3.6 THE COLUMBIA PLATEAU WIND EROSION / AIR QUALITY PROJECT: PREDICTING AND CONTROLLING WINDBLOWN DUST

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1. INTRODUCTION

Windblown dust is a concern within the Columbia Plateau region of the Pacific Northwest United States due to loss of soil productivity. Sharratt (2004), for example, estimated a 1000 kg ha^{-1} loss of top soil from a silt loam near Washtucna, Washington during a single dust storm in October 2003. Windblown dust can also impair visibility (Figure 1). Poor visibility caused by windblown dust has been the cause of numerous fatalities, accidents, and road closures within the Columbia Plateau. In September 1999, for example, poor visibility caused by blowing dust resulted in eight fatalities along Interstate 84 near Pendleton, Oregon (The Seattle Times, Seattle, Washington, 17 October 2000). Likewise, in March 2005, poor visibility from blowing dust resulted in closure of Interstate 90 after a four-vehicle accident occurred near Moses Lake, Washington (The Wenatchee World Newspaper, Wenatchee, Washington, 17 March 2005).

Figure 1. Blowing dust often impairs visibility within the Columbia Plateau as evidenced along a road near Washtucna, Washington on 28 October 2003.

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Windblown dust also contributes to poor air quality across the Columbia Plateau (Figure 2). In 1992, two locations in eastern Washington were declared nonattainment by the US EPA for failure to meet the National Ambient Air Quality PM10 Standard; Wallula, Washington was declared serious nonattainment and Spokane, Washington was declared moderate nonattainment. Elevated PM10 concentrations at both locations were caused by blowing dust originating from agricultural fields.

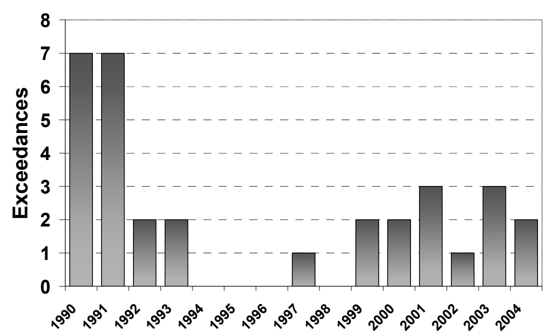

Figure 2. Number of exceedances of the National Ambient Air Quality PM10 Standard at Kennewick, Washington from 1990 to 2004. All exceedances (except those in 2000 and 2002) were associated with elevated dust concentrations caused by high winds.

Busacca et al. (2004) have suggested that windblown dust within the Columbia Plateau has occurred throughout geologic time (over the past 1-2 million years). Cataclysmic floods occurred in the region during the last glacial maximum as a result of successive ice dam failures of Glacial Lake Missoula. These flood waters advanced southwesterly across the Columbia Plateau and scoured the landscape of east central Washington, leaving behind the Channeled Scablands. Sediments from the flood waters were deposited on the southwestern part of the Columbia Plateau and after the flood waters subsided, southwesterly winds suspended and redeposited the sediment over the region. Most soils in the Columbia Plateau are formed from thick deposits of windblown silt, called loess, that in some areas are 75 m deep overlying basalt bedrock.

In 1992, concern over the "nonattainment" designation of the PM10 standard in eastern Washington prompted the first of many meetings among federal, state, and local agencies and farmers in the region. Although the US EPA identified wind erosion as the major cause for the PM10 exceedances in eastern Washington, little was known concerning where wind erosion occurred throughout the region; the climate, soil, and vegetation characteristics that caused erosion; and the control strategies that would mitigate wind erosion. Shortly thereafter, in 1993, the US EPA and Washington Department of Ecology provided funding to identify farming practices that cause wind erosion and to develop control strategies to mitigate blowing dust in the region. This research initiative, initially known as the Columbia Plateau PM10 Project and more recently as the Columbia Plateau Wind Erosion / Air Quality Project, would develop an understanding of wind erosion and PM10 emissions and identify control strategies to mitigate wind erosion and improve air quality in the Columbia Plateau. The USDA Cooperative State Research, Education, and Extension Service (CSREES) currently provide funding for the project.

2. THE COLUMBIA PLATEAU

The Columbia Plateau encompasses an area of about 75,000 km^2 and is located largely within eastern Washington (Figure 3). The Plateau lies between the Cascade Mountains on the west, the Bitterroot Mountains on the east, the Blue Mountains on the south, and the Okanogan Highlands on the north. The Plateau is drained in part by the Columbia and Snake Rivers and gently slopes to the southwest. Soils of the Columbia Plateau are underlain by the Columbia Rivers Basalts.

The Mediterranean climate of the region is characterized by cool and moist winters and hot and dry summers. Annual precipitation ranges from about 100 mm at the base of the eastern slopes of the Cascade Mountains to over 500 mm at the base of the western slopes of the Bitterroot Mountains. Native vegetation consists of sagebrush-steppe in the western Plateau to meadow-steppe in the eastern Plateau. Precipitation and vegetation gradients have resulted in a climosequence of soils from fine sands with low organic matter content (0.5%) on the west side to silt loams with high organic matter content (4%) on the east side of the Plateau. The potential for wind erosion declines from west to east due to an increase in soil aggregation and stability associated with higher organic matter and finer-textured soil. Winds are predominately from the southwest and are strongest in spring and autumn.

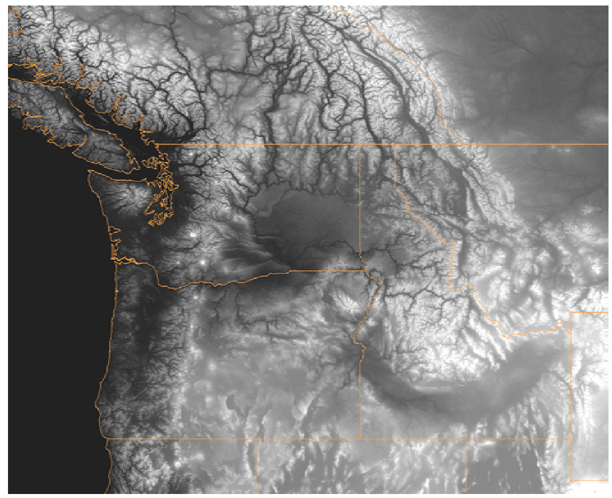

Figure 3. The Columbia Plateau is denoted by the contiguous dark gray area that lies within eastern Washington, north central Oregon, and northwestern Idaho. This image was taken from space and includes political boundaries.

Farming practices vary widely across the Columbia Plateau and are largely dependent on precipitation. Dryland winter wheat – summer fallow (one crop every two years) and irrigated crops predominate in areas with less than about 300 mm of precipitation. Annual winter wheat or winter wheat in rotation with spring crops is dominant in areas with greater than about 450 mm of annual precipitation.

3. PROJECT OBJECTIVES

In 1993, the USDA-ARS, Washington State University, US EPA, and Washington Department of Ecology identified seven objectives for developing a better understanding of farming practices and environmental factors that influence PM10 emissions. In addition, these objectives would identify farming practices most effective at reducing PM10 emissions within the Columbia Plateau. The objectives of this project have evolved with time; currently there are eight objectives, six (objectives 1-6 below) of which were originally identified in 1993. Current objectives include:

3.1 Create baseline data for the Columbia Plateau

Low and moderate resolution data that describe soil properties, vegetation type and cover, topography, climate, and farming practices are needed for simulating wind erosion and PM10 emissions across the Columbia Plateau.

3.2 Quantify and develop simulations of wind erosion and PM10 emissions

Prediction capabilities are needed that estimate soil and PM10 loss from agricultural lands due to wind erosion across the Columbia Plateau. Field data that quantify soil and PM10 loss are also required for testing model predictions.

3.3 Create an emissions inventory for the Columbia Plateau

An inventory is needed to illuminate areas most susceptible to PM10 emissions. These areas could then be targeted for implementing alternative control strategies and USDA Natural Resources Conservation Service conservation programs.

3.4 Develop a regional transport-dispersion-deposition model for predicting regional PM10 concentrations

A regional scheme is needed that simulates the transport and dispersion of wind blown dust originating from lands throughout the Columbia Plateau. The scheme will estimate the probable impact of changing land use and farming practices on PM10 concentrations in urban areas across the Columbia Plateau.

3.5 Develop alternative tillage and cropping systems that will minimize PM10 emissions

Field experiments are needed to test the effectiveness of alternative tillage and cropping systems in reducing PM10 emissions and for improving soil quality.

3.6 Determine the relative impact of human activity on PM10 emissions

Information is needed to determine whether farming has or changes in farming methods have resulted in higher PM10 emissions since farming began in the region in the 1880's.

3.7 Develop awareness among urban and rural communities regarding PM10 regulations and control strategies

Urban and rural communities should be informed about the health risks associated with elevated concentrations of PM10. In addition, these communities should be informed about the constraints associated with adopting alternative farming methods for reducing PM10 emissions from agricultural lands.

3.8 Identify sustainable farming practices by considering the economic and social benefits of alternative tillage and cropping practices

Farming systems must be developed that not only reduce PM10 emissions and improve air quality, but that are economically viable for farmers.

4. PROJECT ACCOMPLISHMENTS

Accomplishments of the project over the past decade have been documented through peer-review publications, annual reports, and books or book chapters. Two books have been published under the auspices of the Columbia Plateau Wind Erosion / Air Quality Project, notably "Farming with the wind: Best management practices for controlling wind erosion and air quality on Columbia Plateau croplands" and "Farming with the wind II: Wind erosion and air quality control on the Columbia Plateau and Columbia Basin" (Papendick 1998, 2004). Selected accomplishments according to project objectives are briefly highlighted as follows:

4.1 Baseline data

Soil property databases were created for the Columbia Plateau. These databases included organic carbon, soil particle size, PM10 content, and volcanic glass content of soils. Soil properties were measured across a range of soil types at 150 locations within the Columbia Plateau. The pattern in these soil properties typically varied longitudinally as illustrated in Figure 4. Soils tend to be finer textured, more fertile (higher organic matter), and have a higher content of PM10 on the east side than on the west side of the Columbia Plateau.

Land use databases are required for modeling regional wind erosion processes and for assessing changes in land use associated with adopting new technologies. Remote sensing has been evaluated as a tool to ascertain soil surface conditions across the Columbia Plateau (Kunch et al. 2001). Although the technology has proven successful in distinguishing contrasting surface conditions, further improvements to the technology are required to estimate surface roughness, residue type and cover, and soil wetness (parameters critical in simulating erosion).

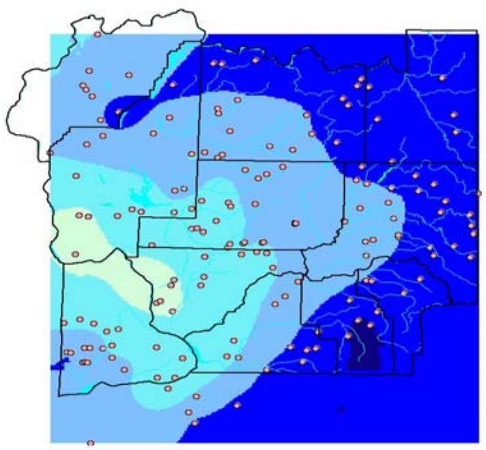

Figure 4. Dispersed PM10 content of soils across the Columbia Plateau domain. PM10 content ranges from 15% in the west (pale green) to 35% in the east (dark blue). Small circles represent soil sampling locations.

4.2 Simulations of wind erosion and PM10 emissions

A wind erosion / PM10 emissions algorithm was developed by Saxton et al. (2000). Soil loss caused by high wind events is empirically determined by:

$$Q = W * SE * e^{(-1.32K)} * e^{(-0.05SC)} * WC \qquad (1)$$

where Q is horizontal soil flux (kg m^{-1}), W is erosive wind energy (g s^{-2}), SE is soil erodibility (kg m^{-1}) (g $s^{-2})^{-1}$, K is surface roughness (cm), SC is surface cover (%), and WC is a soil wetting and crusting factor. The last term in Eq. (1) has not yet been parameterized in the model. PM10 flux is determined according to:

$$F = k * u_f * Q * D * t^{-1} \qquad (2)$$

where F is PM10 flux (g m^{-2} s^{-1}), k is a coefficient (g s) (kg $m^2)^{-1}$, u_f is friction velocity (m s^{-1}), Q is horizontal soil flux, D is the freely suspendible PM10 fraction of the soil (g g^{-1}), and t is time (s). This equation is used in the regional transport scheme for predicting regional PM10 concentrations. The freely suspendible PM10 fraction of the soil is determined by sieving or using a suspension or aspirated chamber (Chandler et al., 2002).

4.3 Emissions inventory

An emissions inventory was recently published by Chandler et al. (2004). The inventory depicts the spatial distribution in potential PM10 emissions based upon soil erodibility and the PM10 content of soil. Soil erodibility decreases across the Plateau from southwest to the northeast while PM10 content of soil increases from west to east (Figure 4). Thus, although soils in the eastern part of the Columbia Plateau have a higher PM10 content, the low soil erodibility creates a low to moderate risk for PM10 emissions in this part of the Plateau. The highest risk for PM10 emissions occurs longitudinally through the center of the Columbia Plateau.

4.4 Regional transport model

A regional transport scheme was developed for predicting regional PM10 concentrations as a result of blowing dust caused by high winds within the Columbia Plateau. The scheme includes using the MM5 model to generate a dense array of surface and upper air meteorological data from which CALMET generates wind and turbulence data on a 4-km grid across the Columbia Plateau domain. The PM10 emissions algorithm, Eqs. (1) and (2), is used to simulate PM10 emissions across the Plateau. Fluxes of PM10 are then used by the CALGRID model to generate temporal and spatial variations in PM10 concentrations across the domain (Figure 5). CALGRID estimates PM10 concentrations by accounting for advection, diffusion, and deposition of PM10. Modeled results have been favorable (Claiborn et al. 1998), although improvements to the PM10 emissions algorithm are needed to provide better predictions of regional PM10 concentrations.

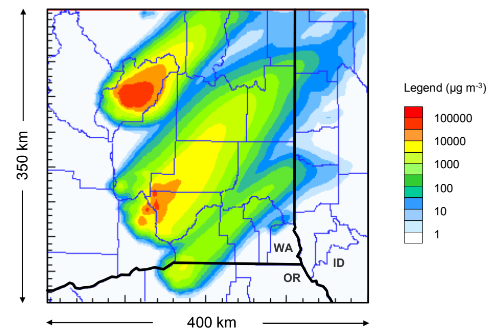

Figure 5. Simulated 24-hour PM10 concentrations across the Columbia Plateau domain on 11 September 1993. The 24-hour PM10 concentration observed at Spokane, Washington was >200 μg m^{-3} and maximum hourly wind speed approached 10 m s^{-1}.

4.5 Alternative tillage and cropping systems

Maintaining roughness or crop residue cover on the soil surface are the two alternatives available to control wind erosion and PM10 emissions from agricultural soils. Horning et al. (1998) reported a soil loss ratio (ratio of soil loss from a treated area to loss from the same area but with a smooth and bare surface) of about 0.2 if the treated area has 25% residue cover or has a random roughness of 3 cm.

Residue cover and roughness can be enhanced through conservation tillage on dryland farms. Schillinger (2001) found that residue biomass at the end of a 13-month fallow period near Lind, Washington could be as much as three times greater for conservation tillage than for conventional tillage. Based upon this data, Papendick (2004) computed a soil loss ratio of about 0.2 for conventional tillage (sweep tillage after harvest to control weeds, chiseling in November, disking in spring, fertilizer injection, and rodweedings during late spring and summer), 0.05 for minimum tillage (chiseling in November, tillage with an undercutter V-sweep implement plus fertilizer injection in spring, and rodweedings during late spring and summer), and 0.04 for delayed minimum tillage (chiseling in November, tillage with an undercutter V-sweep implement plus fertilizer injection in late spring, and rodweedings during summer) averaged over six years. Soil loss can be reduced using minimum tillage and net monetary returns were the same among tillage treatments (Janosky et al. 2002). Thus, the undercutter method of conservation tillage appears to be a sustainable and environmentally sound farming practice for the region.

Annual no till spring cropping (i.e. no summer fallow) in the tradition winter wheat – summer fallow region of the Columbia Plateau has been tested at several sites, but with little success. Although wind erosion can be eliminated by continually maintaining crop residue on the soil surface with no tillage (Thorne et al. 2003), grain yield of annual spring crops is highly variable and presents a high risk to farmers compared to winter wheat – summer fallow. Generally, annual cropping is not yet a profitable system in areas with <300 mm of annual precipitation, especially during drought years (Papendick 2004).

Irrigated cropland in the Columbia Basin is also susceptible to erosion and poses a threat to air quality. The critical period for wind erosion from irrigated cropland is after sowing in the spring and after harvest of low residue crops (potatoes, onions, etc.) in autumn. Cover crops such as cereals and legumes can be sown in the autumn after harvest of vegetable crops that leave little residue on the soil surface. Sufficient growth can be attained with irrigation to provide protection against erosion during late autumn and spring (Papendick 2004). Experiments have been conducted to identify alternative strategies for managing the soil after harvesting high residue crops (corn, wheat, etc.). Since sowing through a large amount of crop residue can be problematic, farmers typically burn or bury residue during the autumn. Modern no-till drills, however, have been developed to sow through large amounts of surface residue and results from a five year cropping systems study indicate that wheat yields are significantly greater using no tillage in a winter wheat-barley-canola rotation than using traditional tillage (burn and plow) in a continuous winter wheat rotation.

4.6 Impact of human activity on PM10 emissions

An understanding of the geologic history of PM10 deposition before and after farming began in the 1880's in the Columbia Plateau will determine whether human activity has affected air quality. Busacca et al. (1998) examined sediment from a lake core sample taken at Fourth of July Lake near Spokane, Washington and found that the sediment flux (atmospheric dust content) has increased four fold in the last 120 years since farming began in the region. Thus, to achieve prefarming atmospheric dust concentrations, farming practices must be identified that will reduce dust emissions.

4.7 Public awareness

The Columbia Plateau Wind Erosion / Air Quality Project has promoted a public awareness of air quality within the Columbia Plateau by disseminating information through 1) on farm testing of alternative management practices to reduce wind erosion and PM10 emissions from agricultural lands. The primary focus of these tests have been on comparing no till annual cropping and intensification of cropping (less frequent fallow) to conventional winter wheat – summer fallow, 2) educational materials including brochures and books. Two landmark publications published by the Columbia Plateau Wind Erosion / Air Quality Project are “Farming with the wind: Best management practices for controlling wind erosion and air quality on Columbia Plateau croplands” (Papendick 1998) and “Farming with the wind II: Wind erosion and air quality control on the Columbia Plateau and Columbia Basin” (Papendick 2004), 3) field days, tours, and growers meetings. These events focus on current research activities and best management practices for minimizing wind erosion and PM10 emissions, and 4) an annual meeting that highlights major research accomplishments over the past year. In addition, presentations are given by local air authorities, state and federal regulatory agencies, and farmers.

4.8 Sustainable management practices

Minimum or delayed minimum tillage has been shown to be as profitable as conventional tillage in the wheat – fallow region of the Columbia Plateau (Janosky et al., 2002). Like conventional tillage, minimum tillage systems create a dust mulch (i.e. a loose, unconsolidated soil layer overlying consolidated soil; this layer has a high resistance to heat and vapor transport) that is important in conserving soil water. Unlike conventional tillage, however, minimum tillage maintains crop residue and roughness on the soil surface to protect against wind erosion (Papendick, 2004).

Sustainable cropping systems, however, are more allusive. In the wheat-fallow region of the Columbia Plateau, winter wheat – summer fallow is more profitable than continuous no till spring cereals or continuous wheat in rotation with other spring crops (Papendick 2004).

5. NEW INITIATIVES

A formal review by the USDA-CSREES in 2004 provided recommendations for new initiatives in research for the Columbia Plateau Wind Erosion / Air Quality Project. Those recommendations included:

- Further developing databases of soil, climatic, topographic, and land use information required as input parameters in wind erosion and air quality models.
- Evaluating the performance of wind erosion models in the Columbia Plateau. The performance of the Wind Erosion Prediction System (WEPS) is of immediate interest since this model will be used by US government regulatory agencies in farm programs.
- The prediction of regional transport hinges upon better estimation of PM10 emissions. Therefore, other PM10 emission algorithms should be tested in the regional transport scheme.
- Determining the importance of turbulence in generating PM10 emissions. PM10 fluxes are estimated from mean wind velocities, but evidence for direct suspension of fine particulates that dominate soils in the Columbia Plateau suggests a more prominent role of turbulence in governing emissions in the region.
- Examining the impact of long term cropping systems on soil chemical, biological, and physical properties and on PM10 emissions.
- Examining the impact of human activities on changes in soil quality.
- Providing more education to farmers through on-farm trials and brochures regarding best management practices that will reduce PM10 emissions.
- Estimating the social costs and benefits associated with adopting best management practices to reduce wind erosion and PM10 emissions.

6. PROJECT INFORMATION

Information about the Columbia Plateau Wind Erosion / Air Quality Project can be obtained from the following website:

http://pnw-winderosion.wsu.edu

The website contains a listing of publications and abstracts since the inception of the project as well as a listing of current research activities. We gratefully acknowledge the current financial support of the project by the USDA CSREES.

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