Chapter 2 : Understanding Wind Erosion

Soil Disturbance and Wind Erosion Processes – **From the Natural Resources Conservation Service (NRCS) National Agronomy Manual**[6]

Wind is an erosive agent. It detaches and transports soil particles, sorts the finer from the coarser particles, and deposits them unevenly. Loss of the fertile topsoil in eroded areas reduces the rooting depth and, in many places, reduces crop yield. Abrasion by airborne soil particles damages plants and structures. Drifting soil causes extensive damage to adjacent land, roads, and drainage features. Sand and dust in the air can harm animals, humans, and equipment. Wind erosion events have caused major highway accidents.

Some wind erosion has always occurred as a natural land-forming process, but it has become detrimental as a result of human activities. This accelerated erosion is primarily caused by improper use and management of the land.

Few regions are entirely safe from wind erosion. Wherever the soil surface is loose and dry, vegetation is sparse or absent, and the wind sufficiently strong, erosion will occur unless control measures are applied. Soil erosion by wind in North America is generally most severe in the Great Plains. The NRCS annual report of wind erosion conditions in the Great Plains shows that wind erosion damages from 1 million to more than 15 million acres annually. Other major regions subject to damaging wind erosion are the Columbia River plains; some parts of the Southwest and the Colorado Basin, the muck and sandy areas of the Great Lakes region, and the sands of the Gulf, Pacific, and Atlantic seaboards. In some areas, the primary problem caused by wind erosion is crop damage. Some crops are tolerant enough to withstand or recover from erosion damage.

Other crops, including many vegetables and specialty crops, are especially vulnerable to wind erosion damage. Wind erosion may cause significant short-term economic loss in areas where erosion rates are below the soil loss tolerance (T) when the crops grown in that area are easily damaged by blowing soil. Figure 2-1 displays the relative crop tolerance to blowing soil.

Tolerant T	Moderate tolerance 2 ton/a	Low tolerance 1 ton/a	Very low tolerance 0 to 0.5 ton/a
Barley	Alfalfa (mature)	Broccoli	Alfalfa seedlings
Buckwheat	Corn	Cabbage	Asparagus
Flax	Onions (>30 days)	Cotton	Cantaloupe
Grain sorghum	Orchard crops	Cucumbers	Carrots
Millet	Soybeans	Garlic	Celery
Oats	Sunflowers	Green/snap beans	Eggplant
Rye	Sweet corn	Lima beans	Flowers
Wheat		Peanuts	Kiwi fruit
		Peas	Lettuce
		Potatoes	Muskmelons
		Sweet potatoes	Onion seedlings (<30 days)
		Tobacco	Peppers
			Spinach
			Squash
			Strawberries
			Sugar beets
			Table beets
			Tomatoes
			Watermelons

Figure 2-1. Crop tolerance to blowing soil.

The wind erosion process is complex. It involves detaching, transporting, sorting, abrading, avalanching, and depositing of soil particles. Turbulent winds blowing over erodible soils cause wind erosion. Field conditions conducive to erosion include:

- loose, dry, and finely granulated soil
- smooth soil surface that has little or no vegetation present
- sufficiently large area susceptible to erosion
- sufficient wind velocity to move soil

Winds are considered erosive when they reach 13 miles per hour at 1 foot above the ground or about 18 miles per hour at a 30 foot height. This is commonly referred to as the threshold wind velocity.

The wind transports single grain particles or stable aggregates, or both, in three ways (Figure 2-2):

Saltation — Individual particles/aggregates ranging from 0.1 to 0.5 millimeter in diameter lift off the surface at a 50- to 90-degree angle and follow distinct trajectories under the influence of air resistance and gravity. The particles/aggregates return to the surface at impact angles of 6 to 14 degrees from the horizontal. Whether they rebound or embed themselves, they initiate movement of other particles/aggregates to create the avalanching effect. Saltating particles are the abrading bullets that remove the protective soil crusts and clods. Most saltation occurs within 12 inches above the soil surface and typically, the length of a saltating particle trajectory is about 10 times the height. From 50 to 80 percent of total transport is by saltation.

Surface creep — Sand-sized particles/aggregates are set in motion by the impact of saltating particles. Under high winds, the whole soil surface appears to be creeping slowly forward as particles are pushed and rolled by the saltation flow. Surface creep may account for 7 to 25 percent of total transport.[7,8]

Suspension — The finer particles, less than 0.1 millimeter in diameter, are dislodged from an eroding area by saltation and remain in the air mass for an extended period. Some suspension-sized particles or aggregates are present in the soil, but many are created by abrasion of larger aggregates during erosion. From 20 percent to more than 60 percent of an eroding soil may be carried in suspension, depending on soil texture. As a general rule, suspension increases downwind, and on long fields can easily exceed the amount of soil moved in saltation and creep.

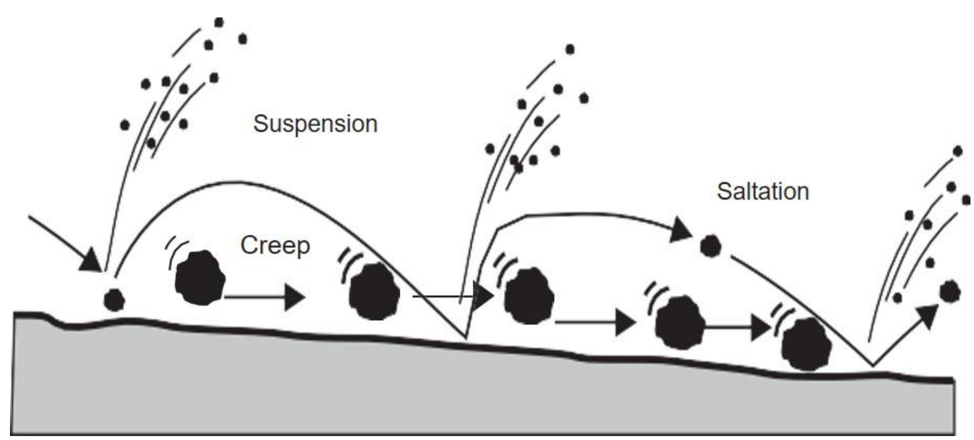

Figure 2-2. The wind erosion process.

Saltation and creep particles are deposited in vegetated strips, ditches, or other areas sheltered from the wind, as long as these areas have the capacity to hold the sediment. Particles in suspension, however, may be carried a great distance. The rate of increase in soil flow along the wind direction varies directly with erodibility of field surfaces.

The increase in erosion downwind (avalanching) is associated with the following processes:

- the increased concentration of saltating particles downwind increases the frequency of impacts and the degree of breakdown of clods and crusts
- the accumulation of erodible particles and breakdown of clods tends to produce a smoother (and more erodible) surface. The distance required for soil flow to reach a maximum for a given soil is the same for any erosive wind. The more erodible the soil surface, the shorter the distance in which maximum flow is reached. Any factor that influences the erodibility of the surface influences the increase in soil flow.

Climate Considerations

Increased aeolian activity and dust emission have important ecological and hazard implications. For example, soil loss and redistribution from aeolian activity affects soil health, nutrient cycles and land potential. Dust emissions impact air quality and long-term health and episodic hazards such as dust storms pose immediate threats to human life. As such, understanding potential climate change impacts to wind erosion and dust emission is critical for applying appropriate management and mitigation practices.

Overall, climate change is expected to increase vulnerability to wind erosion in many landscapes of the Southwest (see Edwards et al.[9] for detailed review). Projected increases in temperature and carbon dioxide (CO_2) concentrations coupled with expected drying and increased precipitation variability are expected to have long-term effects on important limiting controls of erosion, especially vegetation cover and community composition. In addition, the frequency and magnitude of extreme events such as drought, fire and high intensity storms are expected to increase, which could significantly increase vulnerability to wind erosion over multiple scales.

Climate Change Projections

There is very high confidence that CO_2 concentrations and temperatures across much of the West have been increasing over the past century, and that this trend is intensifying.[10] Predictions from the Coupled Model Intercomparison Project (CMIP5) further suggest mean temperatures across the West could increase by ~3.3°C (6°F) by the mid-21st century and ~5°C (9°F) by late-21st century under the Representative Concentration Pathway 8.5 (RCP8.5), which is consistent with recent observations of emissions. Increases in temperature are projected across all seasons but are higher for summer and fall when many plants are already stressed. Projected warming has the potential to impact wind erosion through further increasing evaporative stress and soil moisture deficits, which in part control vegetation cover and plant community structure.

Observed changes in annual precipitation are more variable, but annual drying trends have been observed for much of the Southwest.[11] In general, drying in the Southwest has been observed during spring and summer. Projections for annual precipitation by the mid-21st century under RCP8.5 are more uncertain than for temperature but suggest continued drying,[12] with drier winters and springs but wetter summers.

Surface winds in the US have declined by ~10% over the last 30 years.[13] Patterns of seasonal wind-speed projections for mid-century are consistent with these evaluations but highly uncertain. Despite the projected decrease in mean winds, most projections include an increase in potentially erosive weather events, such as thunderstorms and severe winter storms. Further, warming and drying conditions favor longer term disturbances which increase vulnerability to wind erosion, such as prolonged soil moisture deficits and large fires.

Potential Impacts on Wind Erosion

Projected changes in atmospheric CO_2 concentration, temperature, and precipitation will likely impact vegetation production, cover, and community composition in the Southwest (see Polley et al.[14] and Briske et al.[15] for detailed reviews). Increased CO_2 promotes growth and water use efficiency by plants, but these benefits will likely be limited by water availability. Both Polley et al.[14] and Briske et al.[15] suggest that coupled warming and drying trends in the Southwest will reduce overall net primary production, reducing vegetation cover, and could favor shifts to more woody species. In addition to an overall drying trend, increased variability in precipitation also decreases overall ecosystem productivity and promotes shrub productivity at the expense of grasses.[16] This suggests that prolonged periods of increased variability in precipitation could favor grass-to-shrub transitions, which, once started, are often self-sustaining.

Although lower mean wind speeds are projected across much of the region, any reduction in wind erosion potential could be offset by vegetation responses to climate change. Wind erosion frequency and magnitude depend on the degree of soil exposure to the wind field, which is largely controlled by vegetation cover and community structure. Decreases in overall cover and transitions from high-cover grasses to shrubs with bare interspaces effectively increase long-term vulnerability to wind erosion. In addition, wind erosion and dust emission events are largely driven by frontal passages over much of the region. Dryer winters and springs may further promote increased wind erosion by reducing early season production and thus vulnerability to these events. Local convective winds are also important drivers of dust events in the Southwest. Increased frequency of severe storms would likely increase the frequency of dust-related hazards. Finally, warming and drying could increase the frequency and return interval of wildfires, which would significantly increase wind erosion at local scales during recovery periods.

Given current vulnerability of arid and semi-arid lands to erosion and the uncertainty regarding future trajectories of vegetation cover and community structure, wind erosion should be explicitly considered in management benchmarks and decision support. However, management options to limit wind erosion are largely similar to those already in place to address other disturbances, such as drought, fire, invasive species, and shrub encroachment. As such, implementing active, planned management now that has multiple benefits, including for mitigating erosion, will very likely increase resilience and adaptability in the future.

Weather Events Characterized by High Winds

The majority of dust storms can be classified as convectively driven dust storms, synoptic scale dust storms, and dust channels. Dust storms can occur any time of the year and in some cases appear quickly and disappear quickly. They can be found in practically any location. The basic ingredients for dust storms are high winds exceeding the threshold for wind erosion and dry, erodible soil in the absence of vegetation cover. This section very briefly describes the meteorological drivers creating the winds for various types of commonly encountered dust storms.

The first category are associated with thunderstorms. In the southwest convectively driven dust storms are common during the summer months when we see a seasonal shift in wind direction bringing in moist airmasses. During those times we often see surface dewpoint temperatures rise as shallow airmasses moves toward the region from the south and east. Storms starts out with convection over the higher terrain with smaller storm cells developing over the surrounding smaller mountain ranges. Convective storms grow in size and intensity, steered by upper level winds and pressure gradients. Once these storms reach maturity they then decay, losing energy through falling rain drops. If the lowest level of the atmosphere is dry, the drops eventually evaporate as they fall. Evaporation is a cooling process and as a result we observe cool downdrafts or air falling toward the ground. These descending winds eventually impact the surface and spread out horizontally. The horizontal winds can achieve speeds more than 70 mph over short distances over a time period of a few minutes. Very intense but localized winds include dry microbursts in scale of less than 5-kilometers across. In some cases impacts of evaporation are much larger as in the case of a large thunderstorm or a mesoscale convective complex extending over a hundred kilometers. Winds from these type of storms are called thunderstorm outflow winds and the leading edge of these are called outflow boundaries. In the desert Southwest these outflow boundaries can create dust storms that are often called haboobs. This particular type of dust storm is hazardous due to its quick formation, potential to create very high concentrations of aerosols, and extremely low visibility. Wind directions during these events can come from most any direction and depend on where the convection is located.

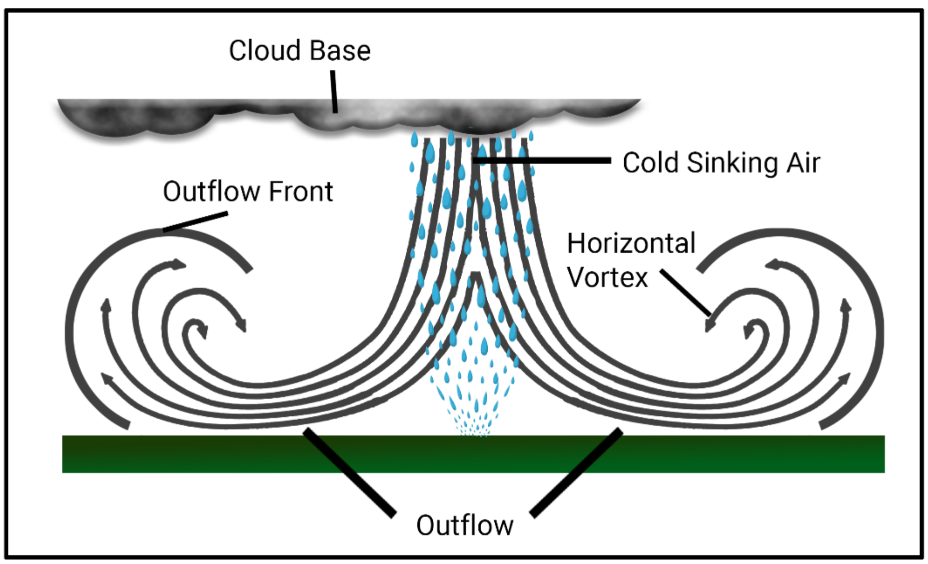

Figure 2-3. Schematic of a thunderstorm outflow event that generates high winds and dust.

The second type of dust storm that occur are from midlatitude cyclones that bring in cold fronts and high winds over the region mainly in the spring. A smaller number of synoptic dust storms occur in the fall and winter. These high winds occur over a much longer period of time compared to the convectively driven ones. In some instances high winds over 30 mph with higher gusts are found in these storms covering more than 12 hours. These systems bring in strong winds from the southwest where winds occasionally reach 50 mph sustained. Winds of this type are straightforward to forecast and local National Weather Service offices provide several days of notice in these cases. Uncertainties in the forecasts of dust storms have been in the timing and location of the high winds, presence of precipitation during the storm, along with the condition of the soils. Synoptic dust storms occur frequently in the afternoon from 3 pm to 5 pm as higher winds aloft mix down toward the ground but can be found throughout the day. The longer duration storms from cold fronts tend to last much longer with some lasting an entire afternoon.

The third type are small in scale on the order of tens to hundreds of meters in size and are called dust channels. Dust channels arise by wind blowing across small erodible areas such as a recently disturbed parking lot, agricultural field or rangeland. Disturbance can be from many activities including building construction, off-road vehicles, and livestock. These type of dust events are particularly hazardous since they are highly localized, hard to predict, can change quickly in response to changes in wind direction and wind speeds. In many instances dust channels tend to be short in duration -less than 5 minutes- but can last longer depending on the meteorological cause of the winds. Another characteristic of these are the dust is often at very high concentrations low to the ground and degrades visibility to passenger vehicles but to lesser amounts for high profile trucks. Meteorological causes for dust channels can vary from thunderstorms to cold fronts.

Other meteorological conditions that are associated with high winds can be from downslope or Fohn winds such as the Santa Ana winds from the Mojave Desert impacting southern California. These winds can be amplified when they flow though valleys or narrow mountain passes. Other causes of dust include dust devils that can create low visibility conditions over small areas.