Erosion by Wind: Modeling☆

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Abstract
Models of wind erosion are used to investigate fundamental processes and guide resource management. Many models are similar in that temporal variables control soil wind erodibility, erosion begins when friction velocity exceeds a threshold, and transport capacity for saltation/creep is proportional to the cube of friction velocity. Conservation of mass equations that incorporate erosion processes have been developed to calculate soil loss, transport, and deposition. Components of the Wind Erosion Prediction System model are illustrated as an example.

INTRODUCTION

Numerous models of wind erosion exist. In regional- and global-scale models, dust generation is often coupled to diffusion, advection, and deposition models.[1] Their applications include prediction of dust impacts on past climates,[2] military operations,[3] health problems,[4] and current weather, particularly in East Asia.[5] Model results also demonstrate that dust is an important contributor to climate forcing.[6] There are numerous challenges in modifying field-scale models for use on large areas.[1,7–9]

Field-scale erosion models are used to predict soil loss, plan conservation systems, and assess offsite impacts of wind erosion.[10,11] Many models exist to simulate specific effects such as sand ripples.[12] Models also serve to increase and synthesize our knowledge about wind erosion of soil.

WIND EROSION PROCESSES

The major factors that control soil wind erodibility are mainly temporal (Table 1), and their range of variation depends on weather, soil management, and soil intrinsic properties such as texture.

To begin erosion, friction velocity must overcome the forces holding particles on the surface. Threshold friction velocities for dry, monodisperse particles have been measured[13] and theoretically analyzed (Fig. 1).[14] For mixtures of sizes, thresholds maybe slightly lower due to particles perched on a surface or higher when sheltered by immobile aggregates.[15] Both surface wetness and high humidity also tend to increase threshold velocities.[16,17] Saltation is not needed to entrain 0.07- to 0.10-mm-diameter particles. Abrasion creates mobile aggregates, and abrasion susceptibility of clods/crust can be characterized by an abrasion coefficient. It can be directly measured or estimated from the crushing energy.[18,19] Intermittent field erosion in the short term is often caused by wind gustiness,[20] but longer term variations may be caused by surface armoring during erosion events.[21]

Modes of soil transport include creep (rolling, 0.8–2.0 mm diameter), saltation (hopping, 0.1–0.8 mm), and suspension (<0.1 mm). The creep/saltation transport capacity q (kg m^{-1} s^{-1}) is proportional to the cube of friction velocity u_* (m s^{-1}). Many formulas for q have been proposed,[15] and one formula is

$$q = \frac{C\rho_a}{g} u_*^2 (u_* - u_{*t}) \quad (1)$$

where C is a coefficient, ρ_a (kg m^{-3}) is air density, g (m s^{-2}) is acceleration of gravity, and u_{*t} (m s^{-1}) is threshold friction velocity. The transport capacity for suspended particles is large, and their downwind discharge can be several

Table 1 Factors that control wind erodibility of a dry, bare soil.

Soil state	Factors
Aggregated (tilled) surface	Aggregate size distribution by layer
	Dry stability of immobile aggregates by layer
	Breakage coefficient of mobile aggregates
	Rock volume fraction (>2 mm diameter) by layer
	Random and oriented surface roughness
Crusted and/or consolidated surface	Crust cover fraction
	Dry stability of crust/consolidated zone
	Thickness of consolidated zone
	Mass, cover, and breakage coefficient of loose soil on crust
	Other parameters same as aggregated surface

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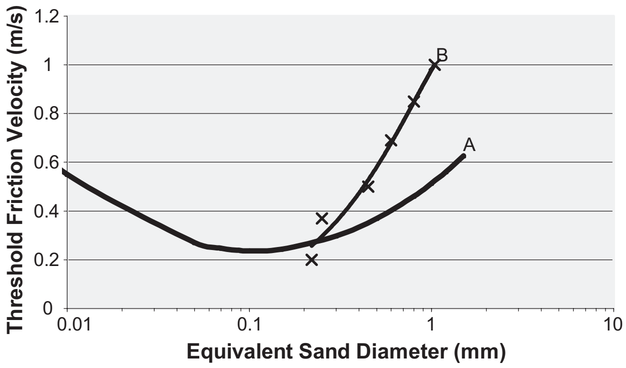

Fig. 1 Threshold friction velocities for monodisperse particles (A)[16] and a particle mixture[17] containing 15% immobile aggregates with maximum diameter of transported particles shown (B).

times that of saltation/creep as illustrated by measurements at dry Lake Owen.[22]

Wind erosion on a field-scale can be modeled using conservation of mass equations in successive control volumes each a few meters in length (Fig. 2).[23] Friction velocity above standing biomass is depleted to simulate wind friction velocity at the soil surface. Sources of saltation/creep discharge include entrainment of loose aggregates by wind drag and splash impacts, and abrasion from immobile clods and crust. Sinks for saltation/creep discharge include trapping by surface roughness, interception by standing biomass, and breakage to suspension-sized particles.

Similarly, sources for suspension discharge include entrainment of loose aggregates, abrasion from clods and crust, and breakage of saltation/creep aggregates. Sinks for suspension include interception by standing biomass and deposition on downwind immobile surfaces. Emission, abrasion, and breakage are modeled separately because the interparticle binding energy increases by roughly an order of magnitude between each process. Moreover, not all processes may be present in a given surface condition, but each can be measured separately using a wind tunnel.[24,25] Analytic solutions for quasi-steady state conservation of mass equations have been developed for saltation/creep and suspension discharge[23] and the predictions validated using measured data from small fields.[26–28]

Field-Scale Wind Erosion Models

The most widely used model has been the empirical Wind Erosion Equation (WEQ).[29] The long-term annual soil loss per unit area (E) is given by

$$E = ICKLV \tag{2}$$

where the factors are soil wind erodibility (I), climate (C), surface roughness (K), field length (L), and vegetation (V).

A continuous, process-based model, the Wind Erosion Prediction System (WEPS), has been developed (Fig. 3) to replace WEQ.[30] In WEPS, weather simulators drive five submodels that simulate surface conditions on a daily basis and erosion on a subhourly basis.

Additional models used to predict erosion include the Revised Wind Erosion Equation, Texas Tech Erosion Analysis Model, Wind Erosion on European Light Soils, Australian Land Erodibility Model, and Integrated Wind Erosion Modeling System.[31–35]

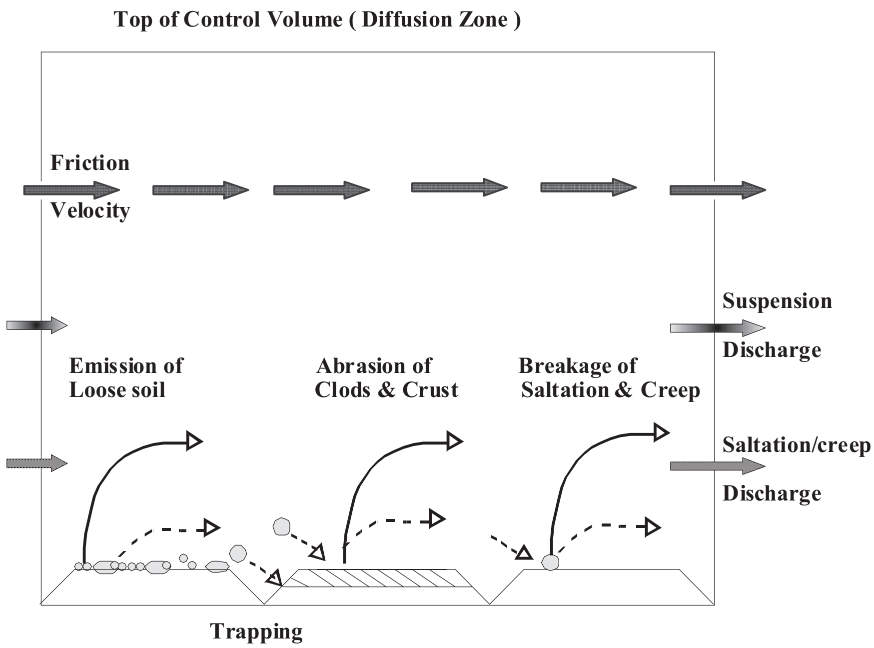

Fig. 2 Schematic of control volume illustrating major wind erosion processes on bare soil.

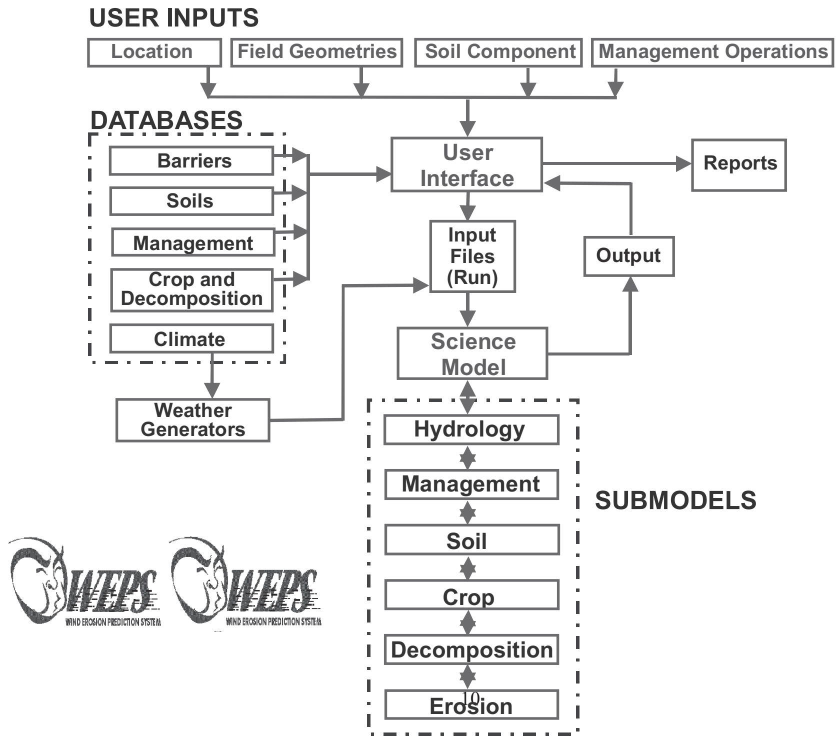

Fig. 3 Flow chart illustrating components of the WEPS field-scale wind erosion model.

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