REPRESENTATIVE HILLSLOPE METHODS FOR APPLYING THE WEPP MODEL WITH DEMS AND GIS

T. A. Cochrane, D. C. Flanagan

ABSTRACT. *In watershed modeling with WEPP, the process of manually identifying hillslopes and channels is very time consuming and can be subject to large variation between users. Furthermore, the representation of hillslope profiles is subjective and can differ between different modelers. To overcome this, modeling procedures called the Hillslope methods were developed that use geographical information systems (GIS) and digital elevation models (DEMs) to assess water erosion in small watersheds with the Water Erosion Prediction Project (WEPP) model. The Hillslope methods are automated procedures to develop hillslope and channel topographic characteristics from DEMs for use in the WEPP model. The objective of this study was therefore to determine which method of creating representative slope profile and representative hillslope profile lengths performs best. Three methods of creating a representative slope profile from DEMs were developed and tested: linear average, exponentially transformed average, and weighted average. Additionally, two methods to determine the representative hillslope profile length, called the Calcleng and Chanleng methods, were evaluated. The Calcleng method calculates a representative length of hillslope based on the weighted lengths of all flowpaths in a hillslope as identified through a DEM. The Chanleng method sets hillslope width equal to adjacent channel length and then computes a hillslope length from hillslope area divided by width. Actual DEMs from six research watersheds were used to test these methods. The results from the application of these methods were compared to each other and to measured sediment data. Results showed that the three methods for determining the representative slopes of the profiles were not significantly different from each other. There were also no significant differences between the Calcleng and the Chanleng methods for sediment yields and runoff from the six watersheds. Theoretically, however, for more complex watersheds, the weighted average method for determination of representative slope profile gradient values and the Chanleng method to determine representative profile slope lengths are the preferred methods. These results help automate the application of WEPP to watersheds using GIS and DEMs.*

Keywords. *Digital elevation models, Geographic information systems, Soil erosion modeling, Topographic analysis.*

One of the most promising models currently used for erosion prediction is the Water Erosion Prediction Project (WEPP) model. WEPP is a process–based continuous simulation erosion model (Flanagan and Nearing, 1995) developed by the USDA–ARS that is applicable to both hillslopes and watersheds. An advantage of WEPP over other existing models such as the popular Universal Soil Loss Equation (USLE) (Wischmeier and Smith, 1978) is that soil loss is estimated spatially at a minimum of 100 points along a profile, and deposition of sediment can be predicted. In other words, soil detachment and deposition on a complete continuous hillslope profile can be calculated, which is important in watershed modeling because it enables enhanced predictions of sediment yields to channels and to the watershed outlet. Additionally, runoff and soil loss are predicted for every rainfall event, allowing detailed temporal analyses and development of probability distributions.

The WEPP watershed model is based on the integration of the WEPP hillslope model, which simulates erosion along a hillslope profile, and a channel routing component (Ascough et al., 1997). Sediment delivery to the outlet of a watershed requires that hillslopes, channels, and their relationships be delineated and identified within the watershed (Baffaut et al., 1997). In WEPP, hillslopes are represented as rectangles that must have a representative length (L), width (W), and slope profile, as shown in figure 1. Hillslopes drain into the top, left side, or right side of a channel, eventually leading to the watershed outlet. A common way of preparing a WEPP watershed simulation is by gathering data about the watershed and manually identifying channels, hillslopes, and slope profiles in a watershed from topographic paper maps or data records. Additionally, climatic data, soils, and crop/management practices are used to define the WEPP parameters for each hillslope. The process of identifying hillslopes, channels, and representative slope profiles is very time consuming and can be subject to large variation between users when done manually.

Integration of WEPP with a geographic information system (GIS) is desirable because it can facilitate and standardize the application of the model between users. An

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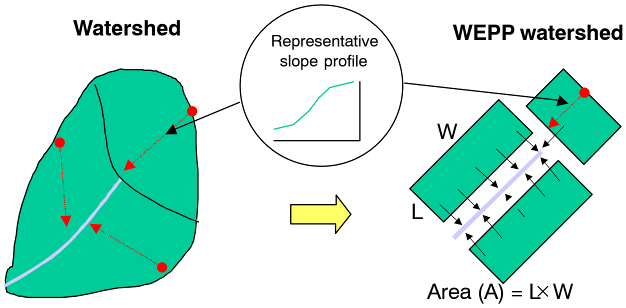

Figure 1. Watershed discretization for WEPP.

initial application of WEPP with a raster–based GIS was conducted by Savabi et al. (1995). In that study, on the Purdue University animal science watershed, the GRASS (CERL, 1993) GIS was used to obtain some of the physical parameters required by WEPP. Even though the use of GIS in that study facilitated the parameterization of WEPP, the extraction of hillslopes, channels, and representative slope profiles from GIS maps was not addressed. Discretization of watershed components using GIS maps could further facilitate and improve the application of WEPP to small watersheds.

Topographic maps provide the most important coverages in the discretization process of WEPP, especially when watersheds have uniform soils and management practices. Digital elevation models (DEMs) in a grid–based format of a certain resolution can be used in GIS to extract hillslopes, channels, and slope profiles in WEPP. To do this, flow–routing algorithms that determine the steepest descent direction and gradient between cells are used. A wide variety of flow–routing algorithms are presented in the research of O'Callaghan and Mark (1984), Jenson and Domingue (1988), Martz and Garbrecht (1992), Tarboton (1997), and Zevenbergen and Thorne (1987). Some of these algorithms have been used to help integrate erosion models, such as the USLE, with GIS (Desmet and Govers, 1996). These functions can be used for WEPP, but substantial manipulation of flow–routing algorithms is required to create additional required input such as representative slope profiles. Furthermore, a variety of methods can also be used to apply WEPP to a watershed using GIS and DEMs.

Another method to facilitate the setup and description of watershed components (e.g., hillslopes and channels) for a WEPP watershed model application using GIS is called the manual method and was first described by Cochrane and Flanagan (1999). This method makes use of the map processing and graphics drawing capabilities of ESRI ArcView and Spatial Analyst (ESRI, 1998). The advantage of this approach is only apparent if the user has a DEM as well as soil and management data represented in GIS maps. Channels are the first components of the watershed that the user has to identify. Their location in the watershed can either be represented by on–screen digitizing or automatically extracted from the DEM by using Spatial Analyst or some other topographic analysis tool. Parameters such as width, shape, depth, and erodibility have to be entered manually for each channel. Hillslopes are then defined by digitizing the hillslope boundaries on the watershed by using on–screen digitizing tools available in ArcView. The user can divide the watershed into as many hillslopes and channels as permitted by the WEPP watershed model code.

A representative profile for each hillslope is defined by drawing a line representing the location of the profile. This line is overlaid on the DEM, using features in Spatial Analyst, to obtain an actual elevation profile. The length of the digitized profile line and the area of the hillslope are then used to calculate a width of the hillslope. Soils, management practices, and crops maps can be used to define the soil and management properties used for each hillslope. Technically, this procedure is the same as manually preparing the WEPP watershed model from paper maps; however, it saves time in defining the components of a watershed, and it allows the user to study several configurations more rapidly (Cochrane and Flanagan, 1999). Another advantage is that it also allows the modeling of special situations (e.g., contouring, terracing, etc., where topographic features are not represented in DEM data) and allows for critical human intervention in defining hillslopes and channels. The disadvantage of this method is that the line that has been digitized by the user to represent a slope profile may or may not be representative of the whole hillslope. The ambiguity of manually selecting this representative profile does not always allow for an accurate comparison of erosion predictions between sets of hillslopes or watersheds. This limitation has led to the need for development of algorithms to automatically calculate representative slope profiles.

GIS analysis using DEMs provides an obvious tool for parameterization of hillslopes, channels, and representative slope profiles for WEPP simulations. However, there are different possible ways of applying WEPP to watersheds using DEMs and GIS. The objectives of this article are: to present three methods used to automatically create representative slope profiles and two methods used to create representative slope lengths, to evaluate these alternatives, and to provide a recommendation for the best methods to use.

Materials and Methods

The procedures developed in this study to apply WEPP automatically using GIS and DEMs have been named the Hillslope methods. The algorithms that are part of the methods have been programmed in FORTRAN and ArcView's Avenue script language. The Hillslope methods also make use of the TOPographic evaluation, drainage identification, watershed segmentation, and subcatchment parAmeteriZation (TOPAZ) automated digital landscape analysis tool (Garbrecht and Martz, 1997) to initially analyze the DEMs. TOPAZ was chosen over other tools because of its ability to overcome limitations of previous algorithms with respect to drainage identification in depressions and over flat surfaces (Garbrecht et al., 1996). TOPAZ has also been validated for a variety of hydrologic conditions and has the ability to generate hydrographic segmentation and channel networks. Setting a minimum channel length in TOPAZ can eliminate undesirable short channel links. Complex junctions of channels, which are not common in nature, can also be eliminated using a TOPAZ module that creates a binary channel network. Finally, output is presented in ASCII format, which is easily incorporated with algorithms to automatically define the watershed components (hillslopes and channels) and representative slope profiles for each hillslope. The steps involved in the development of the Hillslope methods are explained as follows.

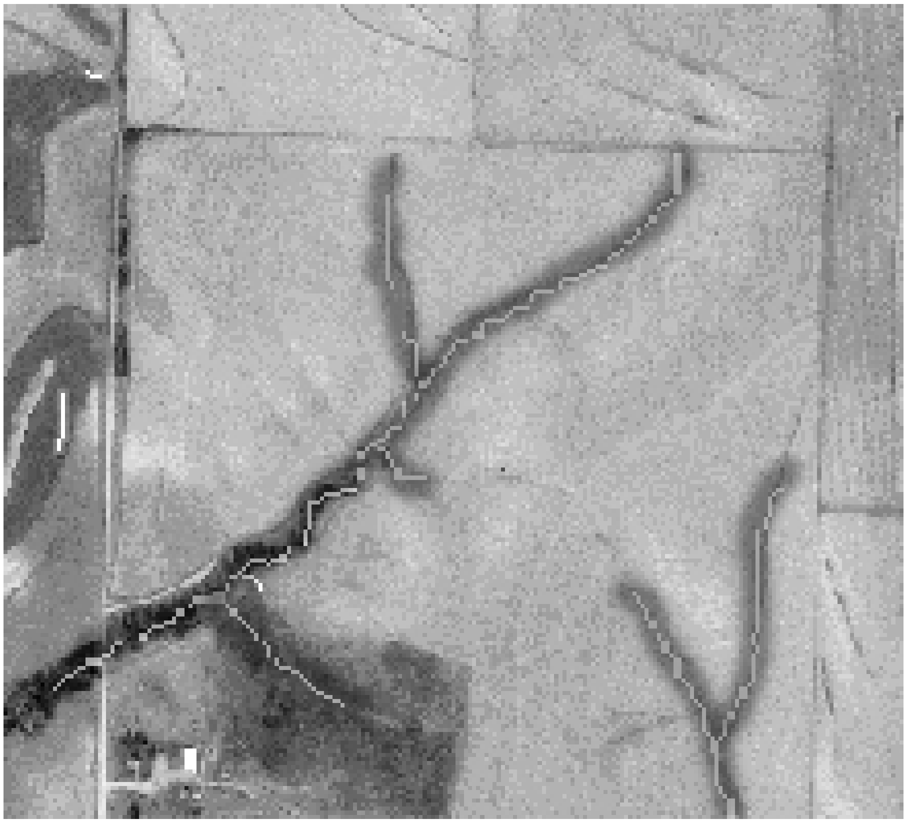

Figure 2. Channel verification with aerial photography.

Identifying Channels

The first step in applying the Hillslope methods is to identify the channels within the watersheds. Channel location and lengths are initially defined by selecting a threshold or a critical source area (CSA). The CSA represents a drainage area whose concentrated water flow defines the beginning of a channel (Garbrecht and Martz, 1997). When using a DEM, the CSA represents a certain number of cells flowing into one single cell (defined as the starting point of a channel). Correct identification of channels may be verified by overlaying channels on aerial photography or field surveys, as shown in figure 2. CSA values, ranging from 0.5 to 4 ha, were determined for six watersheds in the midwest and southeast regions of the country. For these watersheds, there seemed to be a direct correlation between the size of the watershed and the CSA value representing the watershed channels. However, the exact point of channel initiation can be influenced by other factors such as ground slope, soil, management, and climatic factors (Montgomery and Dietrich, 1989; Martz and Garbrecht, 1992). Other WEPP channel input parameters such as actual width, shape, depth, and erodibility have to be provided by the user manually, as these cannot be extracted or derived from a DEM.

Identifying Hillslopes

Hillslopes are defined as a set of grid cells in the DEM that drain to the left, right, or top of each individual channel. If the channel is a secondary channel, meaning that it is created by the junction of two other channels, then there will be one hillslope to the left and another one to the right of the channel, but no hillslope draining to the top of the channel. Hillslopes defined in this way were extracted from the DEM by identifying flowpaths with the aid of the TOPAZ program.

Representative Slope Profiles

The next step in the Hillslope methods is to create a representative slope profile for each of the hillslopes. A representative slope profile can be derived from flowpaths extracted from a DEM. Flowpaths are defined as the route water travels when flowing from one cell to the next, starting from a cell having no water inflow and terminating at a

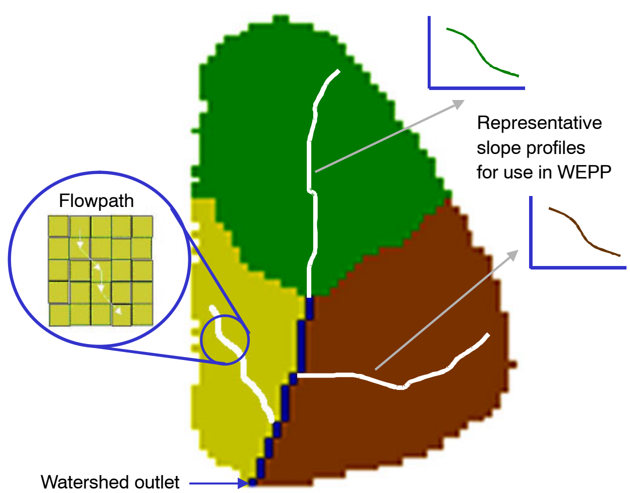

Figure 3. Flowpaths in watershed modeling derived from grid–based DEMs.

channel (fig. 3). Within each hillslope, there may be a large number of flowpaths, some which start at the watershed boundary or at points within the watershed. Many flowpaths may eventually intersect as they approach a channel.

Individual flowpaths with slope values were extracted by analyzing four output files of the TOPAZ program. The first file, called the flopat.arc file, is a raster file defining the beginning and end of flowpaths. Each grid cell in this file has a value from 0 to 4 assigned to it. A zero value means that the cell has indeterminate flow direction. A value of 1 signifies that the cell is at the end of a flowpath, and a value of 2 means that it is at the beginning of a flowpath. The beginning of a flowpath is a cell that no other cells flow into. A value of 3 signifies that the cell is both a beginning and an end of a flowpath. A value of 4 means that the cell has an upstream inflow and a flow vector pointing to a downstream cell that also has a flow vector. In other words, it is a cell in the middle of the flowpath. The second TOPAZ output file, called the flovec.arc file, is a raster of drainage direction. Each grid cell in this file has a number associated with the direction it flows to. The numbers range from 1 to 9, signifying the surrounding cell that the cell drains into. For example, 1 signifies that the cell will drain to the cell directly northwest of it. Similarly, 2 is north, 3 is northeast, 4 is west, 6 is east, 8 is south, and so forth. A value of 5 signifies that the cell does not drain to any other cells, in which case it is considered a sinkhole.

The third TOPAZ output file defines the hillslopes within a watershed. This file is called subwta.arc and each grid cell has a certain number indicating which hillslope it belongs to. The fourth output file is the cell slope file and is called fvslop.arc; it is a raster containing calculated flow vector slope values for each cell in the watershed. The slope values were calculated using the elevation differences between the neighboring cells and the flow vector direction. If a cell had a zero value or an undetermined value (due either to small errors in the DEM or complex topography), then an arbitrary value of 0.001% slope was assigned to the cell to avoid computational problems when applying WEPP. The four TOPAZ output files are combined to create a single large file that contains slope values for each cell of each flowpath in a specific hillslope. This file is then used as the basis for calculations to create a representative slope profile for each hillslope.

A representative slope profile should represent all individual flowpaths within a hillslope and should also represent the effects of slope on erosion predictions using WEPP. We studied three different methods of creating representative slope profiles using flowpaths derived from DEMs that take into account the effects of slope. These methods represent a wide range of possible ways to create representative slope profiles from individual flowpaths.

Linear Average Representative Slope Profile

The first method to develop a representative slope profile from all the flowpaths in the hillslope was created by averaging each cell slope value from a flowpath with all other matching cell slope values from flowpaths in the hillslope. Cell slope values were matched according to their flow distance from the channel. The algorithm used to create this linear average representative profile was:

$$\mathrm{E}_i = \frac{\sum_{p=1}^{m} z_{pi}}{m_i} \tag{1}$$

where

E_i = representative slope value at distance i from the channel

z_{pi} = slope value of flowpath p at distance i from the channel

m = number of flowpaths in the hillslope.

A simple averaging procedure such as this assumes that all slope gradients have equal weight in their influence on soil loss.

Exponentially Transformed Average Representative Slope Profile

In order to accommodate the non–linearity of the relationship between slope and soil loss, a second approach to creating a representative slope profile was tested. This method is called the exponentially transformed average method and can be described by the following equation:

$$\mathrm{E}_i = \ln\left(\frac{\sum_{p=1}^{m} \exp(z_{pi})}{m_i}\right) \tag{2}$$

where

E_i = representative slope value at distance i from the channel

z_{pi} = slope value of flowpath p at distance i from the channel

m = number of flowpaths in the hillslope.

The assumption here is that slope has an exponential relationship with soil loss. However, the effects of flowpath slope lengths are not taken into account with this method.

Weighted Average Representative Slope Profile

The third method of creating a representative slope profile is called the weighted average method. This method consists of weighting flowpaths by their area and length, and then averaging each cell slope value from a flowpath with all other matching cell slope values from flowpaths in the hillslope. Cell slope values for flowpaths were matched according to their flow distance from the channel. Flowpaths with greater area and longer lengths were assumed to contribute proportionally more than smaller and shorter flowpaths to the representative slope profile. Since cells are square, a diagonal flowpath has a longer length than a flowpath with an equal number of cells but with cells flowing horizontally or vertically into each other, hence the reason to consider both area (number of cells) and length. The following equation was developed for the computation of a representative slope profile for a hillslope:

$$\mathrm{E}_i = \frac{\sum_{p=1}^{m} z_{pi} \times k_p}{\sum_{p=1}^{m} k_p} \tag{3}$$

where

E_i = weighted slope value for all flowpaths at distance i from the channel

z_{pi} = slope of flowpath p at distance i from the channel

k_p = weighting factor for flowpath p.

The weighting was done by multiplying the upstream drainage area (a_i, area of cells in the flowpath) times flowpath length ($k_i = a_i \times l_i$). Individual flowpath lengths were calculated by summing the distance between the centers of cells in the flowpath.

Representative Slope Profile Length

The final step in the Hillslope methods is to determine the length of the hillslopes in the watershed. Since equations 1 to 3 were developed to calculate a profile with a length equal to the longest flowpath, it was also necessary to determine the appropriate profile length. Two methods are presented here to calculate the appropriate length of the representative slope profiles. The first, called the Chanleng (for channel length) method, uses the length of the channel to set the width of the adjacent hillslopes, and uses the area of the hillslope (A = L × W) to define the length of the hillslope (fig. 4). In other words, for hillslopes draining laterally into channels, the width of the hillslope was set equal to the length of the adjacent channel. The length of the hillslope was then simply calculated by dividing the total hillslope area by the width.

Because the top hillslope does not have a matching channel length, its representative profile length is calculated using the Calcleng (for calculated length) method. In the Calcleng method, a representative slope profile length is calculated for each hillslope based on the flowpath properties, as shown in figure 4. The length is determined by a method of weighting all flowpaths based on drainage area, illustrated by the following equation presented in Garbrecht et al. (1996):

$$L = \frac{\sum_{p=1}^{n} l_p \times a_p}{\sum_{p=1}^{n} a_p} \quad (4)$$

where

L = hillslope length

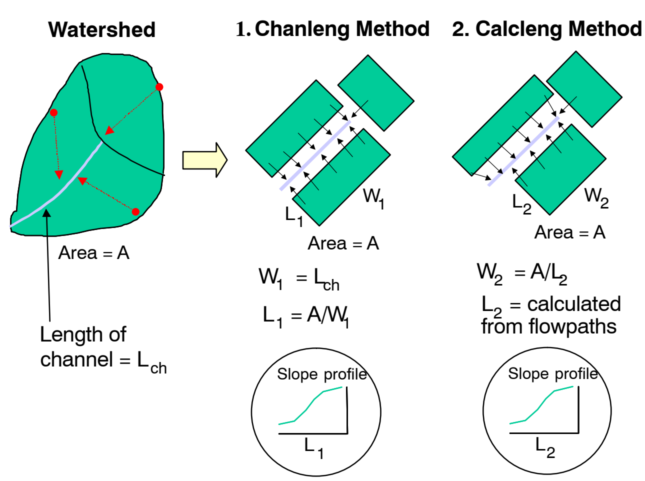

Figure 4. The Chanleng and Calcleng methods for watershed discretization.

l_p = flowpath length

a_p = area represented by the cells in the flowpath

n = number of flowpaths in the hillslope.

The width of the representative hillslope profile is then easily calculated by dividing the total hillslope area by this length. The two main assumptions for this case are that the flowpaths are the routes traveled by water, and that larger and longer flowpaths contribute more than smaller and shorter flowpaths (Garbrecht et al., 1996). In both cases, the original representative profile was truncated at the top so that it was equal to the calculated length starting from the bottom of the hillslope.

In summary, the Hillslope methods consist of identifying the channel network, defining hillslopes draining into each channel segment, and creating a representative slope profile for each hillslope. Simulations of six research watersheds with measured multiple event results were conducted to study possible differences in results between the three methods of creating representative slope profiles and between the hillslope lengths of the Chanleng and Calcleng methods. Statistical methods such as t–tests, P–values, and calculation of RMSE (root mean squared error) values were used to compare event results between methods and measured data. The properties of these USDA research watersheds (Watkinsville P1 and P2 in Georgia; Holly Springs WC1, WC2, and WC3 in Mississippi; and Treynor W2 in Iowa) are fully described in Cochrane and Flanagan (1999).

The six research watersheds represent different topographical and management conditions of typical watersheds in the U.S. They represent 22 different slope profiles (three hillslopes for each of the P1, P2, WC1, WC2, and WC3 watersheds, and seven hillslopes in the Treynor W2 watershed). The Treynor W2 watershed had a crop management system of corn and Monona–Ida–Napier series silt loam soils, and the WEPP input files for this watershed were adapted from Kramer (1993). The Watkinsville watersheds had a variety of management crop systems including wheat, sorghum, barley, soybean, clover, corn, and Bermuda grass and Cecil series sandy loam and silty clay loam soils. The Holly Springs watersheds included diverse crops such as corn, wheat, soybeans, and meadow and a Grenada series silt loam soil. Climatic data were also different for each region. For both the Watkinsville and Holly Springs watersheds, management, soils, and climate files developed by Liu et al. (1997) were used for the simulations. GIS soils maps and field data were used to obtain the representative soil type for each hillslope. Similarly, management maps and field data were used to obtain the dominant management practice for each hillslope in each watershed. For the research watersheds studied, each hillslope had only one WEPP management practice file and a single dominant soil type file.

Results and Discussion

Representative Slope Profiles

A hypothetical comparison of the three slope methods is shown in table 1 as an example. Each slope value represents cell slope at a certain distance from the channel on an individual flowpath. Using the exponential method to calculate a representative slope gradient resulted in a value closer to the higher end of the cell slope range. The linear average method, as its name implies, results in an average

Table 1. Examples of slope calculations using the three averaging methods with different cell slope and flowpath values.

Cell Slope Values (%)	Flowpath[a] Area (m^2)	Length (m)	Slope Value (%) Linear Average	Exp. Trans.[b]	Weighted Average
7	125	25			
5	125	25	5.00	6.04	3.33
3	500	100			
6	125	25			
4	125	25	5.00	5.31	5.00
5	500	100			
1	125	25			
5	125	25	5.00	7.93	8.33
9	500	100			

[a] 5 m cell sizes used as an example for flowpath area and length.
[b] Exp. trans. = exponentially transformed average.

Table 2. Average annual soil detachment, sediment deposition, and sediment yield for simulations using each of the Hillslope methods to create representative slope profiles for Watkinsville watershed P2.

	Soil Loss (kg/m^2)	Deposition (kg/m^2)	Sediment Yield (kg/m)
Top hillslope			
Linear average	1.458	–2.868	96.50
Exp. trans. average	1.469	–2.911	97.15
Weighted average	1.536	–2.429	98.15
Right hillslope			
Linear average	0.641	–0.744	20.63
Exp. trans. average	0.646	–0.735	20.82
Weighted average	0.635	–0.945	19.28
Left hillslope			
Linear average	0.667	–0.786	41.86
Exp. trans. average	0.676	–0.814	42.40
Weighted average	0.687	–0.605	41.23

slope value, and the weighted average value depends on the actual flow lengths and drainage areas of the flowpaths. Table 1 shows how these values can differ in a variety of situations. However, these are only three examples with different slope values. It was therefore important to study what happens when using actual DEMs from research watersheds, in which each cell within each flowpath has a slope value.

Watkinsville watershed P2 will be discussed here as an example of the application of the three methods to create a representative slope profile with an actual DEM. The slope profiles calculated by the three methods are shown in figure 5 for the top hillslope in the P2 watershed, and one can see that there were only minimal differences between the three profiles. WEPP model simulation results of average annual soil detachment, sediment deposition, and sediment yield for all P2 hillslopes are presented in table 2. There were no significant differences in the soil loss, deposition, or sediment yield results between any of the methods used for this watershed. Furthermore, soil loss along the profile was simulated for each of the methods, and again there were no significant differences between them.

Similar results were obtained from all of the other watersheds, indicating that the representative profiles created by the three methods did not differ significantly. Table 3 shows hillslope sediment average annual yields for the Watkinsville and Holly Springs watersheds, which contain three hillslopes each. These results as well as soil loss

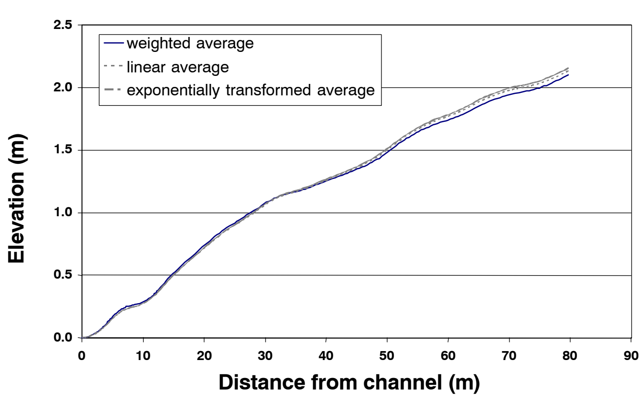

Figure 5. Representative slope profiles using three different methods to represent slope values from multiple flowpaths for the top hillslope profile of Watkinsville watershed P2.

along the profiles show that there is no significant statistical difference between them, even for $\alpha = 0.01$. Similar results were obtained for the seven hillslopes in the Treynor W2 watershed. Similarly, average yearly watershed outlet results were comparable with measured values from each of the watersheds.

The explanation for the lack of difference between representative profile methods originates from the fact that flowpaths within a hillslope follow a path towards the channel that is perpendicular to elevation contour lines. Thus, at equal distances from the channel, most flowpaths have similar slope values. When the equations were applied to these slope values, the resulting representative slopes were not significantly different.

The fact that similar representative slope profiles were calculated by the three methods for all six watersheds is very important. First of all, this means that any of the equations can be used to create a representative slope profile for the hillslopes extracted from a DEM for the watersheds in this study. For the variety of watersheds and hillslopes that were

Table 3. Sediment yield results for the three representative slope methods (all values in kg/yr).[a]

Watershed[b]	Hillslope	Weighted Average	Linear Average	Exp. Trans. Average
Watkinsville P1	Top	13900	16700	16700
	Left	16400	17700	18100
	Right	9180	9550	9770
Watkinsville P2	Top	5330	5130	5240
	Left	2300	2310	2320
	Right	8770	8650	8730
Holly Springs WC1	Top	36100	39600	40000
	Left	7660	8130	8190
	Right	24600	24800	24900
Holly Springs WC2	Top	5840	5910	5940
	Left	4470	4560	4600
	Right	8030	8330	8360
Holly Springs WC3	Top	2310	2530	2560
	Left	2330	2350	2380
	Right	5500	5560	5600

[a] Statistical t–tests show there is no significant difference between the methods at $\alpha = 0.01$.
[b] The Chanleng method was used to obtain hillslope length for these simulations.

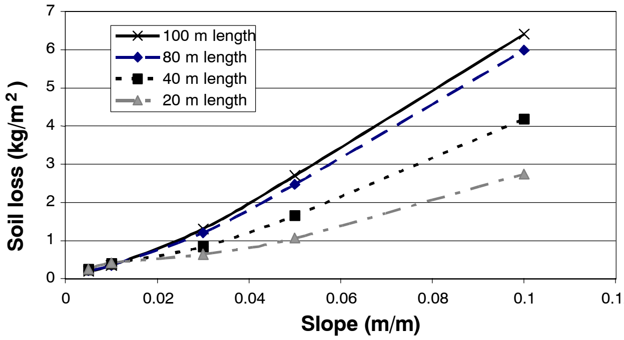

Figure 6. Soil loss predicted by WEPP as a function of slope and length using soil and management conditions of the P2 research watershed in Watkinsville, Georgia.

studied, there is no need to use different equations for different watersheds. However, since one equation has to be chosen for use, we recommend the weighted average method. The weighted average method is theoretically the more robust approach, as it takes into account the drainage area of each flowpath.

The reason the weighted method was chosen is that in extreme cases, where there may be a wider range of flowpath lengths for the hillslope, the length of these slopes can be important. To better illustrate this point, slope is plotted against predicted soil loss in figure 6 using actual conditions of a small watershed in Watkinsville, Georgia. In this example, it is clearly seen that the relationship between slope and soil loss is not linear and in fact may be exponential in nature. Slope length also plays an important role in the relationship between slope and soil loss, as shown in both figures 6 and 7. In figure 7, predicted erosion changes abruptly from a constant value to a variable value depending on slope and length. This change in scale of events between interrill and rill erosion occurs more rapidly as slope increases, which adds to the non–linear nature of the effects of slope and length on soil loss. Similar non–linear relationships between slope and soil loss were observed when using data from the other watersheds. Field experiment studies, such as the work of Zingg (1940), have also shown the non–linear effects of slope steepness and length on soil loss.

An additional example of the importance of taking into account flowpath lengths is presented in figure 8. In this

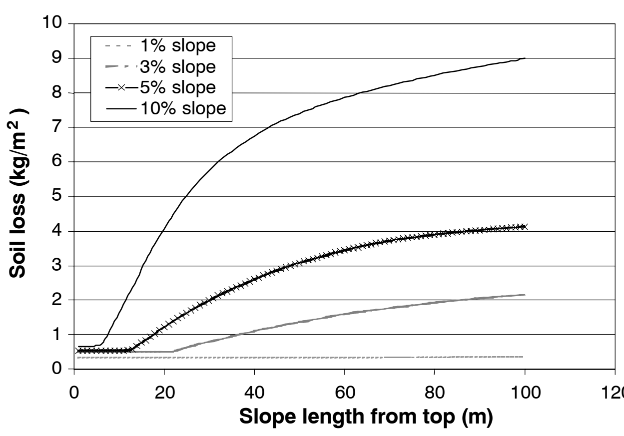

Figure 7. Soil loss predicted by WEPP as a function of hillslope length for different uniform slopes using soil and management conditions of Watkinsville watershed P2.

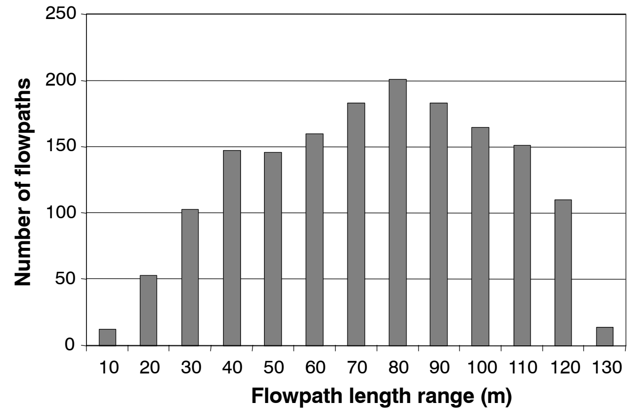

Figure 8. Number of flowpaths in ranges of lengths at 1 m resolution for top hillslope of Watkinsville watershed P2.

figure, an example of the distribution of observed flowpath lengths is shown for the top hillslope of Watkinsville watershed P2 using a DEM with 1 m resolution. Even though this distribution of short and long flowpaths did not have a significant effect on the prediction of erosion, in other extreme cases where there is a greater distribution, it may have an effect. This supports the argument that the weighted average method should be used because it takes into account the varied lengths and drainage areas of all of the flowpaths, which in some extreme cases can make a difference. The weighted average method was used in all subsequent simulations and evaluations of the Hillslope methods in this study.

Representative Slope Profile Lengths

The length of the representative slope profile is an important aspect of the discretization process used in the Hillslope methods. Since a WEPP hillslope is represented as a rectangular surface with a fixed width and length, calculations are greatly simplified in a GIS when the width of the hillslope can be set to the length of the adjacent channel, as is done in the adjacent hillslopes with the Chanleng method. However, this may not produce an adequate representation of the hillslope, and results of runoff or sediment yield may be biased. We conducted model simulations to determine if calculating a representative hillslope length provides better results than defining the length of the hillslope by matching the width of the hillslope with the length of the adjacent channel.

Table 4 shows the results of the comparisons between the Chanleng and Calcleng methods as well as comparisons to measured values. The statistical comparisons between measured and simulated events using the six different watersheds showed that the Chanleng and Calcleng methods predicted similar runoff and sediment yield for most conditions. The P–values in table 4 indicate a statistical analysis of the direct comparison between all events for the Chanleng and Calcleng methods. Large P–values (greater than 0.05) indicate that there was no significant difference between the methods for runoff and sediment yield values from the watershed outlet. In general, however, the P–values were larger for the sediment yield simulations than for the runoff simulations. Cochrane and Flanagan (1999) and Liu et al. (1997) reported that there were differences between observed and simulated runoff results for the Holly Springs WC1 and

Table 4. Comparisons of Calcleng and Chanleng methods for all watersheds.

Watershed	No. of Events	Measured Mean[a] Runoff (m^3), Sediment Yield (kg)	Calcleng Mean Runoff (m^3) (RMSE), Sediment Yield (kg) (RMSE)	Chanleng Mean Runoff (m^3) (RMSE), Sediment Yield (kg) (RMSE)	P–value[b]
Treynor	40	1490	1360 (8780)	1370 (8760)	0.889
W2		29500	39200 (340000)	36000 (316000)	0.347
Watkinsville	36	392	338 (1430)	348 (1440)	0.091
P1		5340	4480 (50155)	4380 (48300)	0.657
Watkinsville	55	123	86 (708)	86 (708)	0.934
P2		529	518 (5270)	528 (5370)	0.658
Holly Springs	284	193	148[c] (2150)	146[c] (2150)	0.111
WC1		344	844 (38700)	879 (41100)	0.928
Holly Springs	257	89	59[c] (941)	59[c] (942)	0.069
WC2		155	285 (10500)	283 (10500)	0.733
Holly Springs	255	67	59 (734)	59 (734)	0.079
WC3		114	166 (8680)	154 (8090)	0.615
Total RMSE:		Runoff	9260	9240	
		Sediment Yield	346000	323000	

[a] Student t–tests, ANOVA, and F–test showed no significant difference between measured events and methods unless indicated.

[b] P–values for the difference between all events of the Calcleng and Chanleng methods: values greater than 0.05 indicate no significant difference between measured and methods values of runoff and sediment yield for the watershed outlet.

[c] Significant difference from measured runoff value at $\alpha = 0.05$.

WC2 watersheds due to possible problems in representing plant and cover relationships.

There were no significant differences, however, in results between the two methods tested here, even though total RMSE values showed that the Chanleng method performed slightly better. The determination of the length of the hillslope seemed to affect runoff more than sediment yield predictions, but in general the differences between the methods were not significant. Given these results, the use of the Chanleng procedure for automated representative slope length determination is recommended. Theoretically, the Chanleng method is more representative in watershed simulations because the contribution from the hillslope to the channel should be made all along the channel length. Structurally, for the application of WEPP, the Chanleng method is also better because of the ease of computation and consistency between channel segment lengths and widths of adjacent hillslope regions. In either case, however, the computational method of the Calcleng method is used to calculate the slope length for hillslopes draining to the top of channels.

Summary and Conclusions

Research was conducted with the objectives of developing, describing, and evaluating methods of automatically creating representative slope profiles and hillslope lengths for the WEPP model using GIS and DEMs. Three methods of creating representative slope profiles from flowpaths were evaluated, and two methods of calculating a representative slope profile length (Chanleng and Calcleng) were developed for watershed modeling and discretization using grid–based DEMs. The TOPAZ program was used to help in the discretization of watershed features such as hillslopes, channels, and flowpaths. The ArcView GIS was used as the platform for a WEPP–GIS interface. Programming was conducted in FORTRAN and ArcView's object–oriented programming language Avenue. Six research watersheds were used to evaluate the methods, and results were compared against each other and against measured sediment yield data.

The three representative slope profile methods tested were the linear average method, the exponentially transformed average method, and the weighted average method. These methods represent a wide range of techniques used to create a representative slope profile for each hillslope within a watershed. The representative slope profile lengths were derived using the Chanleng and Calcleng methods. In the Calcleng method, a representative hillslope length was calculated by a method of weighting flowpath lengths and flowpath drainage areas. This same weighting procedure was used for hillslopes draining to the top of channels in the Chanleng method, but the lengths of hillslopes were calculated differently for hillslopes draining to the sides of channels. In the Chanleng method, for hillslopes adjacent to a channel, the hillslope width was set to equal the channel length, and the hillslope length was calculated by dividing the total area of the hillslope by its set width.

The studies and research on WEPP and GIS using the six research watersheds resulted in the following conclusions. The three methods for determining the representative slopes of the profiles were not significantly different from each other. However, hypothetical examples of extreme cases favor the weighted average approach because this method takes into account the length and drainage area of each possible flowpath. Sediment yield predictions using the Chanleng and Calcleng methods were not significantly different from the observed sediment yields measured at the watershed outlets. There were no significant differences in runoff, soil loss, or sediment yield results in comparisons between the Chanleng and Calcleng methods. The Chanleng method is favored, however, because it is a more realistic representation of the interaction between hillslopes and channels within a watershed and has favorable implications for GIS modeling by matching the hillslope width to the length of the adjacent channel.

The interface developed as part of this work, using the weighted average method to determine representative slope gradients and the Chanleng method to determine slope length on hillslopes, facilitates the application of WEPP to watersheds when DEM data is available. These procedures have also been incorporated into improved software called GeoWEPP (Renschler et al., 2002). These interfaces can help users who are not very familiar with WEPP by automatically defining the required components, and they can also help expert WEPP users in rapidly simulating different conservation scenarios.

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