslope. 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.

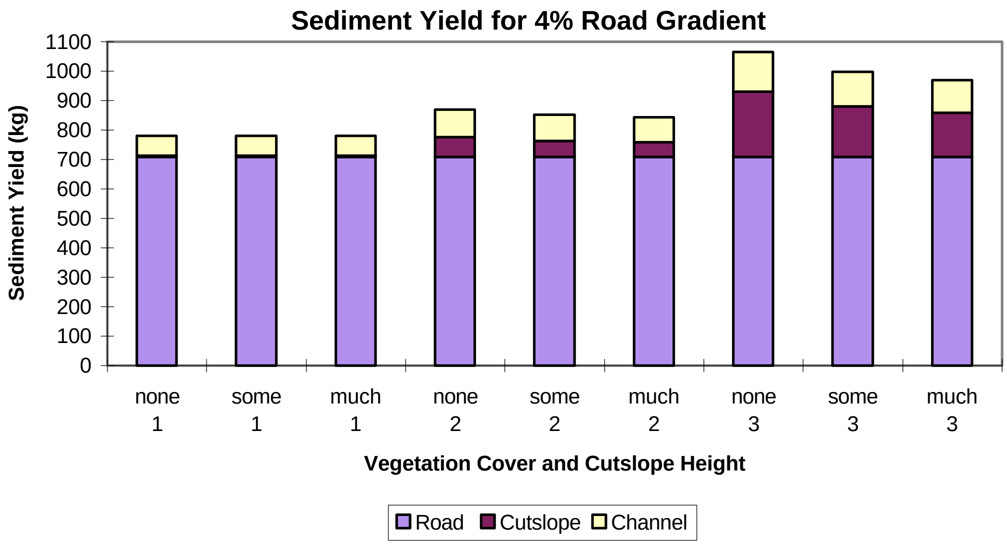


Figure 5. *WEPP's predicted Sediment Yield for Watershed Consisting of a 4% Silt Loam Road 60m long, Channel, and Cutslope for one year in North Bend*

Culverts and Buffers

WEPP can simulate several types of impoundments, including culverts under roadways. Impoundment output summaries give valuable information such as peak outflow rate, outflow volume, peak effluent sediment concentration, total sediment yield, and time to fill an impoundment with sediment (Lindley 1994). This information enables a road manager or designer to make decisions about culvert diameter and spacing and sediment basin size. It can also predict how often to remove the accumulated sediment from the impoundment.

In applying WEPP watershed version to a roadcut scenario with a culvert and buffer, the sensitivity analysis approach revealed several problems with the impoundment files, but overall provided predictable trends when the impoundment problems were bypassed.

In the culvert study, we analyzed several road gradients with a range of length, slope, and diameter characteristics for a corrugated metal culvert. The other road characteristics were held constant throughout the entire analysis. In general, the climate was that for North Bend, Oregon, the soil was a silt, and the vegetation on the two meter wide cutslope was of medium density.

We ran simulations for road gradients of 4%, 8%, and 16%, each with culverts of diameters 8”, 12”, 18”, 24”, and 30”. Changing the diameter caused a change in flow area and friction loss coefficient, which are also input variables. The culvert length was held constant. This set of runs demonstrated two glaring problems with the culvert impoundment file. Many of the combinations simply caused WEPP to crash. An additional group of combinations gave results that were obviously faulty in that the impounding culvert released more volume than it received, insinuating an Artesian well inside the culvert. The few combinations that remained turned out reasonable results.

The reason for the first problem has to do with length, slope, and diameter of the culvert and the type of flow that occurs. When length times slope is less than 0.6 of the diameter, the model fails. Based on one field study, culvert slope is generally at least 10 percent and roads are at least 4m wide with 18” culverts for forest roads. Conversely, information from other forests shows that, in some cases, culverts as small as 12” in diameter are used at gradients as shallow as 4 percent. This indicates that the slope-length problem will be encountered at a significant frequency.

The Artesian well problem is a little more unclear as to the root of the problem, but symptoms that occur can often be pointers. Run time is exceedingly long when WEPP is generating this incorrect type of output. This could point to a numerical integration that is not working correctly. The WEPP programmers have been notified of both problems.

Moving ahead with the working combinations, we added a fillslope beneath the culvert outlet with varied characteristics. Interestingly, this addition digressed back to the Artesian well problem. Scenarios that worked fine with the culvert as the last element in the watershed yielded erroneous results when a fillslope was added below the culvert. In order to bypass these problems with the impoundment files, we chose not to model the culvert as an impoundment at all, but as a nonerodible open channel.

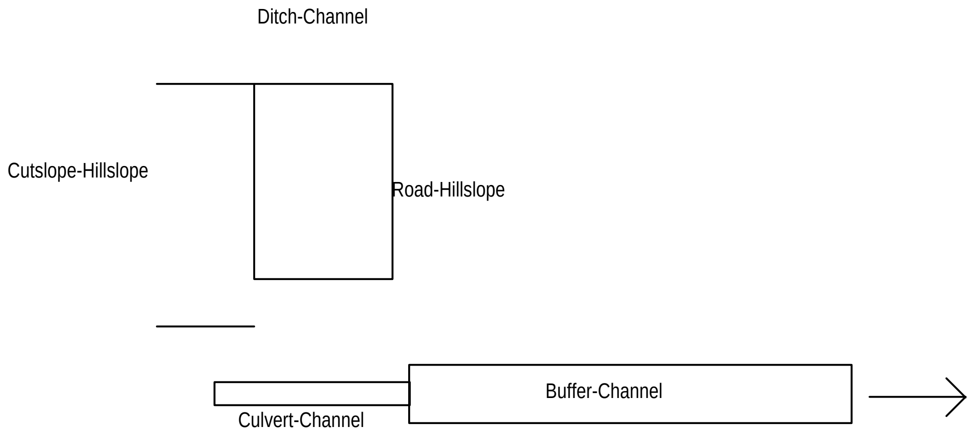


Figure 6. *Plan view of complete watershed structure.*

The structure of the watershed as perceived by WEPP is a series of hillslopes and channels (Fig. 6). Recall that since the road is insloped, the road-hillslope length and width were altered to account for the diagonal overland flow of the water toward the ditch. The effectiveness of the buffer can be quantified by comparing incoming sediment amounts and water voluxmes to outgoing sediment amounts and water volumes. These may vary with road length and gradient, as well as buffer length, gradient, side-slope and roughness. In this study, we have procured sets of WEPP runs to examine volumes and sediment amounts first with buffer length and gradient and second with buffer roughness, holding other variables constant. A similar set of runs showed that buffer channel side slope had no effect on sediment yield or runoff.

To illustrate the effect of buffer length and road length for attenuating discharge, the gradient of the buffer was fixed at 10 percent and the road gradient at 8 percent. For shorter roads and longer buffers, the discharge is smallest. Discharge increased as either road length increases and/or buffer length decreases.

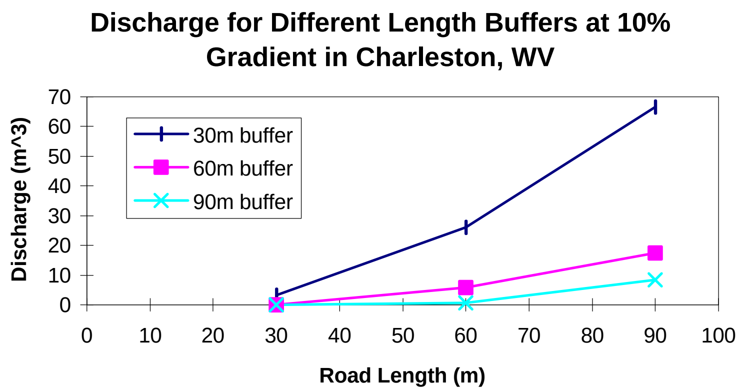


Figure 7. *WEPP's predicted discharges for different road and buffer lengths. Road gradient is 8%.*

Figure 8 shows that as road length increases, sediment yield increases. Sediment yield is generally less for roads which have longer buffers. Possible reason for 30m buffer to be not following trend.....

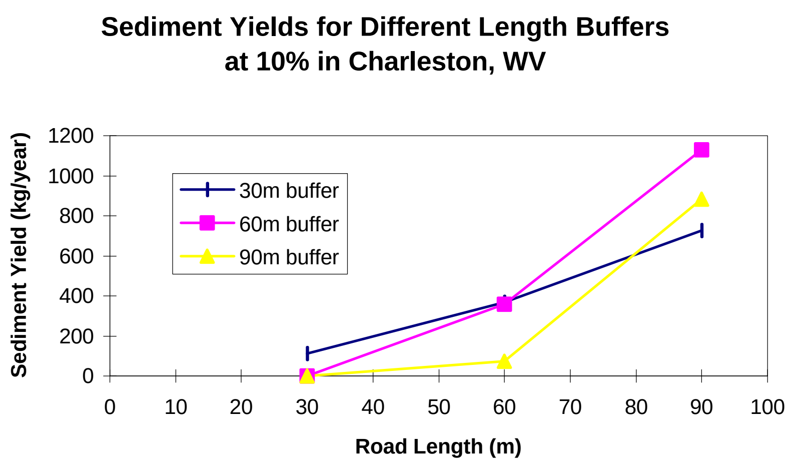


Figure 8. *WEPP's predicted sediment yields for one year for different roads and buffers in Charleston, WV. Road gradient is 8%.*

Using another approach to visualize discharge attenuation, figure 9 shows water entering the buffer as the upper line and water leaving the buffer as the lower curve for one roadcut scenario where the road is 60m long at 3 percent and the buffer is of varying length with a gradient of 8 percent. This graph insinuates that 160m are needed to attenuate the flow caused by the road and cutslope section.

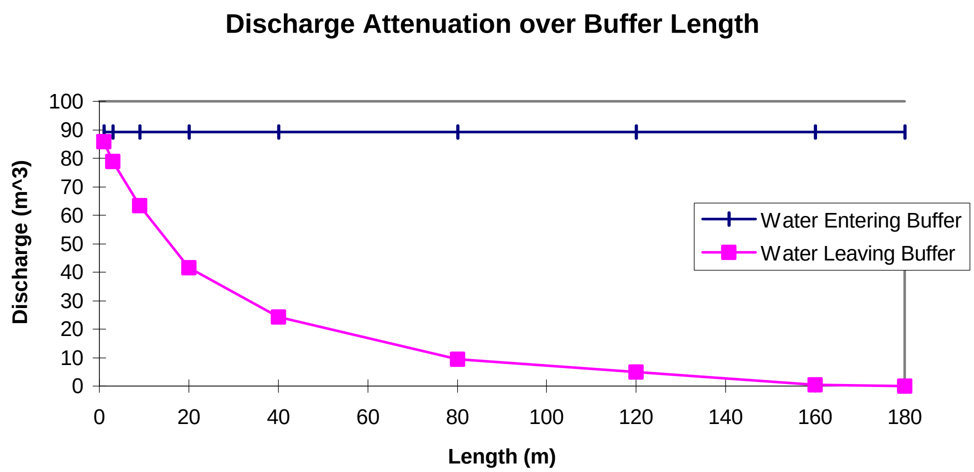


Figure 9. *Discharge attenuation over buffer length with gradient of 8% for one year in Medford, OR.*

The effect of buffer length on sediment yield shows a different initial trend than the volume discharge. Figure 10 depicts that erosion occurs in the buffer channel for a distance of about 80 meters before deposition begins to occur. A regression analysis resembles a second order equation with the y-intercept as the incoming sediment for this trend. This graph insinuates that, for this scenario, a buffer length of at least 160 meters is needed between a 60 meter road cut and a stream corridor if no road sediment is to enter the stream. Since the WEPP watershed version does not give outputs on a storm-by-storm basis, this model will not tell us whether erosion on this scale occurs only for very large storms or if it occurs regularly.

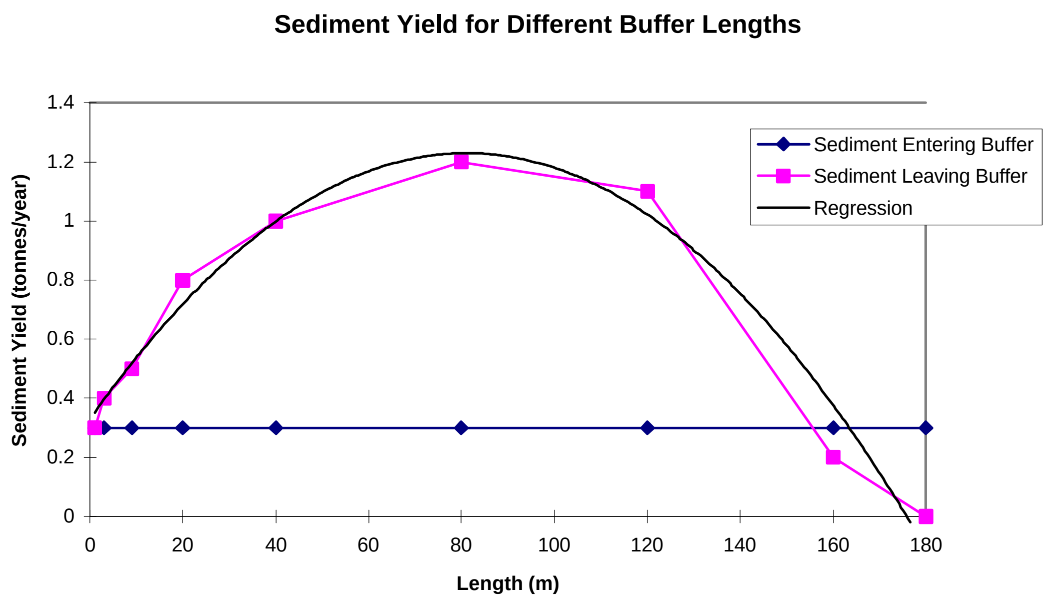


Figure 10. *Sediment Yield for varyinh buffer length with 8% gradient for one year in Medford., OR*

Modeling the fillslope as a channel yielded significantly different results from modeling the it as a hillslope, where the water is evenly spread across the width of the fillslope. *Put one of Susan's graphs here and describe differences between channelized and hillslope buffers. Figure 11.*

To measure the effects of differing fillslope steepness, we fixed the fillslope length at three meters in the model and varied the gradient from zero to sixty percent. The results of both sediment yield and discharge volume were as expected; as the gradient of the fillslope increased, runoff and erosion both increased, but the changes were relatively small. Table 2 illustrates that a fillslope gradient of 8 percent will yield about four cubic meters per year less water volume than a gradient of 60 percent. It also shows that the 8 percent gradient will yield 0.1 tonnes of sediment per year less than the 60 percent gradient. These differences, though notable, are not so enormous that buffer gradient changes in the WEPP model will cause changes in overall erosion and runoff estimates.

Table 2. *Discharge and Sediment Yield data for varying buffer gradients. Buffer length is 3m while road is 60m long at 3% in Medford, OR for one year.*

Buffer Gradient	2%	8%	30%	60%
Water Entering Buffer (m^3/year)	89.2	89.2	89.2	89.2
Water Exiting Buffer (m^3/year)	78.4	78.9	82.2	82.8
Sediment Entering Buffer (tonnes/year)	0.3	0.3	0.3	0.3
Sediment Exiting Buffer (tonnes/year)	0.3	0.3	0.4	0.4
Runoff (mm/year)	142.6	143.7	149.6	150.74

Lastly, we examined how changes in buffer roughness affected discharge and sediment yield. WEPP calculates roughness effects using a bare Manning's n and a total Manning's n. In this analysis, buffer length was fixed at 100m and 8 percent and five different bare n's were chosen. The road was fixed at 60m and 3 percent. We then varied the total n from 0.05 to 1.00. Figure 12 shows the trend that as total roughness increases, sediment yield increases by a small amount, but as bare roughness increases, the sediment increases by a notable amount. The analysis showed no change in runoff for changes in either roughness. It may be noted that for very short buffers, changing roughness causes unpredictable trends in sediment yield and discharge.

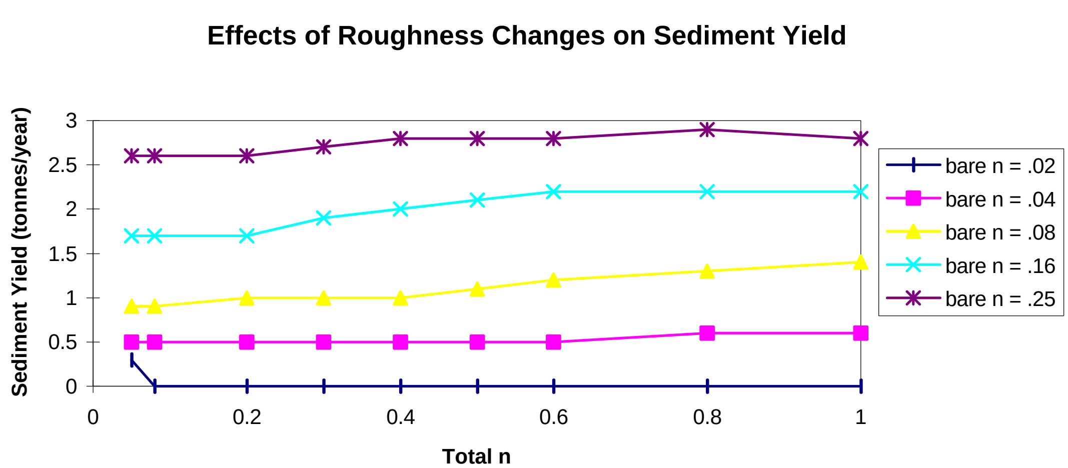


Figure 12. *WEPP's predicted sediemnt yields wiht varied roughness for 60m road at 8% and 100m buffer in Medford, OR*

The buffer portion of this study demonstrates that the most significant variable driving erosion in a road prism is buffer length and to a lesser extent, bare roughness. Parameters such as buffer gradient, channel sideslope, and total roughness are of negligible importance when modeling with WEPP. Also important is how the road prism watershed is modeled, as demonstrated in the comparison between the hillslope buffer and channel buffer.

Validation

Conclusions

References

Lindley, Mark. 1994.

WEPP User Summary. 1994.

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