GeoWEPP – The Geo-spatial interface for the Water Erosion Prediction Project

Chris S. Renschler

University at Buffalo – The State University of New York (SUNY), Department of Geography, 116 Wilkeson Quad, Buffalo, NY 14261, USA, rensch@buffalo.edu.

Dennis C. Flanagan

USDA-Agricultural Research Service, National Soil Erosion Research Laboratory (NSERL), 1196 Building SOIL, West Lafayette, IN 47907-1196, USA, flanagan@purdue.edu.

Bernard A. Engel

Purdue University, Agricultural and Biological Engineering Department, 1146 AGEN, West Lafayette, IN 47907-1146, USA, engelb@ecn.purdue.edu.

James R. Frankenberger

USDA-Agricultural Research Service, National Soil Erosion Research Laboratory (NSERL), 1196 Building SOIL, West Lafayette, IN 47907-1196, USA, jrf@ecn.purdue.edu.

Abstract. *Decision-makers operating at different scales of interest and responsibility have to assess the distribution, extent, and severity of soil erosion and sedimentation. To seek solutions in handling natural and human actions related to this type of nonpoint source pollution, the linkage of distributed assessment models and Geographical Information Systems (GIS) at various spatial and temporal scales is in high demand. The Water Erosion Prediction Project (WEPP) model is a continuous simulation, process-based model that allows simulation of water and sediment balance in small watersheds and on hillslope profiles within those watersheds. This presentation introduces an approach for running WEPP simulations based on using available geo-spatial information through a linkage with GIS. The new Geo-spatial interface for WEPP (GeoWEPP) utilizes readily available digital geo-referenced information from publicly accessible Internet sources such as the U.S. Geological Survey digital elevation models, topographical maps, and land use data as well as Natural Resources Conservation Service soils maps. Together with parameter sets of the WEPP database containing statistical parameter sets from more than 2600 U.S. climate stations, GeoWEPP enables even non-GIS-and-modeling users to derive and prepare valid model input parameters to assess representative conditions in an area of interest. After establishing the main data input for a particular site, various land use scenarios can be evaluated to assist with soil and water conservation planning.*

Keywords. Topography, watershed, decision making, geographic information systems.

Introduction

Decision-makers operating at different scales of interest and responsibility have to deal with different types of environmental problems and seek solutions to handle the complexity of natural and human actions causing these problems. The linkage of environmental assessment tools and Geographical Information Systems (GIS) and their capability in handling available geo-spatial data sources to prepare valid model input parameters for applications at various spatial and temporal scales are in high demand. The expansion and concentration of cultivated acreage, for instance, led to a drastic change in land use as well as water and sediment fluxes in environmental systems. Catastrophic events in the U.S. such as the Dust Bowl during the 1930s or the Mississippi floods in 1993 caused excessive losses of fertile agricultural land and increased concerns about the economic and environmental impact of soil erosion at local, regional, national and global scales. In response to such hazards related to soil erosion, especially from agricultural land, the development and implementation of techniques for natural resource management were fostered by interest groups and policy-driving organizations to support decision-makers in countries worldwide (Troeh et al., 1999).

Soil Erosion Assessment

There is a long history of developing erosion models for soil and water conservation in U.S. research. The most known and applied approach for estimating long-term average annual soil loss is the Universal Soil Loss Equation (USLE) (Wischmeier and Smith 1978) and the Revised Universal Soil Loss Equation (RUSLE) (Renard et al., 1997). Both are simple empirical equations based on factors representing the main processes causing soil erosion. USLE and RUSLE have proven to be practical, accessible prediction tools and were therefore implemented in the U.S. soil and water conservation legislation. However, these model approaches have been used and misused widely at various scales worldwide (see also Wischmeier 1976).

The Water Erosion Prediction Project (WEPP)

In contrast to the empirical model approaches, efforts in erosion process research in the U.S. led to the development of the process-based soil erosion model WEPP (Flanagan and Nearing, 1995). WEPP simulates climate, infiltration, water balance, plant growth and residue decomposition, tillage and consolidation to predict surface runoff, soil loss, deposition and sediment delivery over a range of time scales, including individual storm events, monthly totals, yearly totals or an average annual value based on data for several decades. The WEPP model is a continuous distributed-parameter soil erosion assessment tool that can be applied to representative hillslopes and a channel network at small watershed scales (Ascough II et al., 1997). A comparison of the performance of WEPP with other state-of-the-art erosion models using common data sets showed that data quality is an important consideration and primarily process-based models not requiring calibration have a competitive edge to those in need of calibration (Favis-Mortlock, 1998).

GIS interface for the WEPP model

GIS in model linkages are dominantly used for data preprocessing and visualization of available data sources as well as the handling of data to apply environmental assessment models. A GIS-driven graphical user interface is a user-friendly approach to combine the decision-support of an environmental prediction model and the spatial capabilities of a GIS for practical assessment purposes (Renschler et al., 2000). A useful and successful implementation of an environmental model assessment approach requires the use of widely available data sets and the preparation of model input parameters to allow reliable model predictions. The prototype of a GIS-based interface - the Geospatial Interface for WEPP (GeoWEPP) (Renschler, 2002) - is an interface for using WEPP through a wizard in ArcView 3.2 for Windows 98, 2000 and NT. The currently released testing version of GeoWEPP ArcX 1.0 beta is an ArcView project/extension that starts with a user-friendly wizard (Fig. 1).
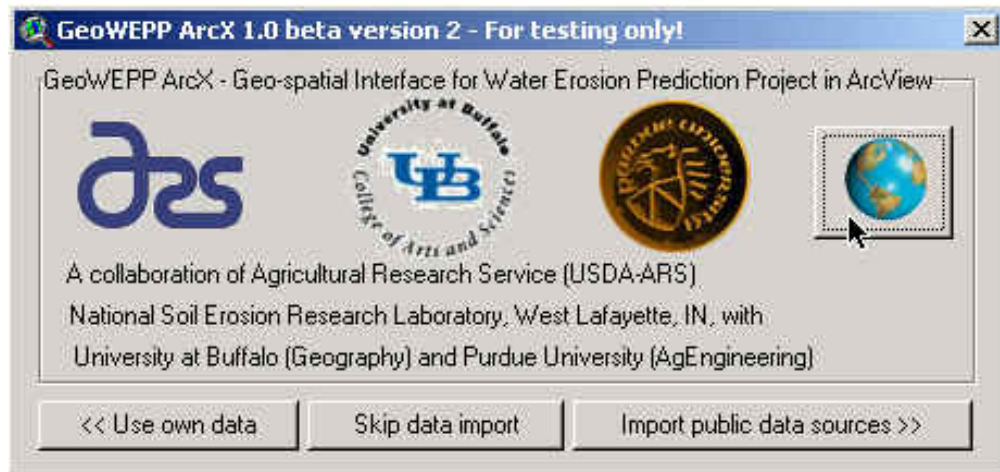
Figure 1. Opening screen of ArcView-based GeoWEPP wizard.

The GeoWEPP wizard allows the user to go through four essential steps to derive topographical input parameters for a WEPP watershed simulation based on a DEM of one's own or from a public source (U.S. Geological Survey (USGS) 1:24,000 scale):

- Import of Digital Elevation Models,

- Orientation to Locate Area of Interest,

- Channel and Watershed Delineation, and

- Other Model Input Parameters.

Import of Digital Elevation Models

The first step of the wizard allows the user to import Digital Elevation Models (DEM) by downloading and interactively importing USGS datasets (Fig 2.). The downloading option allows the user to connect directly to the USDA Geospatial Data Gateway Internet site for downloads (NRCS, 2002) and select the DEM Quad sheet by clicking on an interactive map. The four-step DEM import procedure steps are designed in a way that adjacent DEM quad sheets are automatically merged.
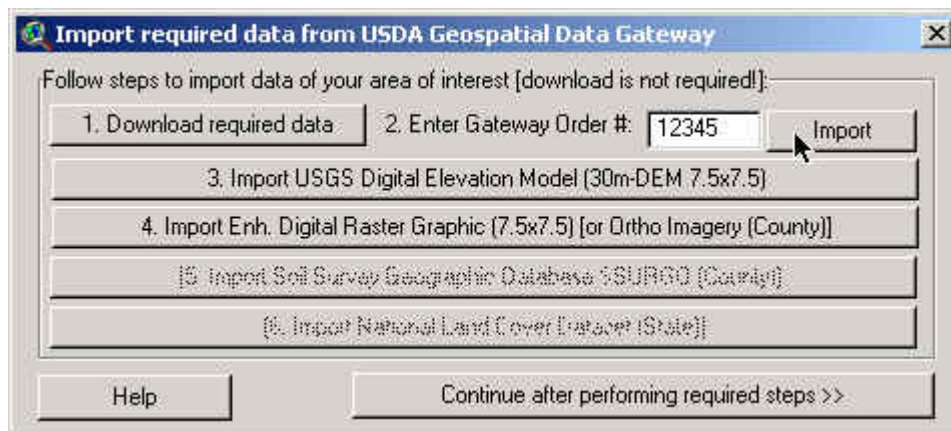

Figure 2.   Screen of wizard to import USGS Digital Elevation Models and Digital Topographical Maps (Digital Raster Graph) at the 1:24,000 map scale.

The display of the imported DEMs is a hill shade map view that allows even DEM-inexperienced people to get an idea about the topography of the selected area (Fig. 3). Note in the case study used, the merged USGS DEMs are of different quality in vertical resolution. In contrast to the 'West Lafayette, IN' 30

m-raster Quad sheet DEM with vertical resolution in meters, the 30 m-raster DEM 'Otterbein, IN' is originally in feet (0.3045 m). The hill shading of the former shows therefore features like terraces due to the relatively large meter steps and appears less smooth than the merged DEM originally in feet. This visualization method encourages the user to recognize the limitations of the different data sources and to be cautious in modeling applications.
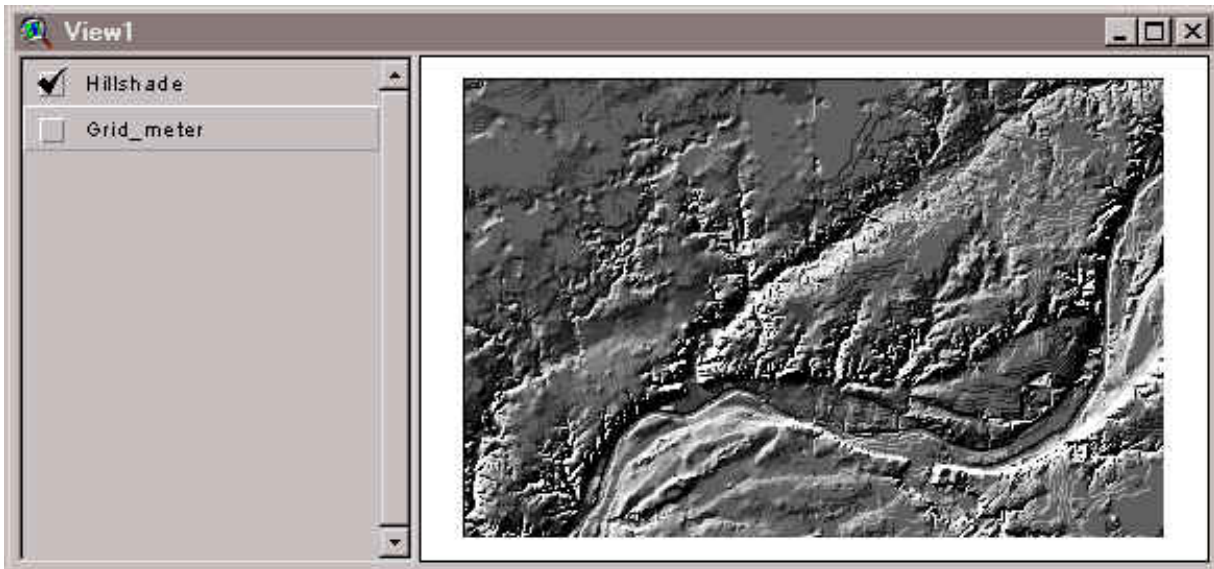

Figure 3. Hill shade view of merged DEMs 'Otterbein, IN' and 'West Lafayette, IN'

Orientation to Locate Area of Interest

While using the DEM import wizard, an option enables the user to additionally download a USGS digital topographical map - also known as Digital Raster Graph (DRG). The DRG image is then used by the wizard as a transparent overlay for the DEM imported in the previous step (Fig 4.). The topographical map includes user-friendly features that allow the user to locate their specific area of interest for an assessment.
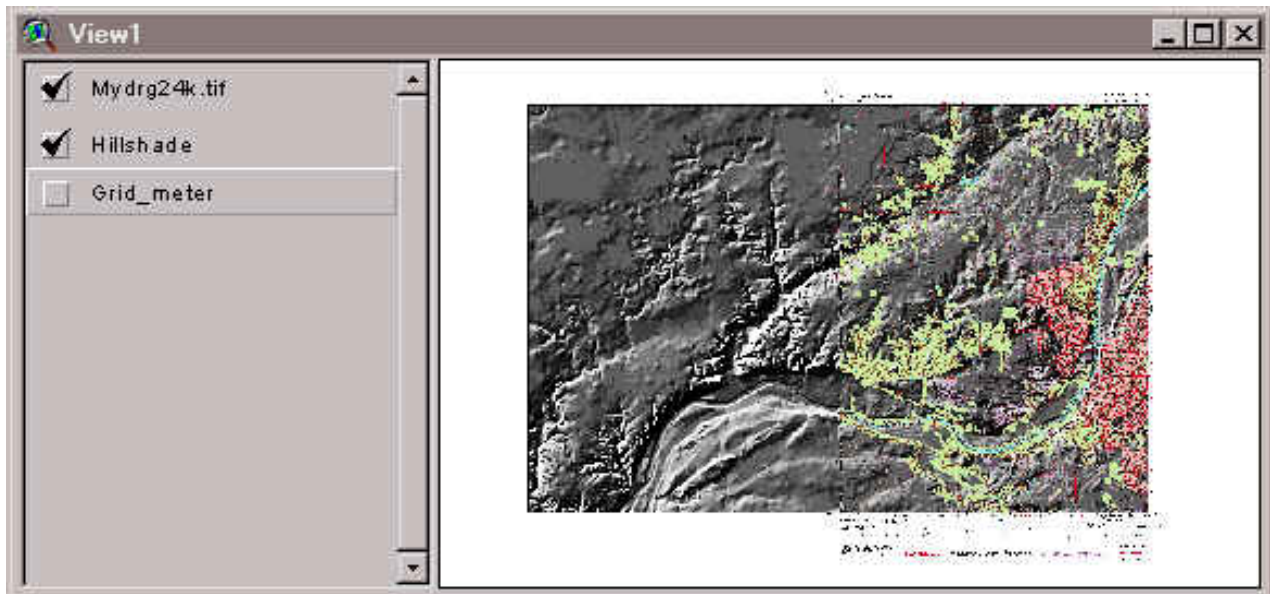

Figure 4. Transparent topographical map over hill shaded DEM scene.

Channel and Watershed Delineation

Based on the imported topographical data of the DEM scene, channel delineation takes place in the next wizard step. Channel parameters and a watershed outlet cell have to be set in the wizard to delineate drainage pattern and a watershed with subcatchments (Fig. 5). The Topographical Analysis Software TOPAZ (Garbrecht and Martz, 2000) is integrated in the wizard.
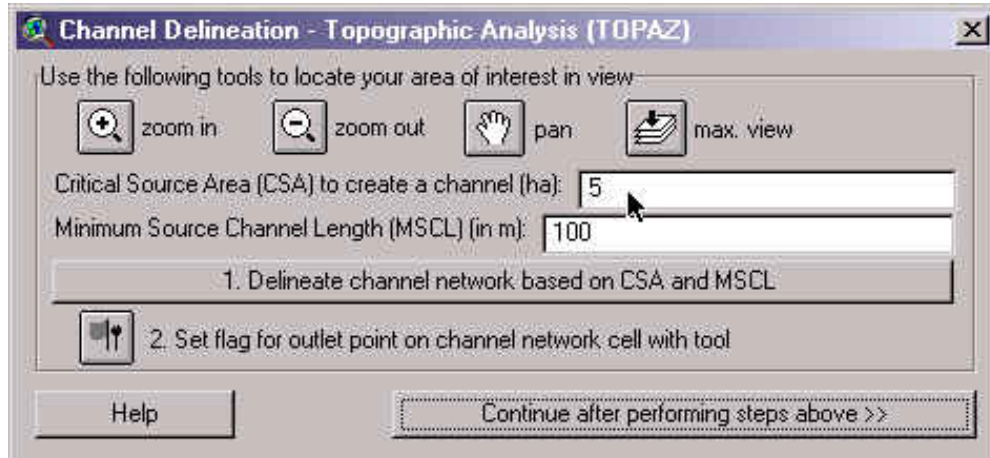

Figure 5. Screen of wizard to delineate watershed characteristics with TOPAZ.

TOPAZ requires a Critical Source Area (CSA) and a Minimum Source Channel Length (MSCL) to derive a channel network (Fig 6). After the network outline is satisfactory to the outline observed in the area (or mapped in the DRG), the wizard offers a tool to set the outlet for the watershed of interest (Fig. 5). The x-/y-coordinates in the view also allow the user to locate precisely a point of interest. After setting the outlet, TOPAZ derives the watershed boundary and subcatchment areas contributing to the channels (Fig. 6). The delineation of channel network as well as watershed boundary and subcatchments can be repeated until it matches the user's area of interest.
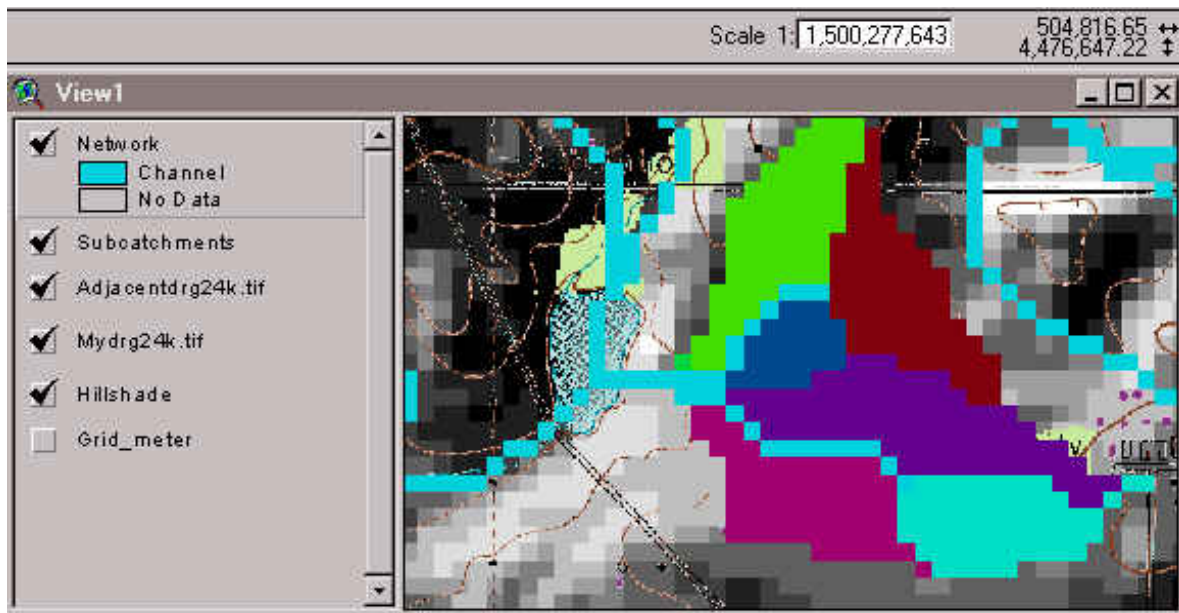

Figure 6. Delineated channel network (blue) and subcatchments in a watershed of interest.

Other Model Input Parameters

Before the model run, the wizard guides the user through various steps to set the required minimum model input parameters for WEPP. Beside confirmation of the automatically selected climate station that is located closest to the watershed outlet, the user has to pick the names of the major soil, land use and channel parameter sets for the watershed provided by pick lists of the latest WEPP model (see also Flanagan and Nearing, 1995) (Fig. 7). An additional tool allows one to optionally change the soil and land use characteristics of the delineated subcatchments by clicking on the area in the map view (Fig. 6). The user should take care here to assure that the channel parameters selected are representative of their watershed, or modify them appropriately.

The second step in this wizard runs the WEPP watershed model in starting up the WEPP TOPAZ Translator (Fig. 8). The translator lets the user get an overview about the main parameter settings and confirm these settings before running the WEPP watershed model. If changes need to be performed before running the model, the translator has to be closed and changes made with the provided tools before running WEPP.
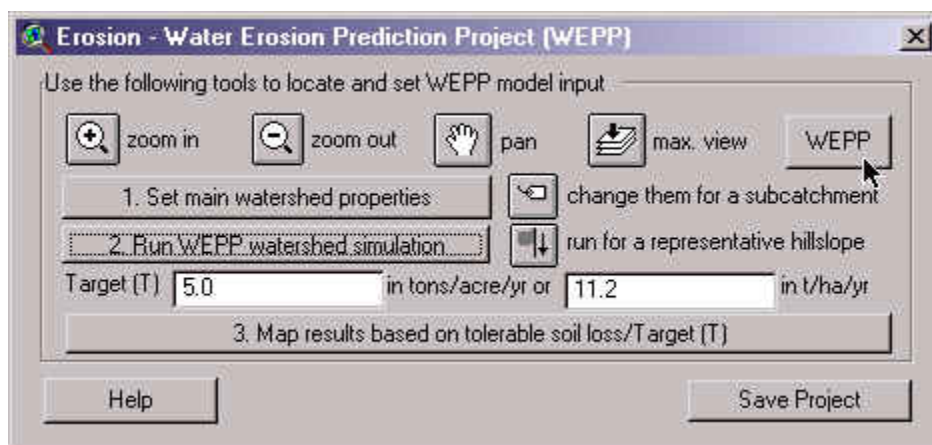

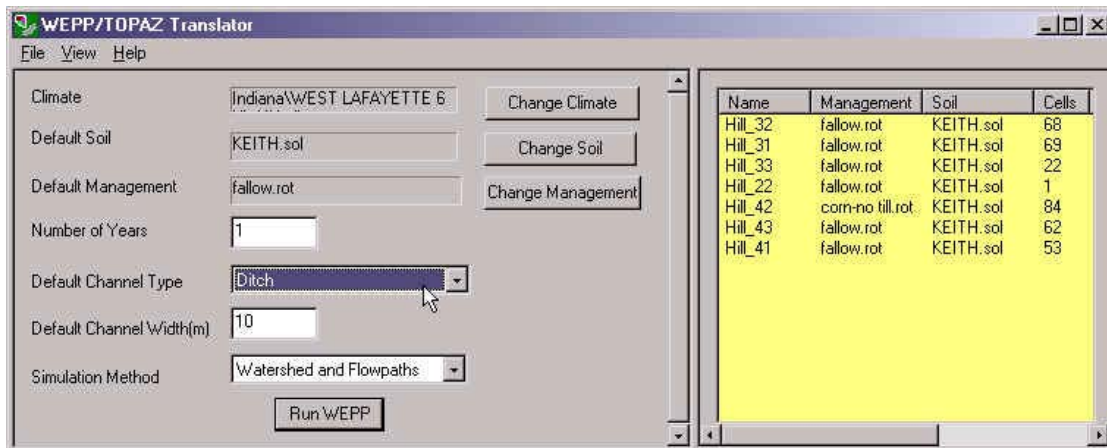Figure 7. Screen of wizard to set WEPP model parameters.

Figure 8. Screen of WEPP TOPAZ Translator to confirm model input settings.

The WEPP watershed simulation can be performed with two simulation methods (or both): (1) a relatively faster Watershed Method that allows one to simulate sediment yields from single representative hillslopes for each subcatchment with a channel routing for the watershed outlet and (2) a longer Flowpath Method that allows one to simulate and merge soil loss along all possible flowpaths within the watershed, but without channel routing. For more information about how to derive representative hillslopes as well as how to merge the flowpath by weighting their results according to flowpath length and contributing area, refer to Cochrane and Flanagan (1999) or Flanagan et al. (2002).

Figure 9. Text file for average annual simulation results for the WEPP Watershed Method.

Assessment Results and Discussion

The WEPP model creates numerous outputs to its model components, including Climate Simulation, Subsurface Hydrology, Water Balance, Plant Growth, Residue Decomposition and Management, Overland Flow Hydraulics, Hillslope Erosion Component, Channel Flow Hydraulics, and Channel Erosion Surface. The current wizard allows you to visualize only a small portion of the WEPP model output of runoff, soil loss, sediment deposition and sediment yield from hillslopes and channel segments. The average annual simulation results for the WEPP Watershed Method are displayed as text file (Fig. 9) and visualized as a map.

Since ArcView 3.2 (surprisingly) does not allow display of negative values for raster maps, the assessment results are mapped as a relative measure to a tolerable soil loss or Target value (T). The concept of a T value (Schertz, 1983) describes in theory the annual replacement rate for a soil type to maintain a sustainable land use. The Natural Resources Conservation Service (NRCS) implemented T that is determined for each location based on properties of root limiting subsurface soil layers, current climate regions and an economic feasibility summarized for soils in land resource regions. T values usually range up to 5 tons per acre per year (11.2 t ha-1 yr-1). Relative to this T value, the results of soil loss and sediment yield are classified (Fig. 10.) and displayed in green colors, intolerable results are shown in red, and deposition areas are in yellow (Fig. 11 and Fig. 12).

The results for the Watershed Method are mapped as sediment yields from each simulated representative hillslope entering a channel segment (Fig. 11). In the case study shown in Figure 11, the hillslopes contributing from both sides to the northern first order channel segment are mapped in reddish colors for sediment yields greater than T (1 T - 2 T). While all other subcatchments are fallow and very vulnerable to soil erosion, the subcatchment with the corn no-till rotation produces the lowest sediment yields mapped in a lush green color (Fig. 11; compare hillslope H_42 in Fig. 8 and Fig. 9). The longer simulation with the Flowpath Method shows a much more detailed assessment for soil loss within the subcatchments (Fig. 12).
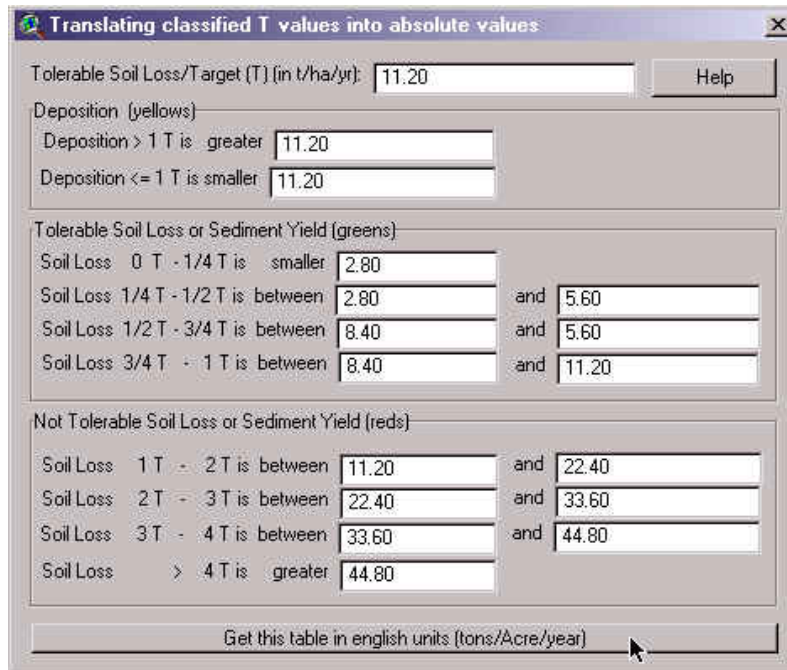
Figure 10. Legend showing the relative classes to the tolerable limit or target value T.

Now it is possible to locate the problem areas (intensive red color) within the two subcatchments also indicated by the Watershed Method (Fig. 11). The results of the Flowpath Method also indicate a problem area in the southern subcatchment that was assessed as tolerable with the Watershed Method. After assessing the effect of this first land use scenario (Fig. 8), the user may change the land use to get acceptable T values for all watershed areas (Please note that the GeoWEPP version presented here is for a single soil and land use in each subcatchment. Future versions are currently under construction to include spatially distributed soil and land use along hillslopes).
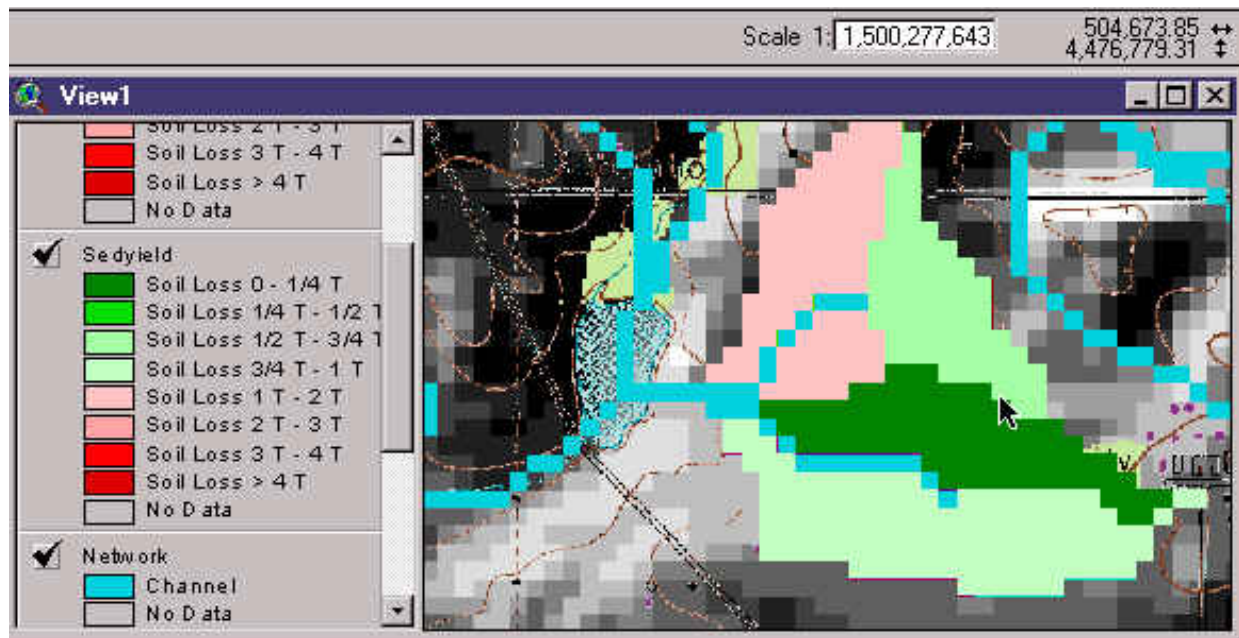

Figure 11.   Map of sediment yield for each hillslope region simulated with the WEPP Watershed Method.
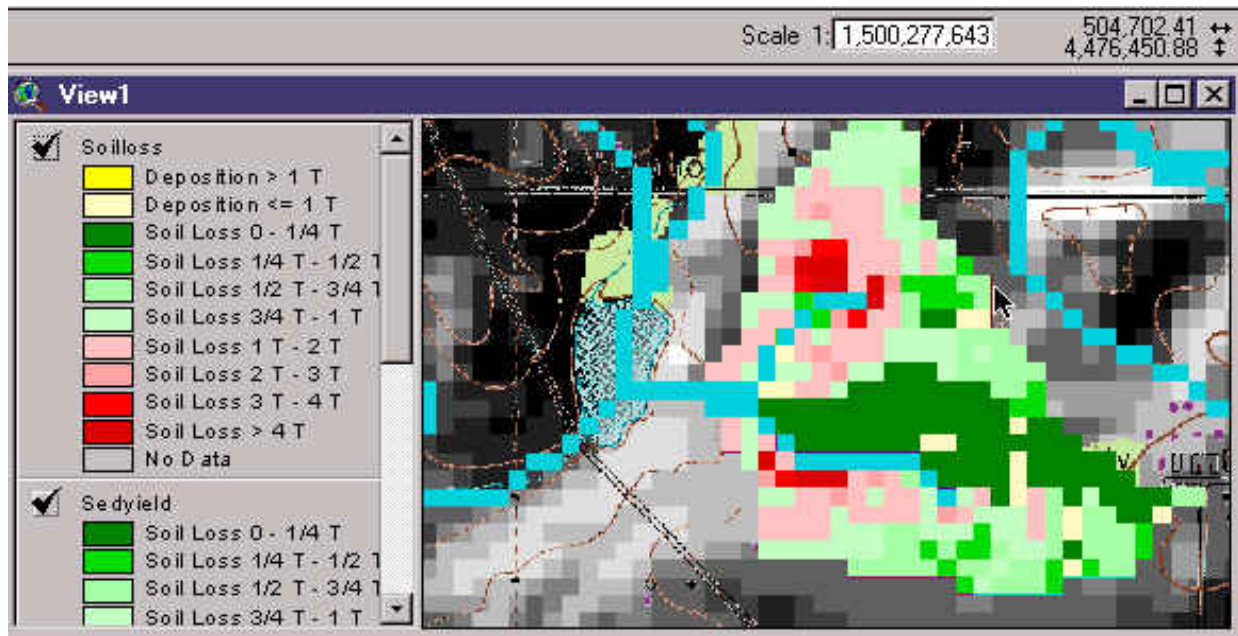
Figure 12.   Map of soil loss of each hillslope raster cell simulated with the WEPP Flowpath Method.

Conclusion

The Water Erosion Prediction Project (WEPP) model is a continuous simulation, process-based model that allows simulation of small watersheds and hillslope profiles within those watersheds. Beside the continuous improvement of the Windows WEPP interface for hillslope and small watersheds, additional work is in progress to allow WEPP simulations based on using digital sources of information through the linkage with Geographic Information Systems (GIS). The Geo-spatial interface for WEPP (GeoWEPP) utilizes digital geo-referenced information such as digital elevation models (DEM) and topographical maps to derive and prepare valid model input parameters and defaults to start site-specific soil and water conservation planning for a small watershed with a single soil and land use for each subcatchment.

The ArcView project/extension GeoWEPP helps GIS beginners and experts obtain data from publicly available data sources in the US to assess spatially distributed sediment yield and soil loss on small agricultural watersheds. The new assessment tool combines GIS and a process-based model to assess land use scenarios to determine the best management practices (BMPs) for a particular watershed of interest. Development of the prototype continues with the prototype available for testing. The final release will include the import of publicly available soil survey data 1:24,000 and the possibility to assess spatially distributed soil units and land use classes for larger non-agricultural watersheds.

The integration of orthophotos, soil surveys, land use maps, climate data, and precision farming data as well as multiple soil and land use within each subcatchment is currently under development. The goal of the GeoWEPP project is to provide a series of interfaces for users with different levels of GIS knowledge that are capable to utilizing these different data sources in a standard format either provided by GIS users, by precision farmers with Global Positioning Systems (GPS) databases and/or through accessing commonly readily available U.S.-nationwide data sets that are free of charge.

Note

The most recent version of GeoWEPP ArcX (1.0 beta version) is free of charge and downloadable at http://www.geog.buffalo.edu/~rensch/geowepp. At its current stage GeoWEPP supports the usage of Digital Elevation Models only. It currently doesn't support the use of digital maps for management or soil layers (future plans). The extension and related executables should not be used as a decision making tool until it has been thoroughly tested and officially released. However, the GeoWEPP project group

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welcomes users to voluntarily test our current version to improve and customize it for a broad range of WEPP and GIS modeling applications.

This beta version is for testing and evaluation only! All information, computer software, and databases containing on this download are believed to be accurate and reliable. The United States Department of Agriculture, Agricultural Research Service, Purdue University, the Purdue University Department of Agricultural and Biological Engineering, and the State University of New York at Buffalo accept no liability or responsibility of any kind to any user, other person, or entity as a result of installation or operation of this software. The software is provided "AS IS", and you, its user, assume all risks when using it.

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