CHAPTER 3

Wind Erosion, Dust Emission and Air Quality Prediction

During the past several years the CP_3 has achieved a number of major advances in developing prediction technology, measurement methods, analytical relationships and computer models to improve estimations of soil erosion by wind, and dust emissions and transport across the Plateau during high wind events. Reliable and accurate prediction capability is a key tool sought by resource agencies and policy-makers to prioritize areas and programs that derive maximum benefits from conservation planning and implementation. These same tools assist public and private agencies to control wind erosion on agricultural lands and improve regional air quality. Computer models and simulations integrate the combined effects of multiple causative factors on wind erosion, and its impacts and control. Combined with weather forecasting, they can also provide an early warning of possible dust hazards in localized areas and downwind from impending high wind events.

Wind Erosion and Dust Emissions Modeling

A significant advancement in prediction technology by the CP_3 was development of a combined wind erosion/PM_{10} dust emissions model that calculates the PM_{10} emitted from the largely horizontal or streamwise movement or flow of eroded soil during dust storm events (Saxton et al., 2000a). The wind erosion component employs a modified version of the Wind Erosion Equation developed in the Great Plains (Woodruff and Siddoway, 1965; also see Papendick, 1998 for additional details). This event-based model estimates the mass transport of eroded soil as a function of wind energy, soil erodibility, vegetative cover, surface roughness, and soil surface wetting and crusting. The equation in factor form is

$$Q_e = f(W_e\ SE, SC, K, WC) \qquad \text{eq 3.1}$$

where:

Q_e = event eroded soil (soil eroded per unit field width over a given time interval),

W_e = event wind energy (energy available for erosion over a given time interval),

SE = soil erodibility (ratio of Q_e:W_e for soil unprotected by SC, K, or WC),

SC = vegetative cover (surface residue or growing plants),

K = soil surface roughness [random (clods) or oriented (ridges)],

WC = soil surface wetting and crusting (soil moisture content and degree of consolidation).

The parameters and relationships required for the prediction methodology were obtained from 1) instrumented field studies conducted at three sites on growers' farms in Washington state, each representing a regional soil class, 2) wind tunnel experiments conducted on fields representing seven soil classes in the state, and 3) laboratory analyses.

Horizontal erosion was determined under natural wind conditions at the three instrumented sites by mathematical integration of sediment collected in gridded, vertical arrays of BSNE aerial samplers (Fryrear, 1986) at heights up to 1.5 m (5 ft), plus creep samplers positioned at ground-level. The BSNE (Big Spring No. 8) field dust /sediment sampler was developed by the USDA/ARS Wind Erosion Research Project at Big Spring, Texas and has been widely adopted to measure soil erosion by wind in the US and many

Table 3.1. Soil loss ratio for a combination of surface random roughness and flat residue cover.[1]

Residue (%)	Random roughness (inches)							
	0.25[2]	0.50	0.75	1.00[3]	1.25	1.50	1.75	2.00[4]
0	0.72	0.51	0.37	0.26	0.19	0.14	0.10	0.07
5	0.56	0.40	0.29	0.21	0.15	0.11	0.08	0.05
10	0.44	0.31	0.22	0.16	0.12	0.08	0.06	0.04
15	0.34	0.24	0.17	0.13	0.09	0.06	0.05	0.03
20	0.26	0.19	0.14	0.10	0.07	0.05	0.04	0.03
25	0.21	0.15	0.11	0.08	0.05	0.04	0.03	0.02
30	0.16	0.12	0.08	0.06	0.04	0.03	0.02	0.02
35	0.13	0.09	0.06	0.05	0.03	0.02	0.02	0.01
40	0.10	0.07	0.05	0.04	0.03	0.02	0.01	0.01
45	0.08	0.05	0.04	0.03	0.02	0.01	0.01	0.01
50	0.06	0.04	0.03	0.02	0.02	0.01	0.01	0.01
55	0.05	0.03	0.02	0.02	0.01	0.01	0.01	—[5]
60	0.04	0.03	0.02	0.01	0.01	0.01	0.01	—

[1]Calculated from equation 3.2.
[2]Very smooth, late fallow condition.
[3]Moderate clods, 1-2 inches, clods in early fallow.
[4]Rough tillage, chiseled or plowed dry following harvest.
[5]Less than 0.01.

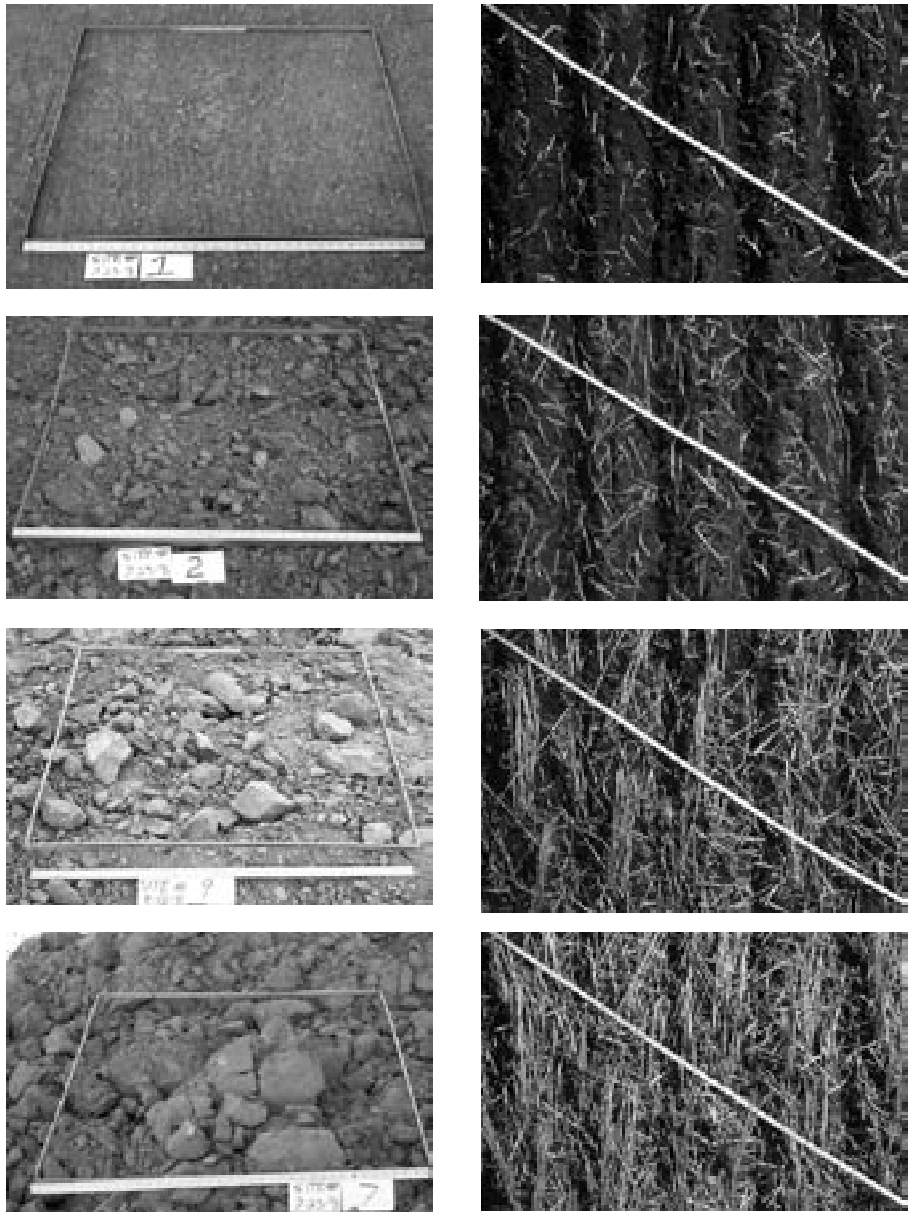

Figure 3.1. *Left: photographs of four levels of soil surface random roughness in inches, top to bottom; 0.22, 0.65, 1.03, and 1.61. Source: McCool et al. (1996). Right: photographs of four levels of flat cereal residue cover in percent, top to bottom; 10, 20, 50, and 65. These values are improved estimates by D.K. McCool, USDA-ARS, Pullman, Washington from re-analysis of these photographs originally made by the USDA-SCS at Kansas State University where cover in percent, top to bottom, was first reported as 15, 30, 50, and 70.*

locations worldwide. Collection efficiency of these samplers depends on both wind speed and particle size.

Event wind energy was determined from published relationships with measured average and threshold wind speeds (wind speed at which soil begins to erode). These relationships show that wind energy at a fixed height is proportional to the 3rd power of the wind velocity above its threshold level over the duration of a storm. The cubic relationship illustrates that soil erosion increases dramatically with incremental increases in wind speeds above the threshold level during dust storm events. Determination of the threshold wind speed has been critical to dust emission prediction using current approaches to modeling wind erosion.

Soil erodibility was calculated as the ratio of eroded soil (adjusted for surface roughness and residue cover present during the storm event) to wind energy. Extrapolation of soil erodibility values to include an additional seven soil classes was made possible by determining a relative erodibility ratio with the portable wind tunnel (Pietersma et al., 1996). This value was determined for each soil class as the ratio of the total soil loss from a standard surface (smooth, bare, dry) of each class to that of the most erodible class of the group. Actual soil erodibility values for the seven classes were derived from a correlation of their relative erodibility ratios with the erodibility values for the three soil classes determined under natural wind conditions at the instrumented field sites.

The effectiveness of surface cover SC and random roughness K for reducing wind erosion was determined from wind tunnel trials for a range of soils and surface conditions on the Columbia Plateau (Horning et al., 1998). Surface cover and roughness were estimated from comparisons with standard photographs (Fig 3.1). The relationship for reducing soil loss by wind erosion was of the form:

$$SLR = e^{-0.05SC}\, e^{-1.32K} \qquad \text{eq 3.2}$$

where SLR = soil loss ratio, K is in inches, and R^2 = 0.51 for the correlation between predicted and measured soil loss ratios.

The soil loss ratio for a given SC or K is the ratio between the soil lost from wind erosion at that percent cover or random roughness and the soil lost with zero residue cover and a smooth surface. Equation 3.2 was used to calculate the soil loss ratios in Table 3.1. The SLRs in the Table indicate that significant reductions in erosion are achieved with modest rates of surface cover and levels of soil surface random roughness.

Soil wetness and crusting are known to significantly reduce wind erosion. However, quantitative methodology was not available for adjusting total eroded soil for these variables. All modeling scenarios assumed that soil wetness and crusting did not limit event-based, streamwise soil movement.

Predicting PM_{10} emissions per storm event was determined from the estimated wind erosion and the amount of PM_{10} size material in the eroded soil coupled with an aerodynamic vertical flux equation. PM_{10} emissions were measured on an event basis by correlating the mass of PM_{10} collected by high-volume constant flow samplers at 1.5 and 2.5 m (4.9 and 8.2 ft) heights with the mass of available PM_{10} in the eroded soil transported below 1.5 m (4.9 ft) during a storm event (Saxton et al., 2000a). Available PM_{10} content of the field soil was determined by a laboratory procedure using a specially designed chamber to re-suspend the fine particulates and entrain them into a continuous air-flow PM_{10} sampler. The ratio of the mass of PM_{10} emitted and the sample mass from which it came is referred to as the "soil dustiness index." (Table 3.2). The table shows that the dust index is highest with the "L" soils and that erodibility does not follow the order of the dust index. Moreover, Saxton et al. (2000a) concluded that the re-suspension procedure with minimal disaggregation likely yields a conservative estimate of available PM_{10} (and thus, predicted emissions) compared with one using an abrasive dust generation method to be discussed later.

The combination wind erosion/emissions model is a unique development that quantifies the production of PM_{10} emissions from field-scale wind erosion calculated using independently measured or simulated climatic, soil and management variables. The theory allows for modeling the emission of other size ranges of particulates as well (e.g., the new $PM_{2.5}$ standard).

The wind erosion/emissions model has a number of potential applications at both the farm and regional levels such as:

1. **Conservation planning.** The model with the necessary input parameters provides the capability to evaluate the effect of various soil and crop management practices on erosion and dust production for different scenarios of wind and soil conditions on a field, farm or soil class scale (Lee, 1998).
2. **Blowing dust-warning index.** The purpose of the index is to improve the accuracy of dust storm forecasts by the National Weather Service and pinpoint the time and locations most susceptible to erosion to provide advanced warnings to State Police and emergency services about impending major dust events (Saxton et al., 2003). The erosion/emissions model can be used to establish algorithms for the most susceptible areas to account for the potential effect of farm management practices and soil conditions (e.g., high, medium, low) on dust concentrations and highway visibility from predicted high wind events.
3. **Expanded Conservation Reserve Program priority area.** Based on wind erosion and air quality impacts, the erosion/emissions model was used to re-evaluate soil classes on the Columbia Plateau that were not previously included in CRP Priority Area determinations for wind erosion (Blaesing-Thompson et al., 2000). The information was used by the USDA's Natural Resources Conservation Service (NRCS) to expand the CRP eligibility designation by 150,000 acres of highly erodible lands that were not included in earlier assessments.
4. **Regional air quality prediction.** The erosion/emissions model was incorporated into the regional-scale air quality transport-dispersion model in 2001 to estimate spatial patterns of PM_{10} emissions from representative soil classes and the resulting atmospheric dust concentrations across the Plateau during high wind events. The new modeling technology provides a potentially valuable method for resource and regulatory agencies to evaluate regional-scale impacts of alternative crop and soil management practices across different soil types on downwind rural and urban air quality (Claiborn and Lamb, 2000; 2001; 2002).

Assessments of Erosion and PM_{10} Emissions Potential of Columbia Plateau Soils

New insights on wind erosion processes.

Traditional wind erosion theory emphasizes saltation as the primary process with particles 70 to 500 µm (micrometer, or 0.07 to 0.5 millimeter) in mean diameter accounting for 50 to 80% of the soil movement during a storm event. Thus, controlling saltation along with surface creep (particles 500 to 800 µm in mean diameter bouncing and rolling along the surface) was thought to be important in the performance of erosion control measures (Chepil and Woodruff, 1963). This is because in addition to movement (primarily horizontal and for short distances) of the larger particles themselves, their bouncing and abrasive action entrain and give rise to the vertical suspension of dust-sized particulates (generally <70 µm) that can remain airborne for long distances (see Fig. 2.1 in Papendick, 1998).

The saltation process has been mathematically described based upon research on soils that contained significant amounts of fine aggregates and coarse particles, i.e., many classified texturally as sands. However, the validity of this theory to estimate wind erosion and dust emissions for the finer textured silty soils prevalent in the extensive loess deposits of the Columbia Plateau is under question (Chandler and Saxton, 2001; Kjelgaard et al., 2002a; Kjelgaard et al., 2003). In these soils 90% of the particles (by mass) have mean diameters less than 100 µm with only a very small fraction of saltator size (USDA, 1967).

Field observations and measurement in CP_3 studies provide evidence that direct suspension, without saltation or creep, is the dominant mechanism of wind erosion of fine loessial soils when wind energy exceeds a threshold speed (Kjelgaard et al., 2002a). Suspension has been associated with mass removal of finer textured soils composed primarily of disaggegated silt and clay where little sorting of the primary particles occurs from wind action. For example, when a major dust storm occurred on September 23-

Table 3.2. Average dust index and soil erodibility for major soils on the Columbia Plateau[1].

Soil map unit[2]	Dust index x 10^{-2} (g g^{-1})	Soil erodibility x 10^{-10} (kg m^{-1}/g s^{-2})
L1[3]	0.68	8.20
L2	0.95	6.10
L3	0.56	4.92
L4	1.09	5.32
L5	0.72	3.05
D_s	0.53	5.27
D_q	0.07	9.84

[1]Adapted from Saxton et al. (2000a). The dust index is the ratio of the mass of PM_{10} emitted in a laboratory re-suspension chamber and the mass of the sample from which it came.

[2]The map units are for the soils in Figure 1.4, Chapter 1.

[3]These data are for the most erodible subset (A) of the L1 and L2 soils as opposed to the (B) subset.

25, 1999 with peak winds of 50 mi hr^{-1}, CP_3 scientists observed significant erosion from a newly-planted wheat field after fallow on a Ritzville silt loam soil (coarse-silty, mixed, superactive mesic Calcidic Haploxeroll) with 40% flat wheat residue cover. However, the soil material collected in BSNE samplers contained only a small fraction of particulates greater than 100 µm in mean diameter, indicating that despite high winds, the bulk of the eroded soil was of suspension size picked up from loosened soil at the ground surface (Saxton, 1999; Chandler and Saxton, 2001).

Kjelgaard et al. (2002a; 2003) used theory from wind velocity profile analysis to determine whether or not saltation is a major factor in wind erosion on the Columbia Plateau. Saltation produces a drag on wind near the soil surface, causing greater wind shear near the surface and a consequential change in the wind speed profile. In their analysis of the natural wind profiles of two major dust storms and one minor event occurring on a Ritzville soil, friction velocity remained a linear function of wind speed for the duration of the storms, providing evidence that saltation was minimal in the erosion process (Chandler and Saxton, 2001; Kjelgaard et al., 2002a). Any saltation that does occur during dust storms is likely suppressed early on by trapping of the larger particles in the fine powder-like soil typical of the Plateau's wheat–fallow system.

Absence of surface scouring, and minimal soil deposition in localized trapping areas such as field boundaries, road ditches, tree or shrub windbreaks, or other obstacles is further indication of suspension-dominated wind erosion compared with dust storms where saltation and creep are the primary mechanisms of transport (Saxton et al., 2000b). Instead, dust eroded by direct suspension (i.e., with little creep or saltation) is distributed across large areas and significant amounts are often deposited hundreds to thousands of miles from its source. Direct suspension is enhanced through soil mixing by intensive tillage associated with the traditional wheat–fallow system and may be subdued in undisturbed surfaces (Blaesing-Thompson, 2000; Blaesing-Thompson et al., 2000).

There are areas of coarse-textured soils on the Columbia Plateau (i.e., fringes along the Columbia River and the southeastern and south central parts of Benton County extending in a northeasterly direction into Franklin and south central Adams Counties) where saltation and creep are the dominant processes of wind erosion. These are mostly sandy areas where the primary particles are too large to be suspended and transported any significant distance from the source. Saltation results in selective loss of the finer and more fertile particulates (aggregated silts, clays and organic matter) while the coarser materials remain. Direct evidence of saltation is the localized accumulation of dunes and soil deposition by trapping behind barriers, along fence lines and in field depressions.

Knowledge of the dominant process of wind erosion is very important in the development of control strategies. For example, if by suspension, the most effective control methods are those that prevent wind speeds at the soil surface from reaching the threshold level because the erosion cannot be controlled once the particulates are airborne (Saxton et al., 2000b). In this case effective control practices should emphasize crop and residue cover, a cloddy soil surface, or combinations of these that is resistant to wind force. Where creep/saltation is the dominant process, effective control can also be achieved by reducing surface wind speed, but additionally by practices that provide for trapping of coarse particles in motion such as furrows, strip-cropping, grass strips and tree or shrub windbreaks.

The need for new theory

According to CP_3 researchers, wind erosion that is dominated by suspension, as opposed to creep/saltation, will require the development of new theory and measurement methods (Saxton, et al., 2000b). For example, the BSNE samplers that are standard for measurement of saltation-induced wind erosion are designed to collect soil that is transported largely in a horizontal direction downwind along a field length (Fryrear, 1986). This sampling method is inadequate for suspension erosion, which has a large vertical component and where sediments may travel at great heights and long distances before fallout.

Preliminary analyses suggest that sediment collected in BSNE samplers stacked in heights ranging from 1.0 to 1.5 m (3.3 to 4.9 ft) above the soil surface likely originated from near the sampler to less than 100 m upwind (Saxton et al., 2000b). However, this conclusion is clouded by the fact that the BSNE sampling efficiency is dependent both on particle size and wind speed. Another gap or deficiency of common research methods is that field-based dust concentration measurements obtained during erosion

Figure 3.2. *"Intensive" field instrumentation site for simultaneous measurement of turbulent wind flow and dust suspension during wind erosion from tilled fallow. The measurements are part of the modeling effort to predict suspension erosion and transport of PM_{10} and $PM_{2.5}$ during high wind events. The site is located approximately 11 miles west of Washtucna, WA on Ritzville silt loam in a 12-inch annual precipitation zone where winter wheat–fallow is the dominant cropping system. Source: J.F. Kjelgaard, WSU.*

events were "event based", i.e., one measurement represented the entire event regardless of variations in storm intensity or its duration. This approach does not allow for measurement of natural variations in emissions during a storm or provide the resolution needed for more accurate simulations that integrate information, e.g., hourly or shorter time periods.

Scientists in the CP_3 now believe that accurate prediction of suspension erosion and fine particulate movement needs to be based on turbulent wind theory and will require improved characterization of turbulent wind fields and associated processes. The development of this advanced technology will require synchronizing measurements of dust concentrations with wind speeds and direction by height over very short times (1 to 5 sec) during erosion events. Because many of the turbulent eddies driving wind erosion are longer than a wind tunnel can practically generate, we expect future advances in wind erosion science will come from field studies.

Two newly instrumented field sites were established in late summer 2001 to provide data for the development of theory and methodology to estimate wind erosion by suspension (Kjelgaard, 2001; Saxton and Kjelgaard, 2001; Kjelgaard and Saxton, 2002). One, a "standard" site 14 miles west of Washtucna, WA was established on Ritzville silt loam to be moved every year but always in an area seeded to winter wheat. The instrumentation package consists of standard BSNE and high-volume PM_{10} samplers arranged to measure the horizontal and vertical dust distribution during an entire storm interval, and a meteorological station equipped with cup anemometers to measure wind speeds and direction at one-minute intervals when speeds exceed the threshold level.

Another "intensive" site 11 miles northwest of Washtucna, WA was established on a winter wheat–summer fallow field of Ritzville silt loam to be studied as a continuous tilled fallow treatment (Fig. 3.2). The instrumentation package consists of continuous recording PM_{10} and $PM_{2.5}$ samplers at heights of 1 and 3 m (3.3 and 9.8 ft) that are synchronized with measurements of 3-dimensional wind speed and direction at the same heights by sonic anemometers. The collection of these simultaneous data for multiple storm events will provide scientists with new information to analytically describe the mechanics of

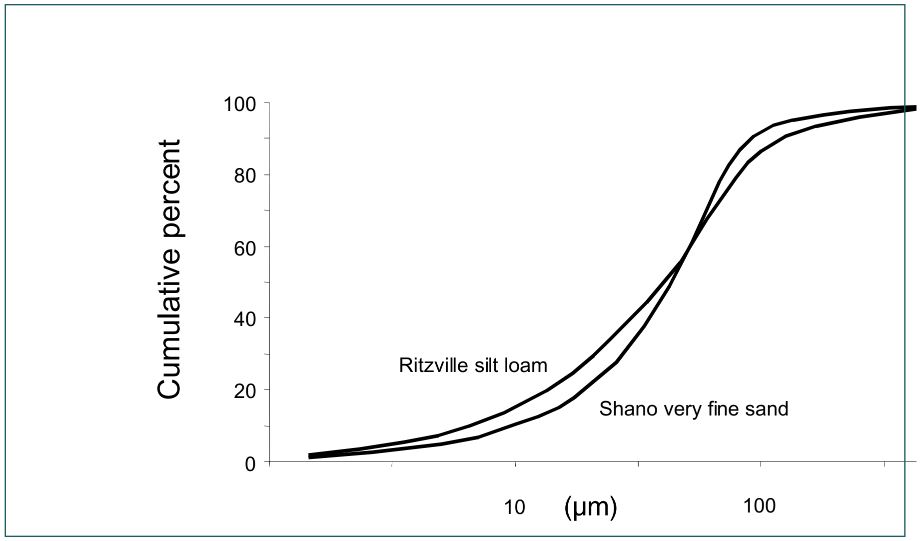

Figure 3.3. *Cumulative percent of non-dispersed soil particles in the size range up to 1000 microns for a Ritzville silt loam and Shano very fine sand, two prominent soils on the Columbia Plateau. The graph shows that 85% of the Shano soil and 90% of the Ritzville soil consist of particle sizes less than 100 microns. Source: Stetler and Saxton (1996).*

wind erosion and dust emissions from the fine-textured, loessial soils that are predominant throughout much of the Columbia Plateau.

The intensive site measurements have already yielded new insights into the process dominating wind erosion on the Columbia Plateau (Kjelgaard, 2001; Kjelgaard et al., 2002b). However, the currently-available instrumentation needs further refinements to allow association of dust concentrations and turbulent eddies in the wind. The USDA-ARS and WSU scientists are exploring the development of new sensor technologies to overcome this obstacle.

Predicting the erodibility of loessial soils

The intrinsic erodibility factor in the empirical wind erosion models for a particular soil is a measure of the maximum erosion possible for a given wind energy when the soil is in a condition that is most susceptible for erosion (bare, smooth, dry, tilled, noncrusted). The Wind Erosion Equation was developed on soils in the Kansas Great Plains where saltation/creep is the primary mode of transport. Under these conditions a useful index of erodibility was determined from the mass percentage of particle sizes less than 840 μm in mean diameter that is readily obtained by dry sieving a sample of the surface inch of soil (Chepil, 1941). However, this measurement has not proved useful on the Columbia Plateau because the entire mass fraction is less than 840 μm in diameter in 90 to 95% of the soils, and less than 100 μm in diameter in 50 to 70% of the soils (Fig. 3.3; Stetler and Saxton, 1996; Saxton et al., 2000b; Chandler et al., 2004).

In earlier work a portable wind tunnel designed by Pietersma et al. (1996) was employed to determine the erodibility of fine-textured loessial soils on the Columbia Plateau for use in wind erosion predictions (Fig. 3.4). Because wind tunnel tests are expensive and time consuming, statistical relationships were derived between wind tunnel-induced soil erosion and dry-sieved soil texture. The results will provide information on potential soil erosion and dust emissions at more sites than could feasibly be obtained by wind tunnel methods.

Two relationships were developed based on whether the erosion process was dominated by saltation or suspension (Busacca, 2000). For saltating soils containing significant amounts of fine and coarse sands (>50%) the relationship was:

Y_{sa} = [1.9 (mass 30-710 μm/mass <30 μm)] + 1.3 eq 3.3

where Y_{sa} = soil erodibility for saltation-dominated erosion. For soils dominated by silt and fine sand (>75%) the relationship was

Y_{su} = 15 (mass 63-30 μm/mass >63 μm) eq 3.4

where Y_{su} = soil erodibility for suspension-dominated erosion. The predicted values from the numerous sites with textural analyses were then converted from wind tunnel erosion units to those of wind erosion during actual wind events (Saxton et al., 2000a).

The predicted data were spatially interpolated across the Plateau region by geostatistical methods and then imported into GIS (Geographical Information System) for display as a map covering the dryland cropping areas (Fig. 3.5; Busacca, 2000; Chandler et al., 2004). The map shows that the soil erodibility (the potential total erosion) is highest in the southwestern part of the Plateau region where soils are sandy and tend to decrease in the northeasterly direction as soils become finer-textured, predominantly silt loams, and less fragile resulting from increased organic matter and better aggregation.

Predicting the available PM_{10} and $PM_{2.5}$ in loessial soils

As previously mentioned, Saxton et al. (2000a) developed two laboratory procedures to estimate the amount of PM_{10} available for suspension from an eroding soil, a value incorporated in their wind erosion/emissions model. The first method, termed "re-suspension", was designed with minimum disturbance to release and capture only the "free" PM_{10} and smaller size particulates of a soil sample. However, during natural wind erosion, aggregated particles are subject to abrasion from collision with other aggregate and primary particles that may increase the amount of PM available for suspension.

Thus, a second laboratory method termed "self-abrasion" was developed that suspends both the pre-existing PM and allows aggregates in a soil sample to tumble and self-abrade, thereby emitting additional particles for measurement with standard PM_{10} and $PM_{2.5}$ samplers (Chandler et al., 2002). The self-abrasion technique utilizes an air stream and mechanical mixing to create an abrasion zone along an elliptical path above the base within a cone-shaped chamber where the larger particles tumble and collide with one another. The cone is coupled with a TEOM (tapered element oscillating microbalance, a continuous recording PM measuring instrument) through an inlet tube that feeds PM released from the soil sample directly into the top of either the PM_{10} or $PM_{2.5}$ measurement device.

Calibration tests with standard PM materials indicated that the self-abrader performed reliably over a wide range of dust sizes. Measurement of soil samples obtained from 42 sites on the Columbia Plateau and four from Texas revealed that the content of available PM increased about five-fold with the self-abrasion technique over that measured by the re-suspension method. The $PM_{2.5}$ content averaged approximately one-fourth to one-third of the PM_{10}. The self-abrasion technique will enable reliable measurements of the available PM fraction over a greater range of soils, including those where a higher clay and organic matter content could result in significant aggregation.

The self-abrader/TEOM method for measuring PM_{10} in soil is expensive and time consuming. A simpler and less costly approach was devised by relating the more easily measured wet-dispersed PM_{10} in a soil sample determined by laser analysis to the PM_{10} determined by the self-abrader/TEOM analysis as (Chandler et al., 2002):

Abrader (available) $PM_{10} = 0.16(\text{dispersed } PM_{10}) - 1.79$ eq 3.5

Although the abrader PM_{10} fraction correlated positively with the soil organic matter and clay content, any association with either of these or with the sand fraction did not improve on the foregoing relationship with dispersed analysis. Moreover, the $PM_{2.5}$ emission potential did not correlate well with the soil organic matter and clay content (Saxton et al., 2000b).

As with erodibility, the predicted available PM_{10} values were statistically analyzed, imported into a GIS, and displayed as a map over the Columbia Plateau (Fig. 3.6; Busacca, 2000; Chandler et al., 2004). The map shows that soils in the western and south-central parts of the region where they are sandier have the lowest PM_{10} contents. Soils have increased amounts of available PM_{10} toward the north, east and southeast where they are higher in silt and clay.

Predicting PM_{10} emission hazards for the Columbia Plateau

The PM_{10} emission hazard was defined as the potential for emission of PM_{10} during wind erosion events. This parameter was calculated for each soil as a product of the available PM_{10} and its erodibility. These data were statistically analyzed, and as with the individual soil erodibility and available PM_{10} data, presented through GIS as a map over the Plateau (Fig. 3.7) (Busacca, 2000; Chandler et al., 2004). The area with the highest PM_{10} emission hazard lies in the northwest and descends south across the eastern part of the the Plateau with the "hot spot" in southeastern Adams County. Additional noncontiguous areas with high hazard are found around the periphery of the Plateau where soils are of moderate erodibility but have a relatively high content of available

Figure 3.4. *The portable wind tunnel designed by the CP_3 has been utilized in much of the wind erosion prediction research on the Columbia Plateau. The machine generates variable wind speeds and simultaneously measures eroding soil including PM size that drifts through a 3.2 x 3.9 x 23.9 ft long rectangular tunnel. It is used to test the effect of soil and cover conditions on erosion loss for different wind speeds and soil types. Source: J.F. Kjelgaard, WSU.*

PM_{10}, are low in organic matter, and have limited soil moisture. There is an area of high hazard in northeastern Spokane County that is outside of the boundary of the Columbia Plateau Major Land Resource Area. The area with the lowest predicted PM_{10} emission hazard is in the western part of the Plateau and extends toward the south where the soil erodibility is relatively high but the soils have relatively low PM_{10} contents.

The distribution of predicted PM_{10} emissions hazard of highest priority from the CP_3 study approximately coincides with map units L1-L4 and portions of the D_q and D_s units of the General Soil Map of Washington (Figs. 1.4, 3.7; Boling et al., 1998). These include a sequence of mostly very deep soils that form the loess hills typical of the region, and small areas of deep and moderately deep soils on ridge tops and south slopes all of which are primarily in dryland production of small grains. Soil map units designated as priority areas contributing to air quality concerns are essentially the same as for the emissions hazard (Figs. 1.4, 3.8). Based on CP_3 research, these map units should be included in delineating areas that are in need of conservation measures to control wind erosion and improve air quality. This is especially true because the traditional winter wheat-summer fallow rotation is the predominant agricultural practice on these lands, and it is where drought effects are most severe.

Measuring and Predicting the Transport and Dispersion of PM from Wind Erosion

An original objective of the CP_3 was to develop a regional model capable of predicting the emission, transport and dispersion of PM from soil erosion by wind, and air quality impacts of wind-blown dust from agricultural areas on the Columbia Plateau. The outcome of this research was the four-component MM5/CALMET/EMIT/CALGRID model developed by a team headed by C. Claiborn and B. Lamb, Department of Civil and Environmental Engineering (CEE), WSU, working in collaboration with the wind erosion/PM dust emissions modeling effort led by K.E. Saxton, USDA-ARS and the Department of Biological Systems Engineering (BSE), WSU.

In the atmospheric dust simulation, archived meteorological data from the University of Washington's

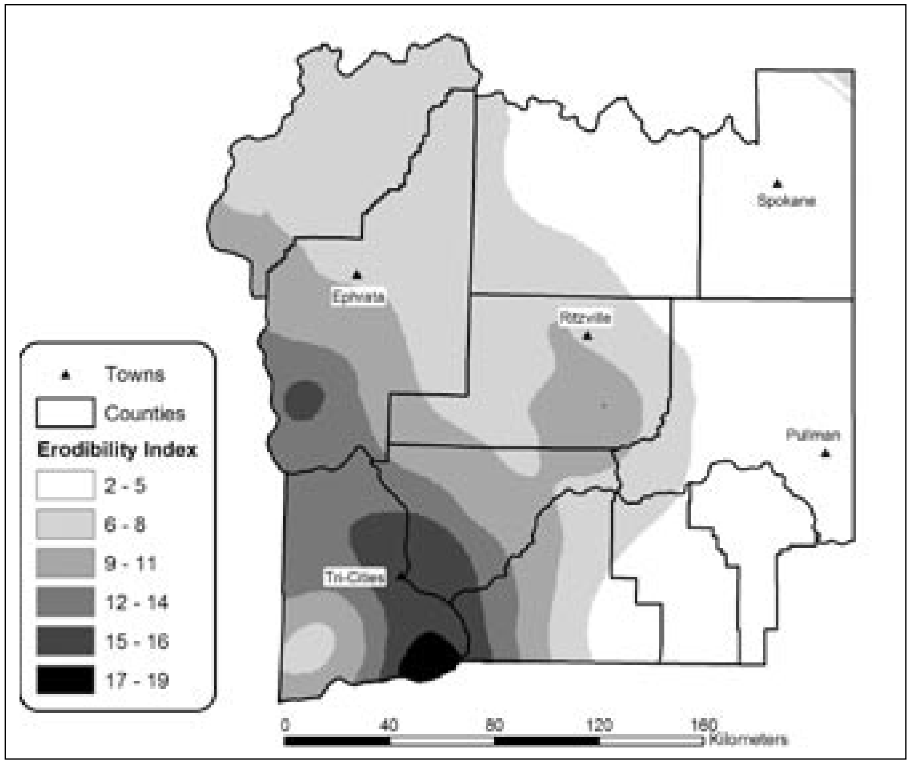

Figure 3.5. *Predicted soil erodibility in units of the wind erosion equation (eq 3.1) for soils of the Columbia Plateau that are dry farmed. Source: Busacca (2000); Chandler et al. (2004).*

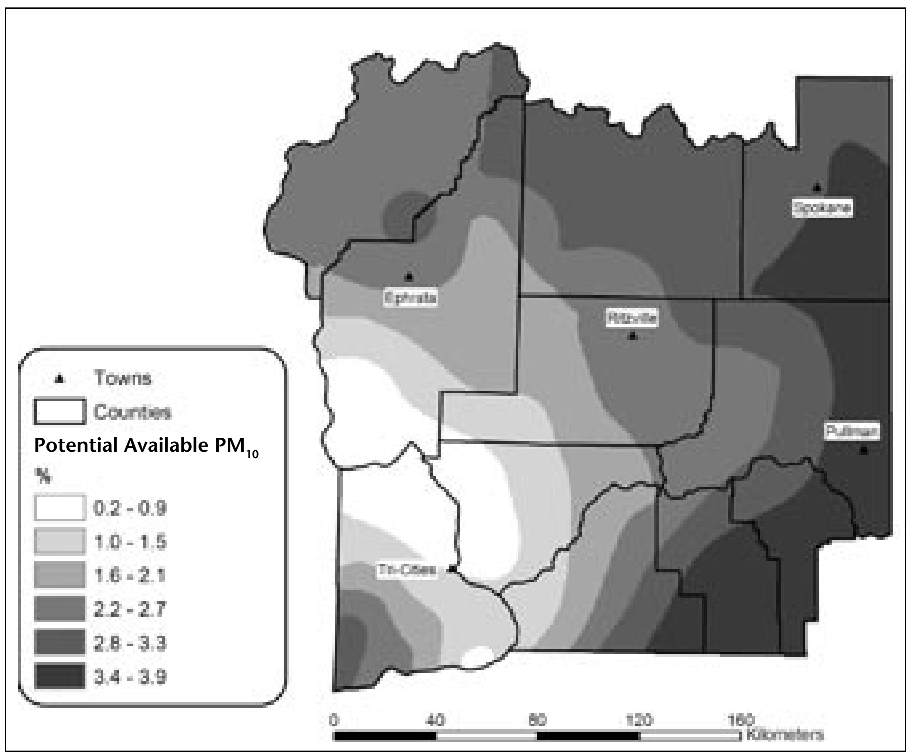

Figure 3.6 *Available PM_{10} predicted from dispersed particle size analysis for soils of the Columbia Plateau that are dry farmed. Source: Busacca (2000); Chandler et al. (2004).*

Mesoscale Model Version 5 (MM5) forecasts for a 7.5-mi (12 km) grid system were merged with measured surface meteorological data through CALMET for calculating gridded wind speeds and turbulence fields over a specified area. These data were then used by the EMIT emission algorithm (the wind erosion/dust emissions model developed by Saxton et al., 2000a) to estimate the vertical flux of PM as a function of the horizontal flux of eroded soil. From these data the final component, CALGRID generates ambient PM concentrations as a function of time over a 2.5-mi (4 km) grid of the entire Columbia Plateau (Lee, 1998).

For verification, predicted PM concentrations for a dust storm event were compared with measured values at monitoring sites. The model is extremely versatile and allows for computations of atmospheric concentrations of PM_{10} for varying storm characteristics, and soil and cover conditions over the whole or a portion of the region as reported in preliminary simulations (Papendick, 1998).

The research has continued to test and improve the accuracy of the regional dust model to determine the impacts of various land use scenarios on air quality over the 24,000 square miles (61,000 km^2) of the Columbia Plateau and Columbia Basin MLRAs. This includes a rerun of computer simulations of six historical dust storms using EMIT and the latest version of MM5. Figure 3.9 displays the latest result for the predicted 24-hr average PM_{10} concentrations from the MM5/CALMET/EMIT/CALGRID model over a gridded area of the Columbia Plateau for a dust storm event that occurred on November 3, 1993. Agreement with the measured concentrations from several locations was within a factor of one to four.

Another test applied the modeling approach to predict PM_{10} concentrations during the major dust storm of September 25, 1999 that caused a 50-car traffic accident and 7 fatalities on Interstate 84 near Pendleton, Oregon. Wind speeds predicted by CALMET agreed well with those measured at Spokane (R^2 = 0.95) and Kennewick (R^2 = 0.99), Washington. The predicted PM_{10} concentrations in Spokane agreed within 30% of measured values in terms of the onset and magnitude of increased concentrations. However, in Kennewick the predicted PM_{10} concentrations were significantly higher (by a factor of three or more) than the measured concentrations, and the predicted peak occurred slightly ahead of the measured peak (Claiborn and Lamb, 2000).

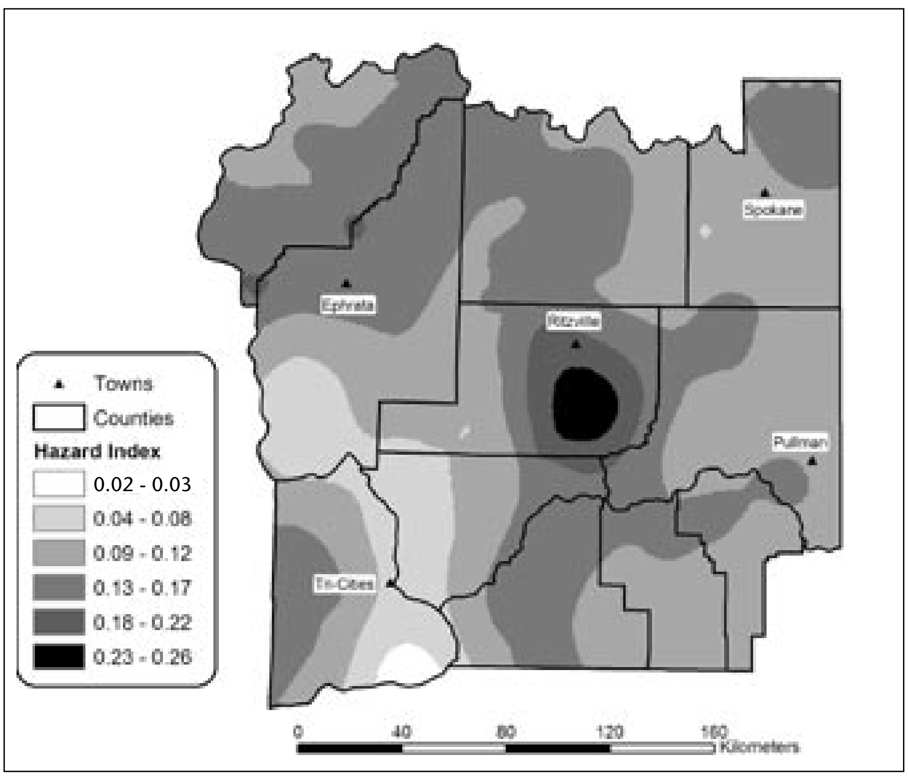

Figure 3.7. *Predicted PM_{10} emissions hazard for soils of the Columbia Plateau that are dry farmed. The emissions hazard is the product of the soil erodibility and the fraction of available PM_{10} in the soil. Source: Busacca (2000); Chandler et al. (2004).*

In general, the EMIT code improved the agreement between predicted and measured PM_{10} concentrations over previous use of a dust coefficient. This is mainly due to the use of soil loss ratios that improved quantification of the effects of surface cover and roughness on erosion, and soil data to predict emission of PM_{10} from eroding soil. Together with the meteorological simulations these represent major advancements in the capability of the CP_3 team to model PM fluxes for Columbia Plateau soils.

As part of the effort to develop new theory and methodology for more accurate modeling of dust emissions by direct suspension from fine-textured loessial soils, the modeling team has 1) tested instrumentation to document the onset of dust production as a function of wind energy and turbulence during high wind events, and 2) developed turbulence theory as a new approach to improve estimates of vertical flux of PM during wind erosion.

These objectives require characterization of discrete wind turbulence along with short time measurements of dust production during storm events. Testing of sonic anemometers at the intensive instrumented field site shows promise to meet the requirements for wind measurements. Wind tunnel calibration tests of the AQ-10 nephelometer against the more sophisticated, modified high volume (MHV) PM sampler indicated that the AQ-10 may perform adequately for field measurement of vertical dust concentrations (Claiborn and Lamb, 2002).

Development of turbulence theory to predict vertical dust flux was based on known eddy covariance (EC) and disjunct eddy covariance (DEC) methods. The EC method calculates the vertical flux of an airborne constituent (PM in this case) from the cross product of the fluctuating vertical wind velocity and the associated particulate concentration. Its limitation is that while instantaneous wind velocities can be adequately measured there is no fast-response dust sensor available for continuous monitoring of dust concentrations. The CEE group is alternatively investigating the use of the DEC method where an instantaneous grab sample that can be measured between short sampling intervals with a slow-response sensor is collected along with a single wind velocity sample. Early tests indicate that the versatile AQ-10 nephelometer may be adequate for this purpose. A preliminary design of a DEC system has been established and is currently undergoing testing (Claiborn and Lamb, 2002).

Summary Observations

A combined wind erosion/dust emissions model was developed that calculates the PM emitted as fugitive dust as a function of the eroded soil with known PM content during dust storm events. The wind erosion component was a modification of the empirical wind erosion equation developed in the Great Plains and calibrated with field data obtained from the Columbia Plateau.

The model performed successfully in preliminary trials as an emissions input subroutine for a regional wind-blown dust transport/dispersion air quality model showing good agreement between predicted versus measured atmospheric PM concentrations during several historic dust storm events. It has potential use for conservation planning and policy decision-making on Plateau lands subject to wind erosion.

New studies indicate that suspension, not saltation as previously believed, is the dominant mechanism of wind erosion of the fine-textured loessial soils that are found on much of the Columbia Plateau farmlands. Measuring and predicting suspension-dominated wind erosion has required the development of new methods and theory.

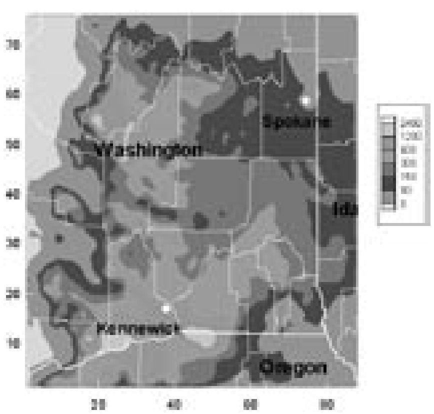

Figure 3.9. *Twenty four-hr average PM_{10} concentrations in micrograms per cubic meter over the Columbia Plateau predicted by the Regional Air Quality Model for the dust storm of November 3, 1993. Agreement with the measured concentrations from several locations was within a factor of one to four. Map supplied by B. Lamb, Department of Civil Engineering , Washington State University.*

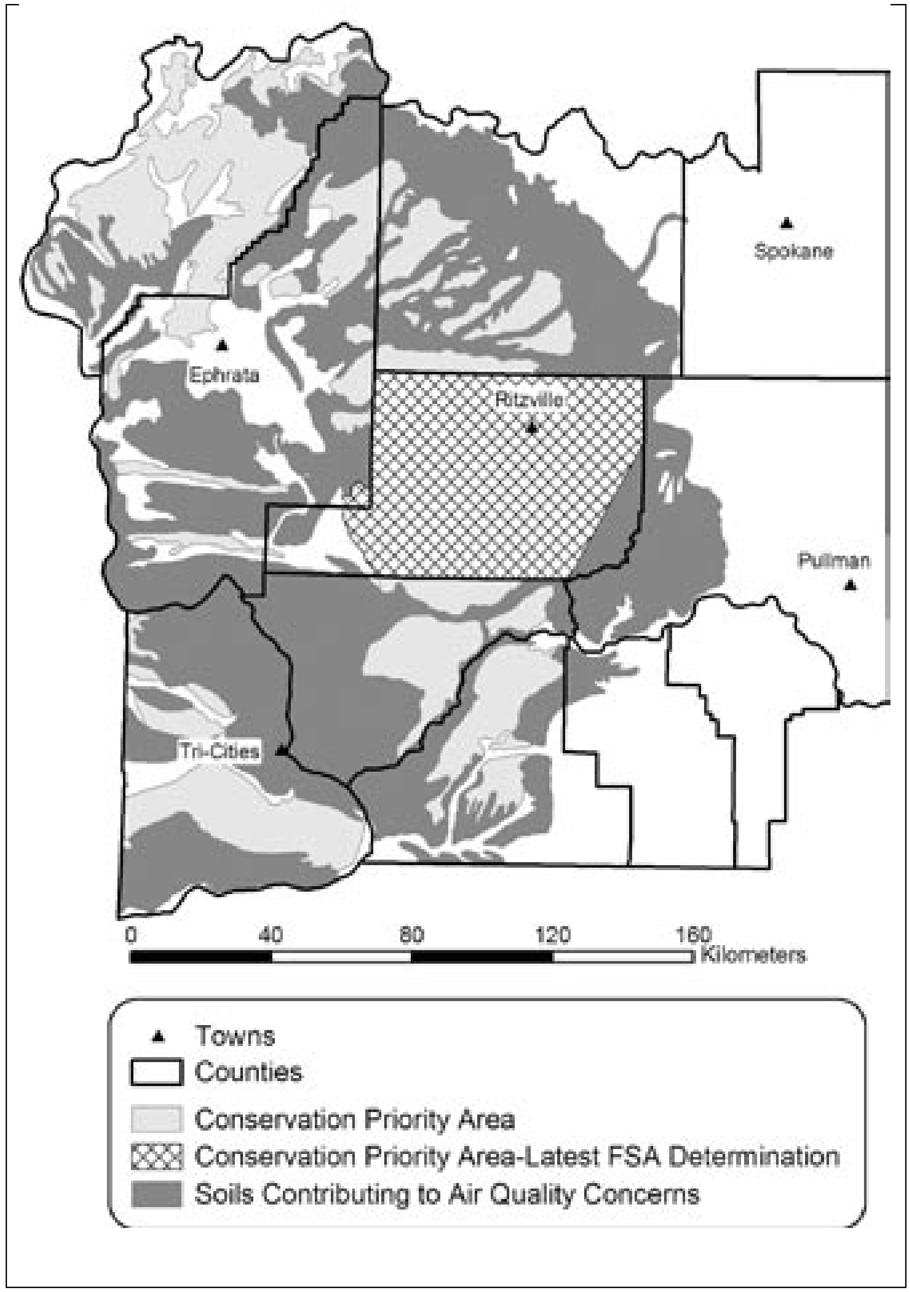

Figure 3.8. *USDA-Natural Resources Conservation Service (NRCS) conservation priority areas map for air quality as affected by soils of the Columbia Plateau that are dry farmed. Source: Busacca (2000); Boling et al. (1998); Chandler et al. (2004).*

New relationships were developed from wind tunnel tests between dry aggregate size and soil erodibility for soils that account for either saltation- or suspension-based erosion and used to predict erodibility at over 150 sites on the Columbia Plateau. The data were analyzed by geostatistical techniques and produced as a map across the study area. The map displays a trend of highest soil erodibility in the southwest portions of the Plateau where soils are sandy and decreasing erodibility extending in a northeasterly direction as the soils become more silty in texture.

Similarly, available PM_{10} was measured in soils from the wind tunnel test sites using a newly designed TEOM (tapered element oscillating microbalance)-based self abrader technique. Correlation of these data with available PM_{10} measured by a simpler and faster laser-based dispersed particle sizing method provided a relationship that was used to calculate available PM_{10} for about 150 soils in the study area. Geostatistical techniques were used to construct a PM_{10} hazard (product of soil erodibility and available PM_{10}) map that showed highest values extend from northwest to southeast across the east central region of the Plateau. The soils here are of moderate erodibility with high contents of PM_{10}, low in organic matter and most are in the low to intermediate precipitation zones.

The regional windblown dust model has been updated with a newer version of a meteorological forecasting system, and incorporation of a dust emissions algorithm (the wind erosion/emissions model). Simulations of historic events with these upgrades are in progress. The improvement to predict soil dust potential with the emissions routine represents a major advance in the capability to model regional atmospheric PM fluxes. Progress has been made with the development of turbulence theory to predict suspension-dominated wind erosion. The use of sonic anemometers and continuous dust sensors shows promise for measurement of three dimensional wind velocities and simultaneous concentrations of PM necessary to obtain air turbulence parameters to calculate vertical PM fluxes from suspension erosion using a gradient method.

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