

CHAPTER 1

INTRODUCTION

1.1. Introduction to watershed modeling with WEPP and GIS

Watershed erosion is a cause of non-point source pollution that can have an adverse effect on the ecosystem and downstream water quality. Consequently, the estimation of runoff and soil loss from small watersheds is becoming more and more important as concerns about surface water quality increase. Unfortunately, it is very expensive and impractical to monitor erosion in all watersheds of interest, hence the need to predict erosion through modeling.

One of the most promising models currently used for erosion modeling 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 also can be predicted. In other words, soil loss 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 an extension of the WEPP hillslope model that can be used to estimate watershed runoff and sediment yield (Ascough et al., 1997). The application of WEPP to a watershed requires that hillslopes be delineated and channels identified (Baffaut et al., 1997). Each hillslope (represented as a rectangle in WEPP) must have a representative length (L), width (W), and slope profile as shown in Figure 1.1. Hillslopes drain into the top, left side, or right side of a channel, eventually leading to the watershed outlet.

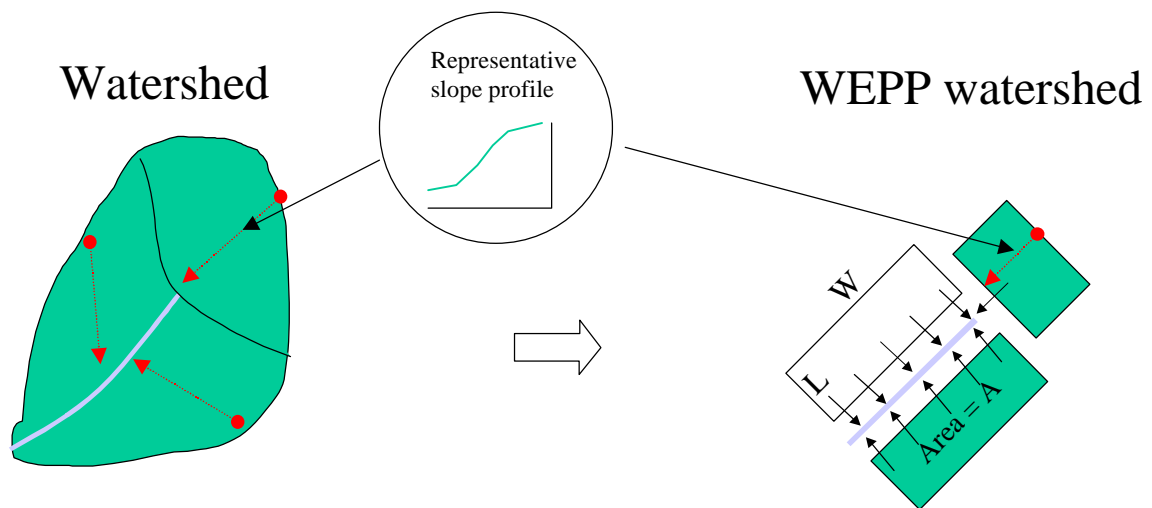


Figure 1.1. Watershed discretization for WEPP.

Integration of WEPP with a geographic information system (GIS) is desirable because it can facilitate and possibly improve the application of the model. An initial application of WEPP with a raster-based GIS was conducted by Savabi et al. (1995). In this 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 this 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.

When dealing with relatively uniform soils and management practices, the primary map used to delineate hillslopes and channels in a watershed is a topography map. Topography in a GIS is usually represented by a digital elevation model (DEM). The most common type of DEM is grid-based, where each grid point is represented by a cell of a certain size or resolution. Extraction of features such as hillslopes and channels can be performed using flow-routing algorithms that determine the steepest descent direction and gradient between cells. Examples of flow-routing algorithms are presented in the research of O'Callaghan and Mark (1984), Jenson and Domingue (1988), Martz and Garbrecht (1992), 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, 1996a). These functions can be used for WEPP, however 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.

GIS analysis using DEM's provides an obvious tool for parameterization of hillslopes, channels, and representative slope profiles for WEPP simulations. However, there are different possible methods of applying WEPP to watersheds using DEMs and GIS. These methods have to be studied by applying them to real watersheds and each method has to be evaluated on how well it performs under a variety of scenarios. The results from the application of these methods will also help us further understand important factors in watershed erosion modeling and could point out limitations in our current model concepts. Another issue that needs to be examined further is DEM resolution. Simulating each watershed using a series of resolutions can address the problem of having less than ideal topographic data for watershed simulations. It is therefore important to evaluate how sensitive the WEPP model and methods are to changes in resolution. A better understanding of the effects of simulation methods, resolution, and other factors affecting watershed modeling with GIS, is important in further developing watershed erosion prediction technology.

1.2. Objectives

The purpose of this study was to develop, describe, and evaluate methods of integrating WEPP and GIS. The first objective was to develop methods for watershed modeling and discretization using grid based DEMs. This involved creating algorithms for the application of WEPP using DEMs and developing an interface between Arc View™ (ESRI, 1998) and WEPP. The second objective was to describe these methods and their application to research watersheds where simulation results could be compared to measured values. Six research watersheds in different regions of the country were used for this purpose. The third objective was to evaluate the methods developed using different DEM resolutions and different runoff and sediment event sizes. To fulfill this objective, a complex statistical analysis was conducted, which compared simulated results to measured values and compared all interactions between methods and resolution. It is believed that the methods developed will facilitate the application of WEPP with available GIS data and that results from the application of these methods to research watersheds will help improve our current knowledge of watershed modeling.

1.3. Organization

This dissertation documents the development, application, and analysis of methods of interfacing WEPP with GIS and DEMs. In Chapter 2, a comprehensive literature review is presented. It covers both erosion models, with particular emphasis on the effects of slope and length on soil loss, and watershed modeling with GIS and DEM. In Chapter 3 the research watersheds used in this study are described. Additionally, the methods developed to apply WEPP with GIS and DEMs are described in detail. The application of these methods to the research watersheds is presented and discussed in Chapter 4. The effects of using DEM of different resolutions and the ability to simulate different sized events are analyzed in Chapter 5. A general summary and conclusions about the methods and their applications with DEMs are presented in Chapter 6. Finally a discussion of opportunities for further research is presented in Chapter 7.

1.4. Definition of terms

The following list describes terms and abbreviations used throughout the text of this thesis.

ANSWERS - Areal Nonpoint Source Watershed Environment Response Simulation (Beasley and Huggins, 1982).

Arc View™ - leading mapping and GIS software by Environmental Systems Research Institute, Inc. (ESRI, 1998).

ARC/INFO - professional GIS by Environmental Systems Research Institute, Inc (ESRI, 1998).

Avenue - Arc View™ object oriented programming language (ESRI, 1998).

Channels – channels, as defined in WEPP applications, are permanent waterways excluding classical gullies and perennially-flowing streams.

CREAMS - Chemicals, Runoff, and Erosion from Agricultural Management Systems (Knisel, 1980).

DEM - Digital Elevation Model.

FORTRAN - computer programming language (FORMula TRANslator).

GIS - Geographic Information System.

GRASS - Raster based GIS developed by the U.S. Army Corps of Engineers (CERL, 1993).

Grids, cells - set of square units used in raster based GIS.

HEC-1 - model developed by the U.S. Army Corps of Engineers, which is designed to simulate the surface runoff response of a river basin to precipitation by representing the basin as an interconnected system of hydrologic and hydraulic components (U.S. Army Corps of Engineers, 1985).

IDRISI - PC based GIS developed at the Clark Labs for Cartographic Technology and Geographic Analysis, Clark University (Eastman, 1997).

KINEROS - A KINematic Runoff and EROSion Model (Smith et al., 1995).

OFE - Overland flow element. An area along a hillslope with uniform soils, crops, and management practices.

RUSLE - Revised Universal Soil Loss Equation (Renard et al., 1997).

TAPES-C - Topographical Analysis Programs for the Environmental Sciences – Contour
(Moore and Grayson, 1991).

TIN - Triangular Irregular Network.

TOPAZ - TOPographic PArAmeteriZation, is an automated digital landscape analysis tool
for topographic evaluation, drainage identification, watershed segmentation and
subcatchment parameterization (Garbrecht and Martz, 1997).

USLE - Universal Soil Loss Equation (Wischmeier and Smith, 1978).

WEPP - Water Erosion Prediction Project (Flanagan and Nearing, 1995).