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An Introduction to the Wind Erosion Prediction System (WEPS)

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***Abstract*.** The Wind Erosion Prediction System (WEPS) was developed by a multi-disciplinary team of USDA scientists in collaboration with other agencies and private cooperators in response to customer requests, primarily USDA-NRCS, for improved wind erosion prediction technology. WEPS is designed to provide estimates of soil loss by wind from cultivated, agricultural fields. It is intended to replace the predominately empirical Wind Erosion Equation (WEQ) as a prediction tool for those who plan soil conservation systems, conduct environmental planning, or assess offsite impacts caused by wind erosion. WEPS also has capabilities for other land management situations where wind affected soil movement is a problem. WEPS 1.0 consists of the computer implementation of the WEPS science model with a graphical user interface designed to provide easy-to-use methods of entering inputs to the model and obtaining output reports. WEPS is a process-based, daily time-step, wind erosion simulation model. As such, WEPS simulates not only the basic wind erosion processes, but also the processes that modify a soil's susceptibility to wind erosion. The structure of WEPS is modular and consists of a user interface, a science model including seven submodels, and four databases. The user interface is used to create input files using information from user inputs and the databases. In a practical application, new input files will usually be created using previous input files as templates modified within the user-interface.

Keywords. erosion simulation, erosion control, dust, PM10, conservation planning.

Introduction

Soil erosion by wind is a serious problem in the United States and the world. Wind erosion is a threat to agriculture and the earth's natural resources. It renders soil less productive by removing the most fertile part of the soil, namely, the clays and organic matter. This removal of clays and organic matter also damages soil structure. In addition to the soil, wind erosion can damage plants, primarily by the abrasive action of saltating particles on seedlings and fruits. Eroded soil can also be deposited into waterways and emitted into the air where it degrades the water and air resources. By affecting these resources, wind erosion can also become a health hazard to humans and other animals. The ability to accurately simulate soil loss by wind is essential for, among other things, conservation planning, natural resource inventories, and reducing air pollution from wind blown sources.

The Wind Erosion Equation (WEQ) was published in 1965 by Woodruff and Siddoway (1965). For years, WEQ has represented the most comprehensive and widely used model in the world for estimating soil loss by wind from agricultural fields. The functional form of WEQ is:

$$E = f(I, K, C, L, V)$$

where, E is the average soil loss (tons/acre/year), I is the soil erodibility, K is the soil ridge roughness, C is the climatic factor, L is the field length along the prevailing wind erosion direction, and V is the vegetative factor. WEQ is largely empirical in nature, derived from nearly 20 years of field and laboratory studies by scientists at the USDA-Agricultural Research Service (ARS), Wind Erosion Research Unit (Chepil, 1958, 1959, 1960; Chepil and Woodruff, 1959). Many improvements were made to WEQ over the next 30 years. Because of the limitations of adapting WEQ to many problems, as well as advancements in wind erosion science and computer technology, the USDA Natural Resources Conservation Service requested that ARS develop a replacement for WEQ (Hagen,1991).

Development of WEPS

Research in the 1980's (Cole et. al., 1983; Cole, 1984; and Lyles, et. al., 1985) provided the initial attempt to outline a processed based approach to simulating wind erosion that would replace WEQ. Following this initial work, the modular structure used in the current WEPS model was developed (Hagen, 1991) and the experimental research needed to support that structure was outlined. Numerous field and laboratory studies were conducted to develop relationships for surface conditions and erosion. Experimental data were collected for weather (Skidmore and Tatarko, 1990), hydrology (Durar and Skidmore, 1995), crop growth (Retta and Armbrust, 1995), residue decomposition (Steiner et. al., 1995), soil (Hagen, et. al., 1995; Potter, 1990, Zobeck and Popham, 1990, 1992), management (Wagner and Ding, 1995), and erosion (Hagen, 1995). Experiments were also conducted to validate that the erosion routines were producing accurate and precise erosion estimates (Fryrear, et. al, 1991).

A multi-disciplinary team was assembled to develop WEPS that included climate modelers, agronomists, agricultural engineers, soil scientists, and crop modelers. The WEPS development project had a multi-agency commitment consisting of the Agricultural Research Service, Natural Resources Conservation Service, and the Forest Service from the U.S. Department of Agriculture, along with the Environmental Protection Agency, the Army Corps of

Engineers, and the Bureau of Land Management. In 2005, WEPS was released to the NRCS for testing and further development for field office conservation planning.

User Requirements

Early in the WEPS development process, input was requested from potential users on the needed capabilities of a new wind erosion simulation model. These user requirements were summarized by Hagen (1991). Based on these requirements, WEPS was designed to:

1. Provide more accurate and detailed estimates of soil loss by wind from agricultural fields. Results for WEQ were an annual average soil loss based essentially on average weather and field conditions. Since erosion is often the result of extreme weather events (e.g., high wind or dry soil), an approach that accounts for such extreme conditions was needed to simulate the extreme soil loss for these events. In addition, WEPS is capable of outputting erosion loss and surface conditions on a relatively fine temporal scale (e.g., hourly). However, for practical purposes, the default time step for WEPS output is two weeks. Such detail allows the user to observe the periods when the excessive erosion occurs and the wind or surface conditions which caused the soil loss (e.g., low vegetative cover). These conditions can then be addressed by altering management or other control measures.

2. Develop more cost-effective erosion control methods. Because of the detail in the soil loss and field conditions provided by WEPS, it is a valuable tool for testing various management scenarios or control methods through simulation. Each scenario can be evaluated before a change is made to farming practices. Surface conditions and management can be observed during periods of excessive loss and adjusted to minimize erosion.

3. Simulate the amount of soil loss by direction. With increasing concern of the offsite impacts of wind erosion on soil, water, and air quality, the capability of WEPS to provide the direction of soil loss is useful. For example, creep and saltation loss to a roadside ditch or waterway will impact water quality, so attention can be focused in these scenarios to controlling loss in that direction. Similarly, suspension loss in the direction of highly populated areas can be simulated with WEPS and control strategies simulated.

4. Separate soil loss into creep/saltation, suspension, and PM10 components. Each of these components have specific characteristics and effects. Creep/saltation are typically deposited locally where they can affect soil and water quality, bury roads and irrigation ditches, or be deposited as dunes in fences or windbreaks. Suspension, by definition, can be lifted into the air and carried great distances. As such, it can be a detriment to air quality, become a health hazard, and reduce visibility along transportation systems. PM10 has been determined by the U.S. Environmental Protection Agency to be a hazard to air quality and a respiratory hazard in particular (U.S. EPA, 1996). Estimating soil loss of each of these components can aid in environmental assessments.

Taking all user requirements into consideration, WEPS is designed to be and aid in: 1) soil conservation planning, 2) environmental assessment and planning; and 3) determining off-site impacts of wind erosion.

WEPS Modeling Approach

WEPS is a process-based, daily time-step model that simulates weather, field conditions, and erosion. As such, it simulates not only the basic wind erosion processes, but also the processes that modify a soil's susceptibility to wind erosion. The initial model release is WEPS 1.0 and is designed to provide the user with a simple tool for inputting initial field conditions, calculating soil loss, and displaying either simple or detailed outputs for designing erosion control systems.

WEPS 1.0 Geometries

To simplify inputs, WEPS 1.0 is designed with specific geometric constraints when specifying the simulation region or field (Figure 1). The simulation region is limited to a rectangular area. However other field shapes such as circles or half circles can also be simulated by defining a rectangle of the same length, width, and area of the desired field shape. The simulation area may be rotated to orient the field correctly on the landscape to account for the effects of varying wind directions.

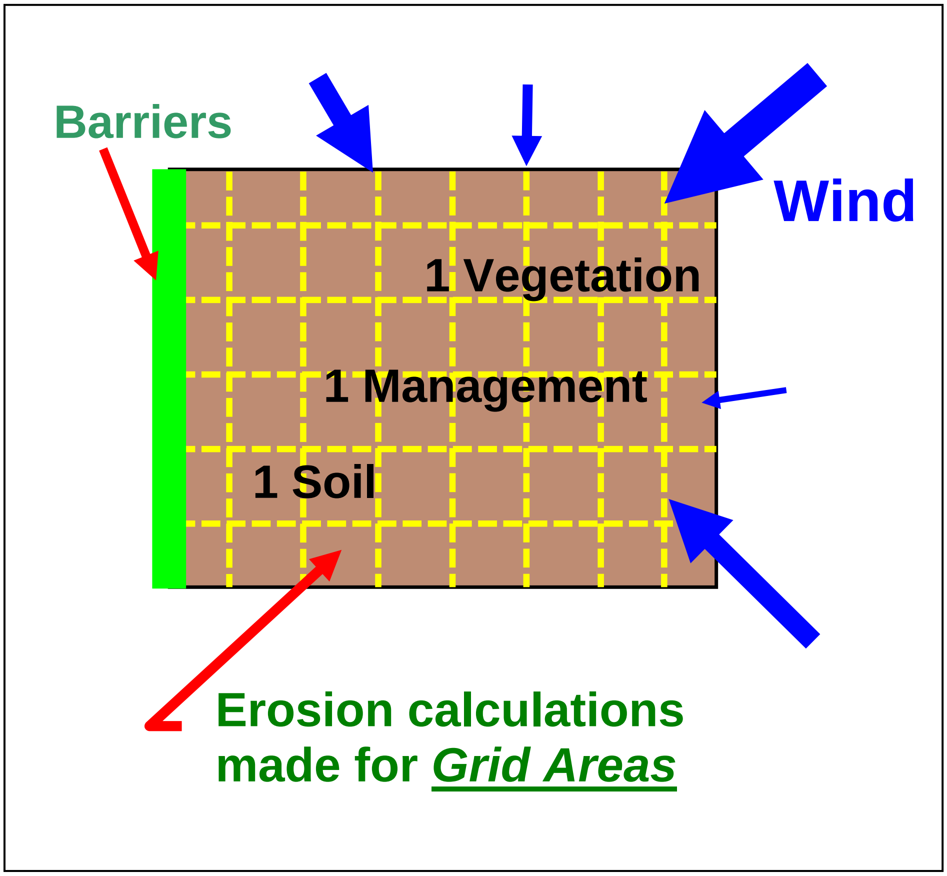

Figure 1. Diagram of WEPS1.0 simulation region geometries.

A uniform simulation region surface is assumed in that only one soil type (uniform soil properties), crop type (biomass properties), and management are uniformly distributed over the field. In reality, fields are often not uniform so the user may select the dominant-critical (i.e, most erodible) soil or crop condition for a simulation. Barriers may be placed on any or all field boundaries. When barriers are present, the wind speed is reduced in the sheltered area on both the upwind and downwind sides of the barriers. The erosion submodel determines the threshold friction velocity at which erosion can begin for each surface condition. When wind speeds exceed the threshold, the submodel calculates the loss/deposition over a series of individual grid cells representing the field. The soil/loss deposition is divided into components of saltation/creep and suspension, because each has unique transport modes, as well as off-site impacts. The field surface is periodically updated during erosion events to simulate the changes caused by erosion. Surface updating during an erosion event includes changes to aggregate size distribution of the surface as fine particles are removed, smoothing of ridge roughness as ridges are eroded and furrows filled with eroded materials.

WEPS 1.0 Model Implementation

The structure of WEPS 1.0 is modular and consists of the science model, coded in FORTRAN 95 coupled with a graphical user interface, which is coded in JAVA. The model also includes five databases, two weather simulation models, and six submodels (Figure 2).

The user interface provides a means for the user to enter initial conditions such as the field dimensions, orientation, barriers, location, management operations, and soil component desired for the simulation region. Field dimensions are entered as a length and width and orientation as an angle deviation from north. The user selects the barrier type from a list accessed through the interface. For location, the user can either select the state and county or enter a latitude and longitude for simulation. The interface then selects the weather stations for which historical weather parameters are used to simulate weather parameters. The soil component is selected from a list of soils supplied by the NRCS Soil Survey Geographic (SSURGO) database for the Soil Survey Area of the simulation region. Management operation and dates are compiled in the Management Crop Rotation Editor for WEPS (MCREW), a spreadsheet type table editor.

Given the user supplied inputs, the interface accesses five databases for climate, soils, management, barriers, and crop growth and residue decomposition for the simulation. These databases provide needed parameters for location and conditions simulated as specified by the user. The interface writes the information needed for a WEPS simulation, obtained from the user and the databases, to input files. The interface also calls the weather submodel which generates weather files containing daily precipitation, maximum and minimum temperatures, solar radiation, and dew-point temperature as well as a daily wind direction and subdaily (e.g., hourly) wind speeds. These input files for a given simulation are collectively known in WEPS as a “Run”. To reduce computation time, a daily time step is used in WEPS, except for selected subroutines in the Hydrology and Erosion submodels, which may use hourly or sub-hourly time steps (e.g., 15 minutes). The science model reads the input run files and calls the Hydrology, Soil, Crop, and Decomposition submodels which account for changes in the soil surface erodibility as influenced by Management and Weather. If surface conditions are such that erosion can occur for the maximum wind speed for the day, Erosion submodel routines are called to calculate soil loss and deposition. Soil erosion by wind is initiated when the wind speed exceeds the saltation threshold speed for a given soil and biomass condition. After initiation, the duration and severity of an erosion event depend on the wind speeds and the evolution of the surface conditions.

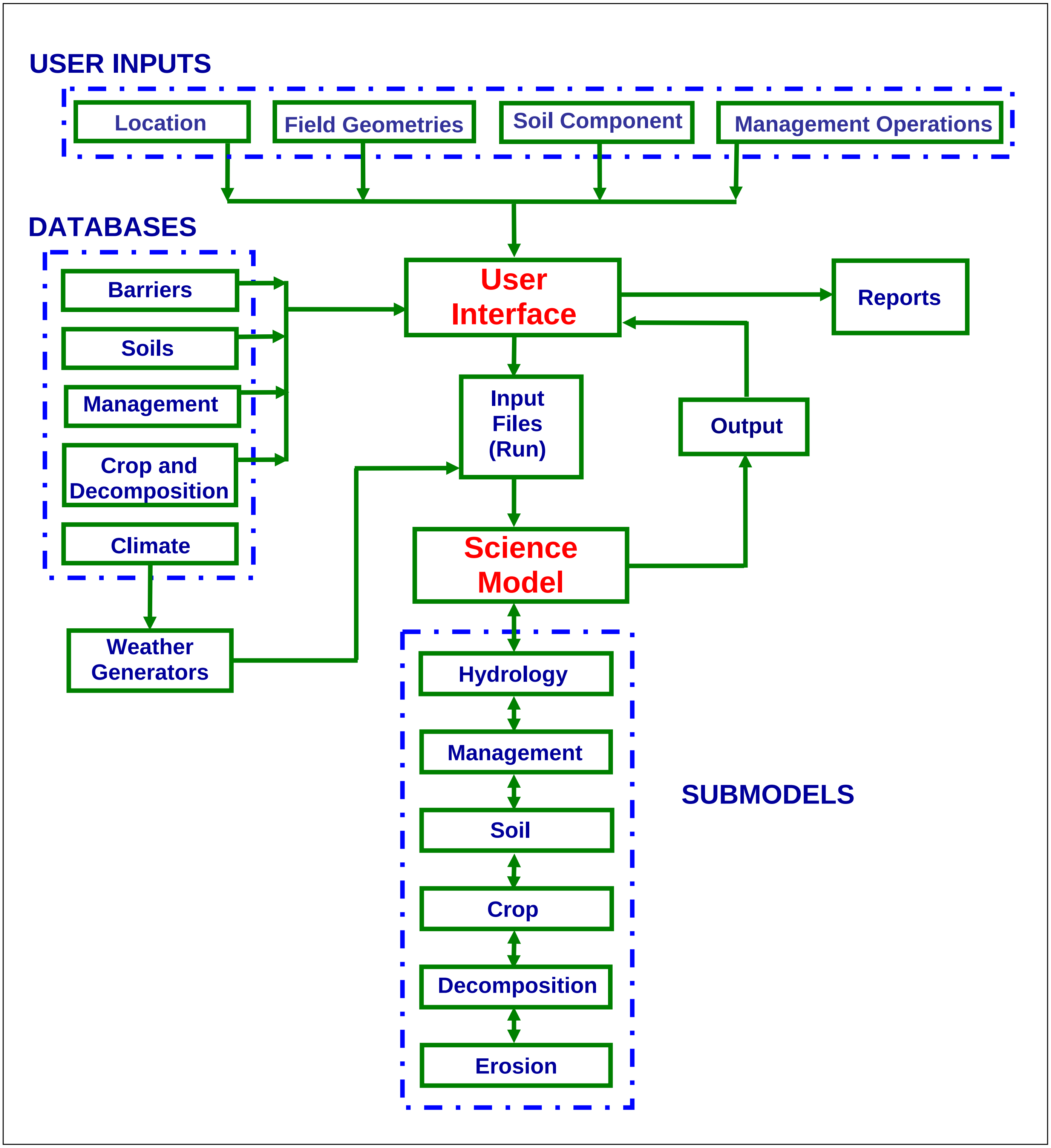

Figure 2. WEPS 1.0 model implementation.

WEPS Model Use

WEPS is a comprehensive wind erosion model with many options for inputs and outputs. For basic simulations however, WEPS 1.0 is simple to operate. Only four types of information are entered on the main screen: 1) describe of the simulation region geometry by defining the field dimensions and field orientation; 2) select the field location for which to generate simulated weather; 3) select the soil; and 4) select a management scenario. For U.S. simulations, the last three may be selected from lists provided with the WEPS model. New input files will usually be created using previous input files as templates modified within the user-interface. By varying inputs, particularly the field management, the user can compare various alternatives to control soil loss by wind. Interpreting the outputs of WEPS is an integral part of using WEPS as a tool to develop conservation plans for controlling wind erosion. WEPS provides options for viewing very detailed outputs by periods (default is two weeks) including soil loss as saltation/creep, suspension, and PM10. Period output is also available for weather parameters such as wind energy, as well as surface conditions such as soil erodibility and biomass amounts. Such information is useful in determining which period is resulting in severe erosion and the conditions that are contributing to the loss. WEPS outputs also include amount of loss for each direction which aid the user in the placement of barriers, strip cropping, or other directional erosion control methods. More detailed features of WEPS and information on use of WEPS outside the U.S., are included in the WEPS User Manual, available from WERU. WEPS also has a Multiple Run Management View option to allow easy comparisons of alternative outputs.

Conclusion

The Wind Erosion Prediction System is a process-based, daily time-step model that simulates weather, field conditions, and erosion. WEPS development was in response to customer requests for improved wind erosion technology. It is intended to replace the predominately empirical Wind Erosion Equation as a prediction tool for those who plan soil conservation systems, conduct environmental planning, or assess offsite impacts caused by wind erosion. The WEPS model is continually being improved with periodic updates. Plans are in place to develop the following enhancements to WEPS for future upgrades: i) provide plant damage estimates, ii) integration with the Water Erosion Prediction Project (WEPP) model, iii) add capabilities for other, non-cropped lands, iv) predict visibility effects of dust storms, v) dust prediction via weather forecasting, and vi) prediction of PM2.5 and PM-coarse (PM10 minus PM2.5), and vii) include capabilities for complex fields in terms of relief, multiple soils, crops, and management on one simulated field.

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