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EFFECTS OF DTM RESOLUTION ON SLOPE STEEPNESS AND SOIL LOSS PREDICTION ON HILLSLOPE PROFILES

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Abstract – Topographic attributes play a critical role in predicting erosion in models such as the Water Erosion Prediction Project (WEPP). The effects of four different high resolution hillslope profiles were studied using four different DTM resolutions: 1-m, 3-m, 5-m and 10-m. The WEPP model used a common scenario encountered in the forest environment and the selected hillslope profiles to calculate the average annual runoff, average annual soil loss and average annual sediment delivery. The DTM resolution affects the slope steepness as well as the erosion and sediment delivery predicted by WEPP. The slope steepness values generated from higher resolution DTMs were less than from lower resolution DTMs. The trends in predicted average annual soil loss as a function of DTM resolution showed the same pattern as for slope steepness.

Keyword: WEPP, Soil Erosion, Digital Terrain Models, LiDAR.

INTRODUCTION

The Water Erosion Prediction Project (WEPP) is a physically based model for simulating erosion and sediment delivery on hillslopes and watersheds from climate, topography, soil, and management attributes (Flanagan & Nearing, 1995). WEPP was developed by the USDA-ARS and is widely used for erosion prediction (Cochrane & Flanagan, 2003) for both hillslopes and watersheds.

Light Detection and Ranging (LiDAR) technology can provide data to make high definition Digital Terrain Model (DTM) and to estimate vegetation attributes that can be adopted to enhance management of watersheds, forests, rangelands, and roads (Hudak et al., 2009). One study noted that high resolution DTM (1-m) created from the interpolation of ground return showed a root mean square error (RMSE) of 0.2390 m for a 1-m DTM (Evans & Hudak, 2007) and another of 1.244 m for a 4-m DTM (Zhang et al., 2009).

Wu et al. (2008) and Yao et al. (2010) showed that slope estimates are less for coarser DTMs. Both studies were limited to resolutions greater than 10 m. Zhang et al. (2009) reported that a 10-m DTM was better at predicting sediment delivery than a 30-m DTM, and that a 4-m DTM did not improve sediment delivery prediction compared to a 10-m DTM in small forested watersheds.

At present there is a lack of studies to test the effects of finer resolution DTMs (<10 meters) on hillslope topography and how the DTM resolution affects the prediction of sediment yield. The purpose of this study was to evaluate the effects of 1-m, 3-m, 5-m and 10-m DTM resolutions on hillslope steepness and soil loss prediction using the WEPP model.

MATERIALS AND METHODS

The project area has 43,000 hectares in the Clear Creek Watershed on the Nez Perce National Forest, north-central Idaho in United States. Clear Creek is a tributary of the Middle Fork of the Clearwater River. The WEPP model was run using scenarios that are typical for forests in this area. Mean annual precipitation is 965 mm. The elevation range of the watershed is from 580 to 2016 m. The management scenario used was moderate burn severity with 50% cover after wildfire on a loam soil. We chose this scenario to simulate the soil loss because forests generally generate little sediment, whereas natural disturbances such as wildfire often result in an increase in sedimentation from forest watersheds (Elliot & Glaza, 2008).

LiDAR data over the study area was collected and classified by vendor Earth Eye LLC, a LIDAR service company. To create the 1-m DTM, all ground points from the LiDAR cloud points were interpolated, resulting in a raster of 1-m vs. 1-m cell size. The 3-, 5- and 10-m DTMs were derived by bilinear interpolation of the 1-m DTM. The bilinear interpolation uses a weighted average of the nearest four input cells around the transformed point to determine the output cell.

All DTMs were first processed using the “fill” function of the Spatial Analyst Extension in ArcGIS 9.3 (ESRI, 2008) because runoff water cannot flow across grid cells that contain a sink or depression. From the fill layer, a slope steepness layer was derived by using an extension of ERDAS IMAGINE (2010) to calculate topographic metrics developed by Bonnie Ruefenacht at the Remote Sensing Applications Center of the USDA Forest Service. To identify the flow path we used an extension in Spatial Analyst in ArcGIS called flow length. We specified the flow length to be the upstream distance along the flow path from the top of the drainage to the center of the given cell. Locations for this study were found that exhibited typical slope shapes: convex (Profile 1); concave (Profile 2); uniform (Profile 3); and complex (Profile 4).

From both the slope steepness and DTM layers, the 3D Spatial Analyst Extension has a function to allow the user to develop a profile of the cell value versus distance along a user defined profile. In our case we selected four slope segments of 30 m that had been manually delineated in ArcGIS following the flow path and curvature of the DTM profile. Slope lengths were limited to 30 m to limit the size of the slope file for the WEPP model. The four segments were resampled at the four different resolutions (1-m, 3-m, 5-m and 10-m). The weighted average (Table 1) was calculated with each slope value along the profile weighted with the distance. All values from the steepness profile (steepness vs. distance down the hill) in ArcGIS were input directly into WEPP and run for 50 years of stochastic climate with the above scenarios to calculate the average annual runoff, average annual soil loss, and average annual sediment delivery.

RESULTS AND DISCUSSION

Table 1 and the Figure 1 show the 30 m segment DTM profiles and the statistics for each 1-m resolution profile. All DTM profiles differ in curvature, average elevation and standard deviation but have the same length; these are intended to represent different situations encountered in the environment. Table 1 and Figure 2 show that steepness increases when the resolution decreases, except for Profile 2, where the mean steepness changes only slightly. Profile 4 showed a large steepness change: the 10-m slope profile is 27% steeper than the 1-m profile, and profiles 1 and 3 showed 25 and 9% increases in steepness, respectively.

The slope steepness results also showed that the standard deviation (Table 1) decreased at the lower resolutions, showing that the higher resolutions have more variation along the profile and are less uniform. Comparison of the 10-m and 1-m DTMs showed that the 1-m DTM has flat areas that are not apparent in the 10-m DTM, making the 10-m slope steeper.

Neither the different profile shapes nor the different DTM resolutions appear to affect the predicted runoff. The soil losses were relatively small because the profile segments were only 30 m in length.

When comparing the soil loss from different profiles and slope resolutions, the results showed that the average annual soil loss increased from higher resolution (1-m) to lower (10-m) resolution, as did the slope steepness. When the 10-m and 1-m results were compared the 10-m results showed there are 0, 42, 14, and 32% greater annual soil losses than the 1-m from profiles 1, 2, 3, and 4, respectively. For Profile 2 (the concave slope) the mean steepness is almost the same for all resolutions, but the 10-m profile had 42% more soil loss than the 1-m profile. This is likely because the bottom of the profile (Figure 2d) was steeper at lower resolution (10-m), where the erosion would be the greatest.

CONCLUSIONS

1. The profile hillslope steepness values were lower at higher resolutions. Higher resolution shows flat areas not apparent in lower resolution.
2. The average annual soil loss tends to increase at lower slope resolution as a consequence of increased slope steepness.
3. There was not much difference in mean steepness as resolution decreased for Profile 2, but the 10-m resolution profile resulted in 42% more soil loss than the 1-m profile.

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Table 1. Elevation statistics from the 1m-DTM and slope steepness results on four selected profiles at four different DTM resolutions

	1m - DTM	1m - Slope	3m -Slope	5m - Slope	10m - Slope
	--m--		------------------------%------------------------		
		PROFILE 1			
Weighted average	1257.2	30.1	35.3	36.0	37.9
Average	1257.4	29.5	34.7	36.3	38.0
Standard deviation	2.7	13.4	5.1	2.2	1.1
		PROFILE 2			
Weighted average	669.4	40.2	40.7	41.6	40.4
Average	669.2	37.6	36.2	34.4	36.0
Standard deviation	4.0	26.8	24.2	21.9	15.6
		PROFILE 3			
Weighted average	972.4	59.7	61.2	62.2	65.0
Average	972.0	60.8	61.3	62.1	64.3
Standard deviation	5.4	10.9	4.0	3.1	3.1
		PROFILE 4			
Weighted average	882.8	34.4	38.5	38.1	43.7
Average	882.9	32.8	37.5	37.6	44.0
Standard deviation	2.6	17.6	10.5	8.7	3.9

Table 2. WEPP-predicted runoff, hillsope erosion, and sediment delivery at four different DTM resolutions on the four selected profiles

	1m - Slope	3m -Slope	5m - Slope	10m - Slope
	PROFILE 1			
Average Annual Runoff (mm)	416.12	413.86	419.60	418.44
Average Annual Soil Loss (kg/ha)	90	110	110	90
Average Annual Sediment (kg/ha)	92	105	106	95
	PROFILE 2			
Average Annual Runoff	419.38	419.34	418.33	419.38
Average Annual Soil Loss	70	80	90	100
Average Annual Sediment	68	80	85	97
	PROFILE 3			
Average Annual Runoff	416.34	416.27	416.26	416.24
Average Annual Soil Loss	260	280	290	300
Average Annual Sediment	260	285	292	298
	PROFILE 4			
Average Annual Runoff	414.40	419.09	418.49	418.53
Average Annual Soil Loss	100	120	90	130
Average Annual Sediment	102	116	89	135

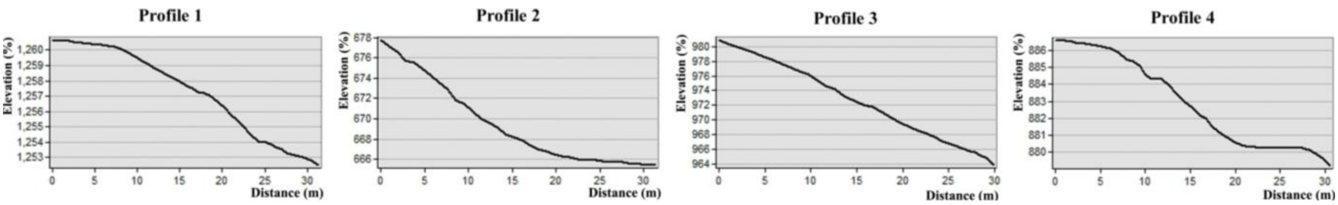

Figure 1. Elevation profile from the 1-m DTM.

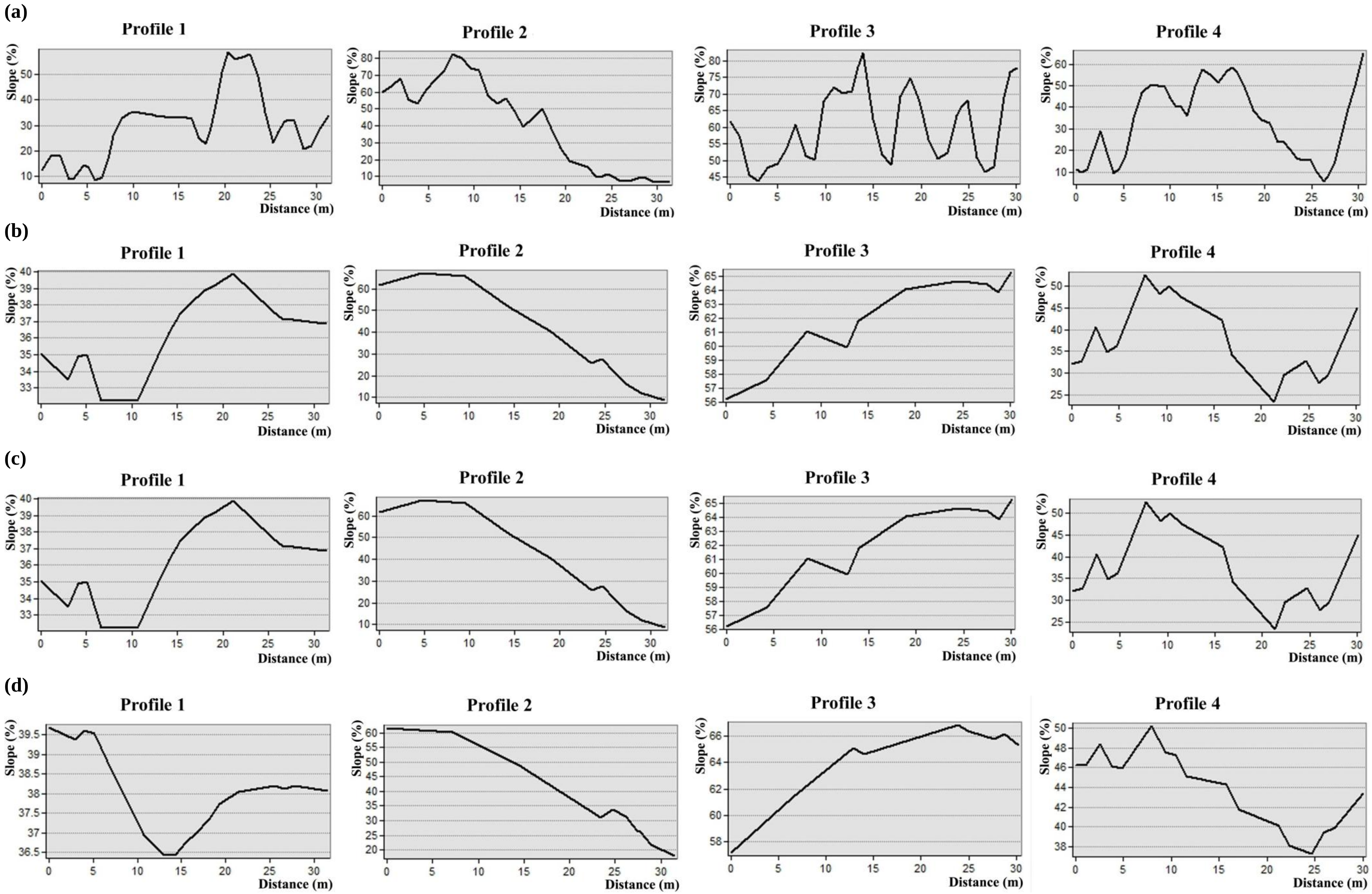

Figure 2. Slope steepness profiles for each site at different DTM resolutions. (a) -1-m hillslope resolution. (b) – 3-m hillslope. (c) – 5-m hillslope. (d) – 10-m hillslope.