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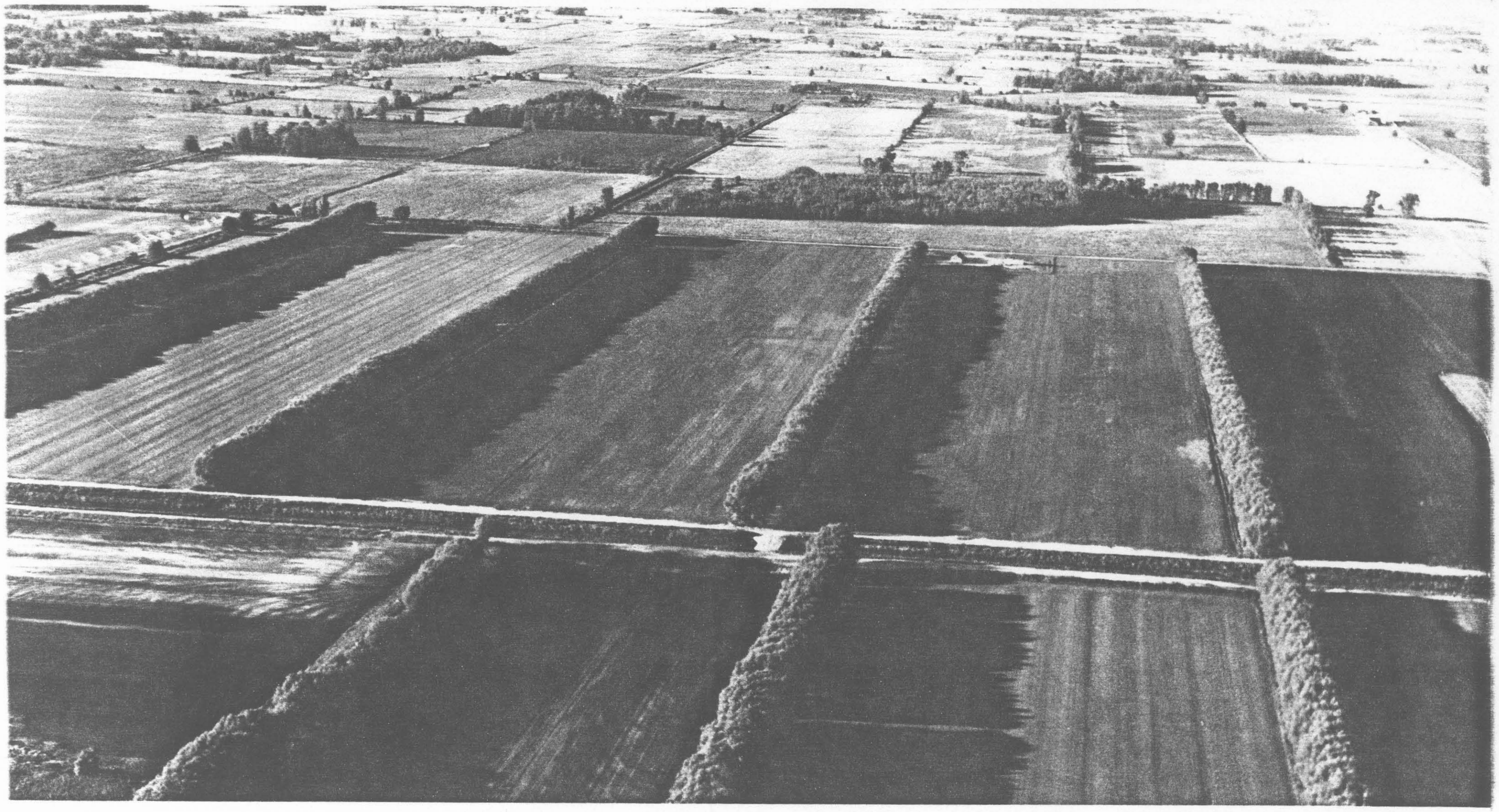

Soil Conservation Service/Frank Stock

A wind erosion prediction system to meet user needs

By L. J. Hagen

WIND erosion is a serious problem in many parts of the world, and extensive aeolian deposits from past geologic eras give evidence that it is not merely a recent phenomenon. However, human impact on global desertification is an issue of current international concern (*21*). Arid or semiarid land now comprises about one-third of the world's total land area, and this land is home to about one-sixth of the world's population (*8, 13*). Development of adequate prediction technology for wind erosion is important to provide producers with guidance in the use of potentially erodible land.

In the United States the primary technology currently used for predicting wind erosion is based on variations of the wind erosion equation (WEQ) (*23, 26*). This prediction system represents integrations over large fields with unchanging surface conditions and long-time scales to produce average annual estimates of soil loss.

To account for seasonal variations in field surfaces, a procedure using repeated solutions of the WEQ to compute soil loss by periods was introduced (*4*), and further modifications of the WEQ computation procedure were developed to allow soil loss estimates to be simulated on a daily basis in the EPIC model (*7*).

However, complex interactions between the variables that control wind erosion are not accounted for in the WEQ calculation procedures. Because of the time and space scales involved, the interactions are difficult to determine. Hence, the current technology represents a mature technology that is not easily adapted to untested conditions or climates far different than that of the central Great Plains where the WEQ was developed. New developments in erosion

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science and the increased availability of powerful personal computers, however, would allow most users of erosion prediction technology to adopt a flexible, process-based erosion prediction technology.

Recently, the U.S. Department of Agriculture (USDA) appointed a team of scientists to take a leading role in combining erosion science with data bases and computers to develop what should be a significant advancement in wind erosion prediction technology. The objective of the project is to develop a new wind erosion prediction system (WEPS) as a replacement technology for the WEQ.

Prediction technology requirement

USDA's Soil Conservation Service (SCS) is a frequent user of wind erosion prediction technology, with several major applications. First, SCS does conservation planning of wind erosion control practices to assist farmers and ranchers in meeting erosion tolerances. Conservation planning in field offices requires a prediction system that will operate on a personal computer, use readily available inputs, and produce answers in a relatively short time. In addition, WEPS must serve as a communication tool between conservation planners and those who implement the plans.

Second, as a part of its periodic National Resources Inventory, SCS collects data at 300,000 primary sampling points and, at central locations, calculates the erosion losses occurring under current land use practices. The analyzed results are used to aid in developing regional and national policy.

Various users of wind erosion prediction technology undertake project planning in which erosion and deposition are evaluated in areas impacted by a proposed project. Researchers also frequently need a physically based prediction technology to assist them in evaluating proposed new erosion control methods. The prediction technology should allow them to make low-cost simulation tests of various combinations of erosion control practices in a variety of climates.

Other users of wind erosion prediction technology investigate a wide range of problem areas. Often, their applications will require development of additional models to supplement WEPS to obtain answers of interest. Some of these diverse problem areas include the following:

- Estimating long-term soil productivity changes.
- Determining physical damage to plants.
- Calculating the on-site and off-site economic costs of erosion.
- Finding deposition loading of lakes and streams.
- Computing the effects of dust on acid rain processes.
- Determining impacts of management strategies on public land.
- Estimating visibility reductions near airports and highways.

Where the technology applies. The development of a new prediction technology requires that a number of questions be answered. An obvious question is where the technology must apply. The major use of wind erosion predictions has been on cropland. Thus, the technology should apply to areas where cropland erodes by wind. Recently, SCS personnel summarized results of a survey of U.S. areas where wind erosion occurs on cropland. The technology also should apply to rangeland areas where wind erosion is significant. Although data on affected range areas are scarce, reports indicate that rangeland erosion is significant in the west central and southwestern United States, where much of the area is in shrub-dominated rangelands (*11, 17*). Thus, a general prediction technology must deal with a wide range of soil and vegetative types, management factors, and climatic regimes.

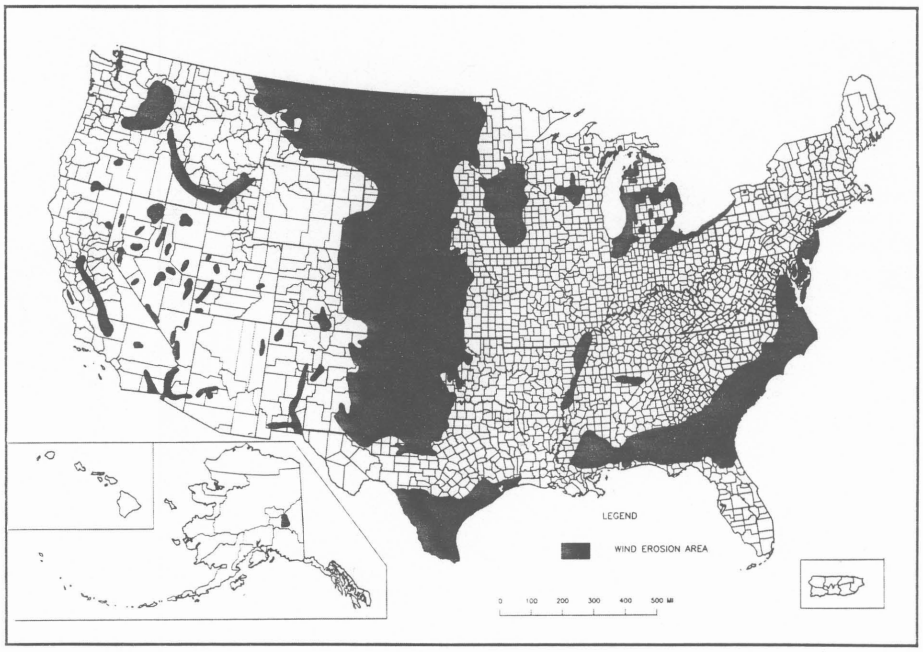
Space scales to consider. A second question is what space scales should the prediction technology consider? In this regard, there are four related issues: (a) What is the space scale modelers should select to efficiently simulate soil erodibility and soil erosion? (b) What is the space scale over which field wind erodibility changes occur that must be input as initial conditions to a model? (c) What are the space scales over which users need answers? (d) Finally, what space scale must be included in the model simulation region?

The scale of (a), often dubbed the grid scale in models, defines the total number of subareas in the simulation region at which erosion is calculated. Areas of scale (b) represent subregions in the simulation region, with their size varying with the management scale used by producers and changes in soil properties. Thus, a subregion is generally made up of one or more grid-scale areas.

The scale of interest to users, scale (c), is often the conservation planning unit for which a management plan is to be designed. This scale, which may involve an entire field or only a portion of it, is dubbed the accounting region. When saltating soil crosses the boundary of the accounting region, it is convenient to have the erosion simulation region encompass an area upwind of the boundary so the user does not need to estimate the soil movement at the boundary. The boundary condition easiest to simulate occurs when the simulation region can be extended, so that no saltation flux crosses its boundaries. Thus, the scale of (d), the simulation region, generally encompasses one or more accounting regions.

A useful scale sequence. From the preceding analysis, it appears that a useful

Areas in the United States where wind erosion occurs on cropland.



sequence of scales results when scales are selected so that $a \leq b \leq c \leq d$. One can then input initial conditions on each user-selected subregion, integrate over the grid regions to obtain answers for the simulation region, and output the answers for accounting regions that are user-selected portions of the simulation region.

Several time scales also must be considered in design of prediction technology. Some of the time scales of interest include: (e) time scale of soil aggregate response to wind forces; (f) time scale of surface erodibility changes in response to wind, tillage, and crops; and (g) time scale of interest to users of the technology.

The choices for time scales of items (e) and (f) must be selected by technology developers. The response time of a saltating soil aggregate system to wind gusts is one to two seconds (*1*). However, limited studies using saltation catchers showed that prediction of saltation flux from short-term average wind speeds of 15 minutes was as accurate as predictions based on shorter wind speed records (*19*). Thus, a minimum time scale to model during erosion is perhaps on the order of 15 to 30 minutes. Tillage often has been simulated as an instantaneous step function, whereas effects on erodibility of other climatic forces and crop growth have been successfully simulated on a daily time step (*25*).

It is important to develop flexible technology that can respond to a wide range of sequences of climatic and management actions. Thus, if one chooses a continuous simulation model with time steps of about 15 to 30 minutes during erosion events and daily time steps between events, one can then integrate over time to meet time scales needed by users, ranging from single storms to long-term averages.

The need for selectable options. To accommodate a range of user questions, the prediction technology output should have several options available to the user. To illustrate output needed on a time scale, consider a user who selects a crop rotation period of two years, a loss accounting interval of one month, and a simulation period of 40 years. The WEPS should then compute one average for the crop rotation and 24 average monthly soil loss/deposition values.

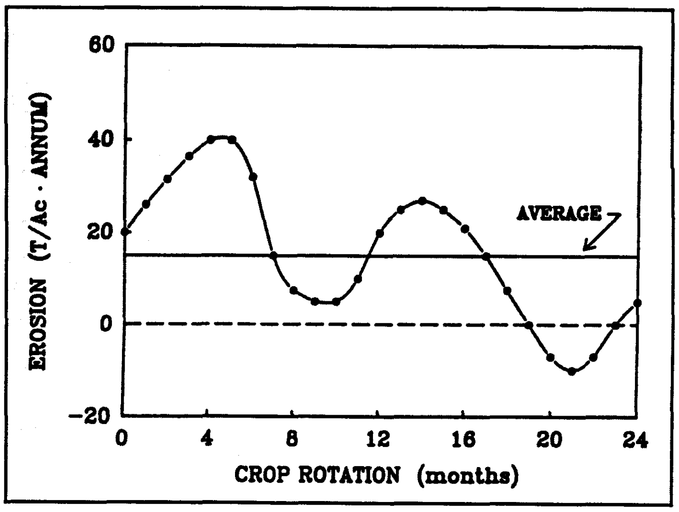
From this information, a user could readily determine if erosion tolerances were exceeded and what portions of the crop rotation cycle contributed most of the erosion. To complete the example, the WEPS output also should provide 24 frequency distributions for the monthly accounting intervals and one frequency distribution of loss/deposition for the rotation interval. This information allows the user to determine the probability of significant erosion events at critical times in the cropping rotation.

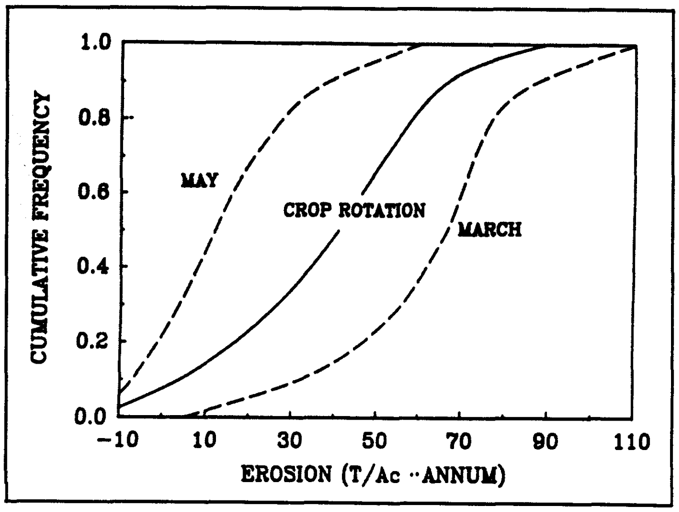
Other output options should include the ability to select output from a variable number of user-defined accounting regions within the simulation region. In some cases, the fraction of soil transported in each mode, which includes creep, saltation, and suspension, needs to be available to users. This is particularly true for those who must use the technology to assess off-site impacts of erosion. Finally, users may need to know the composition of the soil transported in

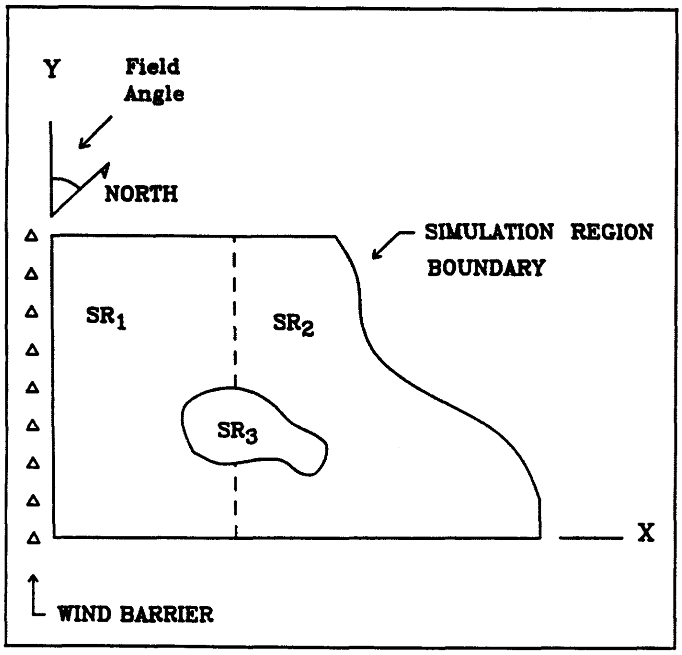
(Right, top): Illustration of needed WEPS output of average soil loss/deposition for loss accounting period (monthly) and for crop rotation interval.

(Right, bottom): Illustration of needed WEPS output showing probability of erosion during selected time intervals being less than the X-axis erosion values.

(Below): Illustration of a complex simulation region with a nonerodible boundary. To model this region, a user must input boundaries of the simulation region, the two cropped subregions that have different management (SR_1, SR_2), the slough (SR_3), the wind barrier, user-selected accounting region(s) within the simulation region, and field angle.







various modes. Although limited studies of composition and enrichment ratios have been carried out (*16, 28*), more research is needed before composition of soil transported by wind can be reliably simulated.

Overview of model

The model development process has two major stages. The objective of the first stage is to develop a wind erosion research model (WERM). WERM will be a daily simulation model written in FORTRAN 77 that can be validated and used as a reference standard for wind erosion predictions. The user interface will provide menus to facilitate preparation of user input files and be written in C language. WERM is scheduled to be operational in 1991.

In the second stage of development, the submodels in WERM will be reorganized to increase computation speed; the data bases will be expanded in size; and a user-friendly input/output section will be added to produce the final WEPS. WEPS is scheduled to be operational in 1993.

In the model, the simulation region will be a field or, at most, a few adjacent fields. Model outputs will be average soil loss/deposition over the accounting region for a user-selected time interval. The model also will have an option to provide users with individual loss components for the creep, saltation, and suspension fractions, as well as individual accounting for deposition of creep and saltation fractions.

The structure of WERM is modular and consists of a MAIN (supervisory) program: a user-interface input section; seven submodels, along with their associated data bases; and an output control section. MAIN has two major functions. First, it calls the subroutines that control preparation of the user input files. Second, it controls the sequence of events in the simulation runs.

The framework of the user interface in WERM is composed of the input/output forms control section and two levels of input parameter files. The control section will use a series of menus and submenus to guide the user in preparing run files that contain all the input parameters needed for single or batch simulation runs. The run files can be created by direct input from the keyboard, by recall and editing of existing run files, or by assembly of second-level submodel input and data base files.

The submodel files consist of input files needed by individual submodels and correspond to sections of the run file. These can be individually prepared, edited, stored, or assembled to form complete run files. Another important function of the user interface section is selection of output options.

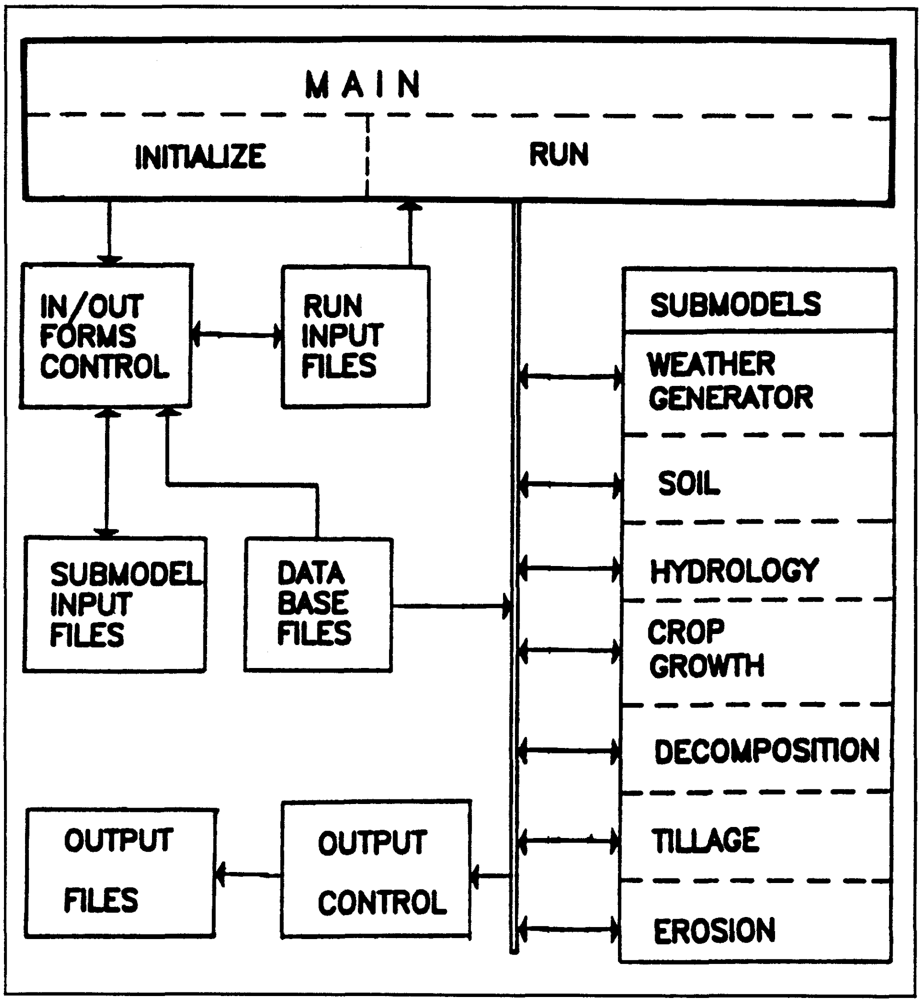
The modular structure permits the modeling team to test and update specific sections of the model during development. It will also faciliate model maintenance as new technology becomes available. In general, the submodels are based on fundamental processes occurring in the field. Extensive experimental work is being carried out simultaneously with model development and is devoted mainly to delineating parameter values that control the processes.

Submodel concepts

Because the model deals with prediction of future events, CROP GROWTH, DECOMPOSITION, SOIL, HYDROLOGY, and TILLAGE submodels seek to predict the temporal soil and vegetative cover variables that control soil erodibility in response to inputs generated by the WEATHER submodel. Finally, if wind speeds are above the erosion threshold, the EROSION submodel computes soil loss or deposition and new estimates of soil and plant variable values over the simulation region.

Weather. The WEATHER submodel will generate variables necessary to drive the CROP GROWTH, DECOMPOSITION, HYDROLOGY, SOIL, and EROSION submodels. The weather generator developed to drive the water erosion prediction project (WEPP) erosion models (*20*) likely will be used as part of the WEATHER submodel. That generator currently generates daily duration, intensity, and amount of precipitation; maximum and minimum temperature; solar radiation; and dew point. The generator will be capable of generating a design storm, a selected storm, or continuous simulation. Efforts to develop generators for wind speed and wind direction are near completion. For the EROSION submodel, maximum daily wind speeds are needed to determine if any erosion will occur. If erosion can occur, then wind speed and direction must be generated at sub-

Diagram of wind erosion research model (WERM) with associated files, data bases, and submodels.



hourly intervals during erosion events.

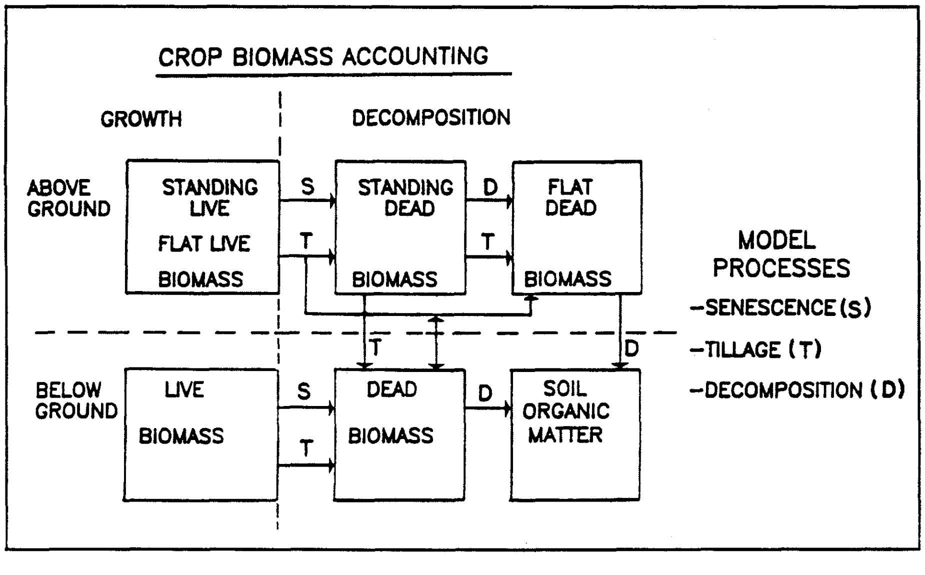
The WEATHER data base will consist of sets of monthly statistical parameters describing the generated weather variables. The parameters have been developed for 1,000 U.S. stations for the WEPP weather generator. The data base of stations reporting wind data is somewhat less, but the available data base of wind stations has been parameterized as well.

Crop. Biomass accounting in the model is accomplished by a CROP GROWTH submodel and a DECOMPOSITION submodel. Crop growth will be simulated by a generalized growth model that calculates potential growth of leaves, stems, yield, and root components. The potential growth will be modified by temperature, fertility, and moisture stresses. A modified version of the EPIC growth model (*25*) has been adapted to accomplish these tasks. Pests and diseases will not be considered as limiting factors.

As input for the EROSION submodel, the CROP submodel will provide the distributions of leaf and stem silhouette area with height, canopy height, canopy cover, and flat biomass cover. Prediction equations for several of these variables in a number of crops have been developed using biomass as the independent variable (*2*).

The need to distinguish between leaf and stem area arises because leaves tend to streamline with the flow and have a drag coefficient of about 0.1, whereas stems tend to remain rigid and have a drag coefficient of about 1.0. Thus, on a unit area basis, stems are about 10 times more effective than leaves in depleting the wind force transmitted to the canopy.

Diagram of biomass accounting in the CROP and DECOMPOSITION submodels.



Primary, temporal soil properties that control wind erodibility

Soil Fraction	*Properties*
All	Surface wetness Bulk density Surface microrelief
Aggregates	Size distribution Dry stability Denisty
Crust	Thickness Dry stability Loose soil above Cover fraction Density

The CROP data base will contain information on specific crops and include parameters on growth, leaf-stem relationships, decomposition, and harvest.

Decomposition. The DECOMPOSITION submodel will keep account of the biomass residues in standing, flat, and buried categories. Such factors as crop carbon-nitrogen ratios, temperature, and moisture will be used to drive the rates of decomposition. In addition to biomass flow paths, there will be a biomass sink called harvest, initiated by the TILLAGE submodel, that will remove biomass from some categories.

Soil. The role of the SOIL submodel is to modify, on a daily time step, temporal soil profile properties between erosion and tillage events. The soil surface configuration is treated as having both oriented and random roughness components that will be updated separately. This is necessary because the effective deposition capacity, aerodynamic roughness, and soil transport capacities all vary as a function of wind direction relative to an oriented roughness, such as till ridges. The temporal soil properties and surface roughness depend on both intrinsic properties, such as texture and secondary temporal properties, as well as climate and management factors (*22, 27*).

The SOIL data base will consist of the intrinsic soil properties that are shown to be useful in predicting the temporal soil properties.

Hydrology. The function of the HYDROLOGY submodel is to simulate the soil energy and water balances. In order to assess water balance, this submodel will account for infiltration, snowmelt, runoff, deep percolation, evaporation, and plant water use. Water added by irrigation will be distributed through the soil profile, and soil subsurface drainage by tile will be approximated. Wind redistribution of snow also will be accounted for in this submodel. Snowmelt is calculated using an equation for melt in open areas (*18*). Potential evaporation is calculated using a combination method (*24*) and then adjusted using Darcy's law of soil water flux to obtain actual evaporation. Runoff is calculated as precipitation exceeding the infiltration rate, assuming the simulation region is composed of subregions of constant slope. Deep percolation from the soil profile is estimated to be equal to the conductivity of the lowermost soil layer, assuming a unit hydraulic gradient.

The soil energy balance will be calculated, and the soil temperature profile will be computed. Soil freeze/thaw cycles and frost depth also will be simulated (*3*).

Tillage. The role of the TILLAGE submodel is to assess the effects of tillage on both temporal soil properties and surface configuration for delivery to the HYDROLOGY and SOIL submodels and to determine biomass manipulation for delivery to the CROP and DECOMPOSITION submodels. The primary temporal soil properties that control the wind erodibility of the soil, along with biomass manipulation and surface configuration, are to be predicted. Predictions will use regression-type equations in which the independent variables likely will fit into three categories: (a) initial conditions, (b) tillage tool (machine) parameters, and (c) physical soil properties. Simulation of the soil manipulations by tillage tools is grouped into four categories: mixing, loosening, inverting, and crushing (*6*). Random roughness will be predicted by the submodel. Height, spacing, and orientation of oriented roughness will be input by the user.

The TILLAGE submodel input files will

consist of user-developed schedules of tillage events, and the TILLAGE data base will consist of tables of parameters for specific tillage and harvesting machines.

Erosion. The EROSION submodel will perform several major tasks. The first task is to compute the surface threshold friction velocities over the simulation region, considering the effects of flat cover, surface roughness, and primary temporal soil properties. The second task is to compute field surface friction velocities based on the wind speed and direction supplied by the WEATHER submodel, considering the effects of hills, barriers, standing canopies, and surface roughness.

During periods when friction velocity exceeds the threshold level, soil loss and deposition will be computed over the simulation region at subhourly intervals. Soil transport by wind erosion is modeled as the time-dependent conservation of mass of two species (saltation- and creep-size aggregates) with two sources of erodible material (emission and abrasion) and two sinks (surface trapping and suspension). In addition, the soil surface conditions are updated periodically in response to the soil loss or deposition that has occurred.

The source and sink terms represent distinct physical subprocesses that can occur during wind erosion. Emission occurs when there is a net loss of loose, saltation/creep-size aggregates caused by a combination of wind shear and saltation impact forces. This loss is typical of the data obtained in wind tunnel tests on soil aggregates (*5, 9*). Trapping occurs when there is a net deposition of saltation/creep-size material over a portion of the surface, such as between ridges (*15*). Abrasion is used here to mean the breakdown of nonerodible-size clods and crust to wind-erodible sizes. This subprocess depends on the horizontal flux of saltating aggregates, the stability of the target, and other factors (*14*).

Sources of the suspension-size material include direct emission from among the soil aggregates, as well as creation of additional material abraded from the clods, crusts, and impacting aggregates during erosion (*17*). The magnitude of the suspension component varies among fields (*12*). In the model, the suspended material is regarded as lost through the top of the control volume, and its deposition is not considered because it generally occurs over a larger area than that encompassed by the simulation region.

In the EROSION submodel, standing vegetative biomass has three major effects on soil movement:

► The structure of a canopy gives rise to its aerodynamic roughness, which determines the friction velocity at the top of the canopy for a given wind speed.

► Leaves and stems deplete a portion of the friction velocity through the canopy and, thus, control velocity near the surface.

► If the surface friction velocity exceeds the threshold, vegetation intercepts some of the saltating particles in flight to further reduce soil movement.

Flat residues are treated as creators of surface cover, and their diameter increases roughness. Thus, flat residues modify aerodynamic surface roughness, protect part of the surface from both abrasion and emission, and may enhance surface trapping.

Model validation

The submodels will be validated using various methods. The weather series generated by the WEATHER submodel will be compared to actual-weather time series to ensure that both produce similar statistical parameters. Using recorded meteorological variables, the temporal soil properties predicted by the SOIL and TILLAGE submodels will be compared to measured soil properties in plot studies. Biomass patterns of major crops will be compared to biomass production predicted by the CROP submodel and biomass reduction predicted by the DECOMPOSITION submodel.

Finally, the EROSION submodel will be validated by instrumenting a series of field-scale sites. This appears necessary because development of the equations describing the erosion subprocesses is being done in laboratory wind tunnels on individual subprocesses. In the field, the subprocesses are combined and operate over larger scales. Initial field-scale validation sites are in operation at Big Spring, Texas; Scoby, Montana; Akron, Colorado; Sidney, Nebraska; Crookston, Minnesota; and Crown Point, Indiana, with additional sites planned for Washington and Kansas (*10*).

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