Wind Erosion Prediction System (WEPS): Overview[1]

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Introduction

The Wind Erosion Prediction System (WEPS) is a process-based, daily time-step model that simulates weather, field conditions, and erosion. WEPS development is in response to customer requests for improved wind erosion technology. It is intended to replace the predominately empirical Wind Erosion Equation (WEQ) (Woodruff and Siddoway, 1965) as a prediction tool for those who plan soil conservation systems, conduct environmental planning, or assess offsite impacts caused by wind erosion.

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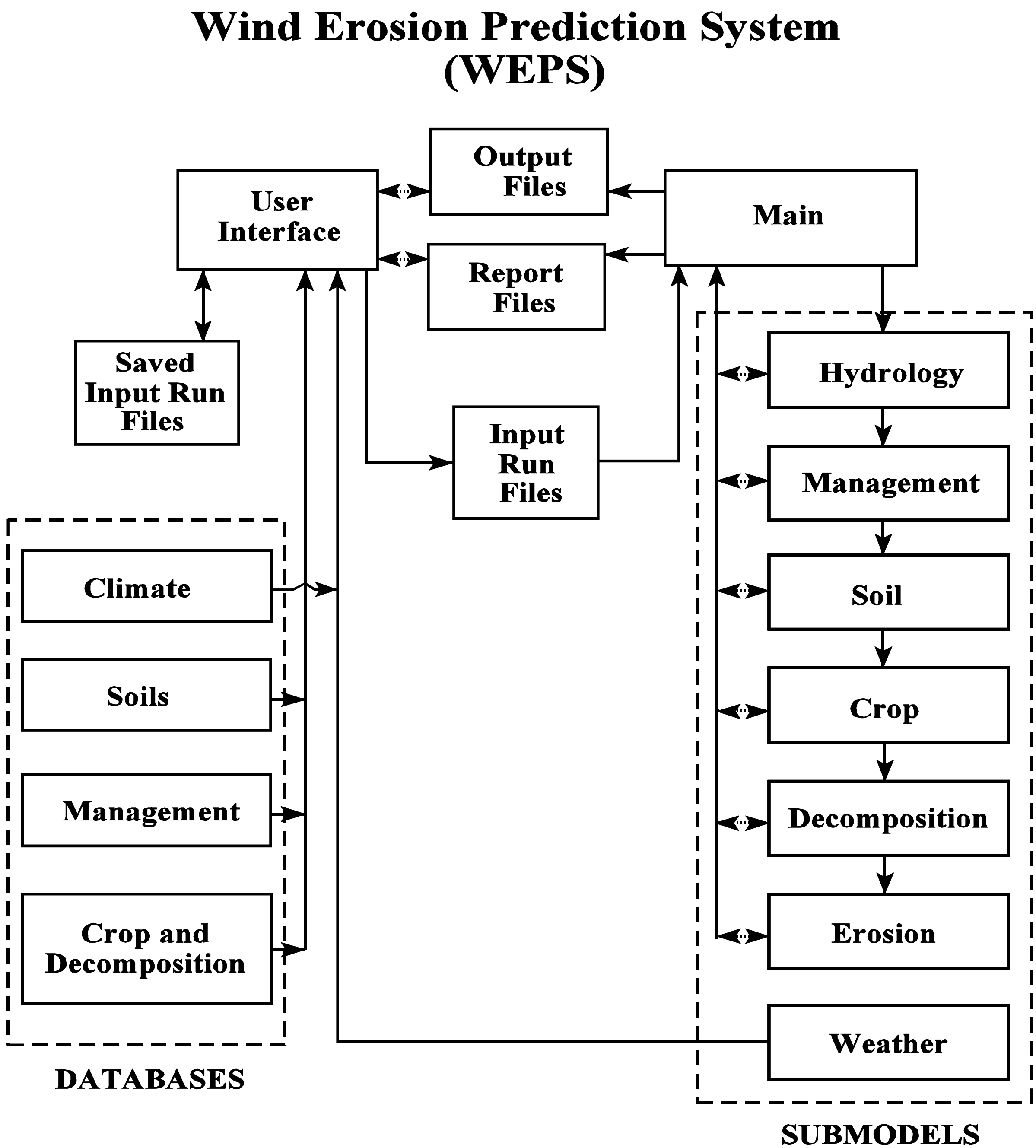

Figure 1. Structure of the WEPS model.

WEPS development involves an ARS-led, national, multidisciplinary team of scientists. It has a multiagency commitment consisting of the Agricultural Research Service (ARS), Natural Resource Conservation Service (NRCS), and Forest Service (FS) from the U.S. Department of Agriculture, along with the Environmental Protection Agency (EPA) and Bureau of Land Management (BLM).

Objectives

The purposes of WEPS are to improve technology for assessing soil loss by wind from agricultural fields and to provide new capabilities such as assessing plant damage, calculating suspension loss, and estimating PM-10 emissions from the field.

Background

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 speed and the evolution of the surface condition. Because WEPS is a continuous, daily time-step model, it 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 MAIN (supervisory) routine, seven submodels, and four databases (Fig. 1). The user-interface is used to create "Input Run" files with information from the databases and the weather generator. In a practical application, new "Input Run" files usually will be created by using previous "Input Run" files as templates modified within the user-interface.

Simulation Region

In WEPS, the simulation region is a field or, at most, a few adjacent fields (Fig. 2). Users must input the geometry of the simulation region and any subregions that have differing soil, management, or crop conditions. Initial conditions also must be specified for the surface and four to 10 soil layers. WEPS can output soil loss/deposition over user-selected time intervals from user-selected accounting regions within the simulation region. Multiple and overlapping accounting regions can be selected by the user to obtain output over various spatial scales in the simulation region. WEPS also provides users with individual soil loss components of creep-saltation, suspension, and PM-10 size fractions. The soil loss components are particularly useful as an aid in estimating off-site impacts of wind erosion.

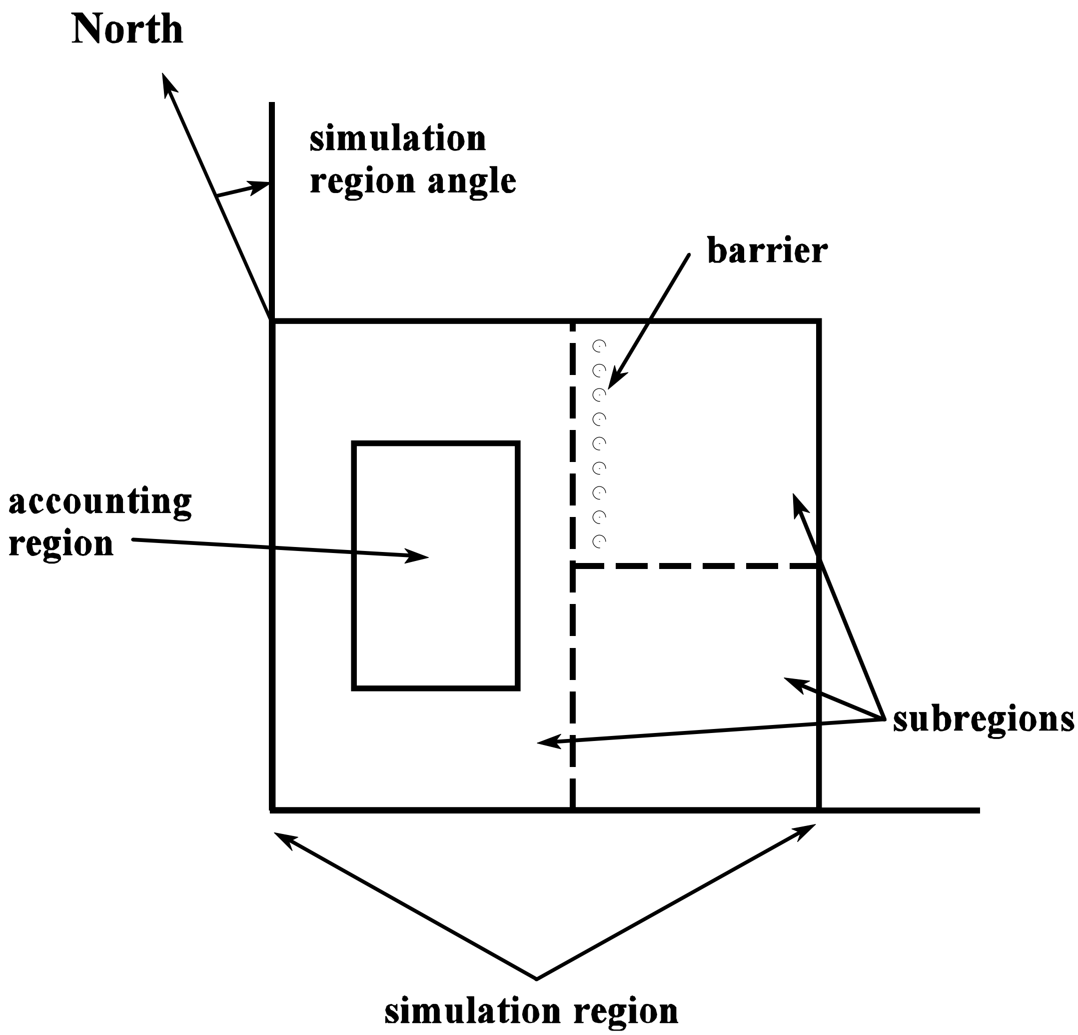

Figure 2. WEPS simulation geometries.

Discrete Time and Space

The time step is controlled by the main program. To reduce computation time, a daily time step is used in WEPS, except for selected subroutines in the HYDROLOGY and EROSION submodels, which use hourly or subhourly time steps. Submodels are called by MAIN (Tatarko, 1995) in the order shown in Fig. 1. Each individual submodel controls the sequence of calculations within itself. However, in MANAGEMENT, field operations are simulated sequentially according to the order in which they appear in the management plan.

Management plans usually cover at least a single year and may cover multiple years. The management plan can be initiated on any given day of the year, typically when there is no growing crop.

Nonhomogeneous sites are simulated by partitioning them into homogeneous subregions and maintaining the individual subregion soil and biomass "states" independently. "Homogeneous" means that the soil type, biomass, and management are similar over a subregion. Therefore, the basic WEPS submodels (except EROSION) were developed so that individual submodels would not require information on how MAIN internally handles nonhomogeneous sites.

Weather Simulated from Climate Databases

WEPS requires wind speed and direction to simulate the process of soil erosion by wind. These and other weather variables are needed to drive temporal changes in hydrology, soil erodibility, crop growth, and residue decomposition in WEPS. The weather generator consists of the programs WINDGEN and CLIGEN and also a user-interface (CLI_WIND), which provide the needed weather variables on a daily basis and wind speed on a subdaily basis (Tatarko et al., 1995).

WINDGEN simulates wind speed and direction for WEPS (Skidmore and Tatarko, 1990; Wagner et al., 1992). It was developed specifically for use with WEPS and stochastically simulates wind direction and maximum and minimum wind speeds on a daily basis. In addition, WINDGEN provides the hour at which the maximum wind speed occurs for each day based on historical records. Subdaily wind speeds are generated within WEPS when needed. A compact database (Skidmore and Tatarko, 1990, 1991) developed for WINDGEN currently consists of 673 location records. It was developed from historical monthly summaries of wind speed and wind direction contained in the Wind Energy Resource Information System (WERIS) database at the National Climatic Data Center in Asheville, North Carolina.

CLIGEN is the weather generator developed for the Water Erosion Prediction Project (WEPP) family of erosion models (Nicks et al., 1987). It is used with WEPS to generate an average annual air temperature as well as daily precipitation, maximum and minimum temperatures, solar radiation, and dew point temperature. Average daily air temperature and elevation for the site are used to calculate average daily air density within WEPS. CLIGEN and its database are described fully in the WEPP documentation (Nicks and Lane, 1989).

Field Conditions Simulated

The HYDROLOGY submodel (Durar and Skidmore, 1995) estimates soil surface wetness; accounts for changes in soil temperature; and maintains a soil-water balance based on daily amounts of snow melt, runoff, infiltration, deep percolation, soil evaporation, and plant transpiration. Snow melt depends on maximum daily air temperature and initial snow water content. Runoff is calculated using a modified version of the curve number method. Water is added to the uppermost simulation layer and excess water is cascaded downward to succeeding layers. Potential evapotranspiration is calculated using a revised version of Penman's combination method. Total daily potential evapotranspiration then is partitioned, based on crop leaf area index, into potential soil evaporation and plant transpiration. Hourly potential soil evaporation rates are estimated from the daily value based on soil water availability. Water redistribution is simulated through a simplified finite difference approach to Darcy's Law.

A soil's aggregation and surface state can dramatically affect susceptibility to wind erosion. Thus, changes in soil and surface temporal properties are simulated daily by the WEPS SOIL submodel (Hagen et al., 1995b) in response to various weather processes like wetting/drying, freeze/drying, freeze/thawing, precipitation amount and intensity, and time. Soil layer properties such as bulk density, aggregate size distribution, and dry aggregate density are maintained on a daily basis. Surface properties, such as random and oriented roughness, crust generation, coverage fraction, density, stability, and thickness, and loose erodible material on crusted surfaces also are accounted for in the SOIL submodel.

The presence of live biomass on the soil surface influences the quantity of soil that can be removed by wind erosion. Therefore, the CROP submodel (Retta and Armbrust, 1995) simulates the growth of crop plants. The crop growth model was adapted from the Erosion Productivity Calculator (EPIC) crop growth model (Williams et al., 1990), which simulates a variety of crops and plant communities while accounting for nutrient and water stresses. It calculates daily production of masses of roots, leaves, stems, and reproductive organs and also leaf and stem areas. Additional capabilities and modifications have been incorporated into the CROP submodel to meet the need for predicting effects of a growing crop on wind erosion. Some of the factors that affect wind erosion are the flexibility and arrangement of individual plant parts, distribution of plant parts by height, and number of plants per unit area (Shaw and Periera, 1982). Thus, leaves and stems are accounted for separately because: 1) stems of young seedlings are roughly 10 times more effective than leaves, on a per-unit-area basis, in depleting wind energy; 2) leaves are more sensitive to sandblast damage than are stems,;and 3) decomposition rates of stems and leaves are different.

The DECOMPOSITION submodel (Steiner et al., 1995) for WEPS simulates the decrease in crop residue biomass from microbial activity. The decomposition process is modeled as a first order reaction, with temperature and moisture as driving variables. Standing

residue is significantly more effective than flat residue at reducing wind energy at the soil surface. Hence, it is maintained separately from flat residue, and the conversion from standing to flat is simulated. The quantities of biomass remaining after harvest are partitioned into standing, surface, buried, and root pools with belowground biomass decomposition calculated for each soil layer. Because crop residue decomposition varies by type and changes with residue age, each pool is subdivided further into 1) the most recently harvested crop pool, 2) the penultimate crop pool, and 3) a "generic" crop pool that contains all older residue mass.

WEPS is expected to reflect the effects of various management practices upon wind erosion, and that is done by the MANAGEMENT submodel (Wagner and Ding, 1995). All major management operation classes are represented, such as primary and secondary tillage, cultivation, planting/seeding, harvesting, irrigation, fertilization, burning, and grazing. Each individual operation is simulated within the MANAGEMENT submodel as a series of physical processes. Those processes include 1) soil mass manipulation (changes in aggregate size distribution, soil porosity, mixing soil and residue among soil layers, and soil layer inversion); 2) surface modification (creation or destruction of ridges and/or dikes that form oriented surface roughness, changes in surface random roughness, and destruction of surface crusts); 3) biomass manipulation (burying and resurfacing residue, cutting standing residue, flattening standing residue, killing live crop biomass, and biomass removal); and 4) soil amendments (fertilization, planting, and irrigation).

Erosion Processes Simulated

The EROSION submodel (Hagen, 1995) decides if erosion can occur based on the current soil surface roughness (oriented and random), flat and standing biomass, aggregate size distribution, crust and rock cover, loose erodible material on a crust, and soil surface wetness. If the maximum daily wind speed reaches 8 m/s at 10m and snow depth is less than 20mm, the surface condition is evaluated on a subhourly basis to determine if erosion can occur. The EROSION submodel simulation performs the following functions: 1) calculates friction velocities based on the aerodynamic roughness of the surface, 2) calculates static threshold friction velocities, 3) computes soil loss/deposition at each grid point, and 4) updates soil surface variables to reflect changes in soil surface "state" caused by erosion.

Summary Comparison of WEPS and WEQ

Users of wind erosion prediction technology encounter a wide range of challenging environmental problems that require solutions. WEQ was unable to meet some of these needs. After extensive consultations with users, the WEPS structure was designed with the capabilities to meet the needs identified. As such, WEPS represents new technology and is not merely an improvement and recoding of WEQ technology. Also, WEPS contains many simplifications to maintain reasonable computation times. Because many users are familiar

with WEQ, a brief comparison of WEPS and WEQ follows to facilitate understanding of WEPS modeling techniques.

WEQ predicts soil loss for a single, uniform, isolated field. In contrast, WEPS provides capability to handle nonuniform areas and to "look inside" the simulation region to obtain predictions for specific areas of interest. In WEPS, spatial variation of the surface is entered by describing a simulation region as a series of subregions including some that are merely sinks (i.e., deposition regions for saltation/creep), such as a water body or drainage ditch. This treatment of spatial variability allows one to determine deposition in critical areas. It also allows one to simulate the interaction of areas with varying erosion rates on soil loss/deposition. For example, a region when simulated in isolation may be a soil loss area, but when simulated as interacting with other regions actually may be a deposition area.

WEQ predicts average erosion along line-transects across the field, whereas WEPS treats the field as two-dimensional. The WEPS EROSION submodel simulates soil loss/deposition at grid points over the entire simulation region. This feature allows users to "look inside" by specifying arbitrary accounting regions within the simulation region and, thus, obtains results averaged over grid points within the accounting region.

WEQ predicts only long-term, average, soil loss. WEPS calculates on a daily basis and allows users to specify the output intervals. Thus, users can obtain outputs ranging from single storms to multiple years. By simulating for multiple years, the probability of various levels of erosion during any period of the year also can be determined.

The largest contrast between the two technologies is that WEPS simulates a wide range of processes to describe field surface conditions and wind erosion, whereas WEQ depends on users to input correct estimates of the field surface conditions. Unfortunately, erosion does not vary linearly with residue cover and other temporal field conditions. Therefore, simply specifying average field conditions as inputs likely will not yield the best estimates of long-term average erosion.

The WEQ contains no feedback loop that modifies the field in response to weather or erosion. In WEPS, the driving forces of weather cause surface temporal properties of the field to change. Thus, in a year with high rainfall, the field soil roughness may be reduced below average, while above average biomass production prevents erosion. However, in a drought year, biomass and aggregate size may be below average, but tillage ridges may then control soil erosion.

The modeling techniques used to simulate processes in WEPS vary. The WEATHER submodel generates stochastic simulated weather variables. Mechanistic and statistical generally relations are used to represent processes in the other submodels. However, a structured design methodology was used. First, the major wind erosion processes, such as emission, abrasion, and trapping were identified. Next, the individual temporal soil and

biomass properties that affect the wind erosion processes were selected. Then, WEPS submodels were designed to simulate the general processes that control both the surface temporal properties and the erosion processes. Finally, parameters from the databases were used to make the simulation of various processes unique for specific soil, crop, and management actions.

Implementation

The current WEPS model is coded in FORTRAN conforming to the ANSI FORTRAN 77 standard. The coding guidelines used, with some minor modifications for WEPS, are outlined in the "Water Erosion Prediction Project (WEPP) Fortran-77 Coding Convention" (Carey et al., 1989). The model can be run in both a DOS and Unix environment. The operation of WEPS is documented fully in the WEPS Users Guide and the science and implementation are described in the WEPS Technical Description (Hagen et al., 1995a) distributed with the WEPS program.

WEPS Updates

The WEPS model is currently in beta testing and continually being improved with periodic updates. The USDA-ARS Wind Erosion Research Unit (WERU) has established several means for obtaining the latest release of the WEPS model, databases, documents, and other related information as they become available.

For users with Internet access, an anonymous FTP site is available for downloading the desired information. The FTP address is: *ftp.weru.ksu.edu* . Login is accomplished by entering "anonymous" at the "Name" prompt and your E-mail address when asked for a "Password". This site contains readme files at each directory level that should help the user to locate the desired materials. WERU also has established a World Wide Web site. The WERU Home Page URL for this site is: *http://weru.ksu.edu* . This site contains all the information available by FTP as well as information about wind erosion research conducted at WERU. Specific WEPS information also can be obtained through E-Mail at *office@weru.ksu.edu* .

Users without Internet access can obtain WEPS update information by contacting:

USDA-ARS, NPA
Wind Erosion Research Unit
Throckmorton Hall
Kansas State University
Manhattan, KS 66506

Phone:(785) 532-6495
FAX: (785) 532-6528

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