Chapter 3 : Modeling and Predicting Wind Erosion

Wind Erosion Equation (WEQ) – **From the WEPS 1.5 User Manual**[17]

The Wind Erosion Equation (WEQ) was first published in 1965 by Woodruff and Siddoway. For years, WEQ has represented the most comprehensive and widely used model in the world for estimating soil loss by wind from agricultural fields. WEQ uses five factors to calculate the erodibility of a given soil.

The equation for 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 and was derived from nearly 20 years of field and laboratory studies by scientists at the United States Department of Agriculture Agricultural Research Service (ARS) Wind Erosion Research Unit.[18–21] Many improvements were made to WEQ over the next 30 years. The limitations of adapting WEQ to many problems and environments, as well as advancements in wind erosion science and computer technology, led to the USDA Natural Resources Conservation Service (NRCS) requesting that ARS develop a replacement for WEQ.[22]

Wind Erosion Prediction System (WEPS) – **Adapted from the WEPS 1.5 User Manual**[17]

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 field processes that modify a soil's susceptibility to wind erosion. It 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 conservation planning and designing erosion control systems.

Research in the 1980's provided the initial attempt to outline a processed based approach to simulating wind erosion that would replace the Wind Erosion Equation (WEQ). Following this initial work, the modular structure used in the current WEPS model was developed 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, hydrology, crop growth, residue decomposition, soil, management, and erosion. Experiments were conducted to validate that the erosion routines were producing accurate and precise erosion estimates.

A multi-disciplinary team assembled to develop WEPS included climate modelers, agronomists, agricultural engineers, soil scientists, and crop modelers. In 2005, WEPS was released to the NRCS for testing and further development for field office conservation planning. In 2008 WEPS was released to NRCS for field office implementation.

Early in the WEPS development process, input was requested from potential users on the needed capabilities of a new wind erosion simulation model. Based on these requirements, WEPS was designed to:

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 conditions), an approach that accounts for such extreme conditions was needed to simulate the extreme soil loss for these situations. 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 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.

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

Simulate the amount of soil loss by direction. With increasing concern about the 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 control loss based upon impacts. Similarly, suspension loss in the direction of highly populated areas and control strategies can be simulated with WEPS.

Separate soil loss into creep/saltation, suspension, and PM$_{10}$ components. Each of these components have specific characteristics and effects. Particles lost through creep/saltation are typically deposited locally where they can affect soil and water quality, bury crops, roads, and irrigation ditches, or be deposited as dunes in fences or windbreaks. Suspension particles, 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. PM$_{10}$ has been determined by the U.S. Environmental Protection Agency to be a hazard to air quality and a respiratory hazard in particular.[23] Estimating soil loss of each of these components can aid in environmental assessments.

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

WEPS Modeling Approach

To simplify inputs, WEPS is designed with specific geometric constraints when specifying the simulation region or field (Figure 3-1). The simulation area may be rotated to orient the field correctly on the landscape to account for the effects of varying tillage, planting, and wind directions.
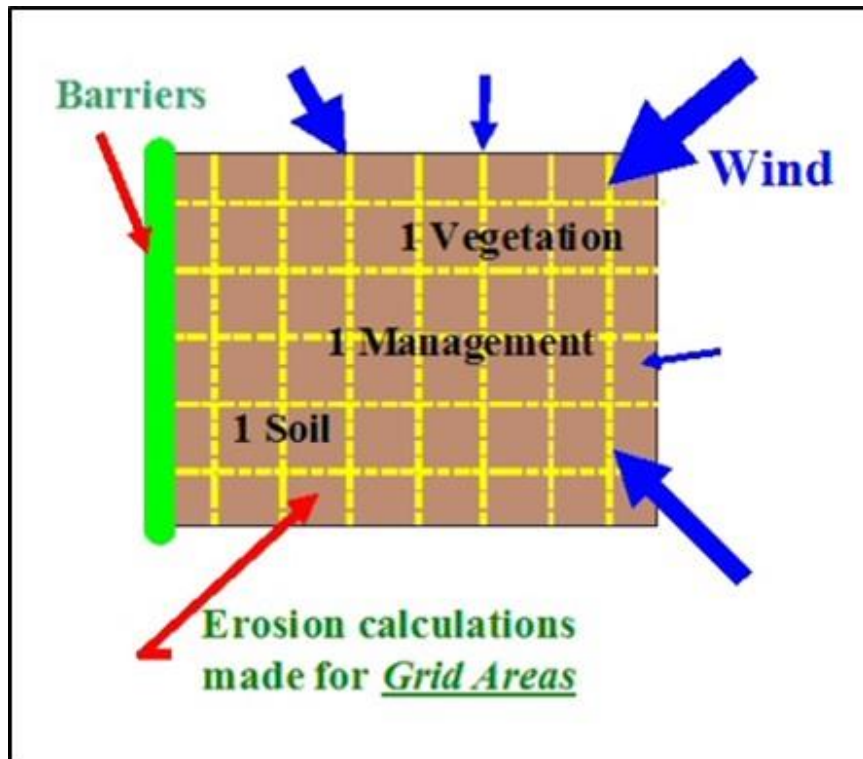
Figure 3-1. WEPS simulation geometries.[17]

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 and 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 surface 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.

Once given 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. WEPS also uses 50 years of climate data containing daily precipitation, maximum and minimum temperatures, solar radiation, and dew-point temperature as well as a daily wind direction and sub-daily (e.g., hourly) wind speeds.

These input files for a given simulation are collectively known in WEPS as a "run". The science model reads the input run files and calls the Hydrology, Soil, Crop, and Decomposition submodels daily which account for changes in the soil surface erodibility as influenced by Management and Weather. If surface conditions for a given day are such that erosion can occur for the maximum wind speed for that 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.

Since WEPS uses 50 years of data to determine the average erosion rates, it is not useful for looking at the effects of single weather events. The SWEEP program (single wind erosion event program) can be used along with the WEPS erosion model to determine the soil losses from individual weather events. This program is not a formal part of the NRCS WEPS package, but is available from the USDA-ARS WEPS website.

Aeolian Erosion (AERO) Model

The Aeolian Erosion (AERO) model was developed by the United States Department of Agriculture Agricultural Research Service (ARS) to address the need for a generalizable, physically-based wind erosion and dust emission model that could be applied to existing standardized monitoring datasets across all land cover types. The need for a generalizable and physically-based model arose from recognition that the strengths of available cropland wind erosion models (e.g., WEPS) for assessing management impacts on soil loss do not currently (2018) extend to rangeland applications. Available cropland wind erosion models and global dust models were also seen as being either too empirically tuned to cropland settings or too insensitive to the subtle, and sometimes not so subtle, effects of rangeland management and vegetation state changes on aeolian sediment transport and dust emission. AERO was developed from a selection of the best-available schemes to represent biophysical controls on sediment transport and dust emission processes. Criteria for scheme selection included a desire for a high

level of process fidelity, low model complexity, and the ability to be applied directly to available soil and ecological monitoring data collected by the Natural Resources Conservation Service's (NRCS) National Resources Inventory (NRI) and the Bureau of Land Management's (BLM) Assessment, Inventory and Monitoring (AIM) programs.[24]

The AERO model draws heavily on the structure of the Shao[25] dust model. The threshold wind friction velocity for soil entrainment is estimated using the Iverson and White[26] threshold equation. A minimally dispersed soil particle size distribution, identified by geographic location and surface soil texture class, is used as input to the equation to produce a size-resolved entrainment threshold. The Fécan et al.[27] scheme is used as a threshold modifier to account for the effects of soil moisture on inter-particle cohesion. The Okin[28] drag partition scheme is used to estimate the probability density distribution of wind friction velocity at the soil surface as a function of the freestream wind velocity, mean vegetation canopy height, and the vegetation canopy gap size distribution. A tiered drag partition can be implemented to assess effects of shrubs, grasses and oriented soil roughness (e.g., due to tillage) on surface wind friction velocities and sediment transport. Horizontal sediment mass flux, Q (g m^{-1} s^{-1}) is estimated when the surface wind friction velocity exceeds the entrainment threshold and is computed for each soil particle size class using the Owen[29] sand transport equation. Size-resolved vertical dust flux, F (g m^{-2} s^{-1}) is calculated using the Shao[25] dust emission scheme as a function of saltation bombardment and aggregate disintegration processes. A dispersed soil particle size distribution and surface wind friction velocity are used to estimate the level of soil disaggregation, with F estimated as the volume of fine particles emitted from the soil surface. AERO outputs can be tailored by application and may include total horizontal (saltation) and vertical (dust) mass fluxes, size-resolved dust mass flux, and gross wind erosion.

AERO can be implemented in three modes: (1) a timeseries mode using field measured inputs of meteorological, soil and vegetation properties; (2) a probabilistic mode using a combination of field measured inputs, spatially-explicit soils data and reanalysis wind speed probability densities queried by geographic location; and (3) a spatial mode in which AERO can be run offline or online with a numerical weather model. The primary intended application of AERO is in probabilistic mode using wind speed from the National Centers for Environmental Prediction (NCEP) North American Regional Reanalysis (NARR) dataset and soils and vegetation inputs from the NRI and AIM programs and/or collected following the standardized methods of Herrick et al.[30] In this mode, AERO estimates are produced at the plot scale (typically measured as ≤ 1 ha) and can be scaled to produce spatially-weighted estimates of Q and F. Spatially-weighted AERO estimates can be produced to assess wind erosion and dust emission responses

to treatments (e.g., tillage, vegetation clearing, seeding) and disturbances (e.g., fire) and at different administrative and ecogeomorphic scales. For example, AERO has been applied to county, state, ecological site (to inform Ecological Site Descriptions - ESDs), Major Land Resource Area (MLRA), and ecoregion-level assessments. At the time of writing (December 2018), AERO is being calibrated in the Agricultural Policy / Environmental eXtender (APEX) farming systems model to support management scenario-driven assessments of wind erosion and dust emission for croplands and rangelands. AERO model development was funded by and supports the NRCS Conservation Effects Assessment Project (CEAP) and the BLM.

It is anticipated that AERO will serve as a tool for conservation planners to evaluate aeolian sediment transport patterns and trends, and following land treatments and disturbances under different climatic conditions (drought, extreme weather phenomenon). By both enhancing wind erosion monitoring and evaluating management and disturbance scenarios, conservation planners, ranchers and farmers will be better prepared to recognize and react to projected adverse climate conditions, and where risk is deemed too high- avoid or delay the proposed treatment. The capacity to run AERO using standardized monitoring data (NRI, AIM) will enable wind erosion and management options to be assessed along other land health attributes and resource concerns managed on private and federal lands.

Currently, AERO is being validated using data from the National Wind Erosion Research Network[31] cropland and rangeland sites across the Great Plains and Western United States and is expected to be released as a fully functional tool by 2020.

Soil Properties and Interpretations

Understanding a landscape's susceptibility to erode by wind begins with determining the relationships between wind speed, surface cover and vegetation. Web Soil Survey[32] is the USDA's platform to find seamless soil survey data for the entire nation. The site is free to the public and is capable of printing professional reports including scientific soil descriptions, soil properties and qualities, suitabilities and limitations for use, and ecological site assessment- all with accompanying high quality color interpretative maps. This section describes the site's capabilities in understanding the relationships of soils and vegetation in mitigating and preventing soil erosion.

Fundamentally, there is a close correlation between wind erosion and the texture of the surface layer, the size and durability of surface clods, rock fragments, organic matter, and a calcareous reaction. Soil moisture and frozen soil layers also influence wind erosion. Wind

Erodibility Group (WEG) and Wind Erosion Index (WEI) -discussed in a later chapter- can be found on this tab under the Soil Erosion section. WEG and WEI are developed from an algorithm of the above properties.

Materials published through Web Soil Survey include some excellent descriptions and definitions of many of the site and soil properties discussed here, written by experts in the field. In an effort to take advantage of the work that has already been done by others and to avoid re-inventing the wheel, so to speak, relevant portions of these descriptions are provided as part of this section, unmodified from their original source and indicated with quotation marks.

The Ecological Site Assessment

The Ecological Site Assessment tab can be used to map out and determine ecological sites for a selected area of interest. From there, the ecological site name can be cross-referenced to ecological site database called Ecosystem Dynamics Interpretive Tool (EDIT), or alternatively the state FOTG, to obtain a reference site description for that ecological site. This description will provide a listing of structural groups of vegetation (grasses, forbs, shrubs/vines, and trees) and their canopy percentage that can be expected if the site is in its reference state. Other states, man-made or natural alterations to the site, are also described in narrative fashion. The description includes other characteristics of the site that directly affect its potential to erode by wind, including biological crusts, surface fragments, litter, bedrock, and bare ground. With both the vegetative composition and a detailed description of the soil surface, reasonable inferences can be made of the site's potential to erode by wind.

Other interpretations available in Web Soil Survey include:

Organic Matter Depletion

Organic matter content in soils is an indicator of soil health. Organic matter is a soil binder and contributes to keeping soil in place when subjected to wind and rain. This interpretation rates the soil's susceptibility to deplete organic matter on a scale of 0 to 1, where 1 represents a soil feature has the greatest ability to enable organic carbon depletion. Several soil features are evaluated, for example- high oxidation rate, low clay surface percentage, well aerated, low antecedent organic matter content, and others. These ratings are then compiled into a rating class.

"Rating class terms indicate the extent to which the soils enable the depletion of organic matter. 'Organic matter depletion high' indicates that the soil and site have features that are very conducive to the depletion of organic matter. Very careful management will be needed to prevent serious organic matter loss when these soils are farmed. 'Organic matter depletion moderately high', 'Organic matter depletion moderate', and 'Organic matter depletion moderately low' are a gradient of the level of management needed to avoid organic matter depletion. 'Organic matter depletion low' indicates soils that have features that are favorable for organic matter accumulation. These soils allow more management options while still maintaining favorable organic matter levels."[33]

Fragile Soils Index

"Soils can be rated based on their susceptibility to degradation in the 'Fragile Soil Index' interpretation. Fragile soils are those that are most vulnerable to degradation. In other words, they can be easily degraded—they have a low resistance to degradation processes. They tend to be highly susceptible to erosion and can have a low capacity to recover after degradation has occurred (low resilience). Fragile soils are generally characterized by a low content of organic matter, low aggregate stability, and weak soil structure. They are generally located on sloping ground, have sparse plant cover, and tend to be in arid or semiarid regions. The index can be used for conservation and watershed planning to assist in identifying soils and areas highly vulnerable to degradation."[34] "Soils are placed into interpretive classes based on their index rating, which ranges from 0 to 1. An index rating of 1 is the most fragile, while a rating of zero is the least fragile."[34]

These values are accompanied by interpretative classes that provide a more detailed evaluation of the susceptibility to erode and/or degrade.

Soil Surface Sealing

"Surface sealing is the orientation and packing of dispersed soil particles that result from the physical breakup of soil aggregates due to raindrop impact. Rapid soil wetting (in dry soils) and high exchangeable sodium percent can also cause aggregates to disperse. Sealing results when clay and silt particles get detached and/or dispersed and become suspended in the infiltrating water, which is moving downward through surface-connected pores. The pores become clogged with the fine particles, which become closely packed and create a surface seal.

Surface sealing is the initial process in the formation of a mineral crust, which is a broader term for a surface feature that is dense, hard, or restricts infiltration. A seal is a more specific term and refers to a surface layer that inhibits infiltration (Heil, 1993)."[35]

Although surface sealing is an indicator of poor soil health and an undesirable condition, in arid areas where water erosion is not a concern, the propensity of a soil to develop a surface seal may be beneficial when it comes to wind erosion.

Reference cited as part of the above-quoted text:

Heil, J.W. 1993. Soil properties influencing hydraulic sealing of the surface on Alfisols in the Sahel. Doctoral dissertation, Texas A&M University. College Station, Texas.

Unpaved Local Roads and Streets

Web Soil Survey defines unpaved local roads and streets as "those roads and streets that carry traffic year-round but have a graded surface of local soil material or aggregate."[36] This interpretation evaluates soil suitability for building these type roads. Attributes include susceptibility to flooding, bedrock, low strength, shrink-swell, and dusty qualities. Each attribute is rated from 0 to 1, where 1 is most limiting. Additionally, a composite rating is compiled from all attributes that indicate whether the soil would be very limited, somewhat limited, or not limited.

Recreational Development

Similar to Unpaved Local Roads and Streets, several recreational development scenarios are rated, including camp areas, off-road motorcycle trails, paths and trails, picnic areas, and playgrounds, with "dusty" being a primary feature evaluated. The importance of these recreational activities becoming very limited due to dust is underscored by realizing that these disturbed areas can serve as a catalyst to start the saltation process into adjoining areas, contributing to a larger suspension problem.

Soil Habitat for Saprophite Stage of Coccidioides

"Valley fever or coccidioidomycosis is caused by the soil-borne fungi *Coccidioides immitis* and *Coccidioides posadasii* which are endemic to the Southwest United States and a few other places in Central and South America. The symptoms of the disease range from none at all to mild cold or flu-like conditions in most people. However, some people experience the disseminated form of the disease, which can kill.

According to Kolivras et al (2001), the life cycle of fungus consists of a saprophytic and parasitic phases. The saprophytic phase lives in soil as entangled mycelia and hyphae. The hyphae grow and mature to produce generally rectangular arthrospores. The arthrospores are 1.5 to 4.5 microns in width and 5 to 30 microns in length. These spores move easily in air currents. The parasitic phase occurs in nature under dry, dusty conditions when a host mammal inhales airborne arthrospores. The fungus in this phase grows as spherules that mature and burst, releasing endospores that can grow into new spherules in the host lungs, inducing valley fever (Kolivras et al, 2001)."[37]

"Many prior maps of endemic areas are made from testing people for reactivity to coccidioidin and not the soil for presence of the fungi (Edwards and Palmer, 1957). The objective of the current study is to use the soil survey database to identify areas that are potentially habitat for this soil-borne fungus. This approach will allow habitat mapping at far finer spatial resolutions than has even been done in the past. This will allow habitat considerations to be targeted in the planning stage of any soil disturbing activity so as to proactively apply dust control methods when needed. The criteria mapped are as follows. The mean annual precipitation (about 230mm) and air temperature (about 20 degrees C) found in the Lower Sonoran Life Zone are used as the optima for habitat. For xeric areas, the rainfall can be somewhat higher and the temperature somewhat lower. Southerly slope aspect, moderate slope gradient, and low surface albedo are used to better capture extreme soil surface temperature effects. Electrical conductivity of over 4dS/m, soil reaction of at least 8.0, or the presence of gypsum in the upper 30cm of the soil are used to indicate an environment high in soluble salts. Some organic matter and water storage must be present in the soil for the saprophytic phase to grow. Soil components fitting all of those specifications, at least marginally, are considered possible habitat for the fungus. Variation in rainfall and temperature from year to year can increase or decrease the range of *Coccidioides* spp (Kolivras et al, 2001)."[37]

References cited as part of the above-quoted text:

Edwards P.Q., C.E. Palmer. 1957. Prevalence of sensitivity to coccidioidin, with special reference to specific and nonspecific reactions to coccidioidin and to histoplasmin. Chest;31(1):35-60

Kolivras, K. N., P. S. Johnson, A. C. Comrie, S. R. Yool. 2001. Environmental variability and coccidioiomycosis (valley fever). Aerobiologia 17:31-42

Range Production

"Total range production is the amount of vegetation that can be expected to grow annually in a well-managed area that is supporting the potential natural plant community. It includes all vegetation, whether or not it is palatable to grazing animals. It includes the current year's growth of leaves, twigs, and fruits of woody plants. It does not include the increase in stem diameter of trees and shrubs. It is expressed in pounds per acre of air-dry vegetation. In an unfavorable year, growing conditions are well below average, generally because of low available soil moisture. Yields are adjusted to a common percent of air-dry moisture content.

In areas that have similar climate and topography, differences in the kind and amount of vegetation produced on rangeland are closely related to the kind of soil. Effective management is based on the relationship between the soils and vegetation and water."[38]

Although range production cannot be considered as any measurement of wind erosion, it can be somewhat of an indicator of potential to erode, particularly during extended drought. Where production is low, the lack of vegetative growth may lead to increased potential for soil to blow. Of course, there are many other soil characteristics that may negate wind erosion, for instance- desert pavement, fragment percentage, litter, biological crust, etc.