CHAPTER 4

APPLICATION TO WATERSHEDS

The Hillslope and Flowpath methods described in Chapter 3 were evaluated using observed data from the ARS experimental watersheds at Treynor, Iowa, Holly Springs, Mississippi, and Watkinsville, Georgia. Additionally, the six watersheds were also simulated using a Manual method. The Manual method represents an expert's application of WEPP to these watersheds. The purpose of simulating the watersheds using a Manual method was twofold. First, the actual performance of WEPP on these watersheds was evaluated. Second, the performance of the automation procedures of the Hillslope and Flowpath methods could be compared to the Manual application. Each method was applied using the same soils, crops, and climate data files. The slope files for the Manual application were created by an expert user selecting representative slope profiles directly from the original topographic maps. The slope files for Hillslope and the Flowpath method were computed using the highest resolution DEM available as discussed in Chapter 3. A DEM with a 5 meter resolution was used for the Treynor watershed and 1 meter DEMs were used for the other watersheds. The analyses, results, and discussion of these applications are presented in this chapter.

4.1. Analyses

A variety of analyses were conducted on all six watersheds to compare the different methods using predicted vs. measured results. The WEPP event-by-event output from each simulation was compared to runoff and sediment loss for each measured event. Event-by-event predictions are important for assessing the model's ability to predict the accurate distribution of events over time. Total runoff and sediment losses from the watershed outlet were also compared and are defined to be the sum of all events where measurements were not zero. Total runoff and sediment loss predictions are important for assessing the long-term effect of watershed soil loss. This can include the effects of sedimentation and water quality in downstream reservoirs and streams, and associated watershed conservation planning.

Additional analyses were also conducted for comparing the methods using runoff and sediment yield from only hillslopes. Since these comparisons excluded simulations of channel erosion, measured watershed outlet results could not be used. However, they were appropriate for comparing the results and performance between methods.

A visual representation of comparisons between the Manual and Hillslope methods was created by plotting predicted vs. measured runoff and sediment yield and using a best-fit regression line as an indicator of fit (Figure 4.1). The coefficient of determination, r^2, indicates the variance about the best-fit line. The slope and intercept of each regression line show the bias between predicted and measured data for the two methods. Tabular data with statistical analysis of all simulations are presented in Table 4.1 for runoff and Table 4.2 for sediment loss. A visual comparison of all three methods for total hillslope erosion is shown in Figure 4.2. Tabular data showing hillslope and channel erosion are provided in Table 4.3.

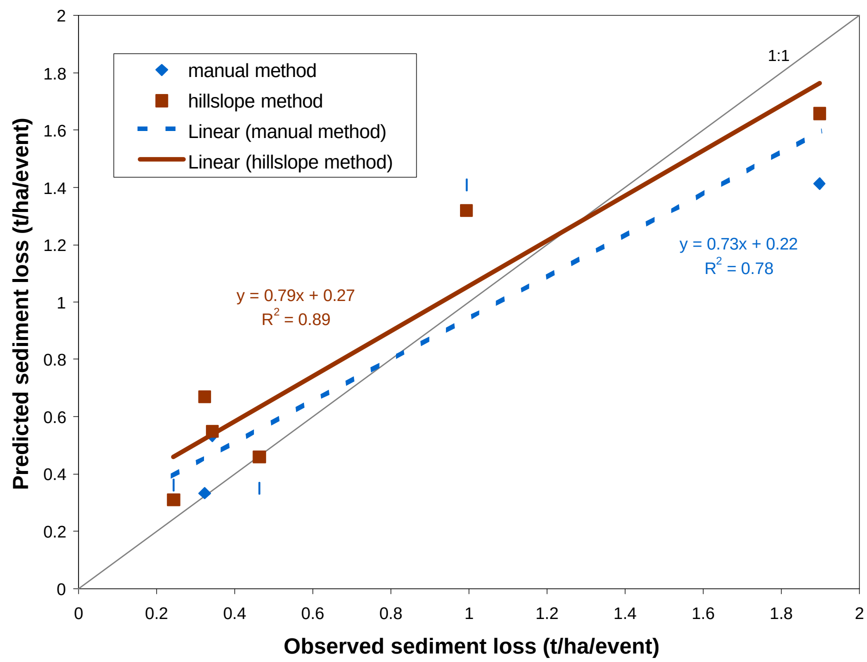

Figure 4.1. Total sediment loss from each watershed (normalized by watershed area and number of events).

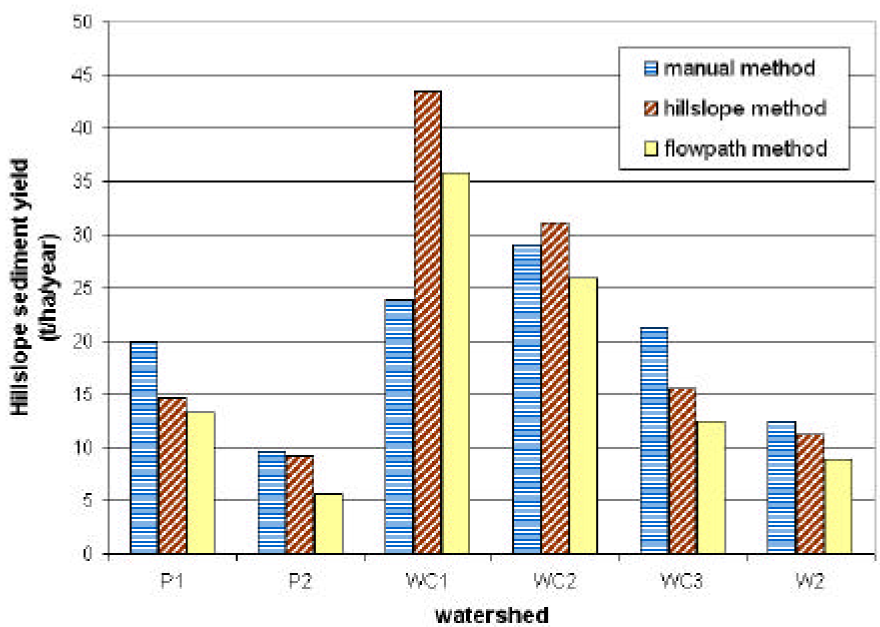

Figure 4.2. Comparison of hillslope sediment yield between methods (channels excluded).

Table 4.1. Runoff and percent deviations of measured events.*

		Runoff in m^3, (% Deviation from observed)			
		Observed	Manual	Hillslope	Flowpath
Watkinsville, p1 36 measured events	Total	**13530**	**11050(18)**	**12170(10)**	**11420(15)**
	Mean	376	307	338	317
	S.D.	482	406	466	430
	Range	29-2202	0-1457	0-1663	0-1557
Watkinsville, p2 55 measured events	Total	**6670**	**4620(31)**	**4730(29)**	**4410(34)**
	Mean	121	84	86	80
	S.D.	228	169	184	169
	Range	16-1151	0-757	0-875	0-815
Holly Springs, wc1 284 measured events	Total	**58780**	**34860(41)**	**41960(29)**	**40970(30)**
	Mean	207†	123	148	144
	S.D.	257	195	223	215
	Range	2-1538	0-1465	0-1674	0-1624
Holly Springs, wc2 257 measured events	Total	**22900**	**14840(35)**	**15160(34)**	**14760(35)**
	Mean	89†	58	59	57
	S.D.	108	84	87	84
	Range	1-787	0-611	0-636	0-616
Holly Springs, wc3 255 measured events	Total	**17370**	**14500(17)**	**15130(13)**	**14510(16)**
	Mean	68	57	59	57
	S.D.	94	92	93	89
	Range	1-667	0-669	0-679	0-652
Treynor, w2 40 measured events	Total	**59620**	**50880(15)**	**54580(8)**	**60790(2)**
	Mean	1490	1272	1365	1520
	S.D.	2139	2578	2665	2584
	Range	93-11031	0-11935	0-12033	0-11695

* Means were tested using student t-test, Duncan's, and Tukey's comparisions of means, all of which gave the same decision results for hypothesis testing at α=0.05. The means of the observed and methods are not statistically different at the 95% confidence level unless otherwise marked.

† Observed and method means were statistically different at the 95% confidence level.

Table 4.2. Sediment yield and percent deviations for measured events.*

		Sediment yield in kg, (% Deviation from observed)			
		Observed	Manual	Hillslope	Flowpath
Watkinsville, p1 36 measured events	Total	**184490**	**137430(26)**	**161210(13)**	**100060(46)**
	Mean	5125	3817	4478	2779
	S.D.	10645	8779	11314	6676
	Range	53-50000	0-41100	0-54300	0-32600
Watkinsville, p2 48 measured events**	Total	**28640**	**21690 (24)**	**28500 (<1)**	**17050 (40)**
	Mean	597	452	594	355
	S.D.	2051	1043	1688	1167
	Range	0-12810	0-5860	0-10651	0-7717
Holly Springs, wc1 207 measured events**	Total	**104870**	**108200 (3)**	**217770(116)**	**306270(192)**
	Mean	507	523	1052	1480
	S.D.	3803	2830	5192	7805
	Range	3-53300	0-35600	0-59900	0-89700
Holly Springs, wc2 199 measured events**	Total	**40150**	**62610(56)**	**64490 (60)**	**82930(106)**
	Mean	202	315	324	417
	S.D.	1601	1415	1486	2132
	Range	1-22152	0-16899	0-17820	0-25646
Holly Springs, wc3 187 measured events**	Total	**29520**	**43900(49)**	**37630 (27)**	**43770 (48)**
	Mean	158	235	201	234
	S.D.	821	1133	929	1170
	Range	1-7476	0-13672	0-10871	0-13679
Treynor, w2 40 measured events	Total	**1181150**	**1674140(42)**	**1568820(33)**	**1469590 (24)**
	Mean	29529	41853	39220	36740
	S.D.	70345	92080	86491	83222
	Range	907-333800	0-375753	0-363200	0-366100

* Means were tested using student t-test, Duncan's, and Tukey's comparisions of means, all of which gave the same decision results for hypothesis testing at α=0.05. The means of the observed and methods are not statistically different at the 95% confidence level unless otherwise marked.

** Number of observed sediment yield events from watershed P2, WC1, WC2, and WC3 were less than measured runoff events for the same watersheds.

Table 4.3. Total WEPP predicted erosion from hillslopes and channels (kg).*†

	Manual method			Hillslope method			Flowpath method
Watershed Name	hillslopes	channels	% channel deposition	hillslopes	channels	% channel deposition	
P1	160900	156300	3	118500	182400	-35	107700
P2	37300	30600	22	35700	37500	-5	21900
WC1	300600	164800	82	546300	316800	72	449100
WC2	136700	92800	47	146700	96000	53	122200
WC3	111000	64800	71	81100	55200	47	64800
W2	2173100	1738800	25	1946100	1635000	19	1547200

* Means of hillslopes for the three methods were tested using student t-test, Duncan's, and Tukey's comparisions of means, all of which gave the same decision results for hypothesis testing at α=0.05. The means were not statistically different at the 95% confidence level.

† Total values may be higher than in Table 4.2 because these include predicted values that were not measured.

The Nash-Sutcliffe Coefficient of model efficiency, NS, was also used as a statistical criterion for evaluating hydrologic goodness of fit between measured and predicted values for each method. This coefficient is calculated as follows (Nash and Sutcliffe, 1970):

$$NS = 1 - \frac{\sum_{i=1}^{n} (Q_i - Q^*{}_i)^2}{\sum_{i=1}^{n} (Q_i - \overline{Q})^2} \qquad [4.1]$$

Where Q_i are the measured values (e.g., sediment leaving watershed) on an event-by-event basis, $Q^*{}_i$ are model predicted values on an event-by-event basis, $\overline{Q}$ the average of measured values (average of all events), and *n* is the number of values. An NS value of 1 indicates a perfect fit between measured and predicted values for all events. A value of zero indicates that the fit is as good as using the average value of all the measured data for each event. The NS values for each watershed are presented in Tables 4.4 and 4.5 for runoff and sediment loss respectively.

Table 4.4. Nash-Sutcliffe model efficiency coefficients for event runoff predicted by the three methods.

	Nash-Sutcliffe Coefficient (NS)		
Watershed	Manual	Hillslope	Flowpath
Watkinsville, p1	0.76	0.77	0.76
Watkinsville, p2	0.82	0.83	0.80
Holly Springs, wc1	0.64	0.70	0.69
Holly Springs, wc2	0.68	0.70	0.68
Holly Springs, wc3	0.77	0.76	0.76
Treynor, w2	0.57	0.57	0.58

Table 4.5. Nash-Sutcliffe model efficiency coefficients for event sediment loss predicted by the three methods.

	Nash-Sutcliffe Coefficient (NS)		
Watersheds	Manual	Hillslope	Flowpath
Watkinsville, p1	0.50	0.39	0.48
Watkinsville, p2	0.67	0.87	0.74
Holly Springs, wc1	0.84	0.54	-0.63
Holly Springs, wc2	0.79	0.79	0.60
Holly Springs, wc3	0.23	0.42	0.13
Treynor, w2	0.36	0.40	0.47

For long-term comparisons, predicted vs. measured total runoff or sediment yield normalized by number of events were plotted together with a regression line fit. Another criterion for long term assessments of predicted vs. measured data is the percent deviation of runoff volume, D_v. This is computed with the following equation:

$$D_v(\%) = \left| \frac{V - V^*}{V} \cdot 100\% \right| \qquad [4.2]$$

Where *V* is the measured runoff volume and *V** is the predicted runoff volume. Percent deviation of total sediment loss can also be computed in a similar fashion. These values are presented as part of Tables 4.1 and 4.2 for total runoff and sediment loss.

4.2. Results and discussion

4.2.1. Runoff

The predicted watershed outlet runoff from the Manual and Hillslope methods included contributions from both hillslopes and channels. The simulations using the Flowpath method assumed that the runoff leaving the watershed was the summation of all runoff entering the channel at specific points along the channel. In other words, it was assumed that the channel was merely a conduit to route the runoff from the hillslopes to the watershed outlet. Using this reasoning, the simulation of runoff from the Flowpath method was compared to measured runoff and simulations of runoff from the Manual and Hillslope methods.

The Nash-Sutcliffe model efficiency coefficient was calculated for all measured runoff events for each of the six watersheds (Table 4.4). Nash-Sutcliffe coefficient values ranged from 0.57 to 0.82, indicating that all three methods produced WEPP simulations that satisfactorily predicted runoff for events over time. There was little variation in Nash-Sutcliffe coefficient values between the Manual, Hillslope, and Flowpath methods. The percent deviation of runoff volume was also calculated for all watersheds using the total runoff volume leaving each watershed for all measured events (Table 4.1). Comparisons of means between the three methods showed no statistical difference, but comparisons to the observed measurement showed that there were statistical differences for the Holly Springs WC1 and WC2 watersheds when using an alpha value of 0.05 (Table 4.1). Differences between observed and WEPP predicted runoff for the Holly Springs WC2 watershed were also reported by Liu et al. (1997). For the Holly Springs WC1 watershed, Liu et al. (1997) did not find differences between the observed and predicted means for runoff, but only 237 selected events from the 284 observed runoff events were analyzed. The additional events could have contributed to the difference between observed and predicted. The presence of some differences in predicted and observed runoff doesn't necessarily suggest that WEPP performs poorly or worse than other models, but is rather a reinforcement of the knowledge that erosion predictions in general contain large factors of error (Liu et al., 1997).

4.2.2. Sediment yield

The Nash-Sutcliffe model efficiency coefficients for sediment loss for all watersheds ranged from –0.63 to 0.87 (Table 4.5). Total sediment loss and percent deviation are presented in Table 4.2. As expected the Flowpath method shows great variability in predicting sediment loss from the watersheds as a result of not simulating erosion in the channels as seen by low NS values and high percent deviations of some watersheds. This effect can either increase or decrease prediction rates depending on whether the channel is erodible or acts as a sediment trap. Table 4.3 shows predicted hillslope erosion for the three methods and percent channel deposition for the Manual and Hillslope method. It is apparent that the three Holly Springs watersheds have channels that are in an advanced depositional mode, whereas the Watkinsville watersheds' channels may not be in such a dramatic depositional mode. Comparisons of hillslope sediment yield between the three methods suggest that they predict similar results, however a visual observation of Figure 4.2 suggests that the Flowpath method's predictions are consistently lower than the Hillslope method. As mentioned in Chapter 3, this may be due to the simulation of a large number of short flowpaths. WEPP simulations of short flowpaths will produce low sediment yields and when these are averaged with the simulations of the other flowpaths, the overall predictions will be lower than those of a single longer representative slope profile as is the case with the Manual and Hillslope methods.

Sediment yield results are comparable between the Manual and Hillslope methods because channels were modeled in both methods. Figure 4.1 shows that both Manual and Hillslope methods performed similarly for total sediment loss for all watersheds. The regression lines indicate both a good fit and a low variance about the lines for the Manual and Hillslope method. The slope and intercept of the regression fit show that the Hillslope method predicts slightly higher values than the Manual method. The figure also shows that for lower observed sediment losses both methods over-predict whereas for large sediment losses the methods under-predict observed values. This is consistent with ideas presented by Nearing (1998) on why soil erosion models over-predict small soil losses and under-predict large soil losses.

From the NS values and the percent deviations of watershed WC1, the Manual method seemed to perform better, while for watersheds P2, WC3, and W2 the Hillslope method appeared better. For the other watersheds, both methods performed equally well. It is believed that the observed discrepancy in accuracy of predictions of the two methods for watershed WC1 is that it has a more complicated topography and channel structure that was modeled in greater detail by the Manual method. As was mentioned in Chapter 3, the original manual application divided this watershed into 9 hillslopes and 3 channels, whereas the Hillslope method only divided the watershed into 3 hillslopes and 1 channel. The other watersheds are either smaller, such as WC2 and WC3, or have less topographical or channel structure complications. The results for the Holly Springs watersheds show an over-prediction of sediment yield (Table 4.2). This is consistent with observations made by Liu et al. (1997) who suggest that this is due to an over-prediction bias for low magnitude erosion events probably due to problems in representing plant and cover relationships. It was also specifically mentioned that the growth of weeds was not well represented by the WEPP model for these watersheds. The channels of these watersheds also acted as sediment traps which, together with the over-prediction of small events, would help to explain large percent deviations of total sediment loss obtained.

One of the biggest advantages of the Flowpath method is that hillslope boundaries do not have to be delineated, which removes the burden of defining hillslopes. Another advantage is the ability to obtain spatially distributed results of erosion or deposition within a watershed as can be seen for Treynor watershed W2 in Figure 4.3. These results can be visually displayed on an event-by-event basis or on a cumulative basis. This visualization approach can be useful in identifying areas of severe erosion within the watershed, but caution should be used when interpreting quantitative results. Spatially distributed results within watersheds have not yet been validated (spatially distributed erosion measurements for watersheds over time are currently not available or are limited to small data sets). However, there are efforts under way to study distributions of erosion within watersheds using specialized tracers such as magnetic beads, which could eventually be used to validate the spatial distribution of erosion within watersheds using the Flowpath method.

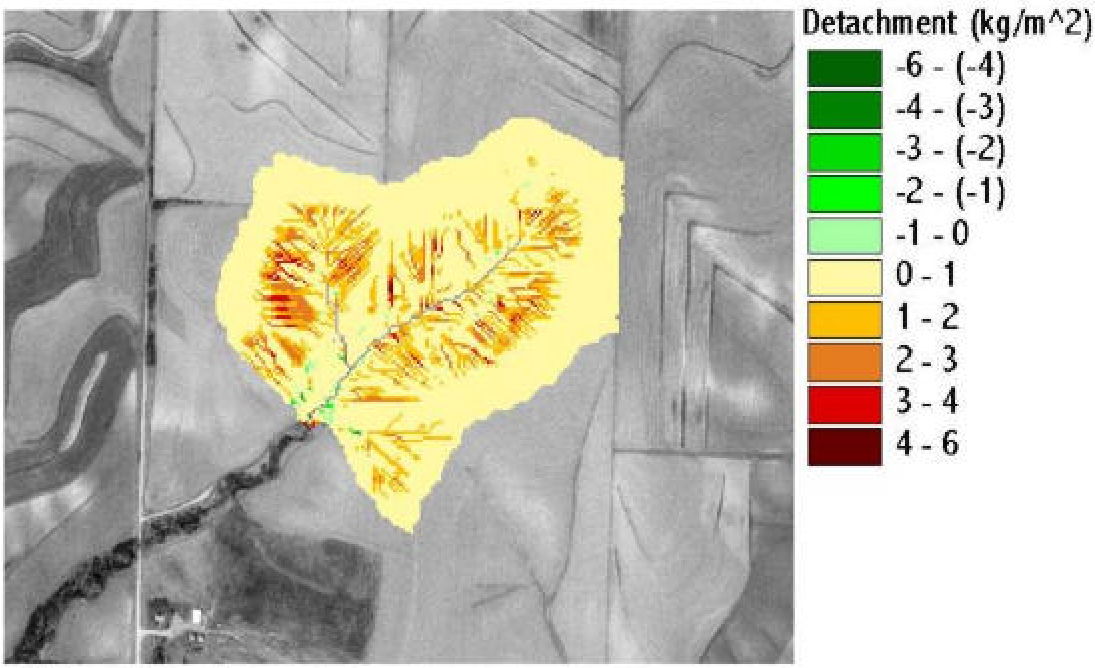

Figure 4.3. Sediment detachment and deposition from flowpath application of WEPP on Treynor watershed W2 over a 6 year period.

There are also other limitations to the application of the Flowpath method. One of them is that it is computationally intensive. Since the resolution of the DEMs of all the watersheds was relatively fine (1m for the smaller watersheds and 5m for the large Treynor watershed), the number of flowpaths in each watershed was very high. For example, for Watkinsville watershed P2, 4671 runs of the hillslope version of WEPP were made. Other watersheds required less runs but were still in the thousands range. Furthermore, the Flowpath method as well as the Hillslope method, relies on DEMs to extract topographic parameters, which leads to the question of what resolution DEM is appropriate for use. This topic will be further examined in Chapter 5.

4.3. Conclusions

The Manual and Hillslope methods were comparable and produced reasonable results for most of the watersheds studied. Simulations of Holly Springs watersheds WC1 and WC2 produced mean event runoff values that were not statistically similar to the observed means, but there was no significant difference between the two prediction methods. No significant differences were observed between the measured sediment loss values and those predicted by the two methods. The Treynor and Watkinsville watersheds were well simulated with both methods for runoff and sediment loss.

The main advantage of the Hillslope method over the Manual method is that major components (e.g., hillslopes, channels, and slope profiles), required for a WEPP model application, are extracted automatically from a DEM. This saves the user valuable time when assessing water erosion in watersheds and can allow the user to quickly assess conditions with different management practices. However, for topographically complicated conditions or watersheds with complicated channel structures, the Manual method has the flexibility to allow the user to model these situations. The main advantages of the Hillslope method over the Flowpath method are that it is less computationally intensive and that it can handle channel erosion.

The Flowpath method is comparable to both the Manual and Hillslope methods for hillslope erosion predictions. However, to apply the Flowpath method to watersheds, development of an adequate channel routing mechanism or modifications of the original WEPP code to enable distributed lateral inflow to channels is necessary. Currently, the advantages of this method over the others are that discretization of hillslopes is not necessary and it has the ability to more easily create visual representations of the results within the watershed.

Ideally the best system would be to provide the user with a combination of the three methods. The Hillslope method facilitates the application of WEPP through an automated simulation and the Manual method would allow the user to verify the simulation and make any pertinent changes. Furthermore, the Flowpath method could be used in situations where hillslopes are difficult to delineate or when severe erosion or deposition locations have to be identified inside the watershed. However, additional research into the effect of DEM resolution on predictions by each method is needed to further identify the best method. This research is presented in the next chapter.