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University of Nebraska–Lincoln

The National Drought Mitigation Center helps people and institutions develop and implement measures to reduce societal vulnerability to drought. The NDMC, based at the University of Nebraska-Lincoln, stresses preparation and risk management rather than crisis management.

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Drought Watch

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Drought Definitions

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URL for this page is http://wa.water.usgs.gov/drought/definitions.html
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Last modified Friday, June 1, 2001

Drought Watch

Providing Hydrologic Science and Data to Water-Resource Managers and the General Public

Definitions of Drought

"Drought is a condition of moisture deficit sufficient to have an adverse effect on vegetation, animals, and man over a sizeable area."

(Warwick, R.A., 1975, Drought hazard in the United States: A research assessment: Boulder, Colorado, University of Colorado, Institute of Behavioral Science, Monograph no. NSF/RA/E-75/004, 199 p.)

- Meteorological drought:
  "A period of abnormally dry weather sufficiently prolonged for the lack of water to cause serious hydrologic imbalance in the affected area." (Huschke, R.E., ed., 1959, Glossary of meteorology: Boston, American Meteorological Society, 638 p.)
- Agricultural drought:
  "A climatic excursion involving a shortage of precipitation sufficient to adversely affect crop production or range production." (Rosenberg, N.J., ed., 1979, Drought in the Great Plains--Research on impacts and strategies: Proceedings of the Workshop on Research in Great Plains Drought Management Strategies, University of Nebraska, Lincoln, March 26-28: Littleton, Colorado, Water Resources Publications, 225 p.)
- Hydrologic drought:
  "A period of below average water content in streams, reservoirs, ground-water aquifers, lakes and soils." (Yevjevich Vujica, Hall, W.A., and Salas, J.D, eds., 1977, Drought research needs, in Proceedings of the Conference on Drought Research Needs, December 12-15, 1977: Colorado State University, Fort Collins, Colorado, 276 p.)
- Definitions from the National Drought Mitigation Center
  Are We Having a Drought Yet?
  Understanding and Defining Drought

- Miscelleaneous Definitions

Because the definition of a drought can be a complex issue, a collection of other definitions of drought follows. Note that particular definitions may not be appropriate for individual circumstances, and that some of the definitions may be quite location specific. Other definitions can be suggested for inclusion by sending email to the maintainer listed at the bottom of this page; be sure to include a full bibliographic reference for the definition.

o Drought: Dryness due to lack of rain... An absolute drought is a period of at least 15

consecutive days to none of which is credited 0.01 inches of rain or more. A partial drought is a period of at least 29 consecutive days, the mean daily rainfall of which does not exceed 0.01 inches. A dry spell is a period of at least 15 consecutive days to none of which is credited 0.04 inches or more... The definitions of absolute drought anf partial drought were introduced in British Rainfall, p. 21, 1887, while that of dry spell was first used in British Rainfall, p. 15, 1919 [from Meteorological Glossary, Air Ministry, 3rd ed., London, 1944, p. 68.] [from Glossary of Geology and Related Sciences, American Geological Institute, Washington, D.C., 1957, p. 89.).

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Understanding and Defining Drought

The Concept of Drought

Drought is a normal, recurrent feature of climate, although many erroneously consider it a rare and random event. It occurs in virtually all climatic zones,. although its characteristics vary significantly from one region to another. Drought is a temporary aberration and differs from aridity since the latter is restricted to low rainfall regions and is a permanent feature of climate.

Drought is an insidious hazard of nature. Although it has scores of definitions, it originates from a deficiency of precipitation over an extended period of time, usually a season or more. This deficiency results in a water shortage for some activity, group, or environmental sector. Drought should be considered relative to some long-term average condition of balance between precipitation and evapotranspiration (i.e., evaporation + transpiration) in a particular area, a condition often perceived as "normal." It is also related to the timing (i.e., principal season of occurrence, delays in the start of the rainy season, occurrence of rains in relation to principal crop growth stages) and the effectiveness of the rains (i.e., rainfall intensity, number of rainfall events). Other climatic factors such as high temperature, high wind, and low relative humidity are often associated with it in many regions of the world and can significantly aggravate its severity.

Drought should not be viewed as merely a physical phenomenon or natural event. Its impacts on society result from the interplay between a natural event (less precipitation than expected resulting from natural climatic variability) and the demand people place on water supply. Human beings often exacerbate the impact of drought. Recent droughts in both developing and developed countries and the resulting economic and environmental impacts and personal hardships have underscored the vulnerability of all societies to this "natural" hazard.

There are two main kinds of drought definitions: conceptual and operational.

Conceptual Definitions of Drought

Conceptual definitions, formulated in general terms, help people understand the concept of drought. For example:

> Drought is a protracted period of deficient precipitation resulting in extensive damage to crops, resulting in loss of yield.

Conceptual definitions may also be philosophically important in establishing drought policy. For example, Australian drought policy incorporates an understanding of normal climate variability into its definition of drought. The country provides financial assistance to farmers only under "exceptional

drought circumstances," when drought conditions are beyond those that could be considered as part of normal risk management. Declarations of exceptional drought are based on science-driven assessments. Previously, when drought was less well defined from a policy standpoint and less well understood by farmers, some farmers in the semiarid Australian climate claimed drought assistance every few years.

Operational Definitions of Drought

Operational definitions help people identify the beginning, end, and degree of severity of a drought. (A "lite" description of operational definitions is also available.)

To determine the beginning of drought, operational definitions specify the degree of departure from the average of precipitation or some other climatic variable over some time period. This is usually done by comparing the current situation to the historical average, often based on a 30-year period of record. The threshold identified as the beginning of a drought (e.g., 75% of average precipitation over a specified time period) is usually established somewhat arbitrarily, rather than on the basis of its precise relationship to specific impacts.

An operational definition for agriculture could compare daily precipitation values to evapotranspiration rates to determine the rate of soil moisture depletion, and express these relationships in terms of drought effects on plant behavior (i.e., growth and yield) at various stages of crop development. A definition such as this one could be used in an operational assessment of drought severity and impacts by tracking meteorological variables, soil moisture, and crop conditions during the growing season, continually reevaluating the potential impact of these conditions on final yield. Operational definitions can also be used to analyze drought frequency, severity, and duration for a given historical period. Such definitions, however, require weather data on hourly, daily, monthly, or other time scales and, possibly, impact data (e.g., crop yield), depending on the nature of the definition being applied. Developing a climatology of drought for a region provides a greater understanding of its characteristics and the probability of recurrence at various levels of severity. Information of this type is extremely beneficial in the development of response and mitigation strategies and preparedness plans.

Disciplinary Perspectives on Drought: Meteorological, Hydrological, Agricultural and Socioeconomic

Meteorological Drought

Meteorological drought is defined usually on the basis of the degree of dryness (in comparison to some "normal" or average amount) and the duration of the dry period. Definitions of meteorological drought must be considered as region specific since the atmospheric conditions that result in deficiencies of precipitation are highly variable from region to region. For example, some definitions of meteorological drought identify periods of drought on the basis of the number of days with precipitation less than some specified threshold. This measure is only appropriate for regions characterized by a year-round precipitation regime such as a tropical rainforest, humid subtropical climate, or humid mid-latitude climate. Locations such as Manaus, Brazil; New Orleans, Louisiana (U.S.A.); and London, England, are examples. Other climatic regimes are characterized by a seasonal rainfall pattern, such as the central United States, northeast Brazil, West Africa, and northern Australia. Extended periods without rainfall are common in Omaha, Nebraska (U.S.A.), Fortaleza, Ceará (Brazil), and Darwin, Northwest Territory (Australia); a definition based on the number of days

with precipitation less than some specified threshold is unrealistic in these cases. Other definitions may relate actual precipitation departures to average amounts on monthly, seasonal, or annual time scales.

Agricultural Drought

Agricultural drought links various characteristics of meteorological (or hydrological) drought to agricultural impacts, focusing on precipitation shortages, differences between actual and potential evapotranspiration, soil water deficits, reduced ground water or reservoir levels, and so forth. Plant water demand depends on prevailing weather conditions, biological characteristics of the specific plant, its stage of growth, and the physical and biological properties of the soil. A good definition of agricultural drought should be able to account for the variable susceptibility of crops during different stages of crop development, from emergence to maturity. Deficient topsoil moisture at planting may hinder germination, leading to low plant populations per hectare and a reduction of final yield. However, if topsoil moisture is sufficient for early growth requirements, deficiencies in subsoil moisture at this early stage may not affect final yield if subsoil moisture is replenished as the growing season progresses or if rainfall meets plant water needs.

Hydrological Drought

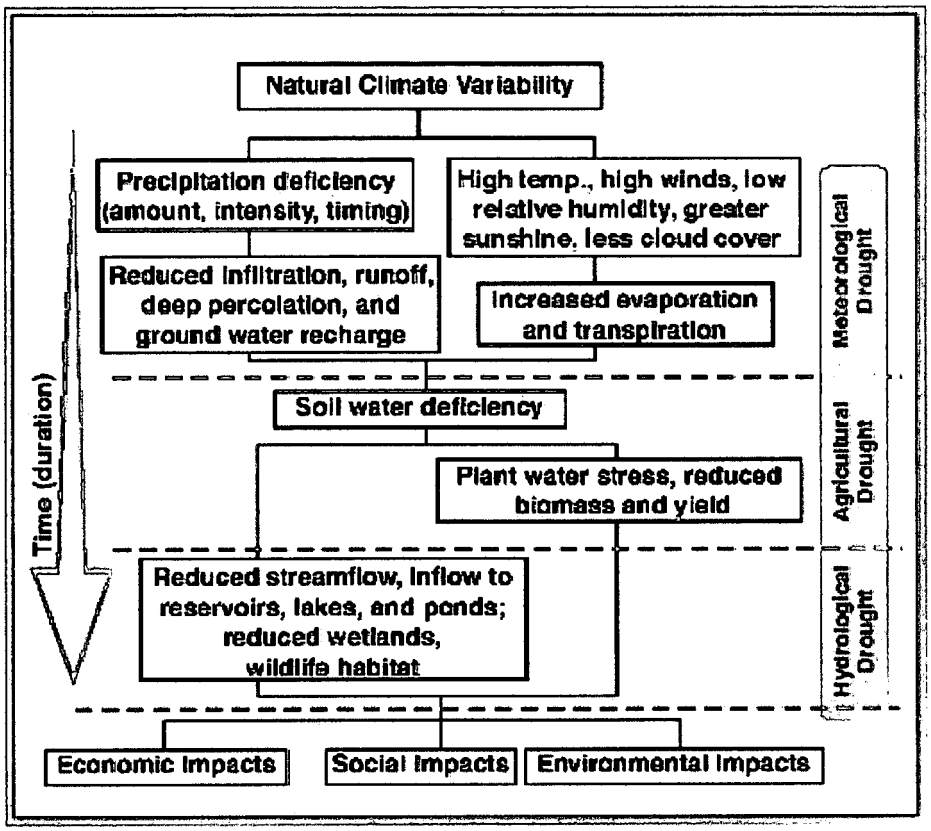
Hydrological drought is associated with the effects of periods of precipitation (including snowfall) shortfalls on surface or subsurface water supply (i.e., stream flow, reservoir and lake levels, ground water). The frequency and severity of hydrological drought is often defined on a watershed or river basin scale. Although all droughts originate with a deficiency of precipitation, hydrologists are more concerned with how this deficiency plays out through the hydrologic system. Hydrological droughts are usually out of phase with or lag the occurrence of meteorological and agricultural droughts. It takes longer for precipitation deficiencies to show up in components of the hydrological system such as soil moisture, stream flow, and ground water and reservoir levels. As a result, impacts are out of phase with those in other economic sectors because different water use sectors depend on these sources for their water supply. For example, a precipitation deficiency may result in a rapid depletion of soil moisture that is almost immediately discernible to agriculturalists, but the impact of this deficiency on reservoir levels may not affect hydroelectric power production or recreational uses for many months. Also, water in hydrologic storage systems (e.g., reservoirs, rivers) is often used for multiple and competing purposes (e.g., flood control, irrigation, recreation, navigation, hydropower, wildlife habitat), further complicating the sequence and quantification of impacts. Competition for water in these storage systems escalates during drought and conflicts between water users increase significantly.

Hydrological Drought and Land Use

Although climate is a primary contributor to hydrological drought, other factors such as changes in land use (e.g., deforestation), land degradation, and the construction of dams all affect the hydrological characteristics of the basin. Because regions are interconnected by hydrologic systems, the impact of meteorological drought may extend well beyond the borders of the precipitation deficient area. For example, meteorological drought may severely affect portions of the northern Rocky Mountains and northern Great Plains region of the United States. However, since the Missouri River and its tributaries drain this region to the south, there may be significant hydrologic impacts downstream. Similarly, changes in land use upstream may alter hydrologic characteristics such as infiltration and runoff rates, resulting in more variable stream flow and a higher incidence of hydrologic drought downstream. Bangladesh, for example, has shown an increased frequency of water

shortages in recent years because land use changes have occurred within the country and in neighboring countries. Land use change is one of the ways human actions alter the frequency of water shortage even when no change in the frequency of meteorological drought has been observed.

Sequence of Drought Impacts



The sequence of impacts associated with meteorological, agricultural, and hydrological drought further emphasizes their differences. When drought begins, the agricultural sector is usually the first to be affected because of its heavy dependence on stored soil water. Soil water can be rapidly depleted during extended dry periods. If precipitation deficiencies continue, then people dependent on other sources of water will begin to feel the effects of the shortage. Those who rely on surface water (i.e., reservoirs and lakes) and subsurface water (i.e., ground water), for example, are usually the last to be affected. A short-term drought that persists for 3 to 6 months may have little impact on these sectors, depending on the characteristics of the hydrologic system and water use requirements.

When precipitation returns to normal and meteorological drought conditions have abated, the sequence is repeated for the recovery of surface and subsurface water supplies. Soil water reserves arereplenished first, followed by stream flow, reservoirs and lakes, and ground water. Drought impacts may diminish rapidly in the agricultural sector because of its reliance on soil water, but linger for months or even years in other sectors dependent on stored surface or subsurface supplies. Ground water users, often the last to be affected by drought during its onset, may be last to experience a return to normal water levels. The length of the recovery period is a function of the intensity of the drought, its duration, and the quantity of precipitation received as the episode terminates.

Socioeconomic Drought

Socioeconomic definitions of drought associate the supply and demand of some economic good with elements of meteorological, hydrological, and agricultural drought. It differs from the aforementioned types of drought because its occurrence depends on the time and space processes of supply and demand to identify or classify droughts. The supply of many economic goods, such as water, forage, food grains, fish, and hydroelectric power, depends on weather. Because of the natural variability of climate, water supply is ample in some years but unable to meet human and environmental needs in

other years. Socioeconomic drought occurs when the demand for an economic good exceeds supply as a result of a weather-related shortfall in water supply. For example, in Uruguay in 1988-89, drought resulted in significantly reduced hydroelectric power production because power plants were dependent on stream flow rather than storage for power generation. Reducing hydroelectric power production required the government to convert to more expensive (imported) petroleum and stringent energy conservation measures to meet the nation's power needs.

In most instances, the demand for economic goods is increasing as a result of increasing population and per capita consumption. Supply may also increase because of improved production efficiency, technology, or the construction of reservoirs that increase surface water storage capacity. If both supply and demand are increasing, the critical factor is the relative rate of change. Is demand increasing more rapidly than supply? If so, vulnerability and the incidence of drought may increase in the future as supply and demand trends converge.

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Colorado Office of Emergency Management

DROUGHT FACTS

Drought is an ambiguous hazard that defies a universal definition. Typically, drought is a shortage of water associated with a deficiency of precipitation. However, water shortages can also be induced by humans. Perhaps it is easier to think of drought as being a function of supply versus demand. Drought occurs when a normal amount of moisture is not available to satisfy an area's usual water-consuming activities.

Drought is a frequent visitor to our semiarid state. The most significant impacts which typically confront the state are related to such water intensive activities as: agriculture, wildfire protection, municipal usage, commerce, tourism, recreation, and wildlife preservation. A reduction of electric power generation and water quality deterioration are also potential problems.

Several times throughout this century Colorado has experienced conditions of drought. The most dramatic drought periods occurred in the 1930s and 1950s, when many states, Colorado included, were affected for several years at a time.

The agricultural business suffered severely during the drought of the 1930s. The situation was exacerbated by poor farming techniques, low market prices, and a depressed economy which caused many to migrate away from farming. At the same time, progress was made toward improving the situation: better agricultural management; establishment of insurance programs; liberalization of credit; and diversification of the regional economy. Other improvements included irrigation; the planting of trees for wind breaks to mitigate soil erosion; and air conditioned tractors to keep dust from the operator. These adjustments moderated the drought in the early 1950s. Impacts were much less severe, although climatological conditions were not that different from those of the dust bowl era.

The drought of 1976-77 was essentially a winter event and was not long in duration. However, it was the driest winter in recorded history for much of Colorado's high country and western slope, and had serious consequences for the ski industry. Another drought that began in the fall of 1980 and lasted until the summer of 1981 also generated costly impacts on the ski industry and initiated a huge investment in snow making equipment. This was the last severe and widespread drought to affect Colorado.

Since 1981, Colorado has seen a sustained overall wet period. A few localized exceptions include a significant, but brief drought in southwest Colorado from 1989 to 1990; a growing season drought in 1994 in northeast Colorado; and a localized drought in southwest Colorado from late 1995 into 1996. La Niña influenced weather patterns in the winter of 1999, leaving the statewide snowpack abnormally low in the spring. While many parts of the country were experiencing drought conditions, abundant moisture in the second half of 1999 resulted in wet conditions over almost all of Colorado.

For more information on drought, try these links: **Drought Links**

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Wind Erosion Simulation Models

Introduction

Although many of the principles of wind erosion were known before the 1930's, the foundations of modern wind erosion prediction technology largely began with the publication in 1941 of Ralph Bagnold's classic book titled "The Physics of Blown Sand and Desert Dunes". Further research was needed for application to agricultural fields, which are generally more complicated than sand dunes. The complications include properties that change over time such as soil aggregate size and stability, crusts, random and oriented roughness, field size, and vegetative cover.

The Wind Erosion Equation

Using wind tunnels and field studies, the late Dr. W. S. Chepil and co-workers set out in the mid-1950's to develop the first wind erosion prediction equation which is now used by the Natural Resources Conservation Service (NRCS) and other action agencies throughout the country. The equation expressed in function form is:

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

where E is the potential average annual soil loss, I is the soil erodibility index, K is the soil ridge roughness factor, C is the climate factor, L is unsheltered distance across a field, and V is the equivalent vegetative cover.

Because field erodibility varies with field conditions, a procedure to solve WEQ for periods of less than one year was devised. In this procedure, a series of factor factor values are selected to describe successive management periods in which both management factors and vegetative covers are nearly constant. Erosive wind energy distribution is used to derive a weighted soil loss for each period. Soil loss for the management periods over a year are added to estimate annual erosion. Soil loss from the peroids also can be added for a multi-year rotation, and the loss divided by the number of years to obtain an average, annual estimate.

WEQ is currently the most widely used method for assessing average annual soil loss by wind from agricultural fields. The primary user of WEQ is the Natural Resources Conservation Service (NRCS). When WEQ was developed approximately 40 years ago, it was necessary to make it a simple mathematical expression, readily solvable with the computational tools available. However, WEQ has fundamental weaknesses because of its equation structures and its empirical representation of erosion processes. Since its inception, there have been a number of efforts to improve the accuracy, ease of application, and range of WEQ. Despite efforts to make such improvements, the structure of WEQ precludes adaptation to many problems.

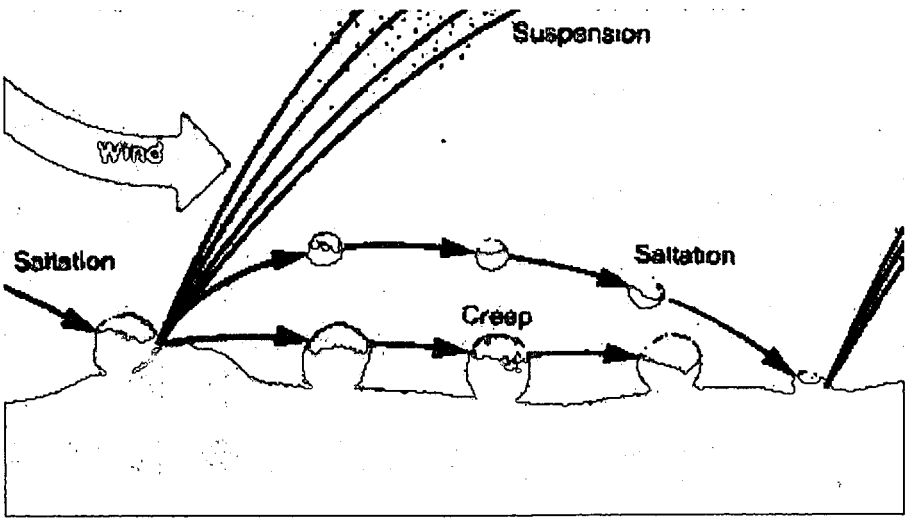
The Wind Erosion Prediction System

Click here for more detailed Overview of WEPS in Adobe Acrobat format
(you must have an Adobe Acrobat Reader installed for your WEB browser)

Wind erosion is a serious problem on agricultural lands throughout the United States as well as the world. The ability to accurately predict soil loss by wind is essential for, among other things, conservation planning, natural resource inventories, and reducing air pollution from wind blown sources.

The USDA appointed a team of scientists to take a leading role in combining the latest in wind erosion science and technology with databases and computers, to develop what should be a significant advancement in wind erosion prediction technology. The Wind Erosion Prediction System (WEPS) incorporates this new technology and is designed to be a replacement for WEQ.

Unlike WEQ, WEPS is a process-based, continuous, daily time-step model that simulates weather, field conditions, and erosion. It is a user friendly program that has the capability of simulating spatial and temporal variability of field conditions and soil loss/deposition within a field. WEPS can also simulate complex field shapes, barriers not on the field boundaries, and complex topographies. The saltation, creep, suspension, and PM10 components of eroding materials can also be reported separately by direction in WEPS. WEPS is designed to be used under a wide range of conditions in the U.S. and easily adapted to other parts of the world.



Soil erosion by wind is initiated when wind speed exceeds the saltation threshold velocity for a given field condition. After initiation, the duration and severity of an erosion event depends on the wind speed distribution 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. Most of the submodels within WEPS use daily weather (from the WEATHER submodel) as the natural driving force for the physical processes that change field conditions. The HYDROLOGY submodel accounts for changes in temperature and water status of the

soil. Changes in the soil properties between management events are simulated in the SOIL submodel. The growth of crop plants is simulated in the CROP submodel, and their decomposition is accounted for in the DECOMPOSITION submodel. Step changes in the soil and biomass conditions generated from typical management practices such as tillage, planting, harvesting, and irrigation are modeled within the MANAGEMENT submodel of WEPS. Finally, the power of the wind on a subhourly basis is used to drive the EROSION submodel.

Click here for the current version of the WEPS Technical Documentation
(you must have an Adobe Acrobat Reader installed for your WEB browser)

This document was last modified on.
Send questions and comments to webmaster@weru.ksu.edu

AN OVERVIEW OF THE WIND EROSION PREDICTION SYSTEM[1]

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Abstract

The Wind Erosion Prediction System (WEPS) is a process-based, daily time-step, computer model that predicts soil erosion via simulation of the fundamental processes controlling wind erosion. WEPS can calculate soil movement, estimate plant damage, and predict PM-10 emissions when wind speeds exceed the erosion threshold. It also can provide the user with spatial information regarding soil flux, deposition, and loss from specific regions of a field over time. WEPS is intended for conservation planning, assessing wind erosion for USDA-NRCS's National Resources Inventory (NRI), and aiding the development of regional and national policy.

WEPS modular design is amenable to incorporation of new features. Thus, WEPS will also be used for estimating long-term soil productivity, determining physical damage to crops, depositional loading of lakes and streams as well as estimate visibility reductions near airports and highways. WEPS will also aid in calculating both on-site and off-site economic costs of erosion and assess impacts of management strategies on public lands when used in conjunction with other models.

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 from to wind erosion.

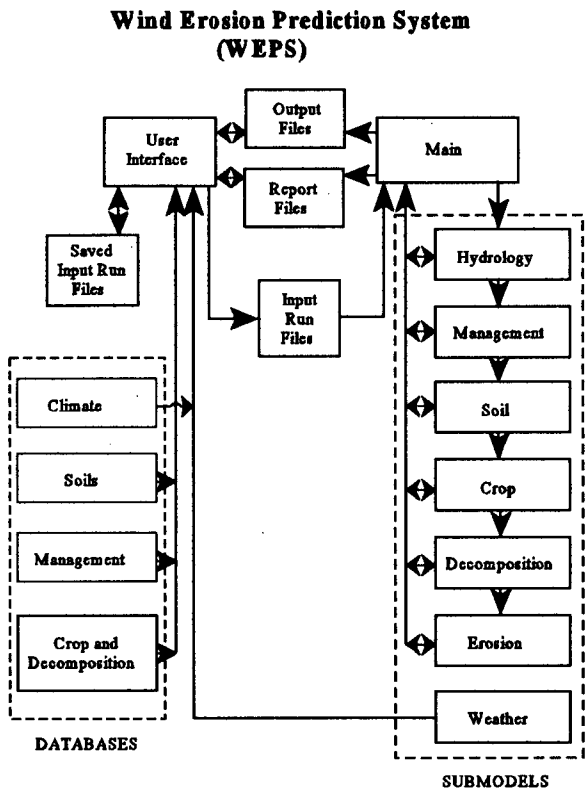

Figure 1. Structure of the WEPS model.

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

[1]Contribution from USDA-ARS in cooperation with Kansas Ag. Exp. Station, Contribution No. 96-205-A

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.

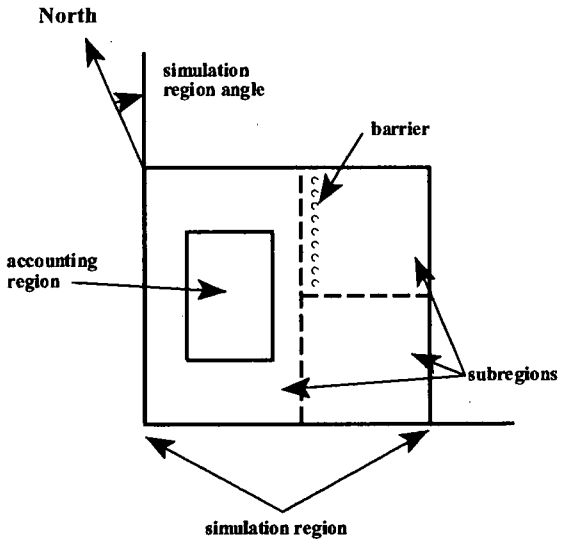

Figure 2. WEPS simulation geometries.

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 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)

an erosion event depend on the wind speed and the evolution of

order shown in Fig. 1. Each individual submodel controls the

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 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

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 [illegible]

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

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: (913) 532-6495
FAX: (913) 532-6528

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