Empirical Method for Determining Fugitive Dust Emissions from Wind Erosion of Vacant Land:

"The MacDougall Method"

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~ Overview ~

This empirical method for determining fugitive dust emissions from wind erosion of vacant land relies heavily on emission factors developed using wind tunnels. The availability of wind tunnel results for the types of vacant land being assessed must be considered when deciding to use this method for a given application. This methodology primarily relies on results from wind tunnel studies based on the use of portable wind tunnels in a field study setting. When gaps in data occur, results from laboratory wind tunnels may suffice as a surrogate data source. Fugitive dust emissions have three different modes: surface *creep*, *saltation*, and *suspension*. Particles larger than ~1,000 microns that are dislodged by wind and traverse the surface, but do not become airborne are moving by *creep*. Particles becoming airborne by a wind event that return to the surface within a short distance are transported in *saltation*. Particles less than ~30 microns react to air stream turbulence; thereby, causing the particles to travel by *suspension*. Wind tunnel results contain emissions from *saltation* and *suspension*. While both modes transport suspended particulate, only PM_{10} is relevant to this methodology of quantifying emissions.

Step 1: Categorizing Vacant Land

Vacant land within the study area must be categorized based upon the potential of the parcels to emit fugitive dust during wind events. Many wind tunnel studies have been conducted in the western United States, and the vacant land descriptions of the wind tunnel test areas should be used to categorize the vacant land within the study area. Wind tunnel tests conducted with particulate size determinations will be very helpful when preparing PM_{10} and $PM_{2.5}$ emission inventories.

Categorization of land types is perhaps the most critical phase of the methodology, due to the categorization variability in wind tunnel studies and existing land-use data, e.g., county master planning and land-use develop database, BELD3, STATGO, etc. Based on the wind tunnel studies and the land-use data, the number of land-use categories may be to be too detailed due to different study methodologies; therefore, the land-use categories may need to be collapsed into general categories for a more workable quantity. However, when collapsing the categories, one should not collapse beyond the applicability of the wind tunnel categories. Descriptions of land-use types from wind tunnel studies and land-use databases are necessary in developing the land-use categories. The aeolian particulate emissions from the surface are strongly dependent on surface features; therefore, vegetation cover is a primary variable for homogeneous grouping. Vegetation cover is dependent on vegetation concentration and type. Does the land have rocks or other sheltering elements? Additionally, the emissive quality of the land type is dependent on surface roughness soil content.

When soil survey data is not available for the study area other sources of approximation may suffice, e.g., data on geology, topography, vegetation, and climate, together with Land Remote Sensing Satellite (LANDSAT) images. Soils of like areas should be identified, and the probable classification and extent of the soils determined. If the study area is limited, it may be practical to conduct a stratified random sampling.

Is the soil crust intact or disturbed? Are there periodic activities on the vacant land such as vehicles or plowing that will change the land from fairly stable to unstable? It is also important to categorize the vacant land condition based upon the time period of the emission inventory. For example, crop land may be categorized as disturbed soil in a November inventory and as having vegetative cover in a July inventory. Areas with several days of snow cover should also be considered. Vacant land in annual inventories will have to be temporally allocated.

Not every parcel of vacant land will necessarily fit into a category that has been wind tunnel tested. For parcels without a specific vacant land type wind tunnel test, assumptions will need to be made of the best representative land type and uncertainties (e.g., actual emissions likely to be higher) noted. Depending on the ultimate use of the inventory, it might be best to over or under predict the potential a specific land type to emit.

Categorization of land types will be beneficial when determining where focus is needed. There are two key elements that will be of value in making this determination: land-use category percentage of total acreage within the study area and the applicable emission factors. Ultimately, the focus will relate to the volume of the emissions and the duration of the emissions generated within land-use categories.

Step 2: Identify Wind Tunnel Emission Factors

Based upon the vacant land categorization, wind tunnel study results should be reviewed and applied appropriately to each category of vacant land. Emission factor units must be converted to be the same units of measure for the entire inventory. Wind tunnel results should be reviewed to determine if "spikes" from the initial portion of the test are presented separately or averaged into an hourly factor. The spike is a natural element of the physical conditions of vacant land. This method accounts for the spike as follows: 1) Spikes should not be included in an hourly factor and 2) The spike values should be included only at the beginning of each wind event.

Step 3: Develop Meteorological Data Set

For the area to be studied, hourly average wind speeds, rainfall, and if available peak wind gust data should be gathered. If a study area is particularly large, several different meteorological data sets may need to be gathered, and each land parcel matched with the meteorological data that impacts that parcel.

Step 4: Determine Land Type Reservoirs, Threshold Wind Velocities, Wind Events and Rainfall Events

Based upon the wind tunnel study results for each vacant land type, the wind speed when emissions were first measured for the vacant land type, should be set as the threshold wind speed. It should be assumed that no fugitive emissions from wind erosion of the land occurred when wind speeds did not exceed the thresholds.

Most vacant land does not have an endless reservoir of the fugitive dust; however, land that has a high degree of disturbance will continue to emit throughout a wind event. Therefore, for each vacant land type, the wind tunnel results should be reviewed and a determination made on the length of time the parcel will emit for a given wind event. It is recommended that an assumption be made that parcels with sheltering elements, vegetated parcels or parcels with a soil crust will only emit during the first hour of a wind event. Parcels with a relatively high silt component or with frequent disturbance will probably continue to emit through a wind event.

What constitutes a wind event must be defined. Because most threshold wind speeds are relatively high, sustained hourly winds of 25 to 30 mph, a wind event may be defined as any time period when winds reach the threshold wind velocities separated by at least 24 hours before a new wind event is defined. For example, winds reach threshold velocities, slow down and three hours later reach threshold velocities, would be defined as one wind event. Winds reaching threshold velocities, slow down and three days later reach threshold velocities again, would be defined as two wind events.

Depending on the soils in an area, rain may have a large impact on wind erosion. Generally, days with rain should not be included in the inventory. If more than one inch of rain falls and there are colder temperatures and/or cloud cover, several days following a rain event should also not be considered. The soils in the study area should be evaluated for their ability to hold moisture. In the desert southwest only those days where rain actually falls should emissions be set to zero. In the Pacific Northwest, west of the Cascade Mountains, the following two to three days should also not be included in the emissions.

Step 5: Develop Emission Inventory Specific Emission Factors

Using the reservoir determination, threshold wind speeds, wind event determination and rainfall factors, determine hours when wind conditions produced emissions from each vacant land parcel for the time period of the emission inventory. Remember that some parcels may have no emissions during some time periods, one hour reservoirs during some time periods, or emissions throughout an entire wind event during some time periods. Generally, several parcels will have the same wind tunnel emission factor over the same time period. The number of hours wind speeds were in each wind speed category should be totaled. The number of hours can then be multiplied by the wind tunnel emission factor and a total emission factor the time period of the inventory can be calculated.

For example, for disturbed vacant land in the desert, sustained hourly winds exceeded 25 mph (the threshold wind velocity) 31 hours during one year, exceeded 30 mph for 9 hours and exceeded 35 mph for 1 hour. The wind tunnel hourly emission factors for the land type are 1 pound/hour/acre at 25 mph, 2 pounds/hour/acre at 30 mph and 3 pounds/hour/acre at 35 mph. For each new wind event exceeding the threshold wind velocity, total the hours exceeding the threshold wind velocity, except hours during and after rain. The resultant hourly emission factor for the year for each acre of disturbed desert land was 52 (based on (31 x 1) + (9 x 2) + (1 x 3)) pounds per acre, which is based on the following formula:

$$EF_1 = (\sum (H_S \times P_S))$$

EF_1 - Hourly Emission Factor
H - Hours
P - Pounds/Hour/Acre by Land Type
S - Land Type Wind Event Subset

Continuing the example, wind events beginning at 25+ mph occurred 4 times during the year, wind events beginning at 30+ mph occurred 3 times during the year, and wind events beginning at 35+ mph occurred 1 time during the year. Generally, the spike occurs during the first two minutes of a wind tunnel run and the spike and is higher than the remainder of the run by a factor of three. Therefore, wind tunnel spike emission factors for the land type are 0.10 pound/hour/acre at 25 mph, 0.20 pounds/hour/acre at 30 mph and 0.30 pounds/hour/acre at 35 mph. (Each of the hourly emission factors is multiplied by 3 and converted to an hourly rate (2/60 = 0.03333).) The resultant spike emission factor for the year for each acre of disturbed desert land was 1.30 (based on (4 x 0.10) + (3 x 0.20) + (1 x 0.30)) pounds per acre, which is based on the following formula:

$$EF_2 = (\sum (E_S \times P_S))$$

EF_2 - Spike Emission Factor
E - Events
P - Pounds/Hour/Acre by Land Type
S - Land Type Wind Event Subset

Using the same time period, stable parcel with a limited reservoir emitting only the first hour of a wind event would have a much lower emission factor. If sustained winds exceeded 25 mph on 12 days, exceeded 30 mph for 4 days and exceeded 35 mph for one day, and the emission factors from the wind tunnel study were the same (usually they are considerably lower), the resultant emission factor for the year for each acre of stable vacant land would be 23 pounds per acre.

Emission factors will vary from time period to time period and from vacant land type to vacant land type. Generally speaking, disturbed lands will have unlimited reservoirs and lower threshold wind velocities leading to much higher emissions that stable or sheltered parcels with one hour reservoirs. An emission factor should be developed for each vacant land category in the inventory.

Step 6: Apply Emission Inventory Specific Emission Factors to Vacant Land Categories

Once emission inventory emission factors have been developed, the number of acres in each category should be multiplied by the factor and the emissions totaled. It may be useful to develop and apply certain factors over shorter time periods and then total the emissions over a longer time period. For example, develop winter factors and summer factors and then total them together for the annual inventory. Annual emissions are calculated as follows:

$$E = A(EF_1 + EF_2)$$

E	-	Annual Emissions
A	-	Parcel Acreage
EF_1	-	Hourly Emission Factor
EF_2	-	Spike Emission Factor

For larger areas, where vacant land categories will change over the duration of an inventory or different meteorological data sets will apply, it is advisable to subdivide the inventory by time period or area, and then total the inventory at the end.

Available Wind Tunnel Data

Several wind tunnel studies have been completed and published:

1. Columbia Plateau PM_{10} Project: Wind Tunnel Calibrations of Continuous Particulate Samplers

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Dr. Brian Lamb
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2. Simultaneous Wind Erosion and PM_{10} Fluxes

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3. Wind Erosion and Air Quality Research in the Norwest U.S. Columbia Plateau: Organization and Progress

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4. Developments in Measurement and Models for Suspension-Dominated Wind Erosion

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5. Simulation and Analysis of the Factors Leading to High PM_{10} Emission Fluxes at the Owens Dry Lake Bed Using an Environmental Wind Tunnel

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6. Field Testing of Dust Suppressants Using a Portable Wind Tunnel

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7. Development of Soil Wind Erodibility Test Methods

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8. Assessment of Wind Erosion Parameters Using Wind Tunnels

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9. Soil Aggregate and Texture Effects on Suspension Components from Wind Erosion

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10. PM_{10} Emission Factors for Owens Lake Based on Portable Wind Tunnel Tests From 1993 Through 1995

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157 Short Street
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11. Comparison of On-and Off-Lake PM_{10} Dust Emissions at Owens Lake, CA

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157 Short Street
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12. Development of Predictive Formula for PM_{10} Emission Rate as a Function of Vegetation Cover

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13. A Wind Tunnel Study of Atmospheric Boundary-Layer Flow Over Vegetated Surfaces to Suppress PM_{10} Emission On Owens (Dry) Lake

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