4th International Conference on Integrating GIS and Environmental Modeling (GIS/EM4): Problems, Prospects and Research Needs. Banff, Alberta, Canada, September 2 - 8, 2000.

Application of the WEPP model with digital geographic information

GIS/EM4 No. 149

Dennis C. Flanagan
Chris S. Renschler
Thomas A. Cochrane

Abstract

The Water Erosion Prediction Project (WEPP) is a process-based continuous simulation erosion model that can be applied to hillslope profiles and small watersheds. One limitation to application of WEPP (or other models) to the field or farm scale is the difficulty in determining the watershed structure, which may be composed of multiple channels and profiles (and potentially other features as well). This presentation describes current efforts to link the WEPP model with Geographic Information Systems (GIS) and utilize Digital Elevation Model (DEM) data to generate the necessary topographic inputs for erosion model simulations. Two automated approaches for applying the WEPP model have been developed and compared to manual application of the model. The first approach (named the Hillslope method) uses information from a DEM to delineate the watershed boundary, channel and hillslope locations, and then configure "representative" hillslope slope profiles from the myriad flowpath data. The second approach (named the Flowpath method) also uses DEM information to delineate the watershed boundary, but then runs WEPP model simulations on every flowpath within a watershed. For a set of research watersheds, the automatic Hillslope method performed as well as a manual application of WEPP by an expert user in predictions of runoff and sediment loss. Tests also showed that the Hillslope and Flowpath methods were not significantly different than each other or different from manual model applications in predictions of hillslope erosion. Additional research work ongoing at the National Soil Erosion Research Laboratory is examining the feasibility of using commonly available digital elevation data (for example from on-vehicle Geographical Positioning Systems (GPS)) to provide input for the automated techniques for driving the erosion model.

Keywords

Soil erosion prediction, process-based model, DEM, WEPP.

Introduction

The Water Erosion Prediction Project (WEPP) model was developed from 1985-1995, by the United States Departments of Agriculture and Interior, and was publicly released in 1995 for application on cropland, rangeland, forestland, and other managed lands (Flanagan and Nearing 1995). WEPP simulates the important physical processes that result in soil erosion by water. The model contains a climate generator, simulates surface and subsurface hydrology, irrigation, plant growth, residue decomposition, effects of tillage, soil detachment by raindrop impact and flowing water, sediment transport and deposition. At the time of its initial release, basic DOS interface programs were provided to assist users in creating input files, managing groups of simulation runs, and generating and viewing output. Since about 1997, next generation Windows™ compatible interfaces for WEPP have been under development and work is near completion on a graphical watershed interface.

However, even with an excellent graphical interface, anything but relatively simple watersheds can still become too difficult for model users to delineate, because of the potentially large numbers of channel nodes and hillslope profiles required. Approaches are needed that can access and use digital elevation data to delineate watershed boundaries, channel locations and slope, hillslope profile locations, and profile topographic inputs required by the erosion model. Additionally, good quality digital elevation data is lacking in many locations in the world, so another current research area is examining the possibility of using elevation data obtained from on-vehicle Geographical Positioning Systems to provide topographic input data for erosion models.

The watershed and hillslope modeling work described here involves linkage of the WEPP model with the ArcView™ 3.0 GIS (software developed by Environmental Systems Research Institute, Inc.) and TOPAZ (TOpographic PArameteriZation tool, developed by the USDA-Agricultural Research Service). TOPAZ (Garbrecht and Martz 1997) was used to delineate watersheds, locate channels, delineate hillslope profiles, and provide information on flow paths within the profiles. New techniques were developed and evaluated to determine representative slope profile inputs based upon the flow paths. ArcView™ was used to process and display the erosion model inputs and outputs.

Problem statement

The major problem addressed by this area of work is "Can automatic techniques be developed and used to delineate a watershed into a reasonable representation of what is physically present, and provide for accurate predictions of runoff and soil loss?" In other words, does a delineated watershed have the proper area, number of hillslope profiles and number of channels? Are the hillslope profiles equivalent to those defined by an expert user, and can they produce model simulation results that are comparable to measured runoff and sediment loss data? Also, if fine resolution DEM data is lacking, are there other commonly available sources of data that can be used to drive the automatic techniques, and what is their impact on model simulation results?

Background

Integration of WEPP or other erosion prediction models with a GIS can facilitate and possibly improve the application of the technology. Savabi et al. (1995) applied the WEPP model at the Purdue University animal science watershed, using a GIS to obtain some of the physical parameters required by WEPP. However, digital elevation data was not available or used in that study. The primary layer required in a GIS to delineate hillslopes and channels is a topography map. Topography is usually represented in a GIS as a Digital Elevation Model (DEM) or a Triangular Irregular Network (TIN). Most DEMs are grid-based, where each elevation point is represented by a cell of a certain size or resolution. Flow-routing algorithms that determine the steepest descent direction and gradient between cells can be used to delineate watershed boundaries, hillslopes and channels. Moore et al. (1991) and Desmet and Govers (1996) provide descriptions of many current flow-routing algorithms. These types of procedures have often been used to integrate simple erosion equations such as the Universal Soil Loss Equation (USLE) (Wischmeier and Smith 1978) with GIS. The ANSWERS, AGNPS, and SWAT (Srinivasan and Arnold 1994) models also all use flow-routing algorithms and GIS maps to predict erosion or runoff. Thus, watershed analysis using digital geographic information has good potential for parameterization of hillslopes, channels, and representative slope profiles for WEPP model simulations.

Methods

The work presented in this paper falls into two areas. First, we present information on approaches to automatically delineate watersheds into hillslopes and channels and conduct WEPP model simulations. Second, we describe a recent study to obtain digital elevation data for an agricultural watershed from commonly available GPS technology.

Automatic watershed and hillslope delineation

In terms of automation of WEPP applications through GIS linkage, two automated approaches were developed and tested against manual applications of the model to a set of six research watersheds which had well-documented soil, management, climatic, topographic, runoff, and soil loss data. The manual application of the model used topographic slope profile inputs to WEPP created by erosion prediction experts, who had for their use field observations, aerial photographs, and detailed contour maps of the sites (Kramer 1993, Liu et al. 1997). WEPP model inputs assume rectangular hillslope areas contributing water and sediment laterally and/or to the top of channel segments (Figure 1).

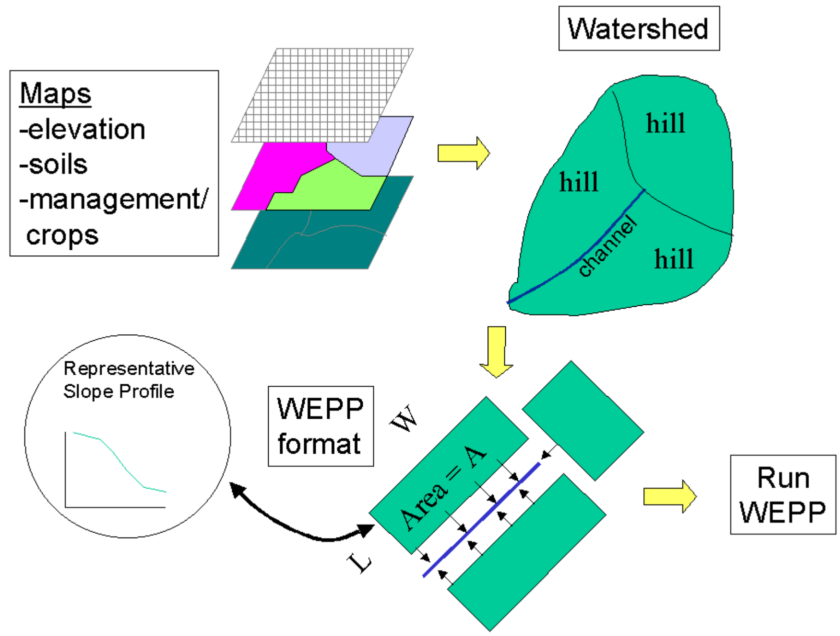

Figure 1. Steps in discretizing a watershed for a WEPP model simulation.

The test watersheds used were one from Treynor, Iowa, three from Holly Springs, Mississippi, and two from Watkinsville, Georgia, with watershed area ranging from 0.6 to 29 ha (Table 1). A TIN for the Treynor watershed was obtained by aerial surveys with ground control (90 points per hectare). For the Holly Springs and Watkinsville watersheds, elevation data were obtained from field survey maps with 5 ft contours, which were digitized. A grid-based DEM was then created for each watershed.

Location	Watershed	Years of simuation	Area [ha]	Soil type / series	Main soil texture	Crops
Treynor, IA	W2	1985-1990	29	Monona-Ida-Napier	Silt loam	Corn
Watkinsville,GA	P1	1972-1974	2.7	Cecil	Sandy loam / sandy clay loam	Wheat sorghum, barley, soybean, clover
Watkinsville, GA	P2	1973-1975	1.29	Cecil	Sandy loam / sandy clay loam	Corn, bermuda grass

Holly Springs, MS	WC1	1970-1977	1.57	Grenada	Silt loam	Soybean, meadow
Holly Springs, MS	WC2	1970-1977	0.59	Grenada	Silt Loam	Corn, wheat, soybean
Holly Springs, MS	WC3	1970-1977	0.65	Grenada	Silt loam	Corn, wheat, soybean

Table 1. Research watersheds used in testing automatic procedures.

Hillslope method

The first automated approach (named the Hillslope method) uses information from a DEM to delineate the watershed boundary, channel and hillslope locations, and then configures a single "representative" slope profile from the flow path information. TOPAZ (Garbrecht and Martz 1997) is used for extraction of flow routing features in a watershed, and was chosen for its ability to overcome problems that other techniques have with drainage in depressions and over flat surfaces (Garbrecht et al. 1996). Additional computer programming in the FORTRAN language was used to process the watershed structure and flow path information generated by TOPAZ into the required WEPP model structure and representative slope profile inputs.

A critical source area (CSA) must be selected first to allow determination of channel location and lengths. The CSA used with a DEM represents a drainage area whose concentrated water flow defines the beginning of a channel (Garbrecht and Martz 1997). Additional channel parameters needed by the WEPP model (width, shape, erodibility, etc.) must be supplied by the user.

In this method, the hillslopes can drain to the left, right, and top of the channels created from the DEM (Figure 1). Individual flowpaths are extracted by analyzing the output files from the TOPAZ program. Flowpaths are the route that water travels when flowing from one cell to the next, and an individual flowpath starts from a cell that no other cells flow into and ends at a channel. A weighted average of all possible flowpaths in the hillslopes is then used to determine a representative slope profile.

Flowpaths are weighted by their area and length, and each cell length of a flowpath is compared to all other matching cell lengths from flowpaths starting from the channel and moving upslope. Flowpaths having greater area and longer lengths were assumed to contribute more than the smaller and shorter ones to the representative profile. Since cells are square, when flow is in a diagonal fashion the flow length is longer than when flow is moving horizontally or vertically into a cell, hence the need to weight by both area (number of cells) and length. The following equation is used to compute the slope gradient at points down a representative profile:

(Notation 1)

where E_i is the weighted slope value for all flowpaths at a distance i from the channel; z_{pi} is the slope of flowpath p at a distance i from channel; and k_p is a weighting factor for flowpath p. Weighting was by multiplication of the upstream drainage area (a_i, area of cells in the flowpath) times the flowpath length ($k_i = a_i * l_i$). Since Notation 1 will predict a profile with a length equal to the longest flowpath, it was also necessary to determine the appropriate length of the profile. For hillslopes feeding channels laterally, the width of the hillslope was set equal to the length of the channel. The length of the hillslope was then calculated by dividing the total hillslope area by the width. The representative profile was then truncated at the top, so that total length was equal to the calculated length starting at the bottom of the hillslope. For hillslope areas draining into the top of a channel, a representative length was determined using an equation similar to Notation 1 from Garbrecht et al. (1996). Once the length is determined, the width of the representative profile is easily calculated by dividing the total hillslope area by this length. See Cochrane and Flanagan (1999) for more details on the procedure.

Flowpath method
The second automated approach (named the Flowpath method) also uses the DEM information to delineate the watershed and hillslope boundaries, but then runs WEPP model simulations on every flowpath within a watershed. The locations where all flowpaths enter a channel are identified, and runoff and sediment delivery to the channel at each point are determined. Width of the individual flowpaths is calculated by dividing the total area of all flowpaths draining to a particular point on a channel by the length of the individual flowpath.

WEPP simulation of channel runoff, detachment or deposition is not performed in the Flowpath Method as the software is currently operational. This is because there are potentially hundreds or thousands of flowpath entry points to a channel, which greatly exceeds the number of allowable channel segments in WEPP (currently limited to a maximum of 75 unique channel segments). A comparison of the Flowpath method to observed soil loss results from the watershed outlets would thus be appropriate only if there is no significant scouring or deposition in the channels. However, erosion on hillslopes can always be compared between the manual, Hillslope, and Flowpath methods.

Other sources of digital topography data

High quality digital elevation data is often not readily available, thus there is a need to explore commonly available topographic information that may be of some usefulness in soil erosion model simulations. Common types of electronic topography data include USGS on-line data, as well as elevation data obtained from GPS technology.

In the U.S., there is total coverage of the land area with elevation data provided by the United States Geological Survey (USGS 2000). The DEM data obtainable is at the 1:24,000 map scale with a 30 m pixel size. While this resolution may be sufficient to delineate watershed boundaries, it might be too coarse to provide for good soil erosion model predictions. The USGS also has a limited set of DEM data available for download at the 1:24,000 map scale with a 10 m pixel size. At this resolution, in addition to delineating watershed boundaries, the data may be sufficient to conduct soil erosion model simulations and expect satisfactory prediction results (Renschler et al. 2000).

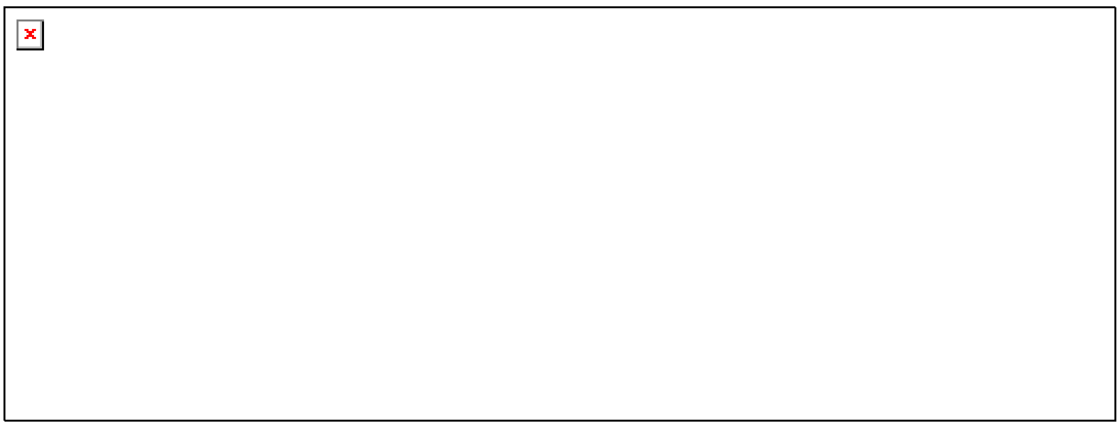

Figure 2. Field experiment in March 2000 to collect elevation data with typical GPS units.

Many agricultural producers are purchasing equipment that integrates precision farming electronics into their tractors, harvesters, and chemical application implements. At the heart of these devices is a Global Positioning System (GPS) that allows for accurate spatial locating of crop yield variability, pest outbreaks, and soil fertility levels. While the latitude and longitude GPS data is of prime interest in precision farming applications, the GPS can also provide elevation data, that may prove useful in soil erosion model simulations.

An experiment was conducted in late March 2000, on Watershed 2 at the USDA Deep Loess Research Station near Treynor, Iowa, to test GPS data accuracy and impact on WEPP model simulations. Four GPS systems were installed on two All Terrain Vehicles (ATV), ranging from a relatively simple and typical farm grain yield monitor to a very expensive, high quality GPS unit (Figure 2). The ATVs travelled at typical field operation speed (5 mph) and followed contours of the watershed at approximately the intervals between passes of a farm harvester (5 m). Elevation data from the GPS instruments is being compared to the previous DEM for the watershed derived from aerial photography, as well as to data from a ground survey using laser equipment conducted at the same time as the GPS measurements. Additionally, data filtering techniques are being examined to enhance the elevation readings. The effect of the various GPS data sources and processing on WEPP model predictions of runoff and soil loss will be studied.

Results and discussion

The automatic techniques for setting up WEPP model watershed simulations were found to produce runoff and soil loss predictions that were not significantly different than those from the manual application of WEPP by an expert user. Since the Hillslope method is the only automatic procedure that currently allows application of the watershed version of WEPP with channel detachment or deposition, it can be directly compared to observed sediment yield from the watersheds (Figure 3). In general, the automatic Hillslope method resulted in WEPP model simulations as good as manual ones by expert users, and the model predicted sediment loss closely matched the observed sediment loss. Cochrane and Flanagan (1999) provide more extensive details of the simulation results, as well as examination of the impacts of DEM resolution.

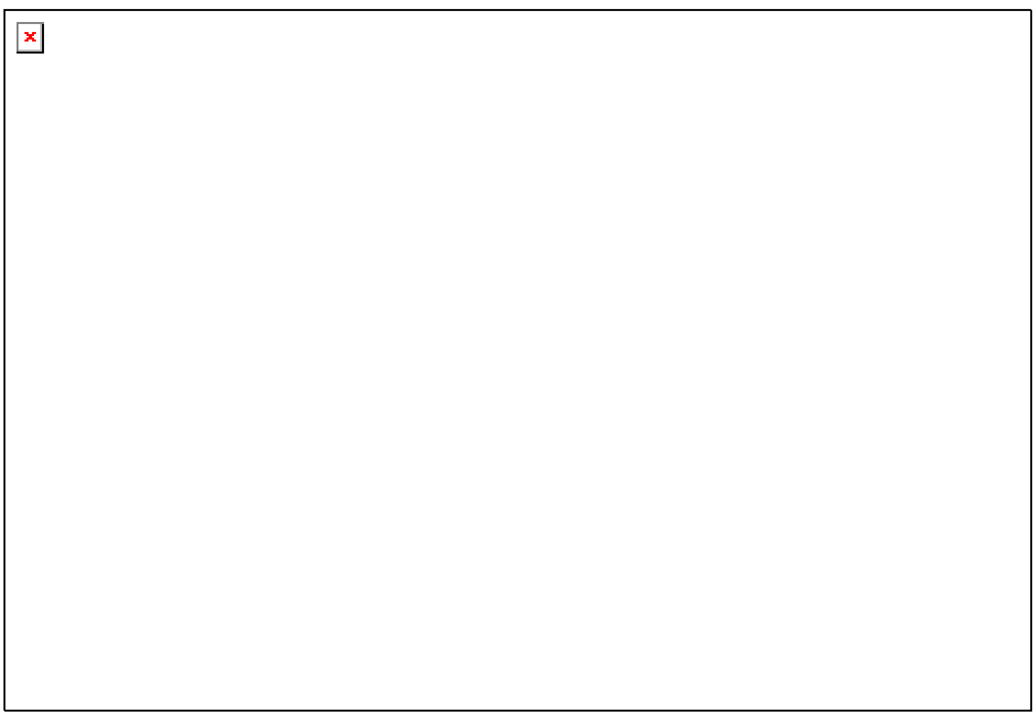

Figure 3. Comparison of WEPP model predicted to observed sediment delivery using data
from the six research watersheds (values normalized by watershed area and number of events).

In terms of comparisons of manual application, the Hillslope method, and the Flowpath method on predictions of total sediment yield from only the hillslope areas within a watershed, the results are presented in Table 2. Statistical tests (student t-test, Duncan's, and Tukey's) at the 95% probability level found that the values for sediment yield predicted for each watershed did not significantly differ as a function of the watershed discretization procedure used (Cochrane and Flanagan 1999).

Watershed	**Manual method**			**Hillslope method**			**Flowpath method**
	Hillslopes [t]	Channels [t]	Channel deposition [%]	Hillslopes [t]	Channels [t]	Channel deposition [%]	Hillslopes [t]
W2	160.9	156.3	3	118.5	182.4	-35	107.7
P1	37.3	30.6	22	37.7	37.5	-5	21.9
P2	300.6	164.8	82	546.3	316.8	72	449.1
WC1	136.7	92.8	47	146.7	96.0	53	122.2
WC2	111.0	64.8	71	81.1	55.2	47	64.8
WC3	2,173.1	1,738.8	25	1,946.1	1,635.0	19	1,547.2

Table 2. Total WEPP predicted sediment yield (t) from hillslopes and channels based on different application methods for the six research watersheds.

Data processing, exploration of filtering techniques, and WEPP model simulations and comparisons using the experimental GPS data sets obtained in the spring of 2000 are still ongoing. However, some preliminary observations can be made from the GPS data collection and data processing activities. These are:

1. In the field, the costliness of a GPS unit does not always equate to ease-of-use and reliability. The lower cost commercial grain yield monitor was one of the easiest to use systems, and very reliable in terms of continuously recording elevation data.
2. Filtering and processing software will likely be necessary to convert the raw elevation data into a form suitable for representing topography and conducting erosion model simulations. This is due to the potential for equipment failure, satellite signal loss, farming operations that involve equipment remaining stationary for periods of time, and lack of coverage of an entire watershed area in a single operation.

3. Visual observations of the collected raw GPS data indicate that there is good potential to use this information in some way, if only to delineate watershed boundaries and channel locations.

Conclusion

Automatic watershed and hillslope delineation procedures show promise in being able to accurately represent topographic features in field situations. In the work reported in this presentation, the automatic techniques did as well as a manual application of the WEPP model in predicting sediment yield from hillslopes and small watersheds when using high quality DEM data. Elevation data obtained from on-vehicle GPS units also appears to be promising as a potential new source of topographic data for erosion model predictions.

Recommendations for future research

Much additional research is needed to make WEPP erosion prediction technology easier to apply to field-sized small watersheds. This work includes:

1. Taking the procedures developed in the automatic watershed discretization research project, and fully implementing them with graphical user interfaces to allow relatively easy application of WEPP with a GIS when appropriate DEM data is available.
2. Expansion of the automatic techniques to allow for nonuniformity of soils and management within hillslope areas. The current procedures were developed using a simplistic approach that assumes a single soil and management for an entire hillslope, whereas this would be the exception in most real world situations.
3. Complete analysis of the experimental GPS data, including determination of the most appropriate filtering procedures. Examination of the effect of the type of GPS system and quality on watershed and hillslope delineation, and ultimately on WEPP model runoff and soil loss predictions. Comparison of results from use of the GPS data to those using topographic data from other sources.

References used

Cochrane TA, Flanagan DC. 1999. Assessing water erosion in small watersheds using WEPP with GIS and digital elevation models. J. Soil & Water Conserv. 54(4):678-685.

Desmet PJJ, Govers G. 1996. Comparison of routing systems for DEMs and their implications for predicting ephemeral gullies. Intern. J. GIS 10(3):311-331.

Flanagan DC, Nearing MA. 1995. USDA-Water Erosion Prediction Project Hillslope Profile and Watershed Model Documentation. NSERL Report 10, USDA-ARS National Soil Erosion Research Laboratory, West Lafayette, IN. (See also: <http://topsoil.nserl.purdue.edu/weppmain/wepp.html>. Accessed 2000 June 29.)

Flanagan DC, Livingston SJ. 1995. WEPP User Summary. NSERL Report 11, USDA-ARS National Soil Erosion Research Laboratory, West Lafayette, IN.

Garbrecht J, Starks PJ, Martz LW. 1996. New digital landscape parameterization methodologies. Proc. 32nd Annual Conf. & Symp. on GIS & Water Res., American Water Resources Association, Herndon, VA, TPS-96-3, p. 357-365.

Garbrecht J, Martz LW. 1997. TOPAZ: An automated digital landscape analysis tool for topographic evaluation, drainage identification, watershed segmentation and subcatchment parameterization: Overview. ARS-NAWQL 95-1, US Department of Agriculture, ARS, Durant, Oklahoma.

Kramer LA. 1993. Application of WEPP 93.005 to HEL watershed. ASAE Paper 93-2051, American Society of Agricultural Engineers, St Joseph, MI.

Liu BY, Nearing MA, Bffaut C, Ascough II JC. 1997. The WEPP watershed model: III. Comparisons to measured data from small watersheds. Trans. of the ASAE 40(4): 945-952.

Moore ID, Grayson RB, Ladson AR. 1991. Digital terrain modeling: A review of hydrological, geomorphological, and biological applications. Hydro. Proc. 5:3-30.

Renschler CS, Engel BA, Flanagan DC. 2000. Strategies for implementing a multi-scale assessment tool for natural resource management: a geographical information science perspective. In this issue: Problems, Prospects and Research Needs. Proceedings of the 4th International Conference on Integrating GIS and Environmental Modeling (GIS/EM4); 2000 Sep 2-8; Banff, Alberta, Canada.

Savabi MR, Flanagan DC, Hebel B, Engel BA. 1995. Application of WEPP and GIS-GRASS to a small watershed in Indiana. J. Soil & Water Cons. 50(5):477-483.

Srinivasan R, Arnold JG. 1994. Integration of a basin-scale water quality model with GIS. Water Res. Bulletin 30(3):453-462.

USGS. 2000. U.S. Geodata Server. <http://edc.usgs.gov/doc/edchome/ndcdb/ndcdb.html>. Accessed 2000 May 29.

Wischmeier WH, Smith DD. 1978. Predicting Rainfall Erosion Losses - A Guide to Conservation Planning. U.S. Department of Agriculture, Agricultural Handbook 537. 85 p.

Authors

Dennis C. Flanagan, Agricultural Engineer, USDA-Agricultural Research Service National Soil Erosion Research Laboratory, 1196 Building SOIL, West Lafayette,

Indiana, 47907-1196 USA.
Email: flanagan@purdue.edu, Tel: +1-765-494-7748, Fax: +1-765-494-5948.

Chris S. Renschler, Assistant Professor, University at Buffalo - The State
University of New York, Department of Geography, 116 Wilkeson Quad, Buffalo,
New York, 14261, USA.
Email: rensch@buffalo.edu, Tel: +1-716-645-2722 ext. 23, Fax:+1-716-645-2329.

Thomas A. Cochrane, Agricultural Engineer, Consultant,
AGTECA S.A., Casilla Postal 6329, Santa Cruz, Bolivia.
Email: cochrane@agteca.com, Tel: +55-43-9994-6878, Fax(USA): +1-775-637-8298