



## **GEOSPATIAL APPLICATION OF THE WATER EROSION PREDICTION PROJECT (WEPP) MODEL**

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## ABSTRACT

The Water Erosion Prediction Project (WEPP) model is a process-based technology for prediction of soil erosion by water at hillslope profile, field, and small watershed scales. In particular, WEPP utilizes observed or generated daily climate inputs to drive the surface hydrology processes (infiltration, runoff, ET) component, which subsequently impacts the rest of the model, including subsurface hydrology (percolation, subsurface lateral flow), hillslope erosion (interrill & rill detachment, sediment transport & deposition), channel hydrology/erosion (channel flow routing, detachment, sediment transport, deposition), plant growth, and residue decomposition. At the hillslope profile and/or field scale, simple Windows graphical user interfaces (GUIs) have been developed to easily specify the slope, soil, and management inputs. Likewise, simple watershed configurations of a few hillslopes and channels can be easily created and simulated with this GUI. However, as the catchment size increases, the complexity of developing and organizing all WEPP model inputs greatly increases, due to the multitude of potential variations in topography, soils, and land management practices. For these types of situations, numerical approaches and special user interfaces have been developed to allow for easier WEPP setup, utilizing either publicly-available or user-specific geospatial information (Digital Elevation Models (DEMs), Geographic Information System (GIS) soil layers, GIS land-use layers). The basic approach used to automatically generate the slope input files for hillslope profiles is to analyze and process a DEM of an area in three iterations: 1) channel network delineation, 2) watershed boundary and subcatchment delineation, and 3) flow-path and representative hillslope profile determination. The TOPAZ digital landscape analysis tool is used for channel, watershed, and subcatchment delineation. In whichever interface is being used, once a user selects a rectangular region of interest within a DEM, TOPAZ delineates the network of channels within that region. The user then selects the outlet point on a channel for their watershed of interest, after which TOPAZ is run again to delineate the watershed boundary and its subcatchments (that will subsequently be used as WEPP hillslopes). The final step before the actual erosion model simulations is to create the slope, soil and management input files for WEPP, using custom software (called Prepwepp) taking data from the extracted land use, soils, DEM, and TOPAZ watershed structures. Specifically, in regards to the hillslope profile slope inputs, there are two options for running WEPP: 1) creating a single representative hillslope profile slope input for each subcatchment based upon an averaging of all the computed flowpaths within a subcatchment; and/or 2) running WEPP model simulations for all TOPAZ-identified flowpaths within each subcatchment. The model slope inputs for each of the channels within the delineated watershed also are obtained from the TOPAZ output. A user has the option of specifying a single soil and land management for each subcatchment, or utilizing information in soil and land use GIS layers to automatically assign these. Once WEPP runs are completed, output is scanned (by Prepwepp), results interpreted, and maps of spatial soil loss are generated and sent to the GIS for display. These procedures have been used within a number of GIS platforms. GeoWEPP is an ArcView/ArcGIS extension that was the first to be developed, and which allows experienced GIS users the ability to import and utilize their own detailed DEM, soil, and/or land use information, or to access commonly available spatial datasets. An initial web-based GIS system that uses the MapServer web GIS software for handling and displaying the spatial data and model results was released in 2004. Most recently, the Google Maps and OpenLayers technologies have been integrated into the web GIS software and WEPP model to provide some significant enhancements over the earlier prototype. This presentation will discuss in detail the logic and procedures for developing the WEPP model inputs, a variety of WEPP GIS interfaces, and future directions.

**KEYWORDS.** Geographic information systems, Soil erosion, Prediction, WEPP.

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## **INTRODUCTION**

WEPP is a process-based, distributed parameter, continuous simulation, erosion prediction model, implemented for use on personal computers (Flanagan and Nearing, 1995). The main computer program was developed by a large team of federal government scientists, university researchers, and action agency representatives from 1985-1995, with an official model release ceremony in Des Moines, Iowa in July 1995. At the time of release, the software available was a science model written in FORTRAN, and a rudimentary DOS-based interface written in the C-language. A Windows-based stand-alone interface written in the C++ language was subsequently created by USDA-ARS (Flanagan et al., 1998) for hillslope profile and small watershed simulations. GIS-linked model applications were also initially created in the late 1990's, and web-based applications of the model have been developed by several agencies as well since then. This paper will describe a variety of WEPP model geospatial interfaces, the procedures used within the software programs for creating the necessary WEPP model inputs, and display of the model outputs.

## **BACKGROUND**

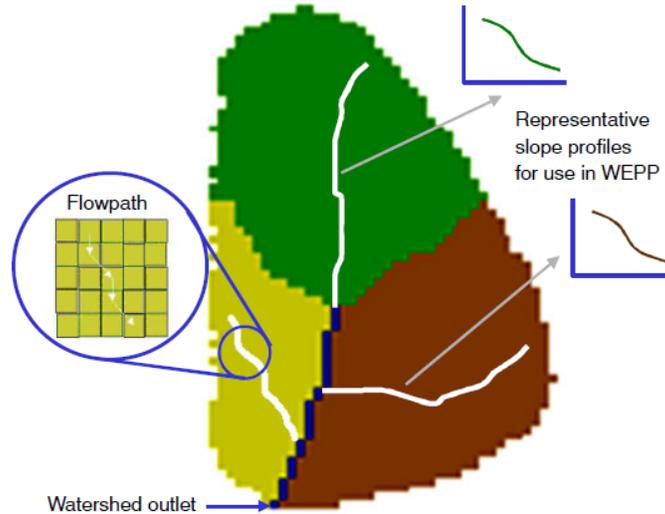
WEPP is a large and complicated physically-based soil erosion prediction model, based upon the fundamentals of soil hydrologic and erosion science. The FORTRAN model (v2010.1) currently consists of 230 subroutines that simulate a myriad of processes, including water infiltration into soil, surface runoff, soil detachment by raindrops and by flow shear stress, sediment deposition, soil water percolation, evapotranspiration, plant growth, residue management and decomposition, and irrigation.

The WEPP model can be applied to either hillslope profiles (1-100 m in length) or small watersheds (up to about 260 ha) which are comprised of multiple hillslopes, channels and impoundments. For a hillslope profile model simulation, the minimum input requirements to the model are climate, slope, soil, and cropping/management input files. In watershed simulations, additional inputs needed are a watershed structure file, channel parameter files (for each channel), and impoundment parameter files (for each impoundment, if any). All inputs to WEPP are in flat ASCII text files, which makes it relatively easy for the creation of user interfaces by either the model developers, or by outside user groups. For example, ARS has created several WEPP interfaces (Windows, GIS-linked, web-based), while the Forest Service (FS) also has created a number of their own targeted web-based interfaces.

For application of the WEPP model to hillslope profiles, the standalone Windows interface (Flanagan et al., 1998) may be the best tool, in that it allows complete control of all of the model inputs. Thus, very detailed simulation studies can be conducted in which extremely nonuniform slope, soil, and/or cropping/management inputs can be described and identified spatially on the profile by hand. Observed climate data, including precipitation information from recording rain gauges, can also be processed into WEPP input format for continuous simulations, or single storm climate input files can be created.

Any of the several hundred WEPP model input parameters can be accessed and modified within the Windows interface. This is especially useful in a research situation, where large amounts of observed data related to surface cover conditions, soil moisture, soil texture, climate, etc. have been collected, and the model is being exercised in a calibration/validation study. For other types of hillslope profile simulations, such as model application by an action agency user, databases are available for climate, soils, and cropping/management that allow for very quick and easy model simulations of existing and alternative scenarios, for land management and soil conservation planning. The simple web-based hillslope model interfaces are also an attractive alternative for these types of applications, as they only require a computer with a web-browser and an internet connection.

When moving up in scale to a larger field or a small watershed, development of model inputs by hand becomes increasingly difficult and tedious, due to the increasing number of watershed elements (hillslope profiles, channels, impoundments) which must be identified, correctly placed in the watershed structure, and parameterized. At these larger scale applications, utilization of available spatial data sets, particularly topography (elevations), soils, and land use becomes extremely helpful.



**Figure 1. Example delineated watershed showing three subcatchments (hillslopes) and main channel (in blue). The inset shows a flowpath derived from a grid-based DEM (from Cochrane and Flanagan, 2003).**

## USE OF DIGITAL ELEVATION MODEL DATA

Cochrane and Flanagan (1999, 2003) described the development of two methods to integrate digital elevation models (DEMs) with the WEPP model. These procedures were named the Hillslope methods and the Flowpath method. The two Hillslope methods (Chanleng and Calcleng) consist of the discretization of the watershed into representative hillslopes and channels from a DEM (Cochrane and Flanagan, 2003). A channel network is extracted from a DEM using the critical source area (CSA) concept (Garbrecht and Martz, 1997), and then hillslopes are defined as the subcatchment areas that drain to the left, top, or right of each channel segment. A “representative” hillslope profile for a WEPP model simulation in a subcatchment is then created using the flowpath information derived from the DEM (Figure 1). All of the many flowpaths (which are the paths that water moves from a DEM grid cell of locally high elevation within a subcatchment, downwards cell-to-cell until it reaches a channel grid cell) can be obtained as output from the TOPAZ program (Garbrecht and Martz, 1997), and this output includes spatial location of points on the flowpath, distance from the terminal point on the channel along the flowpath, and the slope gradient at each point.

The representative profile is created by averaging all of the slope values on the flowpaths at distances away from a channel. The weighting utilizes the slope gradient values at the points along the flowpath, the entire contributing area of the flowpath (area of all the grid cells in that flowpath), and the entire length of the flowpath with the equation:

$$S_i = \frac{\sum_{p=1}^n s_{pi} * k_p}{\sum_{p=1}^n k_p} \quad (1)$$

where  $S_i$  is the weighted slope value at distance  $i$  from the channel for all flowpaths in a subcatchment,  $s_{pi}$  is the slope gradient of an individual flowpath  $p$  at distance  $i$  from the channel,  $k_p$  is the weighting factor for flowpath  $p$ , and  $n$  is number of flowpaths in the hillslope. The weighting factor is  $k_p = a_p * l_p$ , where  $a_p$  is the contributing area of a flowpath (sum of all contributing grid cell areas) and  $l_p$  is the entire flowpath length (Cochrane and Flanagan, 1999).

Following this, the actual representative hillslope length needs to be set. For hillslopes on the left and right side of a channel, the hillslope width is set equal to the channel segment length, and then the representative hillslope length is computed by dividing the total subcatchment area by the hillslope width (this is the Chanleng method). Since the initially computed representative profile will be as long as the longest flowpath, the actual final profile has to be truncated to the newly computed length, and all points above that length deleted.

For hillslopes that flow to the top of a channel, a representative profile length is computed using an equation similar to the previous equation:

$$L_R = \frac{\sum_{p=1}^n l_p * a_p}{\sum_{p=1}^n a_p} \quad (2)$$

where  $L_R$  is the representative hillslope profile length, and  $l_p$  is the flowpath length (Cochrane and Flanagan, 1999). The representative hillslope width is computed by dividing the total subcatchment area by the  $L_R$  value (this is the Calcleng method).

The WEPP model simulation is then run using the representative hillslope profile slope input that is unique for each subcatchment, and the channel slope input files as well as the watershed structure file derived from the DEM. Soil detachment or sediment deposition are computed at 100 points (or more) on each profile, and runoff and sediment delivery are predicted for each hillslope. Runoff and sediment from the hillslopes are then routed through the channels and impoundments to the watershed outlet. The runoff and sediment generated for each subcatchment are mapped back as output layers in the GIS interface being used. Since the representative profile that was simulated is rectangular and the actual subcatchments almost always irregular in shape, it is not possible to create maps of spatial soil loss and deposition for watershed simulations using representative hillslopes.

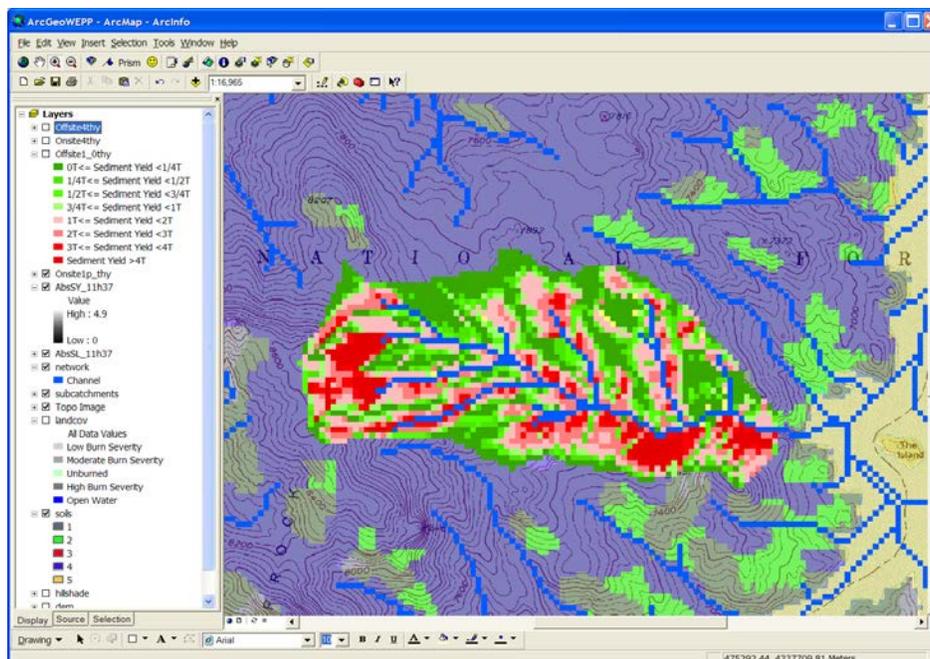
In the Flowpath method, we apply the WEPP model to all flowpaths within a watershed and each subcatchment. The slope gradient values along each flowpath are used directly in the WEPP slope input files. Depending upon the size of the watershed being simulated and the resolution of the DEM, there may only be a few representative hillslopes that are simulated, but several hundred (or thousand) individual flowpaths that are modeled.

When flowpaths are simulated by WEPP, they often converge, especially at lower slope positions adjacent to a channel. In these cases, the spatial soil loss results from multiple flowpaths that intersect in a single DEM grid cell are averaged. The output results for soil loss (or deposition) predicted at each grid cell are then mapped out for display within a GIS.

Some custom software programs have been created, to control the flow of information from a GIS and DEM into TOPAZ, handle the outputs from TOPAZ for watershed and subcatchment delineation, and process the TOPAZ flowpath output into slope file inputs required by the WEPP model for watershed and/or flowpath simulations. This software also handles WEPP model output, converting numerical information in ASCII files to graphical layers that the GIS can display (see Frankenberger et al., 2011).

## GEOWEPP

GeoWEPP was the first geospatial interface to the WEPP model (Renschler et al., 2002; Renschler, 2003). It was originally an ArcView 3.2 extension, which has subsequently been updated to function within the ArcGIS 9 system. The software was initially developed by ARS-NSERL and Purdue University, and is now available at the URL: <http://www.geog.buffalo.edu/~rensch/geowepp/>.



**Figure 2. Application of GeoWEPP to a burned forested region in Jefferson County, Colorado draining into the southwest portion of Cheesman Lake. Results for spatial soil loss from a 10 year model simulation shown.**

The GeoWEPP ArcGIS extension is used in conjunction with the standalone WEPP Windows interface (Flanagan et al., 1998) and the ArcGIS software (ESRI, 2011), installed on a personal computer. GeoWEPP allows a user to access and import commonly available topographic, soils, and landuse information, to conduct a WEPP model simulation. It utilizes the procedures described in the previous section to process data from a DEM using TOPAZ to create a channel network, delineate a watershed and subcatchments, and generate flowpaths for WEPP model slope inputs and development of representative hillslope profile slope inputs. Figure 2 shows output from an example application of GeoWEPP for a forested region in Colorado that had experienced a wildfire.

GeoWEPP is very useful for in-depth model applications by experienced GIS users, particularly those who are able to manipulate and process unique spatial topographic, soils, or landuse information. The main disadvantages of this software are that it requires substantial resources (high-end PC for GIS application, expensive ArcGIS software) and considerable GIS knowledge to successfully utilize custom datasets.

## WEB-BASED GEOSPATIAL WEPP INTERFACE

Shortly after the development of GeoWEPP, efforts began at the NSERL to create web-based interfaces to WEPP for both hillslope and watershed simulations. Other efforts in natural resource modeling had successfully been implemented on the Internet by Purdue University and elsewhere. The USDA-Forest Service had also created a number of easy-to-use web-based WEPP interfaces, targeted towards specific applications such as forest road design, timber harvest areas, and wildfire area remediation

(Elliot, 2004). Basic WEPP model applications for hillslope profiles can be conducted at the NSERL web site: <http://milford.nserl.purdue.edu/>.

The same general procedures for processing DEM data described earlier, and implemented within the GeoWEPP ArcView/ArcGIS extension were utilized in creating a prototype web-based WEPP GIS interface (Flanagan et al., 2004). This initial system used the open source MapServer environment originally developed at the University of Minnesota (<http://mapserver.org/>). The spatial data available on the server at the NSERL are:

- National Elevation Dataset from USGS, 30-m coverage for the US, that was pre-processed and clipped by state boundaries with a 1-km buffer.
- National Land Cover Dataset from USGS.
- STATSGO Soils Data from USDA NRCS at a regional scale with the SOILS5 ID linking to existing WEPP soils data. Only data for a very limited number of states was populated.
- Climate Data – Daily climate inputs are generated with CLIGEN (Nicks and Gander, 1994), the weather generator program for WEPP. The geographic location of the user's watershed determines the closest CLIGEN station data to use.

Users locate the area where the WEPP watershed model is to be applied by viewing topographic map images (digital raster graphs) and orthophotos. These data are not kept on the local NSERL server, but are instead retrieved on demand from TerraServer USA using the Web Mapping Services protocol. Other data such as roads, rivers, and county boundaries are kept on the local server and are also used for orientating the user. The image data are not used in making a WEPP model run.

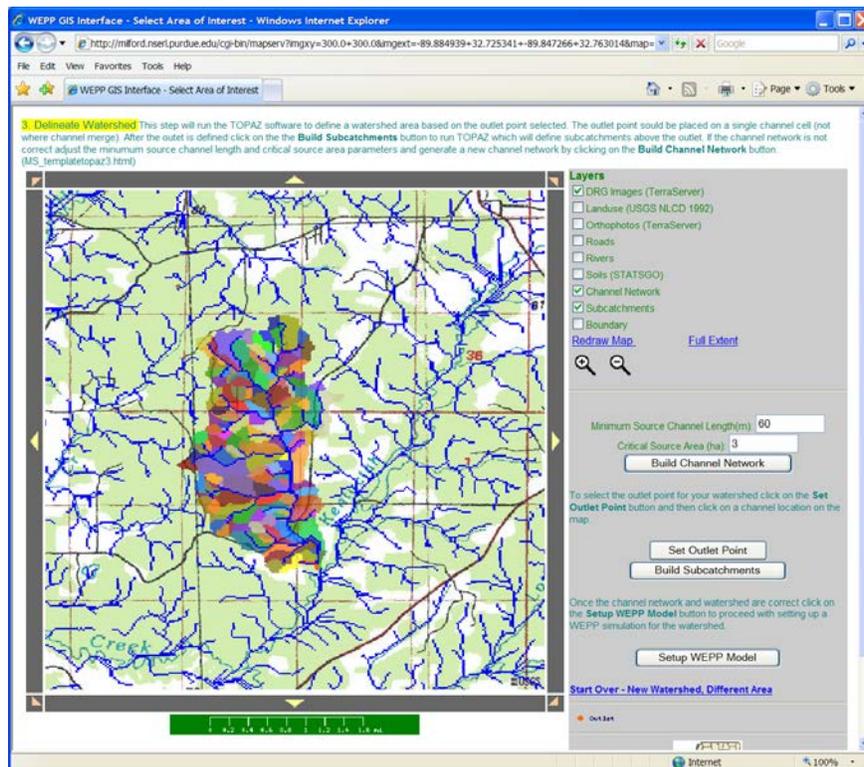


Figure 3. First generation WEPP web-based GIS interface using MapServer.

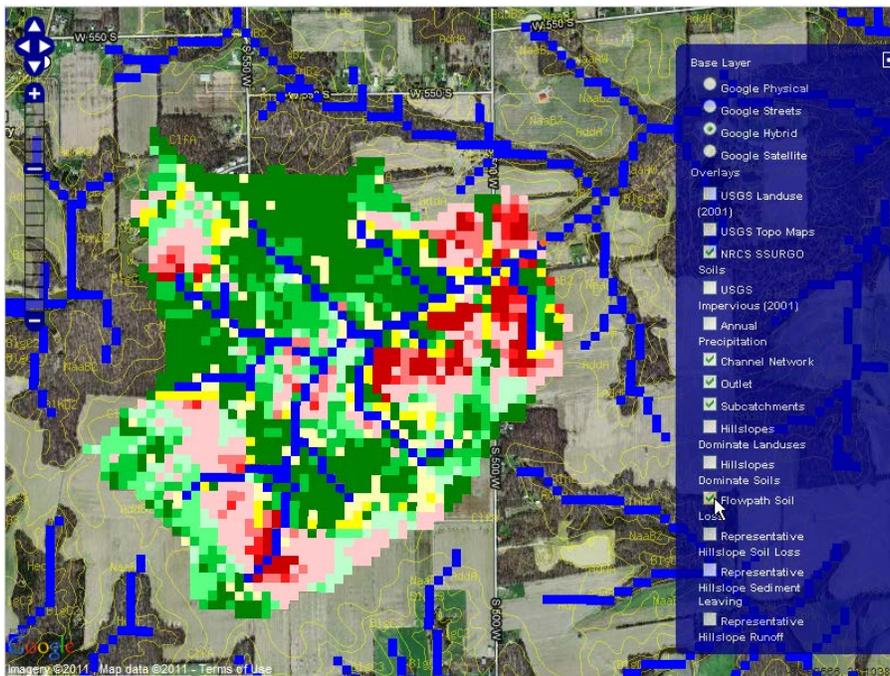
The current system is comprised of five major pieces of software. As a user zooms into an area of interest to model with WEPP, data for display is obtained from the TerraServer site and from local spatial data on the NSERL server. The MapServer GIS software sends image data to the client's Web-browser and handles requests for zooming and panning. When the exact location of interest is

identified, the custom NSERL TopazPrep software (written in C++ and PHP) handles extracting an area of the DEM to process with TOPAZ.

The first run of TOPAZ delineates the channel network, and then from the channel network the user selects a watershed outlet point. The second run of TOPAZ defines the watershed and subcatchments from the outlet. Area is limited to 0.25 degrees latitude by 0.25 degrees longitude, in order to ensure that TOPAZ can handle the extracted DEM and to allow for a reasonable response time. If the watershed delineated is acceptable, the Prepwepp program is executed which generates WEPP inputs from the extracted DEM, land use, soils and TOPAZ watershed structures. Prepwepp is also custom software written in C++ and PHP. WEPP is then run on the watershed (subcatchments and channels) and/or flowpaths and Prepwepp interprets the results and produces maps which are sent to the client using MapServer. A screen shot of this interface is shown in Figure 3, with channel networks, watershed and subcatchments shown, delineated with the TOPAZ program.

### CURRENT GEOSPATIAL WEPP INTERFACE DEVELOPMENT

During the past two years, development of a next-generation web-based WEPP GIS interface has been underway, through a cooperative project with the USDA-Forest Service (FS) and Washington State University (WSU), funded in part by a grant from the US Army Corps of Engineers, Great Lakes Research Initiative. Targeted initially towards forested watersheds bordering the Great Lakes, this new tool utilizes the most current technologies.



**Figure 4. Newest WEPP web-based watershed interface using OpenLayers and Google Maps, showing the spatial soil loss results of a 10-year model simulation in southern Indiana, just southwest of Columbus, Indiana.**

The web server is located at WSU, and is running the Ubuntu Linux distribution. PHP, HTML, and JavaScript languages were used to write the main user interface, while the open-source OpenLayers package (OSGeo, 2010) is utilized to display image layers in geo-referenced space. The interface supports connections to outside GIS data servers through the use of Web Mapping Services (WMS, OGC, 2006). The MapServer software, used in the previous WEPP web GIS interface, converts GIS data into images and does reprojections of data layers compatible with the Google Maps image layer. Other custom programs are used to clip the DEM data to the screen view, call TOPAZ, process the

TOPAZ outputs for channel, watershed, subcatchment, and flowpath delineations, invoke the WEPP model simulations for the watershed and/or flowpaths, and process the WEPP runoff, soil loss, and sediment yield output for display in the GIS. See Frankenberger et al. (2011) for more details. An example screen shot of the new interface for a small field watershed in Indiana is shown in Figure 4.

## CONCLUSION

Internet-based geospatial interfaces are very powerful tools that can allow even a novice WEPP model user to quickly and easily create and complete watershed evaluations for land management impacts on runoff, soil erosion, and sediment loss. The newest web-based WEPP GIS interface that has been developed provides additional features and functionality, which should be of great value to action agency personnel conducting watershed assessments.

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