A GIS-Based Methodology to Estimate Annual Valley-wide
PM-10 Emissions for Clark County, Nevada

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ABSTRACT
Clark County, Nevada is currently classified by United States Environmental Protection Agency (U.S. EPA) as a non-attainment area for airborne particulate matter with an aerodynamic diameter of less than 10 microns (PM-10). Responsible agencies in the region are working to identify methods and strategies to bring the region into attainment of the PM-10 standards. It is extremely important to estimate annual valley wide PM-10 emissions and identify the zones with high emissions in order to implement such a strategy. This paper presents a Geographic Information Systems (GIS) based methodology to estimate annual valley wide PM-10 emissions using Clark County as a case study. The estimates depend on the extent of disturbed and undisturbed vacant land area, emission factors by soil group, and wind speeds for the 1999 design year. A database is developed consisting vacant land area, disturbed land area and undisturbed land area of each book and section. Wind tunnel field tests are conducted to estimate emissions at 78 sites. Wind tunnel results are categorized by wind speed range and corresponding site soil group in order to estimate emission factors by soil group and the wind speed range. Wind speed data collected at air quality monitoring stations are obtained from the Clark County Health District. It is assumed that wind speeds near each monitoring station are the same as at the station. The proximal area over which the wind speeds are same is obtained by constructing Thiessen polygons around each wind speed monitoring station using "thiessen" command at "arc" prompt in Arc/Info. Wind speed data and emission factor data at each wind tunnel site are combined using an Arc Macro Language (AML) program to estimate valley-wide PM-10 emissions, identify zones with high emissions, and explore the ability of Arc/Info to carry out such computations.

INTRODUCTION
        Health problems arising from particulate air pollution effects on breathing and respiratory systems are an issue of concern in not only urban areas but also in rural areas in United States. Several airsheds are currently classified by United States Environmental Protection Agency (U.S. EPA) as a

non-attainment area for airborne particulate matter with an aerodynamic diameter of less than 10 microns (PM-10). Non-attainment areas are identified based on standards set by the Clean Air Act Amendments of 1990. As per the standard, areas with an average yearly rate of 50 micrograms per cubic meter and an average 24 hour rate of 150 micrograms per cubic meter are considered as non-attainment areas (U.S. EPA 1994). In the western United States, PM-10 emissions are mainly from natural and miscellaneous sources such as fugitive dust (unpaved and paved roads), agricultural and forestry activities, wind erosion, wildfires, and managed burning. Potential solutions to mitigate these emissions include controlling emissions from construction sites by consolidating building and grading permits, implementing dust control plans, inspection of construction vehicles and issuing separate trenching permits, road paving, limiting use of unpaved haul roads and parking areas, control emissions from paved roads by cleaning streets and shoulder stabilization, and increased use of alternate fuel vehicles and reformulated fuels.

Clark County, Nevada, which includes Las Vegas, is currently classified as a non-attainment area by U.S. EPA. A significant portion of PM10 emissions are windborne emissions from vacant lands. Responsible agencies are working to establish methods and schedules to mitigate the air pollution problem. Clark County is required to conduct an Emissions Inventory of all sources of PM-10, including estimates of annual area wide PM-10 emissions from wind erosion. A State Implementation Plan (SIP) must be created to describe how PM-10 will be reduced. The SIP should identify the zones and appropriate causes of high emissions in order to implement necessary control measures.

This paper presents a Geographic Information Systems (GIS) based methodology to estimate wind-eroded PM-10 emissions by soil group of the study area using the 1999 design year for Clark County as a case study. The soil group could either be based on the soil properties and composition or on the wind erodibility factor. The PM-10 estimates depend on the extent of disturbed vacant land in the vacant land inventory, wind tunnel field data by soil group and wind speeds.

GIS-BASED METHODOLOGY
The proposed methodology explores the capabilities afforded by GIS in order to estimate PM-10 emissions for the study area. The methodology is discussed using Clark County, Nevada as the study area. It includes the following steps.
1) Create study area coverage,
2) Generate soil coverage,
3) Create wind speed monitoring station's coverage and their proximity,
4) Identify book, section, vacant area, soil type based on soil properties and composition and wind erodibility group (WEG) based on the wind erodibility factor of each polygon,
5) Identify soil type and WEG of each wind tunnel location,
6) Estimation of Emission Factors by Soil Group, and
7) Estimate PM-10 emissions.

Step 1: Create Study Area Coverage
The study area includes only the area within the US Bureau of Land Management's Land Disposal Boundary in Clark County, Nevada. GIS coverage is created by identifying all "books" and "sections" within the land disposal boundary. One book number corresponds to a specific township and range and there are 36 sections in each "book", each section approximately covering 1 square mile. The database containing vacant land area, disturbed land area and undisturbed land area of each "book" and "section" was collected on 11/29/1999 from the Clark County Health District. The data may vary from day-to-day based on request from parcel owners. However, for simplicity, it is assumed that the total vacant land area, disturbed land area and undisturbed land area of each "book" and "section" is constant during all the days in 1999. The database is converted from Microsoft Access® format to an Info file and then joined with the polygon attribute table of the study area to generate a new polygon attribute

table which includes data pertaining to vacant land area, disturbed vacant land area and undisturbed vacant land area of each book and section

Step 2: Create Soil Coverage

The soil coverage is generated based on the data downloaded from the National Soil Survey Geographic (SURGO) Database maintained by the United States Department of Agriculture (USDA 1995) Natural Resources Conservation Service (NRCS) Soil Survey Division. The soil coverage is generated using the downloaded spatial data and attribute data pertaining to map unit soil symbol, detailed soil composition and its area, and, the WEG. Soil composition of each polygon is expressed in terms of the name of composition, percent of composition and area of composition within the polygon. The WEG is based on the major soil composition of the top soil layer in the polygon. A program is written using Arc Macro Language (AML) to generate the coverage with soil composition and WEG. The major (three-digit) soil type of each polygon is established based on the percentage soil composition.

Step 3: Create Wind Speed Monitoring Station Coverage and Their Proximity

The wind speed monitoring stations as point coverage is created using the air quality monitoring station location data obtained from the Clark County Health District (CCHD). Hourly average wind speed data for the design year 1999 collected at each of these air quality monitoring stations was obtained from CCHD. It is assumed that the wind speed data collected at a station is the same over an area surrounding the location of the station. The proximal area over which the wind speeds are same is obtained by constructing "Thiessen polygons" around each wind speed monitoring station. Each wind speed monitoring station is within a polygon and wind speed at any point within this polygon is assumed to be the same as that observed at this station.

Step 4: Identify Book, Section, Vacant Area, Major Soil type and WEG of Each Polygon

The study area coverage created in Step 1 is overlaid on the Thiessen polygon coverage created from the wind speed monitoring stations point coverage using the "identity" feature in Arc/Info to find "book", "section" and vacant area of each polygon belonging to each wind speed monitoring station. The soil coverage created in Step 2 is overlaid on the resulting coverage to generate a new coverage. The polygon attribute table of the new coverage contains data pertaining to "book", "section", vacant land area, disturbed vacant land area, undisturbed vacant land area, major soil type and WEG of each polygon belonging to each wind speed monitoring station. This data is written to an output file.

Using the vacant land area, disturbed vacant land area and undisturbed vacant land area obtained above could lead to erroneous estimates of PM-10 emissions. This is because the vacant land area, disturbed land area, and undisturbed land area are attributes available in the "info" tables but are not adjusted to each polygon obtained due to the overlay. For example, consider a polygon in the proximity of wind speed monitoring station 1 whose area is 100 acres (Figure 1). When the study coverage and soil coverage are overlaid on this polygon, the 100 acre polygon is divided into several small polygons (Figure 1). Each small polygon has its area, data from the study coverage such as book, section, vacant land area, etc. and data from the soil coverage such as major soil type, WEG, etc. Since, tabulated data are copied to the new table, it might so happen that two small polygons could have exactly the same "book", "section", and vacant land area. However, the entire vacant land area in a particular section could fall in any one of the small polygons, or may have been distributed amongst polygons if it is on a boundary. It is hard to quantify the proportion of vacant land area shared by small polygons. To solve this problem, a program was written in the C programming language to approximately adjust the vacant land area, disturbed vacant land area and undisturbed vacant land area among the small polygons with common "book" and "section" number in proportion to their areas. This avoids duplication and over-estimation of vacant lands area, hence, PM-10 emissions.

Step 5: Identify Soil Type and WEG of Each Wind Tunnel Location

GIS coverage with locations of all wind tunnel sites is created using the geometric coordinates of each location. The soil coverage is then overlaid on the wind tunnel coverage using the "identity" command at "arc" prompt in Arc/Info to generate a new coverage. The resulting point coverage attribute table consists of data pertaining to major soil type, soil type name and WEG of each wind tunnel location. This data is written to an output file. Each location is assigned a general soil type that ranges from 1 to 9 based on its major (three-digit) soil type. These are based on the study conducted by Speck and Mckay (1985) for the Las Vegas area.

PM-10 estimates can be calculated either using the general soil type or the WEG. The main drawback of estimating PM-10 emissions based on general soil type properties is that one has to manually assign or write a code to identify the general soil type based on the major (three-digit) soil type. These are not pre-established values based on soil survey. Aside from this, emissions are mainly due to wind erosion. Hence, it is opined that using emission factors based on WEG would yield realistic results rather than the general soil type. In general, there are 10 WEGs which range from 1 to 9 and 4L. However, results obtained from using both soil type and WEG are presented in this paper.

Step 6: Estimation of Emission Factors by Soil Group

The steady-state flux and spike emissions of each soil group by wind speed range are estimated using data collected at wind tunnel locations. Spike emissions represent high initial emissions rates observed in the first 1 to 2 minutes of a wind tunnel test run, followed by lower, steady-state emissions for the rest of the run. Spike data were separated from steady state data to avoid overestimating emissions when using 10 minute wind tunnel runs to estimate total emissions for wind erosion events of durations exceeding 10 minutes. The estimates are geometric means of the samples collected. The data collected are broken down into two categories, 1) collected at a wind tunnel location established in a disturbed (unstable) area, and, 2) collected at a wind tunnel location established in an undisturbed (stable) area.

Data collected in disturbed areas are categorized based on the soil group of the location and the wind speed at the time of data collection. The steady state fluxes in disturbed areas for each soil group are the geometric sum of all the flux emissions in a wind speed range collected at the same soil group divided by the total number of samples collected in disturbed areas in the given wind speed range. The spike emissions in disturbed areas are the geometric sums of all the spike emissions in a wind speed range collected at the same soil group divided by the total number of samples collected in disturbed areas in the given wind speed range. Data collected in undisturbed areas are categorized based on the soil group of the location and wind speed at the time of data collection. Flux and spike emissions in undisturbed areas are calculated as discussed previously.

The geometric means are calculated only if the number of samples in any soil group and wind speed range category is at least 2. If the number of samples collected in disturbed areas (or undisturbed areas) by soil group is less than 2, then the geometric means of flux and spike emissions in disturbed areas (or undisturbed areas) are calculated based on the number of samples in the wind speed range. Spike emissions are calculated using a similar procedure. A program is written in C programming language to estimate these emissions.

Step 7: Estimate PM-10 Emissions

The data obtained is used along with wind speed data collected in the year 1999 to estimate PM-10 emissions. Estimating PM-10 emissions include the following sub-steps.
1. Identify the soil group of each polygon in the study area.
2. Consider wind speed data in year 1999 at wind speed monitoring station 1.
3. Identify all polygons with the soil group, disturbed vacant land area and undisturbed vacant land area, which fall in the proximity of wind speed monitoring station 1.

4. Select criterion for the minimum wind speed limit, v, (say, 20 mph) above which erosion and emissions occur, and identify all hours at which wind speed is greater than v mph.
5. Consider hour 1 at which wind speed is greater than v mph.
   - Multiply the _disturbed_ area of each polygon with the flux emission factor of the corresponding soil group. Similarly, multiply the _undisturbed_ area of each polygon with the flux emission factor of the corresponding soil group.
   - Multiply the _disturbed_ area of each polygon with the spike emission factor of the corresponding soil group. Similarly, multiply the _undisturbed_ area of each polygon with the spike emission factor of the corresponding soil group.
6. Consider hour 2 at which wind speed is greater than v mph,
   - Multiply the _disturbed_ area of each polygon with the flux emission factor of the corresponding soil group. Similarly, multiply the _undisturbed_ area of each polygon with the flux emission factor of the corresponding soil group.
   - If the time difference between the previously estimated spike emissions and this hour is _greater than_ 24 hours, then multiply the disturbed area of each polygon with the spike emission factor of the corresponding soil group, and, multiply the undisturbed area of each polygon with the spike emission factor of the corresponding soil group. (The soil is assumed to regenerate the loose material that contributes to a spike if there is a resting period greater than 24 hours.)
   - If the time difference between the previously estimated spike emissions and hour 2 is _less than_ 24 hours, then do not use the spike emissions factor. (The soil is assumed to be depleted of the loose material that generated the spike, and the depletion does not sufficiently regenerate in 24 hours for the spike to occur)
7. Repeat Step 6 for all remaining hours at which wind speed is greater than v mph in chronological order.
8. Repeat steps 2 to 7 for all wind speed monitoring stations.
9. Sum all the flux and spike emissions for all wind speed monitoring stations in disturbed and undisturbed land areas to obtain the PM-10 emissions of the study area.

RESULTS

As stated previously, the Bureau of Land Management Land Disposal Boundary within the Las Vegas valley is considered as the study area. The locations of wind tunnel sites to collect emission samples are shown in Figure 2. Table 1 shows sample PM10 emission factors estimated from samples collected at sites located in Glencarb soil. The minimum wind speed limit, v, to estimate emission factors is established equal to 20 mph. The vacant land area, disturbed vacant land area and undisturbed vacant land area are also set as variables in the model. Table 2 shows WEG, disturbed vacant land area, undisturbed vacant land area, total vacant land area of a few sample polygons located in the study area. The model allows the end user to test various scenarios. In this paper, three different scenarios are tested. They are 80 percent of vacant land area is undisturbed (stable), 86 percent of vacant land area is undisturbed (stable) and 90 percent of vacant land area is undisturbed (stable).

Results obtained for three different cases are presented. Table 2 shows PM10 estimates considering 86 percent of vacant land area is undisturbed in a few sample polygons located in the study area. Figure 3 shows PM-10 emissions by WEG and general soil type for each of the three cases. Estimates show that values obtained from using WEG as the criteria are generally higher than those obtained from using general soil type as the criteria. Further investigation would be warranted to conclude which one is close to real world data. As expected, the PM-10 estimates per year in the valley increase as the disturbed vacant land area increases.

Figure 4 shows a GIS map of the study area divided into small polygons and classified based on annual PM-10 estimates based on WEG considering that 86 percent of the vacant land area is undisturbed. This map helps identify zones with high emissions so that appropriate control measures could be first implemented in high emission areas.

CONCLUSIONS

Potential health hazards affecting breathing and respiratory systems due to air pollution resulting from particulate matter of size less than 10 microns could be reduced by establishing methods and strategies to control PM-10 emissions. Accurate area-wide PM-10 estimates identifying zones and causes of high emissions are essential to implement the mitigation strategies. This paper presents a GIS-based methodology to estimate annual area-wide PM-10 emissions based on general soil type or wind erodibility group (WEG) of the land area. The estimates based on the extent of disturbed vacant land in the vacant land inventory, wind tunnel field data by soil group and wind speeds. Results obtained by changing the percent of disturbed vacant land area/undisturbed vacant land are presented. The GIS-based methodology not only has the potential to estimate PM-10 emissions but also identify zones with high emission to implement control measures.

REFERENCES

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KEYWORDS
PM10
Emissions
GIS

| Wind Speed Range	Disturbed Soils		Undisturbed Soils	
	Flux Emissions ton/acre/hr	Spike Emissions ton/acre	Flux Emissions ton/acre/hour	Spike Emissions ton/acre
0 – 10	0.011	0.002	0.007	0.001
10 –15	0.011	0.002	0.007	0.001
15 – 20	0.001	0.002	0.002	0.000
20 –25	0.009	0.003	0.001	0.002
25 – 30	0.008	0.001	0.003	0.001
30 – 35	0.008	0.002	0.004	0.001
35 – 40	0.006	0.002	0.004	0.001
40 – 45	0.014	0.002	0.008	0.002
45 – 50	0.020	0.005	0.008	0.002
50 – 55	0.016	0.003	0.008	0.002
55 – 60	0..08	0.003	0.008	0.002
60 – 65	0.011	0.002	0.008	0.002
65 – 70	0.011	0.002	0.008	0.002
>= 70	0.011	0.002	0.008	0.002

Table 1 Sample table showing emission factors estimated from sites in Glencarb soil (WEG 1).
Units are in US customary units (1 ton = 2000 pounds; 1 acre = 43,560 square feet)

| Polygon #	WEG	Disturbed Vacant Land Area (acres)	Undisturbed Vacant Land Area (acres)	Total Vacant Land Area (acres)	PM10 Emissions (tons/year)
1	9	92	357	449	1
2	4	77	394	471	1
3	3	9	269	278	1
4	5	76	322	398	38
5	5	21	136	157	26

Table 2 Characteristics of a few sample polygons and estimated PM10 emissions in each polygon for the 1999 design year.
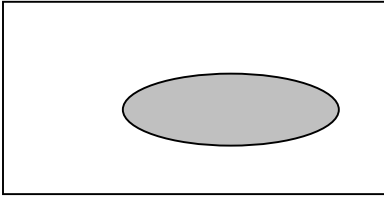
(a) Vacant land area (shaded) in the proximity of wind speed monitoring station 1
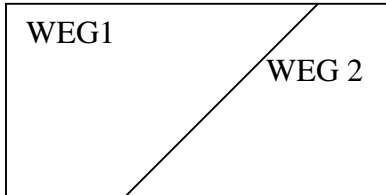
(b) Soil coverage
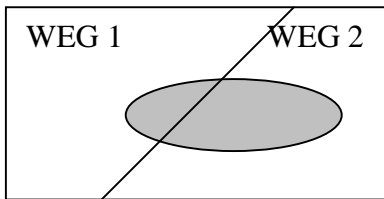
(c) Overlay soil coverage over the wind speed monitoring stations and their proximity

Figure 1. Proximity of a wind speed monitoring station, soil coverage and distribution of vacant land area.
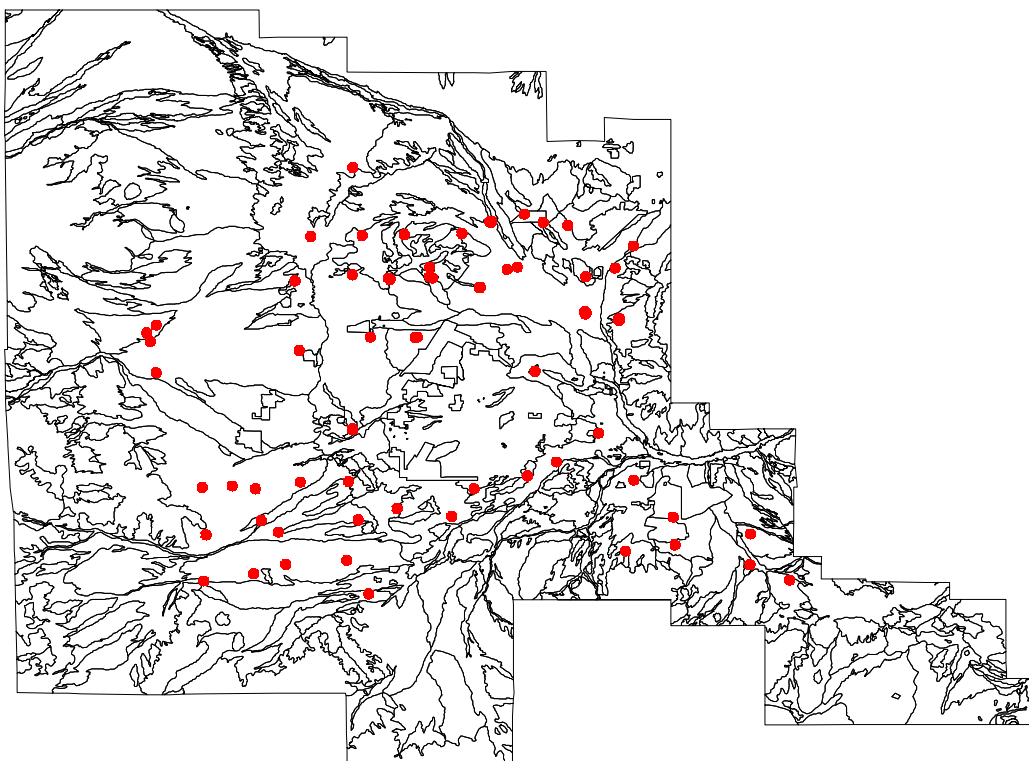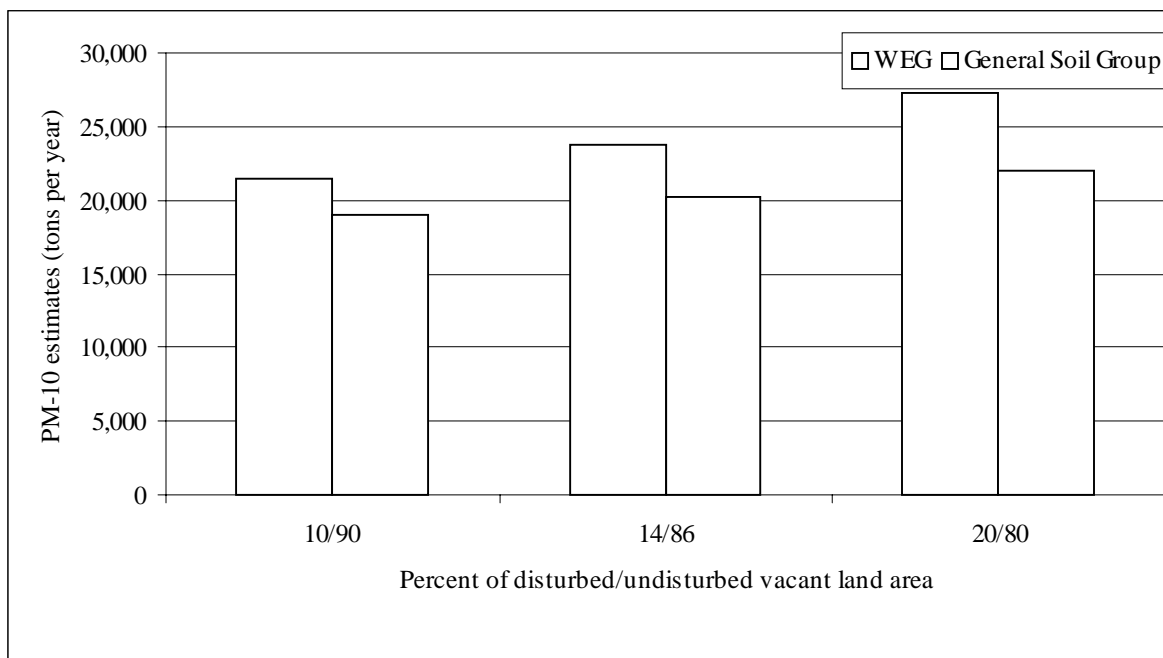
Figure 2. Wind tunnel sites in the study area.

Figure 3. PM-10 estimates by percent of disturbed vacant land area for Clark County, Nevada.

PM10 Estimates by WEG
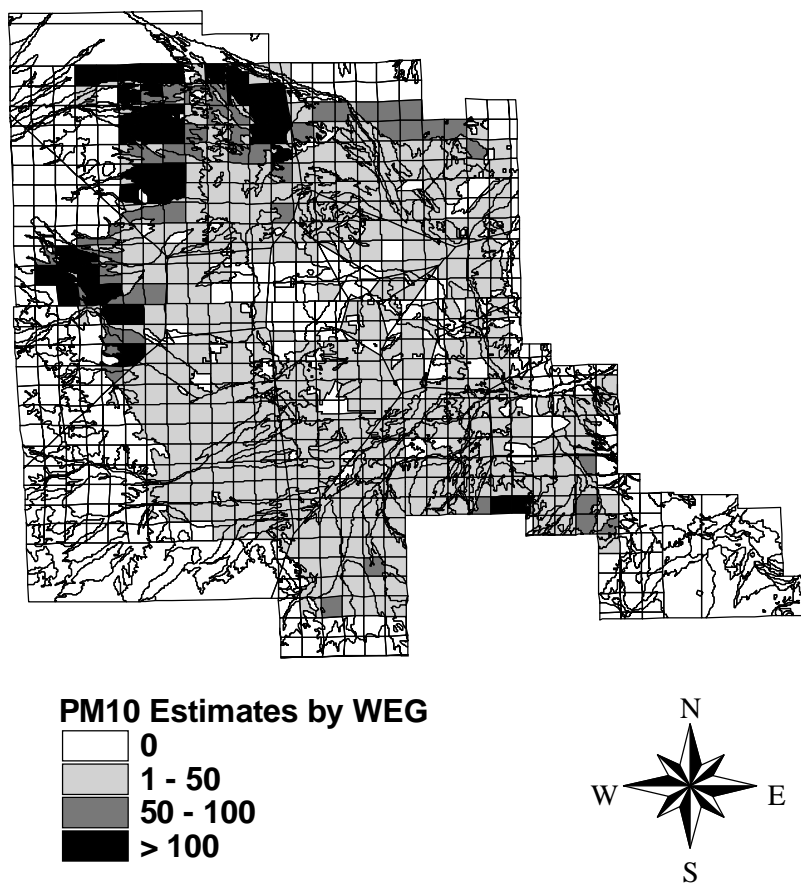- 0
- 1 - 50
- 50 - 100
- > 100

 Figure 4. Map depicting estimated PM-10 emissions (23,763 tons) for the 1999 design year, estimated based on WEG and assuming 86% stable (undisturbed) land Individual grid cells shaded with 1999 estimated emissions in tons.