ARIZONA DEPARTMENT OF ENVIRONMENTAL QUALITY

MEMORANDUM

AQD: AAS:EVAL:PGH:061-4-5-2001

TO: Mike George, Manager, Assessment Section

FROM: Peter Hyde

RE: Air quality modeling protocol for elevated particulates concentrations in Tucson in 1999

DATE: June 4, 2001

Preface

This final version of the modeling protocol for elevated particulates in Tucson – part of the Tucson Natural Events Action Plan – incorporates comments received by the Department in May and June 2001 into the May 2, 2001, draft protocol. These comments concern dust emissions from construction and sand and gravel sources. The last item in the section about the emissions inventory (page 7) addresses these comments. In addition, a minor change in the method of modeling is described in the last paragraph of the document (page 9).

Summary

Exceedances of the PM_{10} standard in 1999 in Tucson will be analyzed by building definitive, near-field emission inventories around the monitors and by estimating the concentrations from these inventories with an air quality dispersion model. This modeling will determine the contribution of each of several major source categories to the elevated PM_{10} concentration, thereby providing the necessary information for carrying out Best Available Control Measures (BACM) on these sources.

Introduction

Six exceedances of the 24-hour standard of 150 $\mu g/m^3$ for particulates 10 microns and smaller (PM_{10}) occurred in Tucson in 1999. Two sites, Orange Grove and South Tucson, and four different dates were involved. These elevated concentrations ranged from 165 to 235 $\mu g/m^3$ and were all associated with high winds. The Pima County Department of Environmental Quality petitioned the Arizona Department of Environmental Quality in June 2000 (PCDEQ, 2000), to consider the elevated concentrations as exceptional and natural events. The Department evaluated the request and determined that

(1) all four exceedance days showed the influence of unusually high winds and met the U. S. Environmental Protection Agency's criteria set forth in their 1996 Natural Events Policy, and

(2) two of the four exceedance days met all the State criteria for an exceptional event (Schafer, 2000).

The Department's natural event policy (ADEQ, 2000) then requires that the anthropogenic sources that contributed to the exceedances be quantified through air quality modeling. These various sources of dust on these high wind days will then be subjected to PM_{10} BACM. The adoption of these measures will ensure that the emissions from all the contributing controllable sources will be reduced to a minimum, with the result that on future high wind days the PM_{10} standard will still be achieved.

Because of the regulatory implications of BACM, which would entail considerable additional effort and cost to reduce dust emissions, the actual causes of the exceedances need to be clearly determined and all the contributing controllable sources identified. This work is to be done by the construction of a definitive emissions inventory and the application of a suitable air quality model. The description of how this inventory is to be constructed and how the modeling is to be performed is the subject of this modeling protocol.

General considerations of elevated PM_{10} concentrations

Before describing the modeling protocol, a few remarks on the general nature of elevated PM_{10} concentrations are in order. Of paramount importance in understanding elevated PM_{10} concentrations in urban areas is that most of the dust is generally not transported from outlying desert areas into the city; rather, it is generated within the urban area. This dust generation is a consequence of the multitude of freshly disturbed land surfaces -- unpaved roads and alleys, recently graded lots, riverbeds, unpaved parking lots, and so forth -- acted upon by vehicular traffic or construction equipment, as well as by the occasional high winds. The long-term monitoring record in Arizona shows that elevated PM_{10} concentrations are limited to the urban areas, and that these elevated urban concentrations range from 1.5 to 7.0 times the value of the background concentration. The most recent three years of data are presented in Figure 1 and Table 1 for selected urban and background sites. Table 2 lists the PM_{10} exceedances in Tucson in 1999.

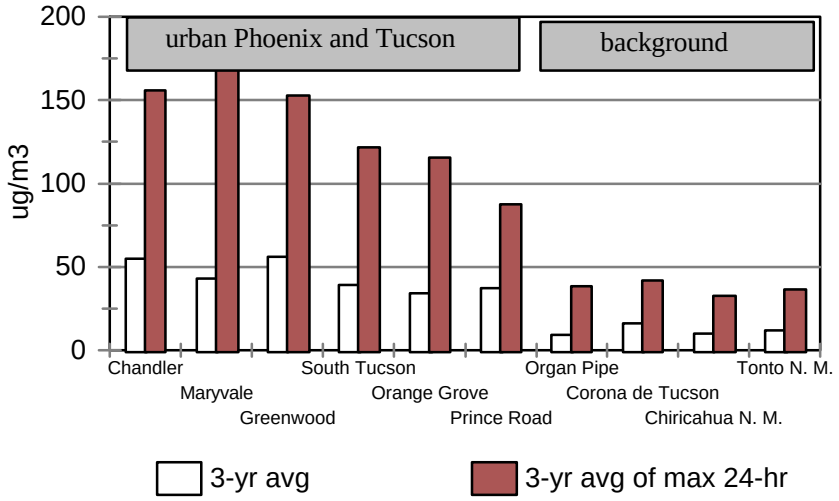

Figure 1. Urban versus background PM_{10} concentrations

Table 1. PM_{10} concentrations in urban and rural Arizona for 1997-99

(Units are µg/m^3)

annual average		maximum 24-hour average			
location	3-yr avg	1997	1998	1999	3-yr avg
Phoenix					
Chandler	55	221	136	110	156
Maryvale	43	345	92	104	180
Greenwood	56	220	121	117	153
Tucson					
South Tucson	39	72	79	214	122
Orange Grove	34	68	44	235	116
Prince Road	37	62	83	118	88
Background					
Organ Pipe	9	75	22	18	38
Corona de Tucson	16	34	41	51	42
Chiricahua N. M.	10	35	35	28	33
Tonto N. M.	12	42	31	36	36

Table 2. Tucson PM_{10} exceedances in 1999 of the 24-hour average standard of 150 µg/m^3

(Units are µg/m^3)

date	South Tucson	Orange Grove
3-7-99	207	169
10-20-99		176
12-3-99	214	235
12-23-99		165

Another example of this division between urban and background PM_{10} concentrations is illustrated by a Las Vegas study, in which PM_{10} was monitored near an urban construction site and at a background desert site. Hourly concentrations were examined in terms of the frequency distribution of the wind speeds. The urban construction concentrations ranged from 60 to 70 µg/m^3 for wind speeds less than 14 miles per hour, in contrast to the desert background concentrations of about 15 - 20 µg/m^3. Under higher wind speeds, however, the urban concentrations increase from 90 to over 400 µg/m^3, again in contrast to the desert background site, whose concentrations increased to a maximum of 75 µg/m^3. This highest PM_{10} background concentration occurred only at wind speeds in excess of 22 miles per hour (Watson and Chow, 1999).

Other studies and data could be cited, but they would merely reinforce the point; namely, that elevated PM_{10} concentrations in urban areas, even under high winds, arise primarily from local urban emissions. Ambient background concentrations are always present, of course, and will be accounted for in this modeling analysis. These background concentrations comprise a small fraction of the elevated urban concentrations. For the case of the December 3, 1999, elevated PM_{10} concentrations in Tucson, the salient point is that both the elevated concentrations and their casual emissions were both decidedly local.

Modeling protocol

Dates selected for modeling

Since exceedances were recorded on four different dates, all four dates could be treated with an air quality dispersion model and the contributing sources to the elevated concentrations determined. The four dates had much in common: dry and windy conditions with afternoon gusts from 29 to 56 miles per hour. Three dates had maximum gusts from 29 to 36 miles per hour, but the fourth, December 3, 1999, had the highest gusts of 56 miles per hour. Given the similar conditions on all four dates, a modeling exercise to determine source contributions on any one of

the four would be sufficient. Since, in air quality modeling one generally examines the worst case conditions, and because both wind gusts and PM10 concentrations were highest on December 3, 1999, the Department has decided to limit its numerical modeling to this date.

Emissions inventory

As discussed previously, elevated PM_{10} concentrations in high winds are generally caused by nearby rather than regional dust emissions. With high winds throughout an airshed, dust is suspended into the turbulent surface winds wherever erosional losses to the surface occur and wherever earth-moving and other dust producing activities are taking place. At any particular point within the airshed, the PM_{10} concentration is the sum of three components: the localized or near-field emissions, the urban foreground, and the ambient background. The ambient background is that concentration of PM_{10} that prevails across the Sonoran Desert in the absence of any urban activity. The urban foreground component results from the entire upwind airshed's emissions, but is reduced by the propensity of surface-base emissions of PM_{10} to fall back to the surface rather quickly, thus avoiding long transport times. The near-field component of concentration, on the other hand, can be related to the close-in, upwind emissions from erosional and activity-produced dust. Although these PM_{10} particles have the same deposition velocities as those in the urban foreground, their proximity to the point of monitoring ensures that they reach the sampler and contribute more heavily to the concentration. Because the total concentration is dominated by the near-field component, the emissions inventory that will go into the air quality model need not extend too far from the monitor. For the modeling of the December 3, 1999, elevated PM_{10} concentrations, the emissions inventory is a square 2.4 kilometers on a side with the monitor at the center.

This size is a compromise between building an emissions inventory for the entire urban area or for a much smaller area, for example, one kilometer squares. Constructing an inventory for all of urbanized Tucson would be a massive project well beyond the scope of work of this air quality modeling. The emissions inventory employed in this work is between 1.2 and 1.7 kilometers from the monitor (the former distance is directly from the monitor to the edge of the square; the latter, to the corner of the square along a hypotenuse). This area provides a sufficient mix of potential sources placed close enough to the monitor such that their suspended emissions are readily transportable to the monitor. PM_{10} particles, if entrained by turbulent winds upward to the atmospheric mixing height, have residence times of about a day. Light scattering and light extinction data from December 3, 1999, show that elevated PM_{10} concentrations were limited to 10:00 a.m. to 5:00 p.m. This implied shorter residence time results from the surface-based emission areas, whose suspended particles remain airborne for much shorter times. An inventory that encompasses a diversity of sources but is limited in extent to capture the transportable particulates suffices for the source attribution work of this project.

For both the South Tucson (ST) and Orange Grove (OG) monitors, these 2.4x2.4 kilometer inventories will be produced. Each square is divided into 36 smaller squares 400 meters on a side, and all pertinent emission details will be determined for each 400x400 meter square. This gridded

emissions inventory will be built in the following steps:

(1) Satellite photographs of the respective ST and OG regions will be obtained and divided into 36 individual maps representing the 400x400 meter squares.

(2) Pima County staff will take the maps into the field and verify all the pertinent land use features that could figure into the inventory, writing notes on the maps to indicate the presence or absence of all potential emission sources. These sources will be divided into the following categories:

- roads: primary, secondary, and unpaved
- parking lots: paved and unpaved
- construction: buildings, roads, surface mining, miscellaneous
- cleared land: agricultural and other.

(3) Information from the annotated maps will be coded in electronic format, with the following data entered for each 400x400 meter square:

- the percentage of land in each of the categories given in section 2, and

- the average daily vehicle count and diurnal distribution for each roadway.

(4) Emission inventory totals will be calculated on an hourly basis and totaled by category for the 24-hour period. These calculations involve selecting the appropriate emission factors, entering representative hourly wind speeds, and running a preprocessor called GRIDTEST8 (ADEQ, 2001). The emission factors will be either the standard AP-42 (U. S. Environmental Protection Agency Handbook of Air Pollutant Emission Factors) or more recently determined factors from California and elsewhere (Watson and Chow, 1999). Wind directions and speeds will be taken from the nearest representative sites. The preprocessor program calculates the hourly emissions by grid for all the source categories, and includes wind-generated emissions for those hours with winds greater than the threshold value of 15 miles per hour. The emissions are tabulated in the format required by the air quality model.

(5) The ST and OG emission inventories will then undergo a series of quality control checks, including comparison with each other, comparison with metropolitan inventories, cross-checks on the reasonableness of the road mileage within each square, a visual check to see that the squares with the highest and lowest emissions are consistent with the mix of land use and activities, and so on. Where anomalous or inconsistent emissions are found, the maps, notes, coding activities, and emission calculations will be reviewed to uncover and fix any errors. Final emission inventories will be generated by the preprocessor for the air quality modeling.

(6) *(Additional material to the May 2, 2001, draft protocol)*

In the choice of emission factors, discussed in the fourth point above, attention will be given to any documented cases of emission controls in place during the December 3, 1999, percentage contribution to the predicted concentration of PM_{10} exceedances. Where such evidence of controls is forthcoming, the standard reductions from the uncontrolled emission rate will be applied. For example, in the case of unpaved haul roads at a large construction site, the standard control efficiency applied for adequate watering of the haul road is 80%. This means that the uncontrolled emissions are reduced by 80% through this watering.

Air quality modeling

Of the available air quality models that would simulate elevated PM_{10} concentrations, the Industrial Source Complex Short Term (3rd version) – ISCST3 – model will be applied to the December 3, 1999, concentrations in Tucson. This numerical model is a steady-state, Gaussian dispersion model that has been approved by the U. S. Environmental Protection Agency and that has a long history of applications in both the industrial and urban settings. The model has a number of options, including simulating concentration variations induced by buildings and by mountainous terrain. For this application, the model will initially be exercised in flat terrain and without any building downwash algorithms. Should either of these options prove necessary, then they will be used, although that would mean obtaining the dimensions of all buildings close to the monitors.

In addition to emissions, the model requires some meteorological data, primarily surface wind speeds and directions, and estimates of atmospheric mixing height. All of the relevant meteorological data will be assembled and examined, with every effort made to use site-specific data. Data from nearby and reference sites will also be examined and used as necessary. The technical analysis for the State's Natural Exceptional Events plan relied on meteorological data from a network of statewide sites that included the Tucson International Airport. In comparing the exceedance day meteorological data with the statistics of wind speed and rainfall occurrence, county and state staff used the statistics from this site in determining the suitability of particular day as an exceptional event. Given the relative proximity of the ST and OG sites to the airport, this underlying analysis would appear to representatively robust.

The output from ISCST3 is a series of 24 hourly PM_{10} concentrations. The ST and OG monitors, however, provide only an integrated, 24-hour average concentration. To compare the predicted and observed hourly concentrations, the measured 24-hour average concentrations will have to be divided into their hourly components. This division will be performed with all the available data, including the hourly variation of light scattering and light extinction in Tucson on December 3, 1999, as well as the diurnal variation of tapered element oscillating membrane (TEOM) PM_{10} from representative days in Phoenix (there are no TEOM data in Tucson).

Air quality models require estimates of background concentrations that would be present

independent of the source's emissions. For December 3, 1999, with one third of the hours with high winds and two thirds with low winds, background concentrations will be developed separately for the two regimes. Recalling that the resultant concentrations at the monitors are the sum of the nearby emission sources, the ambient background, and urban foreground concentrations, analyses will have to carried out to estimate the background and foreground concentrations. PM_{10} concentrations from various background sites will be examined, such as the Tucson Fairgrounds, Rillito, Organ Pipe National Monument, Sahuaro National Monument West, Palo Verde Nuclear Generating station, Hillside, and so on. The goal of this analysis will be to estimate realistic ambient background concentrations under both high and low wind conditions. On December 3, 1999, only the ST and OG monitors were operating, since this date did not fall on the every sixth day schedule, when other Tucson, Phoenix, and background monitors were in operation. The paucity of filter PM_{10} data on this date will necessitate that other windy days from several years be analyzed to develop a better understanding of urban foreground concentrations under high winds.

The predicted concentrations from ISCST3, which result only from the near-field emissions, will be augmented by the urban foreground and ambient background values to give a "total estimated value." When the hourly total estimated values and the hourly PM_{10} concentrations derived from the measurements are compared, validation efforts and quality checks will be made to improve the model's performance. These may include some sensitivity and diagnostic tests; but, since the goal is to achieve only reasonable agreement with the measurements, this phase of the modeling will not be overly extensive. The most accurate agreement between predictions and observations is not essential for the overarching goal of the modeling: i.e. to determine the relative contribution of sources within the near-field to the elevated concentrations. This relative source contribution depends on the mix of sources and their strengths in the inventory and on the dynamics of the atmospheric model, not on the overall agreement between the total estimated and measured concentrations.

The relative nature of this work can be contrasted with air quality modeling performed to demonstrate compliance with a National Ambient Air Quality Standard. This standard is a specified upper numerical limit to the concentration of an air pollutant. Air quality modeling produces estimated concentrations for a future year of attainment. These concentrations determine whether the standard is achieved. Consequently, in the modeling of the base-case year, the predicted concentrations must agree quite closely with the measured concentrations, in order for the future year estimates to have any reliability. The successful validation of the simulated with the measured concentrations is one of the most labor-intensive aspects of this "absolute" air quality modeling. Determining relative contributions for a given set of sources – the goal of the Tucson natural events modeling – can be successfully accomplished without such intensive validation efforts.

[The following paragraph differs from the draft protocol]

Lastly, ISCST3 will calculate the contributions from the individual source categories to the net concentration by running the emissions from each source category separately. In estimating the net concentration at a receptor from all sources, ISCST3 treats the emissions from individual source categories by summing their collective contribution to yield a single predicted concentration. When the emissions from a single source category are input to the model, then the concentration reflects only that category. Running each of the categories separately, then, provides a means to determine its relative contribution to the net concentration. The percentage contribution to the predicted concentration of PM_{10} of each of the source categories from #2 above will determine which sources will be subject to BACM under the Natural Events Action Plan.

References

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ADEQ, 2000: "Arizona Department of Environmental Quality Technical Criteria Document for Determination of Natural Exceptional Events for Particulate Matter Equal to or Less Than Ten Microns in Aerodynamic Diameter (PM_{10})", May 31, 2000

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