Arizona Department of Environmental Quality

Analysis of $PM_{2.5}$ Exceedances in Pinal County Arizona:

Demonstration that $PM_{2.5}$ Concentrations are Driven by Local Sources of

PM_{10} Near the Cowtown Monitor

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Invalidation

Analysis of $PM_{2.5}$ Exceedances in Pinal County Arizona:

Demonstration that $PM_{2.5}$ Concentrations are Driven by Local Sources of PM_{10} Near the Cowtown Monitor

Summary

In 2006, the EPA revised the 1997 $PM_{2.5}$ (particulate matter smaller then 2.5 microns in size) National Ambient Air Quality Standard (NAAQS), setting the 24-hour average standard to 35 µg/m³, but leaving the annual average standard at 15 µg/m³. Since then, the EPA has sent notice to the State that the Cowtown monitor in Pinal County exceeds both the annual average and 24-hour average $PM_{2.5}$ NAAQS, but only requested that the State send a recommendation for a nonattainment area boundary for the annual average standard. Further, EPA indicated that it may favor a proposal in which Pinal County and eight other surrounding counties (approximately 58,000 square miles) be designated as a $PM_{2.5}$ nonattainment area. Any proposal, however, would be based solely on violations of the $PM_{2.5}$ NAAQS measured at the Cowtown monitor located in the Town of Maricopa in Pinal County. The Cowtown monitor frequently records $PM_{2.5}$ concentrations above the established 2006 ambient $PM_{2.5}$ 24-hour standard. Yet, unlike most other existing $PM_{2.5}$ nonattainment areas, the elevated $PM_{2.5}$ concentrations measured at Cowtown are not primarily from combustion, medium- or long-range transport of emissions, or secondary particle formation. Rather, they are the result of very high localized $PM_{2.5}$ concentrations as a component of PM_{10} and from emissions generated within a few kilometers of the monitor.

This memorandum demonstrates that the monitored $PM_{2.5}$ exceedances are largely, if not entirely, a product of local sources — primarily, nearby agriculture and related activities, including geologic dust, manure particles, and, on occasion, smoke and soot. Results presented in a 2005 source apportionment study[1] carried out by the Pinal County Air Quality Control District (PCAQCD), as well as statistical analysis of recent PM_{10} and $PM_{2.5}$ air quality data, study of meteorology data, and back trajectory analysis will each demonstrate that local sources of PM_{10} are the most significant contributors to elevated $PM_{2.5}$ concentrations at the monitor. One of the major implications of this analysis is that no $PM_{2.5}$ specific control measures will be necessary to attain the NAAQS; i.e., controls capable of attaining the PM_{10} NAAQS will result in attainment of the $PM_{2.5}$ NAAQS. Further, these findings would support a recommendation to establish $PM_{2.5}$ nonattainment area, if it is at all necessary, covering only that geographic area directly affecting the Cowtown monitor and nearby areas with the same primary sources of PM_{10} and, thus, $PM_{2.5}$.

[1] PCAQCD staff, "Pinal County Air Quality Control District Source Apportionment Study," July 29, 2005

Introduction

As a technical support document to the Pinal County nonattainment area boundary recommendation, this paper will present several analytical methods to help regulators better understand ambient $PM_{2.5}$ pollutant concentrations in Pinal County, AZ. the objective of this paper is to discuss the factors which have likely contributed to the 29 $PM_{2.5}$ exceedances recorded at the Cowtown monitor during 2006, 2007, and 2008.

It should be noted that EPA has notified the State that a nonattainment designation needs to address violations of the annual average $PM_{2.5}$ NAAQS. Any analysis of annual average data, however, would be a fruitless exercise for a large number of reasons. Understanding the nature and causes of elevated $PM_{2.5}$ concentrations is best accomplished by looking at the smallest unit of analysis – the 24-hour average concentrations in this case. Evaluation of the exceedances of the 24-hour average NAAQS will shed ample light on all the issues that affect the violations of the annual standard, and, further, all control measures that are implemented to address the annual average will, by necessity, need to reduce emissions every day of the year.

The Cowtown, Pinal County, monitor has exceeded the $PM_{2.5}$ standard 30 times during calendar years 2006, 2007, and 2008. On April 17, 2006 there was a fire at the Hyponex Corporation facility, located in the town of Maricopa, AZ, which may have impacted the Cowtown monitor. The 30 days are listed in chronological order in Table 1.

Table 1: A total of 30 days exceeded the current $PM_{2.5}$ standard of 35 µg/m³ during 2006, 2007, and 2008.

RUN DATE	$PM_{2.5}$	RUN DATE	$PM_{2.5}$
1/11/2006	36.2	4/12/2007	45.4
1/17/2006	39.4	4/30/2007	53.9
2/22/2006	44.3	5/30/2007	37.0
4/17/2006 *	48.5	6/5/2007	44.2
5/5/2006	48.9	6/17/2007	48.2
5/23/2006	46.2	10/9/2007	38.3
5/29/2006	38.2	11/8/2007	44.7
6/16/2006	36.4	11/26/2007	46.8
10/2/2006	35.0	3/25/2008	41.7
10/20/2006	47.9	4/12/2008	40.7
11/1/2006	37.0	4/18/2008	35.9
12/1/2006	69.4	4/30/2008	39.6
12/7/2006	47.9	5/6/2008	40.4
12/13/2006	46.3	6/23/2008	36.8
2/23/2007	59.7	11/20/2008	38.1

* Hyponex fire

The Cowtown monitoring site is located approximately four miles southeast of the City of Maricopa and 15 miles south of the Phoenix urban area at 37580 W. Maricopa/Casa Grande Hwy. (Lat. N 33°63' Long. W 111°58'). The site lies within the irrigated desert plain, with active and retired agricultural operations to the north, northwest, and east. A grain-processing complex and three cattle-feedlot companies operate within a short distance of the monitor, to the south, southwest, and southeast. The source makeup near the Cowtown monitor suggests that nearby sources have a high potential to contribute to elevated $PM_{2.5}$ concentrations at the monitor; thus, any boundary recommendation must take into consideration these nearby sources. Most existing $PM_{2.5}$ nonattainment areas within the United States are affected by long-range transport of primary and secondary particles from combustion, as well as locally generated primary and secondary particulates. However, after an investigation into the primary causes of the Cowtown exceedances, this does not appear to be the case for the Cowtown monitor.

Results from a 2003 source apportionment study and from recent ongoing source attribution work at the Cowtown monitoring site will be used to evaluate sources near the Cowtown monitor. CMB (Chemical Mass Balance) modeling will determine relative source contributions at both the Cowtown and other Pinal County monitors. An investigation into the meteorological factors on each of the 30 exceedance days, and statistical analysis of the $PM_{2.5}$ data from Cowtown and other monitors, will demonstrate that local sources are driving the elevated $PM_{2.5}$ concentrations at Cowtown.

Source Apportionment

In 2003 PCAQD embarked on a rigorous source apportionment study to identify which emission sources are contributing to elevated particulate matter concentrations in the Pinal County agricultural basin. The study required extensive field work to collect ambient PM_{10} and $PM_{2.5}$ samples from five monitoring sites and three local source types, within Pinal county. The ambient and source-specific samples were chemically speciated and source-receptor chemical profiles were modeled with CMB (Chemical Mass Balance). The results of that study are presented in a 2005 report prepared by PCAQD titled "Pinal County Air Quality Control District Source Apportionment Study" and are summarized in this memorandum.

PCAQCD co-located filter based Mini-Vol monitors capable of measuring $PM_{2.5}$ and PM_{10} at five existing monitoring sites: Casa Grande, Coolidge, Cowtown, Pinal County Housing and Stanfield. All the existing sites had at least one Federal Reference Method (FRM) monitor configured to measure ambient PM_{10} concentrations and one site had an existing FRM monitor configured to measure ambient $PM_{2.5}$ concentrations. The Mini-Vol monitors operated in parallel with existing FRM monitors. Data collection occurred in October and November of 2003. The fieldwork also required that soil and feedlot surface material samples be collected to characterize unpaved road dust, agricultural dust and feedlot dust. DRI (Desert Research Institute) analyzed the material on the filters using various chemical methods, which provided refined source profiles or "fingerprints" for Pinal County soils and feedlots.

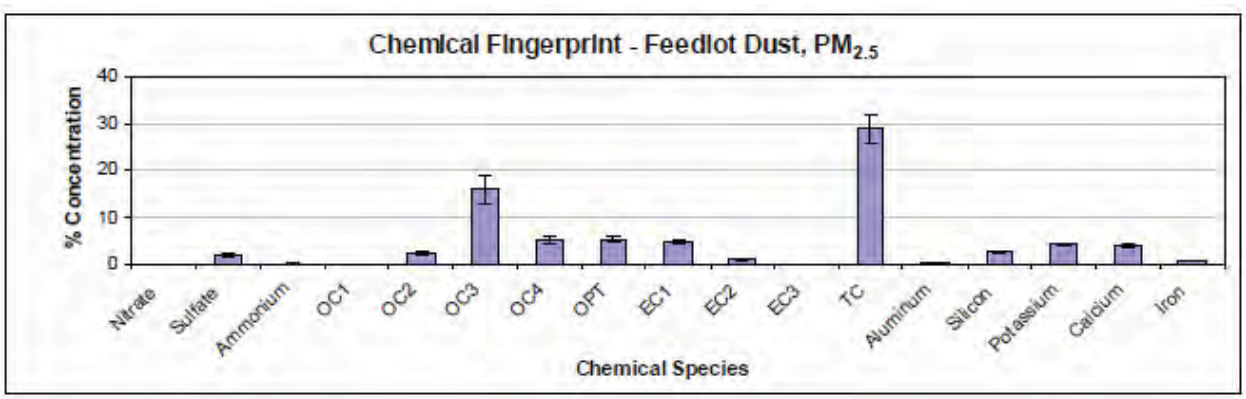
Table 2: The source apportionment modeling required chemical source profiles from seven source types, the eight source type was unclassifiable.

Source ID	Source Description	Notes
Soil	Geologic Soil	Existing 1990 Phoenix/Tucson - ag, unpaved roads, desert soils (Pinal County soils were updated for 2003)
Feedlot	Feedlot Soil	5 samples collected from nearby Cowtown feedlot soil
MvEmi	Motor vehicle Sources	Phoenix motor vehicle composite / Texas BRAVO [2]roadside exhaust
VgBrn	Vegetative Burning	BRAVO open burning – mesquite/shrubs/brush/dry grass piles
ColPP	Coal Fired Power Plant	BRAVO stack emissions from Texas electric utility
AmSulf	Ammonium Sulfate	Secondary ammonium sulfate
AmNitr	Ammonium Nitrate	Secondary ammonium nitrate
Other	Unclassified	Sources not modeled

Fine dust samples were collected from five different locations from each of the three Pinal County sources (feedlots, unpaved roads and agricultural fields) and were then shipped to the laboratory for chemical analysis. The new source specific chemical fingerprints for feedlots, unpaved roadways and agricultural fields, were then used as input to the CMB model, along with the other existing source profiles, to determine source contributions at each of five monitors. Motor vehicle, vegetative burning, coal power pant, ammonium sulfate and ammonium nitrate fingerprints were acquired from existing source profiles.

The chemical source profiles for feedlot dust, unpaved road dust and agricultural field dust are presented in Figures 1, 2 and 3 below.

Figure 1: Source specific chemical fingerprint for feedlot dust. The samples were collected from five locations at a feedlot near the Cowtown monitor, during October and November 2003 and analyzed



[2] BRAVO - Big Bend Regional Aerosol and Visibility Observational Study

Figure 2: Source specific chemical fingerprint for unpaved road dust. The samples were collected from five locations along an unpaved road near the Cowtown monitor, during October and November 2003.

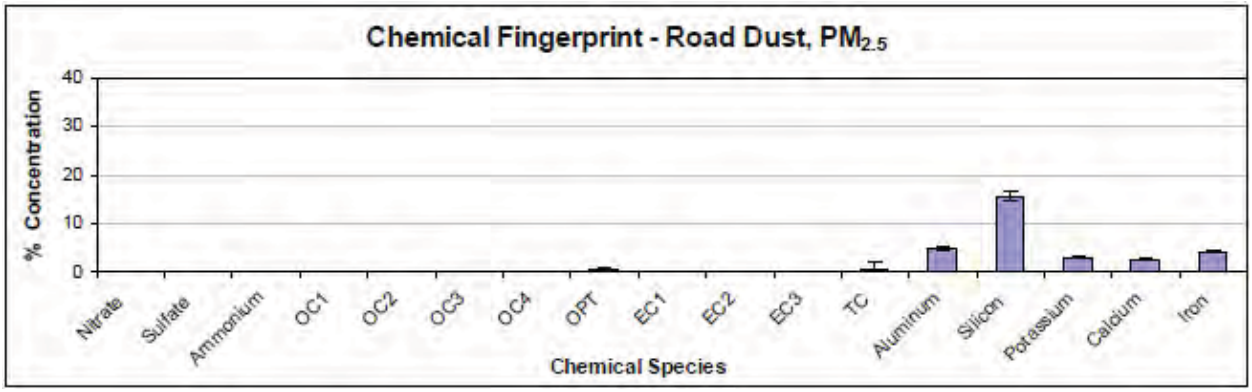
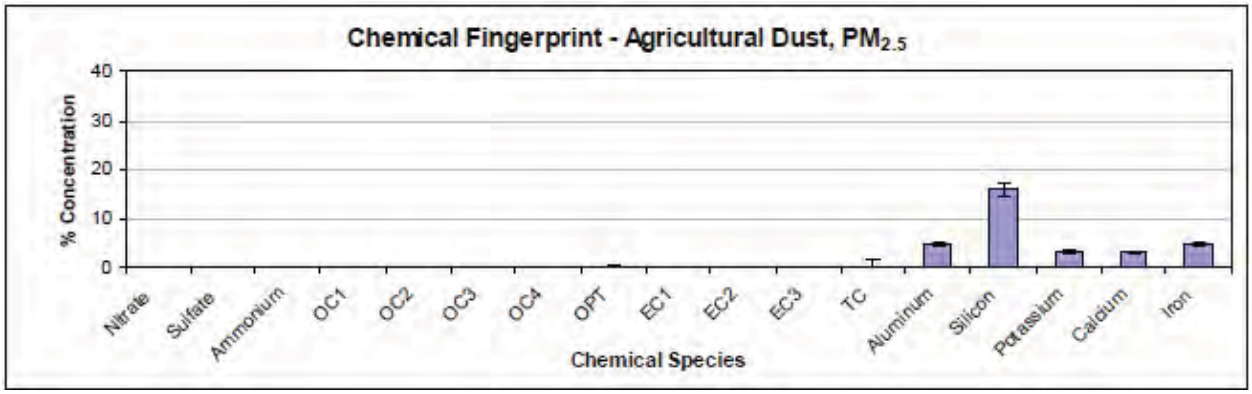


Figure 3: Source specific chemical fingerprint for agricultural dust. The samples were collected from five locations within an agricultural field near the Cowtown monitor, during October and November 2003.



Figures 1-3, illustrate the comparative chemical fingerprints from Pinal County, for fine particulate matter ($PM_{2.5}$). Shown are the percent concentrations of 17 chemical species and their analytical uncertainties, including water soluble nitrate, sulfate and ammonium, the eight carbon species (organic carbon fraction (OC1-4), pyrolysis of organic carbons to elemental carbons (OPT) and elemental carbon fraction (EC1-3), as well as the total carbon (TC), and five metals typical of most soils (aluminum, silicon, potassium, calcium and iron).

The chemical fingerprints are derived from an assortment of chemical analyses, including X-ray Fluorescence spectrometry (XRF) for elemental species like aluminum, silicon and iron, Ion Chromatography (IC) for sulfates and nitrates, Atomic Absorption (AA) for potassium, Automated Calorimetry (AC) for ammonium and Thermal/Optical Reflectance (TOR) for the carbon fractions (OC1-4, OPT, EC1-3 and TC). The relative abundance of each compound or compound group makes up the source signature. For example, the feedlot dust has a substantial amount of Total Carbon (TC) and OC3, with OC2, OC4, OPT and EC1 shares following close behind. The OC1, OC2, OC3, OC4, OPT, EC1, EC2 and EC3 designations refer to eight

separate carbon fractions, defined by temperature, oxidation atmosphere, and He-Ne laser light (J.C. Chow, 2001). One purpose of the TOR analysis is to distinguish, for example, diesel combustion from wood smoke particulate sources or in the case of Cowtown, to help catalog any organic carbon species associated with the feedlots, like cow manure, and distinguish them from other carbon rich sources. The Feedlot Dust sample differs from the Agricultural and Road Dusts in that it contains a substantial amount of total carbon (TC) which is the total of the concentrations of the carbon species, particularly of OC2, OC3, OC4, OPT and EC1.

Three ambient samples collected on high wind days on October 18 and 21 2003 and November 8 2003, from the Cowtown monitoring site were also analyzed using the same analytical methods used to profile the three nearby sources (feedlots, agricultural fields and unpaved roads). The chemical profiles from the Cowtown monitoring site indicate that feedlot emissions do contribute to the ambient $PM_{2.5}$ sample, while unpaved road dust and agricultural dust, albeit evident in the sample, are less conspicuous.

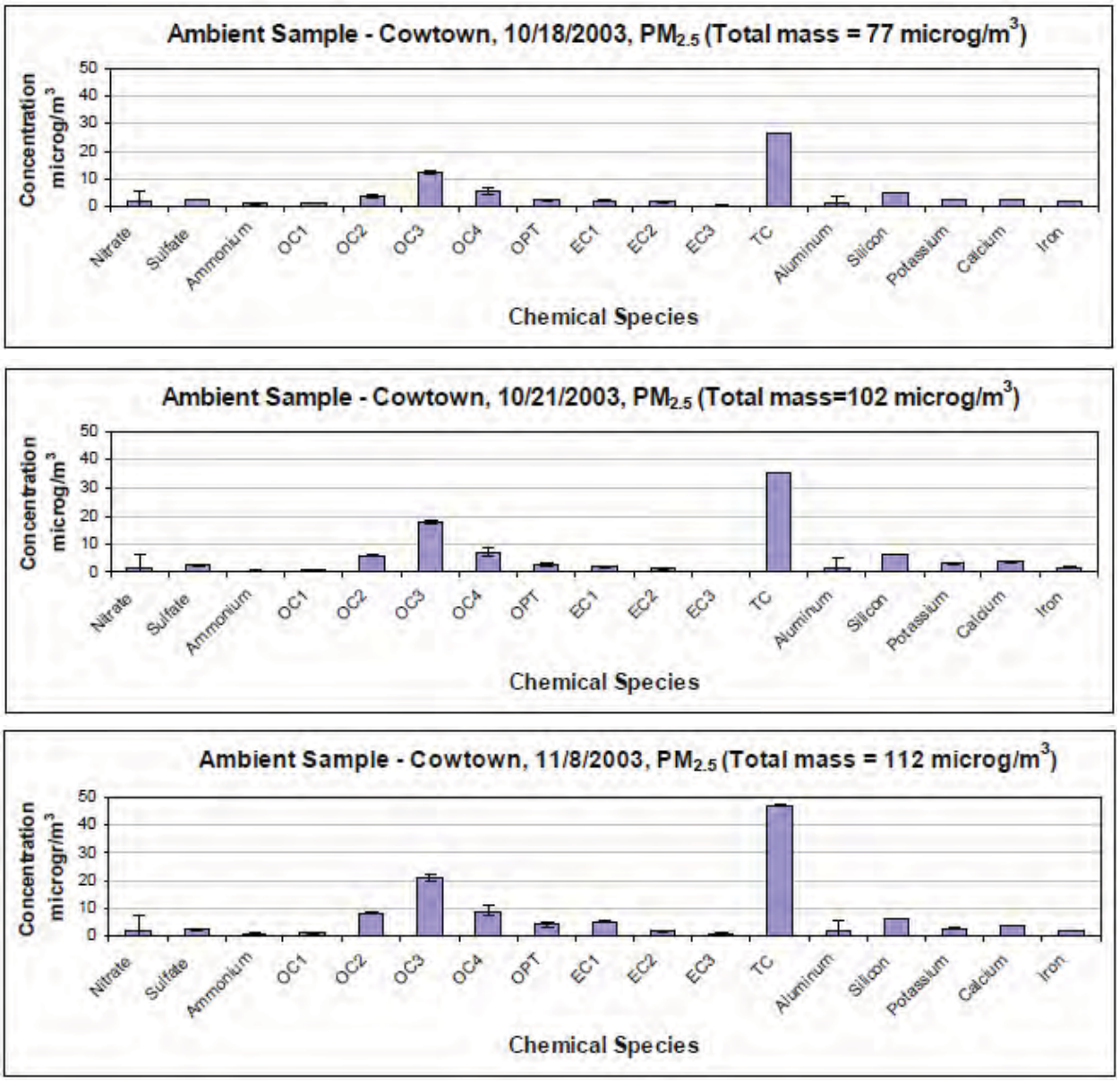
The three ambient samples are similar to the Feedlot Dust fingerprint since they all contain substantial amounts of total carbon (TC) with large proportions of OC2, OC3, OC4, OPT and EC1. This shows that the ambient samples do contain substantial amounts of the Feedlot Dust, as was confirmed by the Chemical Mass Balance (Version 8) receptor modeling results.

With the source and receptor profiles created, the CMB model was then used to evaluate source contributions at each Pinal County monitoring site. This receptor-oriented model is a good choice for this type of source contribution analysis, since we are attempting to identify and apportion source categories to the observed $PM_{2.5}$ concentrations from each monitoring site, but have limited source specific emissions inventory data and meteorology. Receptor-oriented models focus on the chemical profiles of ambient samples collected at the receptor and apply a mass balance approach to identify and apportion the sources. Source-oriented dispersion models, on the other hand, rely on real-world meteorology to transport the pollutant from the source to the receptor. Although dispersion models are generally capable of estimating quantitative impacts from sources, limitations in the model's ability to simulate complex meteorological conditions, like stagnation and varying qualities of emission inventories, make dispersion models insufficient for apportioning sources.

Fortunately, the CMB model can overcome the need to simulate complex meteorology and temporally resolved source specific emission inventories by establishing a source / receptor relationship based on an effective-variance least squares method (EVLS)[3], by analyzing and comparing the chemical characteristics of each ambient sample and source profile. The CMB model however, may not be the best choice to establish a quantitative measure of impacts from any particular source, but may be used to demonstrate relative impacts from sources or source categories at each monitor.

[3] http://www.epa.gov/scram001/receptor_cmb.htm

Figure 4: The sample source profiles from Cowtown for three high concentration days in 2003 (October 18 2003, October 21 2003 and November 8 2003).



Seven source categories (including one category for unclassifiable compounds), each with speciated source profiles from potential nearby and distant sources, were modeled along with each speciated set of samples collected from each Pinal County monitoring site. At the Cowtown monitor, the CMB model estimated that, on average, 49% of $PM_{2.5}$ at the monitor originates from feedlots and is the major component of the eight source types presented in Table 2. The CMB modeling results are consistent with the findings from the speciated source profile analyses, whereby feedlot emissions appeared prominent in the three ambient samples collected from the Cowtown monitor.

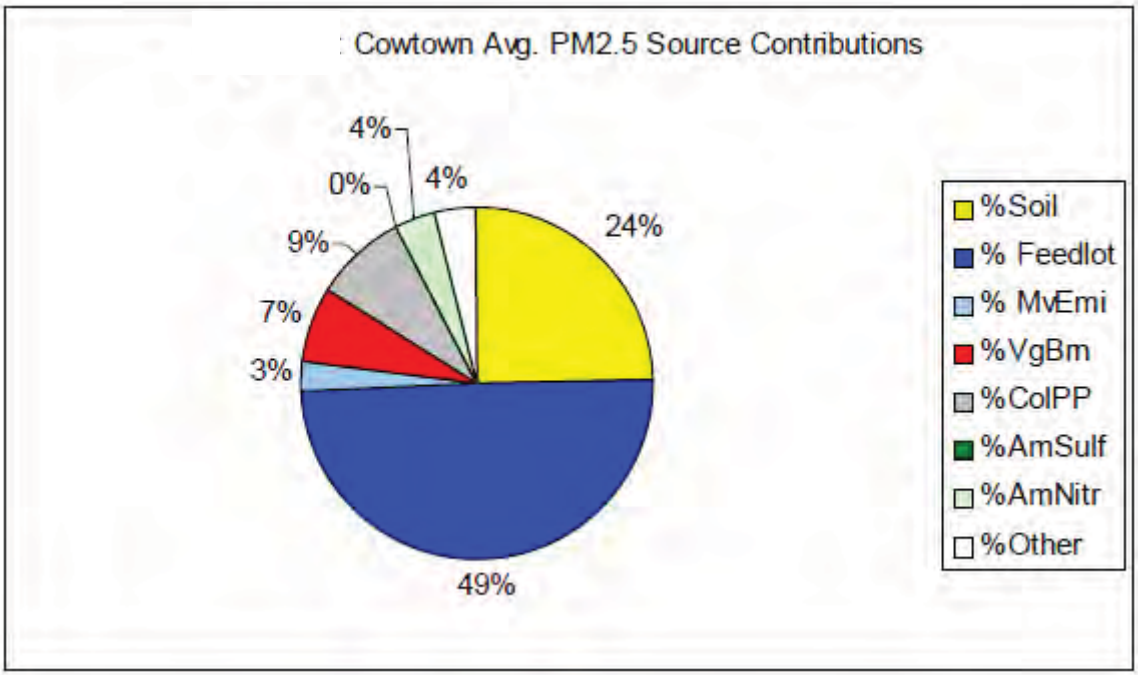
The average source category contributions from the remaining four monitoring sites were compared to the average source category contributions from the Cowtown monitor. That conclusion indicated that the Cowtown monitor is the only monitoring site in Pinal County where feedlot emissions dominate the $PM_{2.5}$ samples. Geologic soil was the dominate source category for each of the remaining four monitoring sites. It is also worth mentioning, that the PM_{10} samples from the Cowtown monitor were also dominated by feedlot emissions, which supports the *$PM_{2.5}$ as a function of PM_{10}*, data analysis presented later; that analysis shows that when $PM_{2.5}$ exceeds the standard, so does PM_{10}.

Source Apportionment - Primary Components of Cowtown $PM_{2.5}$

Nine 24-hour ambient $PM_{2.5}$ samples were collected from the Cowtown monitoring site during October and November 2003. The nine ambient samples were speciated and modeled using the CMB model to estimate the relative source category contributions at the Cowtown monitor. Based on the ambient sample data and CMB modeling, the most abundant source category for $PM_{2.5}$ was feedlot soils with an average contribution of 49% of the total. The second highest source contribution was the geological soil category with an average contribution of 24%. Cowtown was the only monitor in the Pinal County study area where the geological soil category did *not* have the highest source contribution. (See Figure 5) The average 24-hour $PM_{2.5}$ concentration at Cowtown was also well above any other Pinal County site at 67$\mu g/m^3$, as recorded by the Mini-Vol $PM_{2.5}$ sampler. Three samples had a recorded $PM_{2.5}$ Mini-Vol concentration above 100 $\mu g/m^3$, October 21, 2003, October 27, 2003, and November 8, 2003. On all three dates, the meteorological data indicates inversion conditions with light winds throughout the day, which further indicates that distant sources are not likely to have been major contributors to the highest recorded days during this study period.

The coal-fired power plant source category was the third most abundant category with an average relative contribution of 9%. This contribution from the coal power plant source category is a bit perplexing, however. According to the most updated state-wide emissions inventory, the nearest coal power plant is approximately 82 miles to the south east of the Cowtown monitor, and although it is possible for stack emissions to transport long distances, the stagnant meteorological conditions which were evident on the highest recorded $PM_{2.5}$ days, would likely have served to mitigate or even prevent any long range pollutant transport from affecting the Cowtown monitor on those days. Given that several exceedances were recorded on stagnant days, the relative contribution from the coal power plant source category is expected to be less than the third most abundant. This is particularly true at the Cowtown monitor, since it is located near several local sources of $PM_{10/2..5}$ and just 50 meters to the north of the Union Pacific Railroad tracks. However, although it is the third most abundant source category, the relative contribution from the power plant signature is only 9%, while geologic dust and feedlots together comprise 73% of the total $PM_{2.5}$.

Figure 5: Average source contributions predicted by the CMB model at the Cowtown monitor according to the 2003 source apportionment study. Feedlots are the predominant category at Cowtown.



It is possible; however, that the coal power plant profile was confused with the locomotive emission profile or even with feedlot emissions, since both locomotives and feedlots, like power plants, can have high measures of total carbon (TC) in their speciation profiles. However, locomotive sources were not modeled in the 2003 CMB analysis, so a locomotive emission profile was not readily available for comparison to the coal fired power plant profile. In any event, coal power plant emissions typically have more traceable heavy metals like selenium (Se) in the exhaust stream, which would make it difficult to confuse diesel exhaust from locomotives with coal power plant emissions. In fact, locomotive emissions may be more likely confused with heavy duty diesel vehicle emissions. But, if the locomotive emission profile were mixed-in with vehicle exhaust profile, locomotives would only likely be marginally responsible for any elevated $PM_{2.5}$ concentrations, since vehicle emissions are only on average 3% of the total ambient $PM_{2.5.}$ However, no evidence appears to support that locomotive emissions have been confused with any of the seven source profiles, including the coal power plant source category.

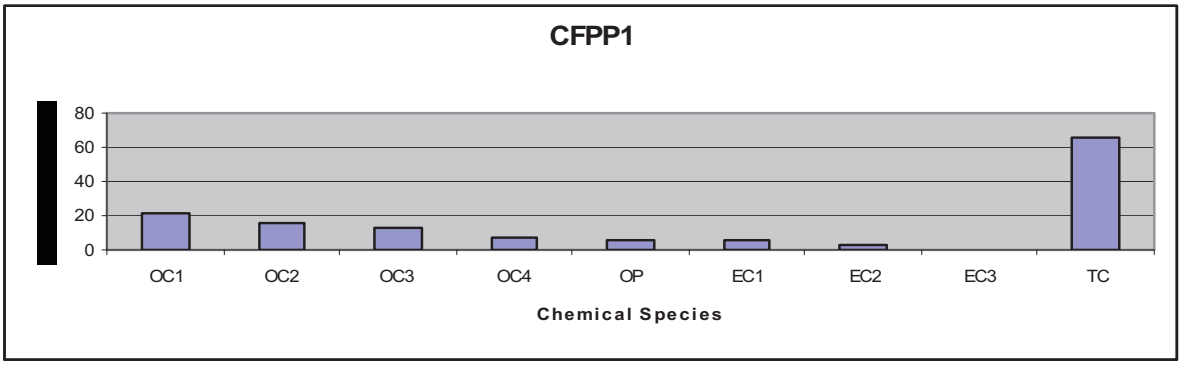
It is also unlikely that the coal fired power plant signature was confused with feedlot emissions. The carbon fraction profiles for the three power plants used as source profiles in the PCAQCD study are substantially different then that of feedlot signature. Figure 6 below illustrates the BRAVO carbon profiles for the three power plants. Each profile is different than that of the feedlot profile illustrated in Figure 1. The feedlot signature measures an abundance of TC and OC3, yet CFPP1, 2 and 3 (Coal Fired Power Plants 1, 2 and 3) each only indicate an abundance of TC, yet OC3 remains unsubstantial relative to the other carbon fractions.

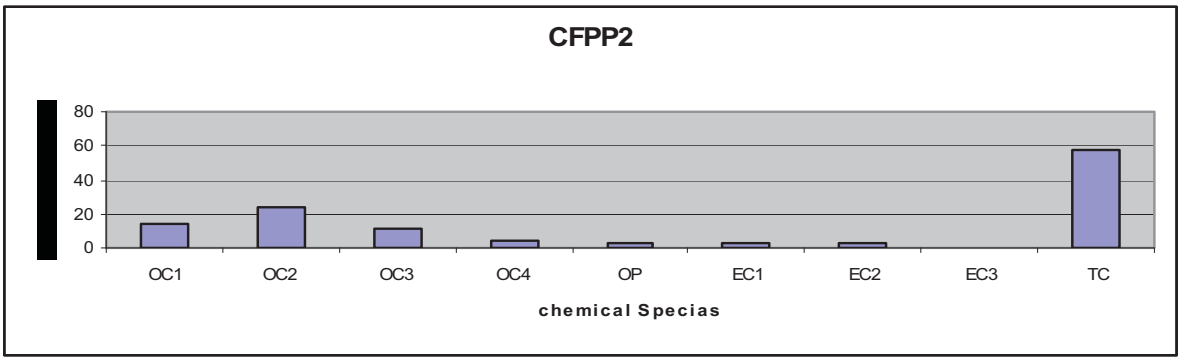
One explanation may be that the coal power plant category is entirely erroneous. The CMB modeling in the PCAQCD source apportionment report made use of both source specific chemical profiles for geologic and feedlot dust in addition to source profiles from the BRAVO study. As part of the BRAVO study, six coal power plants were profiled and all but two (plant numbers two and three) used lignite coal as a fuel, which is not used as a fuel in Arizona. However, the PCAQCD study, used three of the BRAVO coal power plants signatures, plant one (CFPP1), plant two (CFPP2) and plant three (CFPP3). CFPP2 and CFPP3 are described in the BRAVO study as using low-sulfur Western coal as fuel, similar to the fuel used in Arizona coal plants. However, CFPP1 has no such description, leaving some uncertainty as to what type of fuel CFPP1 uses. Furthermore, the PCAQCD report makes no mention of how the CMB model made use of the three profiles. So, the coal power plant contribution at Cowtown and in Pinal County should likely be considered unknown.

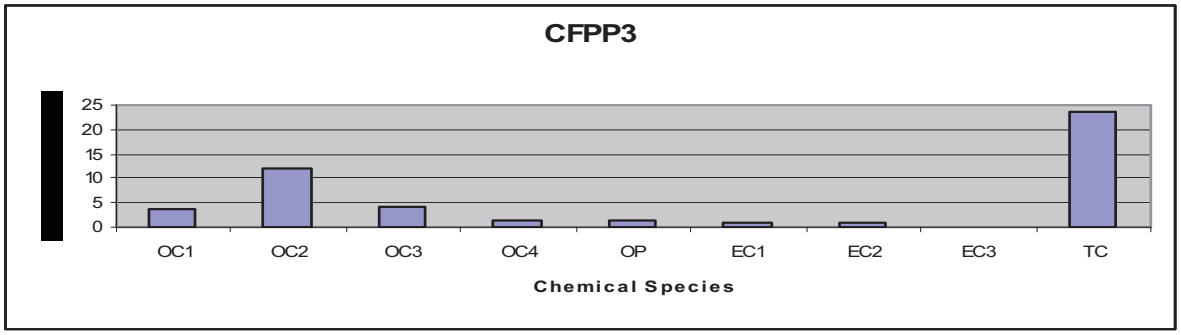
ADEQ has no data that suggest or supports that emissions from gas- or coal-fired power plants contribute to the $PM_{2.5}$ problem in Pinal County. Transport of windblown $PM_{2.5}$ to the Cowtown monitor has not been documented in Pinal County. To the contrary, the 2005 PCAQCD source apportionment report estimated that, on average, 49% of $PM_{2.5}$ at the Cowtown monitor originates from feedlots. While this study concludes that coal fired power plants may have contributed to the $PM_{2.5}$ concentrations measured at Cowtown:

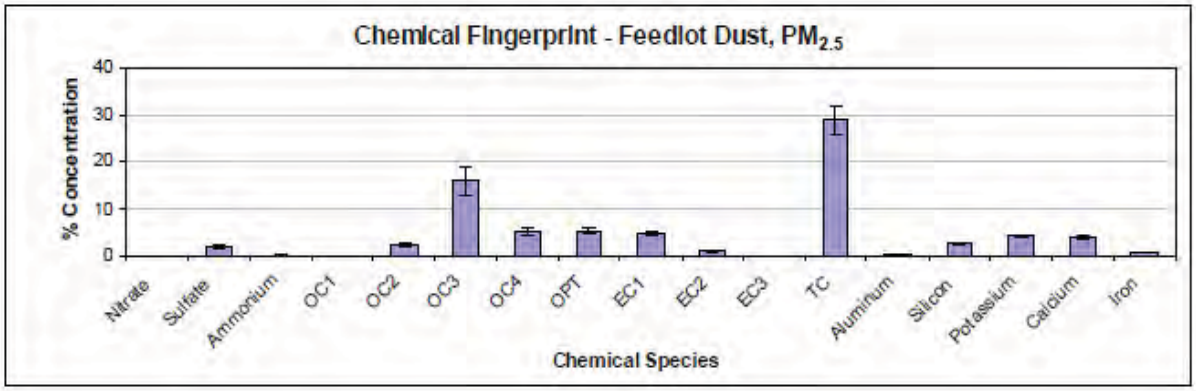
- The coal power plant proportion is small when compared to the portion of particulate apportioned to dust from soil and feedlots (the feedlot proportion increases with increasing $PM_{2.5}$ concentration) and is smaller when exceedances of the 24-hour average standard is exceeded;
- The most important marker of long-range emissions transport from coal power plants is secondary sulfate particles, the presence of which in the ambient samples was not at all in proportion to the amount of particulate attributed to coal power plants;
- ADEQ has very high confidence in the other "chemical fingerprints" used for the source apportionment analysis and the results relating to those sources (e.g., feedlot dust, soil, vegetative burning), but power plant signatures are poorly documented and significant nearby sources, such as railroad locomotives, were not included, which reduces the reliability of the results regarding power plants;
- Even if one assumes the coal power plant apportionment is correct, it is evidenced at all of the Pinal County sites, not just the only violating monitor, Cowtown; and
- Trajectory analyses described later in this paper show that for the range of meteorological conditions when exceedances of the 24-hour average standard are measured, winds in most cases would be carrying emissions from these plants (85 to 140 miles southeast of the violating monitor) away from the monitor rather than towards it.

Figure 6: Coal fired power plant (CFPP) carbon fraction signatures according to the BRAVO speciation profiles and the feedlot profile from the PCAQCD study.









Source Apportionment - Comparison with other $PM_{2.5}$ monitors

Samples collected at each of the five Pinal County monitoring sites were analyzed and their chemical profiles were modeled with CMB. The CMB modeling results indicate that soil dust is the major contributor at each monitor – Casa Grande, Coolidge, Pinal County housing and Stanfield.

The Casa Grande monitoring site is located in the downtown area of Casa Grande. There are no agricultural fields, dirt roads, feedlots or large construction projects in the area immediately surrounding the monitoring site. The CMB modeling results (Figure 7) indicate that geologic soil, coal power plants and automobile exhaust are the top three source categories contributing to this monitor.

The Coolidge monitoring site is located on the eastern side of the agricultural basin and is located near the edge of town. The site is located in a residential neighborhood and approximately ¼ of a mile west of active agricultural fields. The agricultural basin extends north of the Coolidge site a substantial distance. Although, approximately six miles east of the Coolidge site the landscape generally changes back to native desert and that landscape continues to the eastern boundary of the County with increasing elevations further to the east. The CMB modeling results (Figure 8) indicate that geologic soil, coal power plants and vegetative burning are the top three source categories contributing to this monitor.

The Pinal County Housing site is located in the heart of the agricultural basin. The site is immediately surrounded by native desert; beyond that open field agriculture dominates the landscape for at least ten miles in all directions. The CMB modeling results (Figure 9) indicate that geologic soil, coal power plants are the top two source categories, with vegetative burning and feedlot emissions tied for third.

The Stanfield site is located near several feedlots and dairies and is generally surrounded by open field agriculture. The community of Stanfield only extends ¼ to ½ a mile in all directions from the site, beyond that open field agriculture dominates the landscape. Sizeable feedlot operations and dairies lie approximately three miles to the north, east, and west. The CMB modeling results (Figure 10) indicate that geologic soil, coal power plants and vegetative burning are the top three source categories contributing to this monitor.

Even though each monitoring site is surrounded by a different source mix, soil emissions contribute the most to all monitors, except Cowtown. Coal power plants, vegetative burning and automobile exhaust are also prominent at each of the sites and although each site is relatively distinct from the other, the source profiles predicted by CMB are generally similar. The exception, again, is the Cowtown monitor, where feedlot emissions are dominant.

Figures 7, 8, 9 and 10: The CMB modeling results for each of the four monitoring sites (Casa Grande, Coolidge, Pinal County housing and Stanfield). The figures illustrate the average relative percent $PM_{2.5}$ source contributions for ten samples collected and analyzed at the Casa Grande monitoring site. (MvEmi = Motor Vehicle Emissions, VgBrn = Vegitative Burning, ColPP = Coal Fired Power Plant, AmSulf = Ammonium Sulfate, AmNitr = Ammonium Nitrate)

Figure 7 Casa Grande Avg. PM2.5 Source Attributions

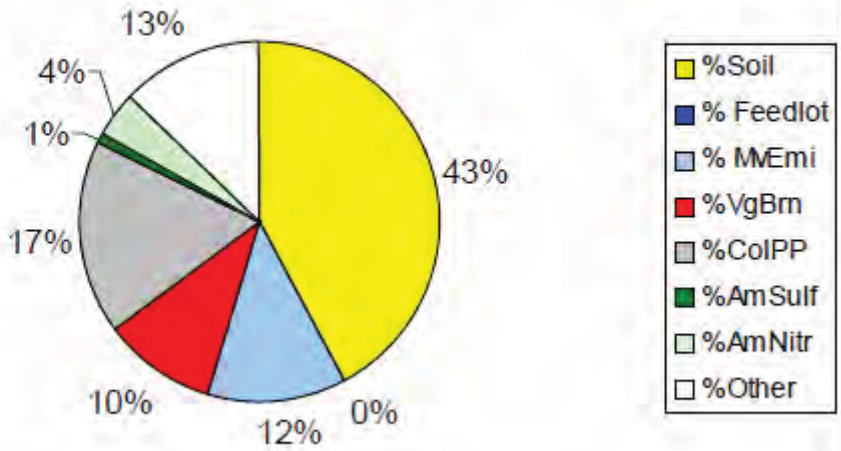


Figure 8 Coolidge Avg. PM2.5 Source Contributions

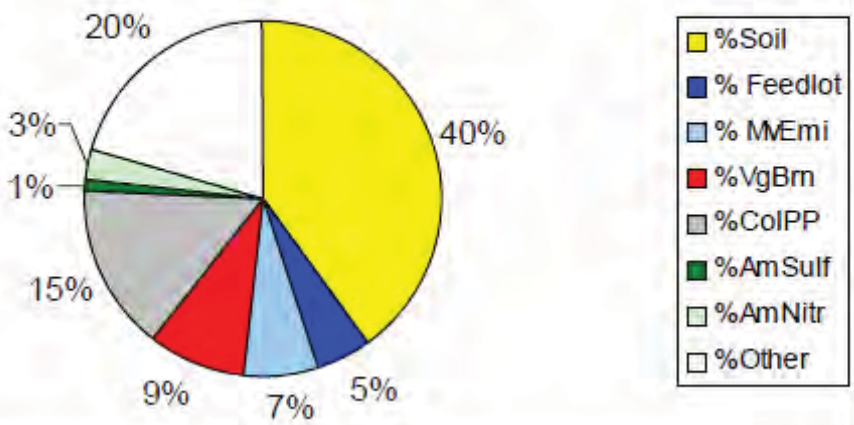


Figure 9 Pinal County Housing Avg. PM2.5 Source Contributions

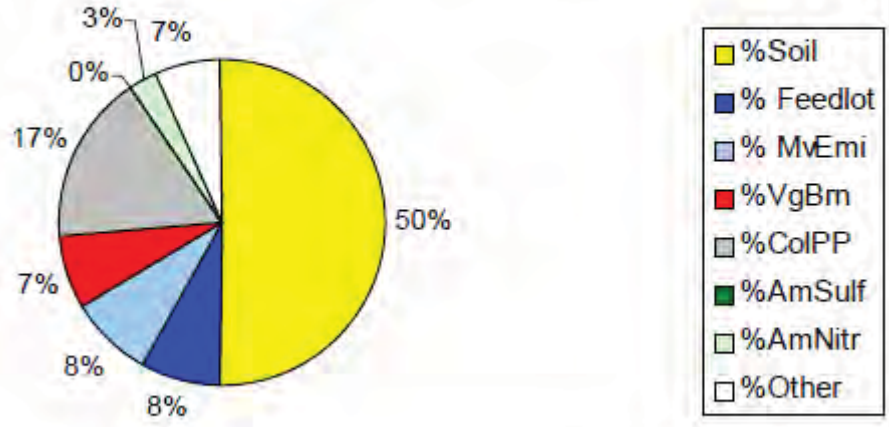
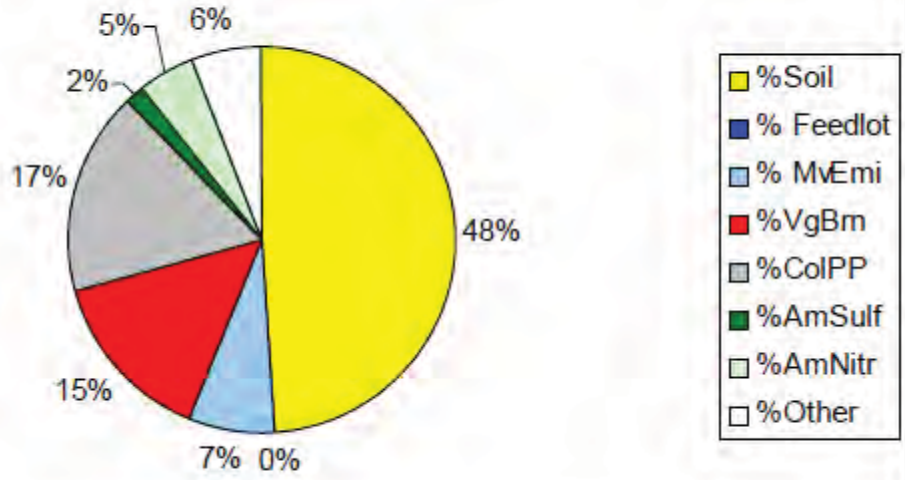


Figure 10 Stanfield Avg. PM2.5 Source Contributions



Meteorological Analysis

Site Geography

The Cowtown monitor is situated about 17 miles northwest of Casa Grande and 30 miles south of downtown Phoenix, Arizona. It is in the northern part of the Sonora Desert. The elevation of Cowtown is approximately 1,200 feet above sea level and separated from Phoenix by two mountain ranges – the Estrella Mountains (peak of 4,511 feet) and Phoenix's South Mountains (peak of 2,330 feet). Natural drainage is to the north via the Gila River. The Salt River merges with this drainage, which continues to run east to west on the north side of the above-mentioned mountain ranges. The Gila River then flows south to Gila Bend, eventually colliding with the Colorado River in Yuma, Arizona, an elevation near 250 feet above sea level.

Site Climatology

Temperature
Daily temperatures can fluctuate as much as 40 to 50 degrees Fahrenheit daily depending on atmospheric moisture, cloud cover and surface composition. The large fluctuations can play a role in the strength of afternoon surface breezes under high pressure. They can also increase the likelihood of morning surface inversions (where the surface becomes significantly colder than the air above it), especially during the winter. The normal January high temperature in Casa Grande (17 miles southeast of Cowtown) is 65°F and the normal low is 38°F. The normal July high temperature is 105°F and the low is 78°F.

Precipitation
The northern part of the Sonora Desert receives very little rain, typically between 5 to 10 inches annually. There are two distinct rain seasons in this part of the Sonoran Desert – winter (associate with low pressure systems and attached cold fronts) and summer (Monsoon wind shift with increase moisture from Mexico).

Wind
Strong winds typically occur when low pressure systems with attached cold fronts push through the region. This pattern is often seen in the spring and fall season. Characteristically as the system approaches, winds increase out of the southwest, moisture levels increase (depending on how much moisture is available) and atmospheric pressure decreases, resulting in increased vertical mixing. This turbulent atmosphere can trigger wide-spread areas of blowing particulates, especially in the absence of rain. After the front passes, decreasing winds shift out of the west and much cooler, drier air fills in behind the system. This can produce strong morning inversions that trap particles near the surface in shallow mixing depths.

Another scenario where strong winds may occur is during the summer Monsoon season where thunderstorms typically develop over mountainous areas as well as the open desert. Because the storms can develop anywhere, winds can come from any direction. As storms become severe,

microburst outflow winds can exceed 60 mph along the surface, again producing local and wide-spread areas of blowing particles.

Inversions

The typical profile from the surface to the bottom of the troposphere (approximately 11 miles above the surface) shows temperatures decreasing with increasing height. Warm air naturally rises and mixes with cooler air in an effort to reach equilibrium. The rate at which temperatures decrease is dependant on moisture. A dry air mass has a temperature decrease of about 5.5°F per 1,000ft in elevation (dry adiabatic lapse rate), and a saturated air mass has a temperature decrease of 3°F per 1,000ft (moist adiabatic lapse rate). Sometimes there can be a surge of warmer air aloft that cause temperatures to increase with height rather than decrease. Other times, the surface cools at a much more rapid rate than the air above. Both conditions produce the same result - a temperature inversion. Under an inversion, there is very little vertical mixing and typically weak horizontal winds due to high pressure. As the sun heats the surface in the morning, the temperature inversion weakens as the air at the surface warms. If the surface temperatures surpasses that of the air above it, the inversion breaks and vertical mixing ensues. Weak inversions (1-5°F) may break within an hour of sunrise. Sometimes, however, strong inversions (15-20°F) may not break at all, possibly keeping the air and its accumulated pollution trapped near the surface for several days at a time.

Stagnation

Stagnation conditions occur when a stable air mass remains over an area for an extended period of time, which can last as long as several days. In Arizona, this most often occurs during the winter months when a large ridge of high pressure sets up over most of the western United States. Afternoon desert temperatures may reach 70-80°F during these episodes under sunny conditions. Winds tend to be light both vertically and horizontally, primarily driven by topography. The typical surface flow is up-slope during the afternoon and down-slope during the night time and morning hours. Calms can be common and persistent. Under these conditions, pollution accumulates in the lower levels of the atmosphere, potentially leading to PM_{10} and $PM_{2.5}$ exceedances. Summer stagnation events may occur in late June and early July until Arizona Monsoon pattern sets up.

$PM_{2.5}$ Exceedance Days from 2006-2008

Table 3: A total of 30 days exceeded the current $PM_{2.5}$ standard of 35 µg/m³ during 2006, 2007, and 2008. 9 days were subject to stagnant conditions, 16 days had high winds and 5 days cannot be classified as windy or stagnant. This suggests that the PM2.5 exceedances are not directly associated with high or low winds.

RUN DATE	Meteorology	$PM_{2.5}$	RUN DATE	Meteorology	$PM_{2.5}$
1/11/2006	STAGNANT	36.2	4/12/2007	WIND	45.4
1/17/2006	STAGNANT	39.4	4/30/2007	WIND	53.9
2/22/2006	WIND	44.3	5/30/2007		37
4/17/2006 *	WIND	48.5	6/5/2007	WIND	44.2
5/5/2006	WIND	48.9	6/17/2007	WIND	48.2
5/23/2006	WIND	46.2	10/9/2007		38.3
5/29/2006	WIND	38.2	11/8/2007	STAGNANT	44.7
6/16/2006	WIND	36.4	11/26/2007	STAGNANT	46.8
10/2/2006	WIND	35	3/25/2008	STAGNANT	41.7
10/20/2006		47.9	4/12/2008		40.7
11/1/2006	STAGNANT	37	4/18/2008		35.9
12/1/2006	STAGNANT	69.4	4/30/2008	WIND	39.6
12/7/2006	WIND	47.9	5/6/2008	WIND	40.4
12/13/2006	STAGNANT	46.3	6/23/2008	WIND	36.8
2/23/2007	WIND	59.7	11/20/2008	STAGNANT	38.1

* Hyponex fire

Exceedances by Season

Looking at the weather pattern on the days that exceeded the $PM_{2.5}$ Federal health standard at the Cowtown monitoring site, 15 days (50%) occurred during the spring time. There were ten exceedance days (33%) in the fall. Four exceedance days occurred in the winter and just one in the summer. As noted above, strong winds due to low pressure systems accompanied by cold fronts are typically seen during the spring and fall months in Arizona. With 25 of the 30 exceedance days (88%) occurring during these seasons, it would appear that a large portion of the $PM_{2.5}$ exceedances are a result of non-stagnant events.

Exceedances by Wind Event/Stagnation

A closer look at horizontal and vertical wind speeds at the Cowtown monitor on the days that exceeded the $PM_{2.5}$ Federal health standards shows that 17 of the 30 days (56.3%) had relatively strong sustained winds with positive vertical mixing. Nine exceedance days (30.3%) were due to relatively light horizontal winds that could be classified under stagnant conditions. The final

four days (13.3%) have relatively low average wind speeds but strong enough peak wind gusts to neither be classified as wind or stagnation event.

As expected, 14 of the 17 (82%) high-wind exceedance days occurred in either the spring or fall. Two were in the winter (Feb. 22, 2006 and Feb. 23, 2007) and the last one occurring on the third day of summer (June 23, 2008). Seven of the nine stagnant days (77%) occurred in the spring or fall where only two (Jan. 11 and 17, 2006) were in the winter. The final four days that were neither classified as high-wind or stagnant all occurred in either the spring or fall.

The Cowtown $PM_{2.5}$ location is susceptible to exceeding the Federal health standard primarily during the spring and fall months. The majority of those exceedances are due strong winds while a large minority of exceedance days are due to inversions under stagnant conditions.

Back Trajectory Analysis

A series of back trajectory analyses were conducted using the NOAA (National Oceanographic and Atmospheric Administration) HYSPLIT (HYbrid Single-Particle Lagrangian Integrated Trajectory) model. The model is capable of computing air parcel trajectories in either a forward or backward mode and is a common tool used to examine long range transport. Forward trajectories can compute the path forward of an air parcel as it leaves a known point, while back trajectories can compute the path an air parcel traversed to get to a known point. The HYSPLIT model was used to compute back trajectories for each of seven design days: January 11, 2006, February 22, 2006, June 16, 2006, October 2, 2006, October 9, 2007, March 25, 2008, and June 23, 2008. The model results are used to estimate which sources may have contributed to the $PM_{2.5}$ exceedances at Cowtown on those days. The seven design dates represent seasonal high wind and low wind episodes for 2006, 2007 and 2008 on days when the Cowtown monitor exceeded the $PM_{2.5}$ standard.

For each day, HYSPLIT was used to compute a midnight, morning, afternoon and evening back trajectory. Each trajectory represents an air parcel as it moves through the atmosphere over twenty four hours, starting at 2300 hours and adjusted back every six hours for a total of 4 trajectories for each of the seven days. Each trajectory moves backwards from the end point at Cowtown to the, yet unknown, starting point, twenty four hours earlier. But, for ease of interpretation, it may be more practical to discuss the trajectories as moving forward, even though the HYSPLIT model calculated the paths in reverse.

If one were to consider only the yellow line, in Figure 11a below, and move forward, the air parcel begins near Chandler, AZ at 6AM on January 10, 2006 and travels south for most of the day. The parcel then turns toward the north near Cowtown and at 6AM January 11, 2006 (twenty four hours later), the air parcel arrives at Cowtown. The green trajectory is next in the series and also begins near Chandler, AZ. But, this trajectory begins at 12PM on January 10, 2008 and travels south for most of the day, until it changes direction to the west and arrives at Cowtown at 12PM on January 11, 2006. The blue trajectory begins at 6PM on January 10, 2006 and arrives at Cowtown at 6PM January 11, 2006. The red trajectory begins at midnight January 10, 2006 and arrives at midnight January 11, 2006. Each of the trajectories for the seven design days begin at

the same times (6AM, 12PM, 6PM and 12AM) and travel for 24 hours, for each date. On this day, most of the winds were coming from the north and east and due to stagnant conditions, the winds were moving very slowly. On most other days, the typical wind direction is from the southwest, as seen in the remaining HYSPLIT analyses.

The January 11th modeling results indicate that the majority of 24-hour trajectories do not traverse any likely $PM_{2.5}$ sources until the air parcel nears the Cowtown monitor. For example, on June 23, 2008 (Figure 11g), each trajectory begins in the south-southwest area of the state and travels steadily towards the Cowtown monitor. Since no obvious $PM_{2.5}$ sources are located along the trajectory (beyond the area near Cowtown) only local $PM_{2.5}$ sources could have caused the exceedance on that day. The same is true for June 16, 2006 (Figure 11c), October 2, 2006 (Figure 11c), October 9, 2007 (Figure 11e), and March 25, 2008 (Figure 11f), only when the parcel nears the Cowtown monitor, does the air parcel traverse any $PM_{2.5}$ sources. However, January 11, 2006 (Figure 11a) and February 22, 2006 (Figure 11b) are somewhat different from the other five days, because some trajectories begin near the Phoenix and Yuma, urban areas. On January 11, 2006 (Figure 11a), the yellow, green and red trajectories originate from the Phoenix metropolitan area and on February 22, 2006 (Figure 11b) the yellow and green trajectories begin near Yuma, AZ. The January and February 2006 trajectories may indicate some tendency for air pollution from these urban areas to migrate towards Cowtown at those select times, but during the vast majority of the 24 hour trip, the air parcel did not pass over any likely $PM_{2.5}$ source(s). When the air parcel nears the Cowtown monitor, however, the majority of the trajectories will traverse nearby feedlot and agricultural sources.

The HYSPLIT model was also used to investigate the wind flows nearby the Cowtown monitor during times when the $PM_{2.5}$ monitor was measuring elevated hourly concentrations. The hourly PM_{10} data profiles (Continuous $PM_{2.5}$ was not available, so PM_{10} is used as a surrogate for $PM_{2.5}$) are provided for each figure. Detailed HYSPLIT output images illustrating the time varying air parcel trajectories layered on top local and distant sources is provided for each modeled day and are illustrated in the following figures (11a-h):

Figure 11a: January 11, 2006 (stagnant) modeled Cowtown back trajectories. There was a weak ridge of high pressure overhead that resulted in very light surface winds much of the day. The HYSPLIT 24-hour back trajectory shows the surface winds generally out of the north and east. The exceedance on this date appears to be attributed to stagnant conditions. During the times when ambient hourly PM10 was high, winds were coming from the southeast in the morning and southwest in the evening. The image on the left illustrates four color coded wind trajectories. The markers indicate the location of the air parcel, one hour before it reaches the Cowtown monitor. The red shaded areas are agricultural lands; the brown shaded areas are feedlots. The image to the right illustrates the long range 24-hour trajectory. The graph at bottom is the hourly PM10 data from the Cowtown monitor and is color coded the same as the trajectory maps to indicate the ambient PM10 concentration at the monitor one hour before the air parcel reaches the monitor. The brown and pink line at 150 µg/m³ indicates when the 24-hour PM10 standard was exceeded (12:00 hrs). Hourly PM2.5 data was not available, so hourly PM10 was used as a surrogate for PM2.5.

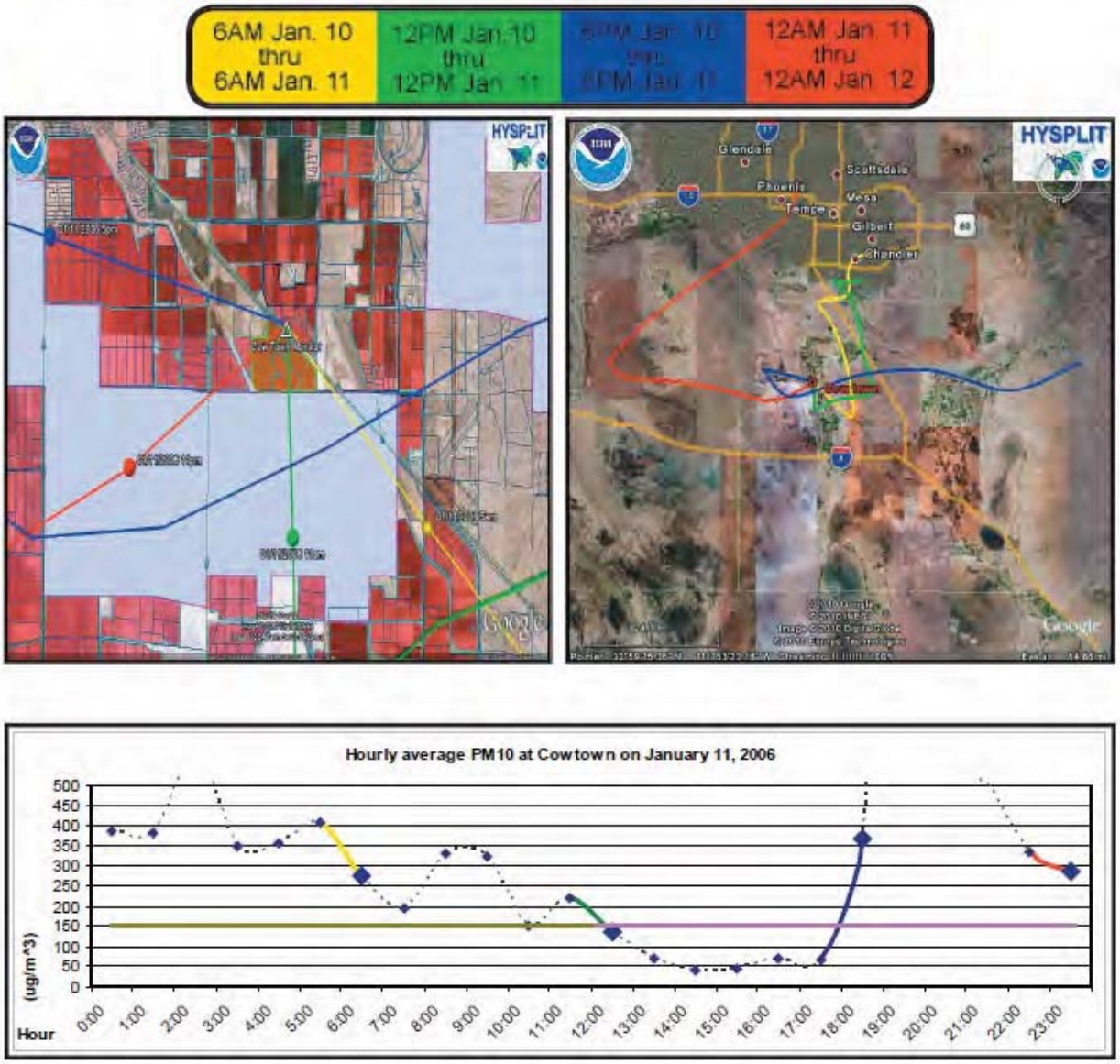


Figure 11b: February 22, 2006 (wind) modeled Cowtown back trajectories. On this date, a large trough of low pressure approached the region from the west. Strong surface winds caused widespread areas of blowing dust across the region. As expected, the HYSPLIT 24-hour back trajectory model shows these near-surface winds out of the west and northwest during this period. The image on the left illustrates four color coded wind trajectories. The markers indicate the location of the air parcel, one hour before it reaches the Cowtown monitor. The red shaded areas are agricultural lands; the brown shaded areas are feedlots. The image to the right illustrates the long range 24-hour trajectory. The graph at bottom is the hourly PM10 data from the Cowtown monitor and is color coded the same as the trajectory maps to indicate the ambient PM10 concentration at the monitor one hour before the air parcel reaches the monitor. The brown and pink line at 150 μg/m³ indicates when the 24-hour PM10 standard was exceeded (22:00 hrs). Hourly PM2.5 data was not available, so hourly PM10 was used as a surrogate for PM2.5.

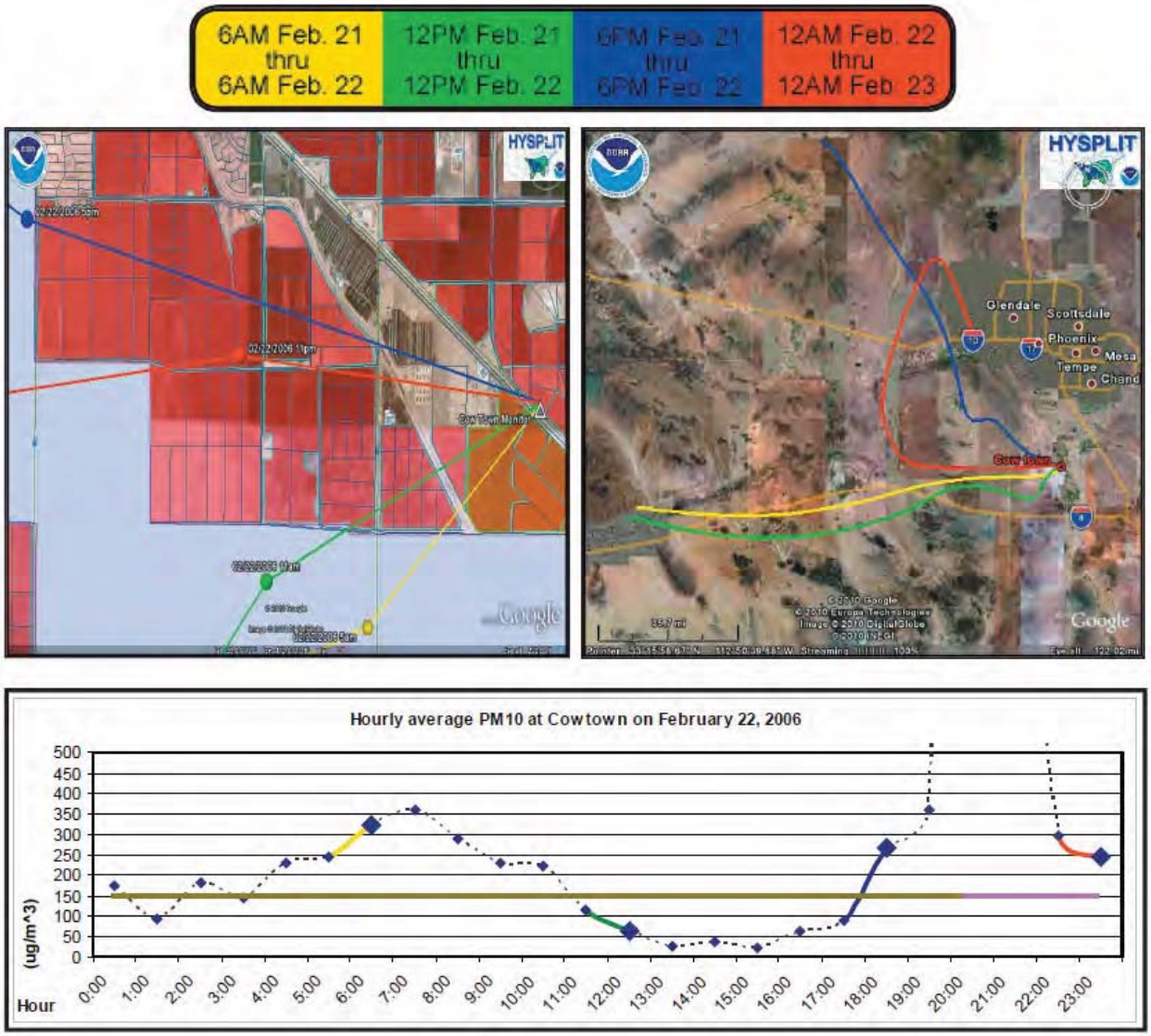


Figure 11c: June 16, 2006 (wind) modeled Cowtown back trajectories. On this date, a large trough of low pressure swept through the region. Strong surface winds caused wide-spread areas of blowing dust, resulting in the exceedance at the Cowtown monitor. Southwest and northwest near-surface winds are pictured in the HYSPLIT 24-hr back trajectory model for this date. The image on the left illustrates four color coded wind trajectories. The markers indicate the location of the air parcel, one hour before it reaches the Cowtown monitor. The red shaded areas are agricultural lands; the brown shaded areas are feedlots. The image to the right illustrates the long range 24-hour trajectory. The graph at bottom is the hourly PM10 data from the Cowtown monitor and is color coded the same as the trajectory maps to indicate the ambient PM10 concentration at the monitor one hour before the air parcel reaches the monitor. The brown and pink line at 150 µg/m³ indicates when the 24-hour PM10 standard was exceeded (09:00 hrs). Hourly PM2.5 data was not available, so hourly PM10 was used as a surrogate for PM2.5.

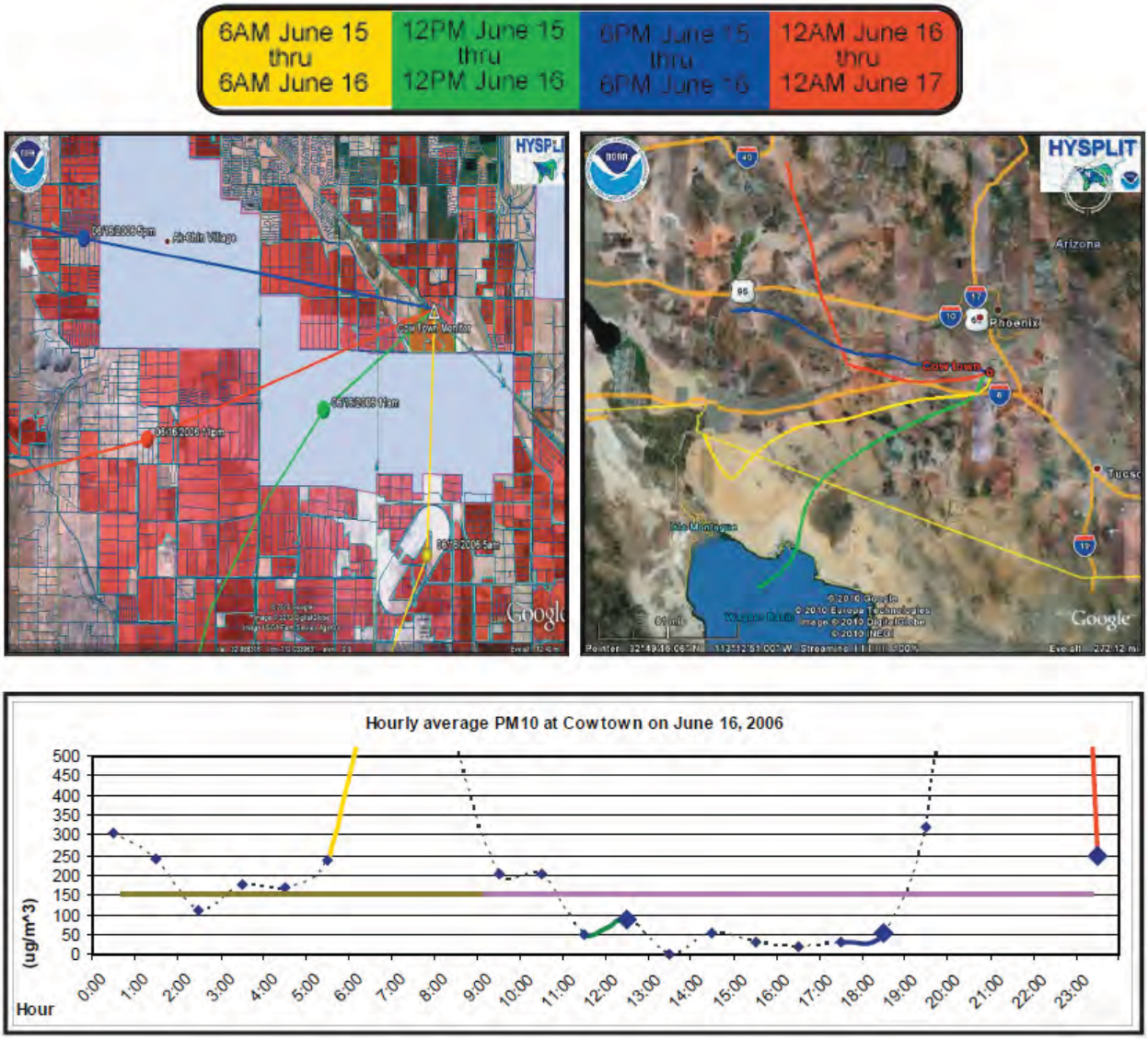


Figure 11d: October 2, 2006 (wind) modeled Cowtown back trajectories. On this date, Arizona was under the influence of high pressure to the southeast and an approaching trough of low pressure to the northwest. The increasing pressure gradients resulted in breezy to gusty surface winds during this period which likely contributed to the Cowtown exceedance on this date. The HYSPLIT 24-hr back trajectory model verifies the approaching trough of low pressure with winds out of the south during this period. The image on the left illustrates four color coded wind trajectories. The markers indicate the location of the air parcel, one hour before it reaches the Cowtown monitor. The red shaded areas are agricultural lands; the brown shaded areas are feedlots. The image to the right illustrates the long range 24-hour trajectory. The graph at bottom is the hourly PM10 data from the Cowtown monitor and is color coded the same as the trajectory maps to indicate the ambient PM10 concentration at the monitor one hour before the air parcel reaches the monitor. The brown and pink line at 150 µg/m³ indicates when the 24-hour PM10 standard was exceeded (07:00 hrs). Hourly PM2.5 data was not available, so hourly PM10 was used as a surrogate for PM2.5.

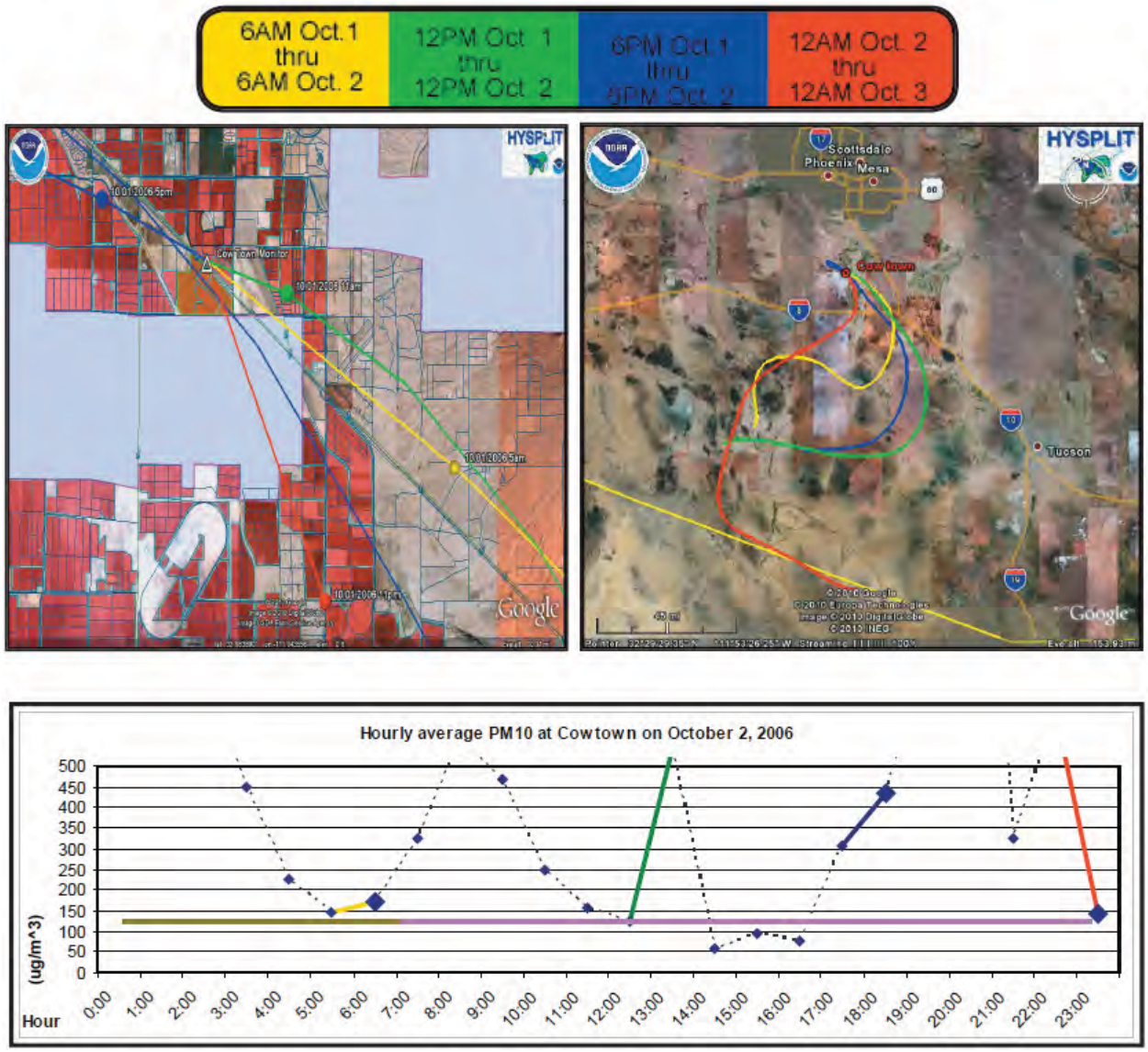


Figure 11e: October 9, 2007 (moderate winds) modeled Cowtown back trajectories. A weak ridge of high pressure overhead on this date resulted in mostly light surface winds during this period. The Cowtown monitor, however, showed several hours near 10 mph. Therefore, this date could not be classified as either high-wind or stagnant. The HYSPLIT 24-hr back trajectory model shows the variable wind directions a typical high pressure system would produce. The PM2.5 exceedance at Cowtown on this date was likely due to several days of accumulating particulates in the local area. The image on the left illustrates four color coded wind trajectories. The markers indicate the location of the air parcel, one hour before it reaches the Cowtown monitor. The red shaded areas are agricultural lands; the brown shaded areas are feedlots. The image to the right illustrates the long range 24-hour trajectory. The graph at bottom is the hourly PM10 data from the Cowtown monitor and is color coded the same as the trajectory maps to indicate the ambient PM10 concentration at the monitor one hour before the air parcel reaches the monitor. The brown and pink line at 150 μg/m³ indicates when the 24-hour PM10 standard was exceeded (13:00 hrs). Hourly PM2.5 data was not available, so hourly PM10 was used as a surrogate for PM2.5.

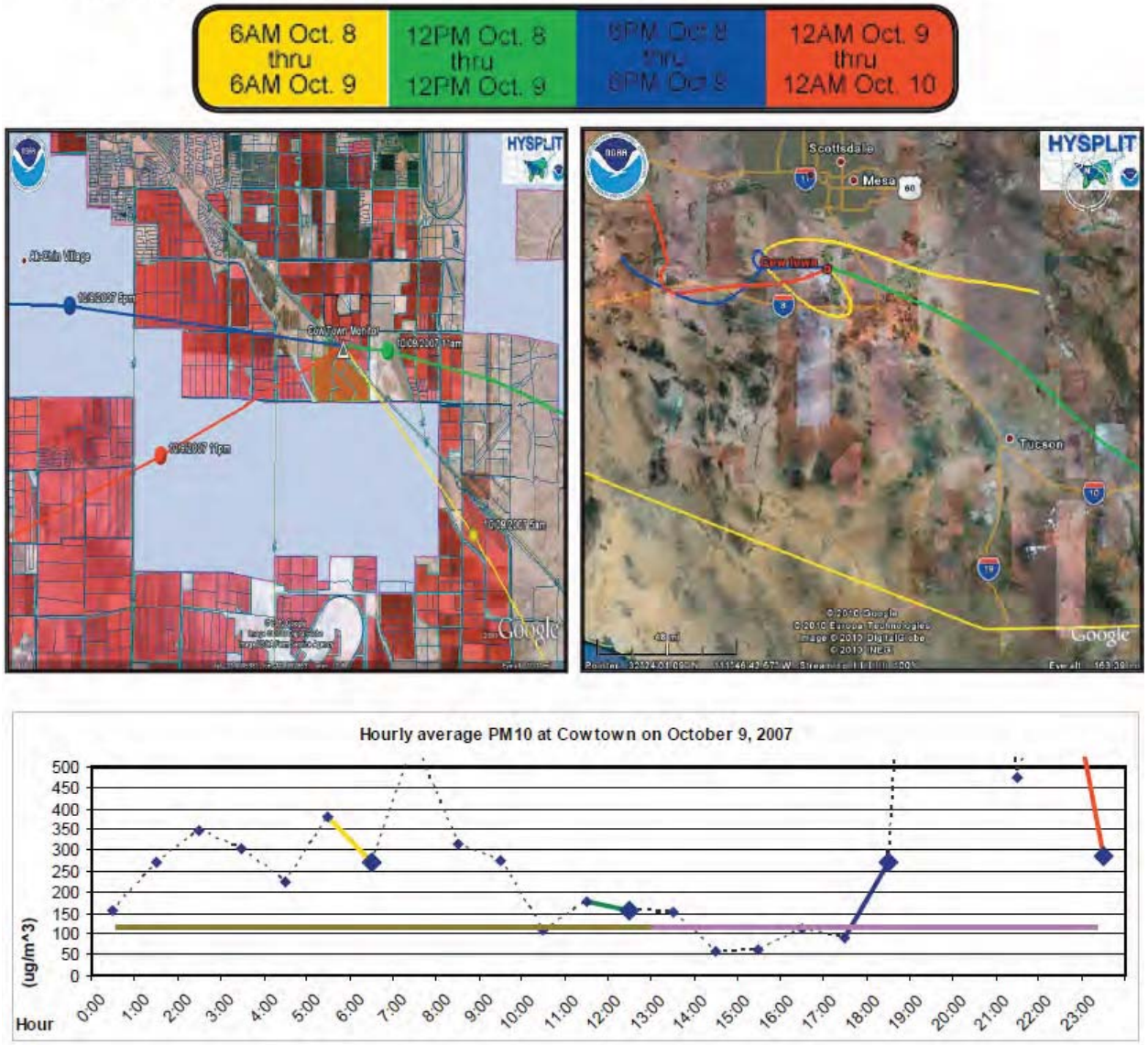


Figure 11f: March 25, 2008 (stagnant) modeled Cowtown back trajectories. A large ridge of high pressure to the southwest produced very light winds at the surface for several days during this period. The HYSPLIT 24-hr back trajectory model shows winds out of the southwest on this date. With very light surface winds, it appears that the stagnant conditions can be attributed to the exceedance at Cowtown. The image on the left illustrates four color coded wind trajectories. The markers indicate the location of the air parcel, one hour before it reaches the Cowtown monitor. The red shaded areas are agricultural lands; the brown shaded areas are feedlots. The image to the right illustrates the long range 24-hour trajectory. The graph at bottom is the hourly PM10 data from the Cowtown monitor and is color coded the same as the trajectory maps to indicate the ambient PM10 concentration at the monitor one hour before the air parcel reaches the monitor. The brown and pink line at 150 μg/m³ indicates when the 24-hour PM10 standard was exceeded (10:00 hrs). Hourly PM2.5 data was not available, so hourly PM10 was used as a surrogate for PM2.5.

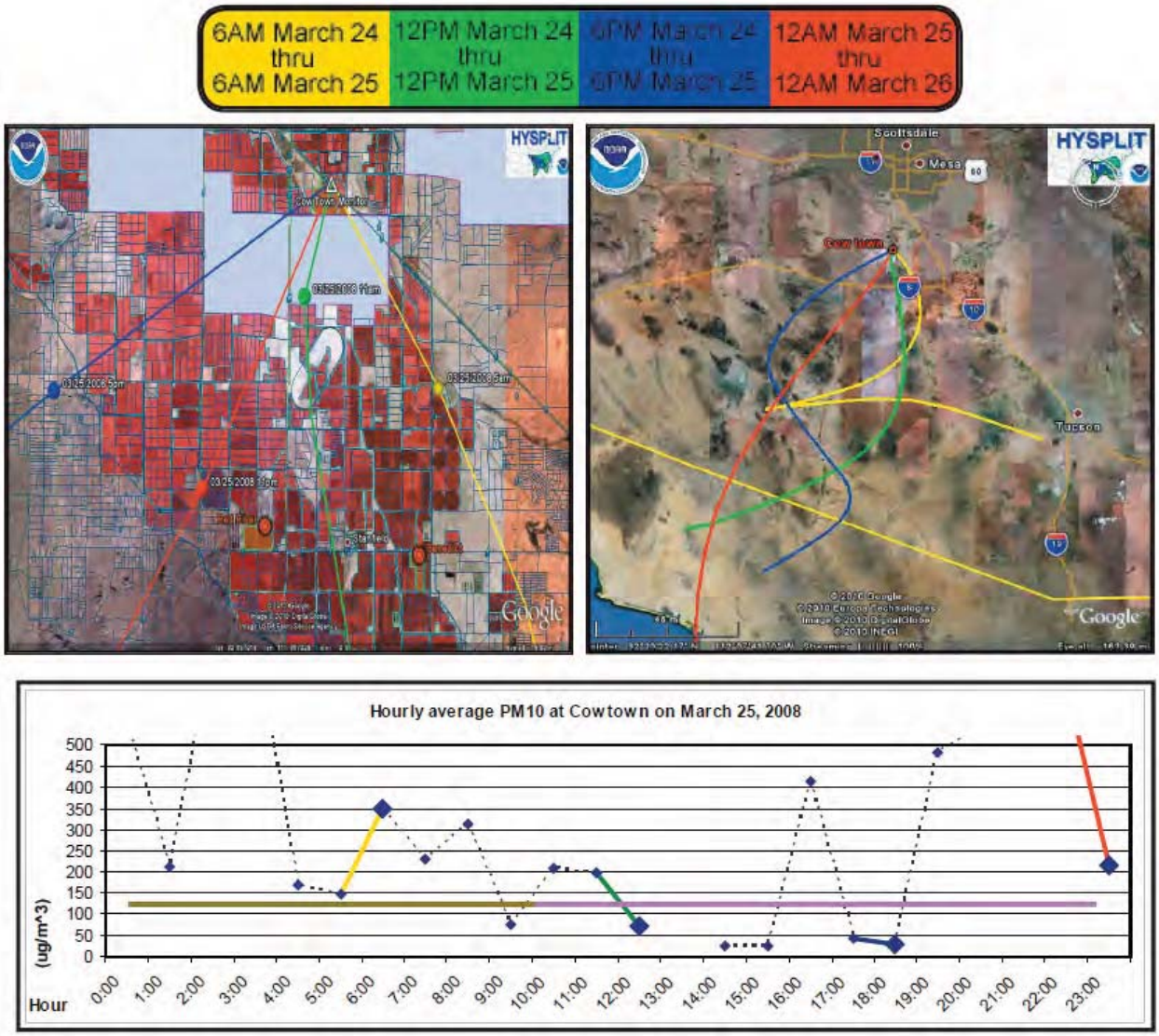
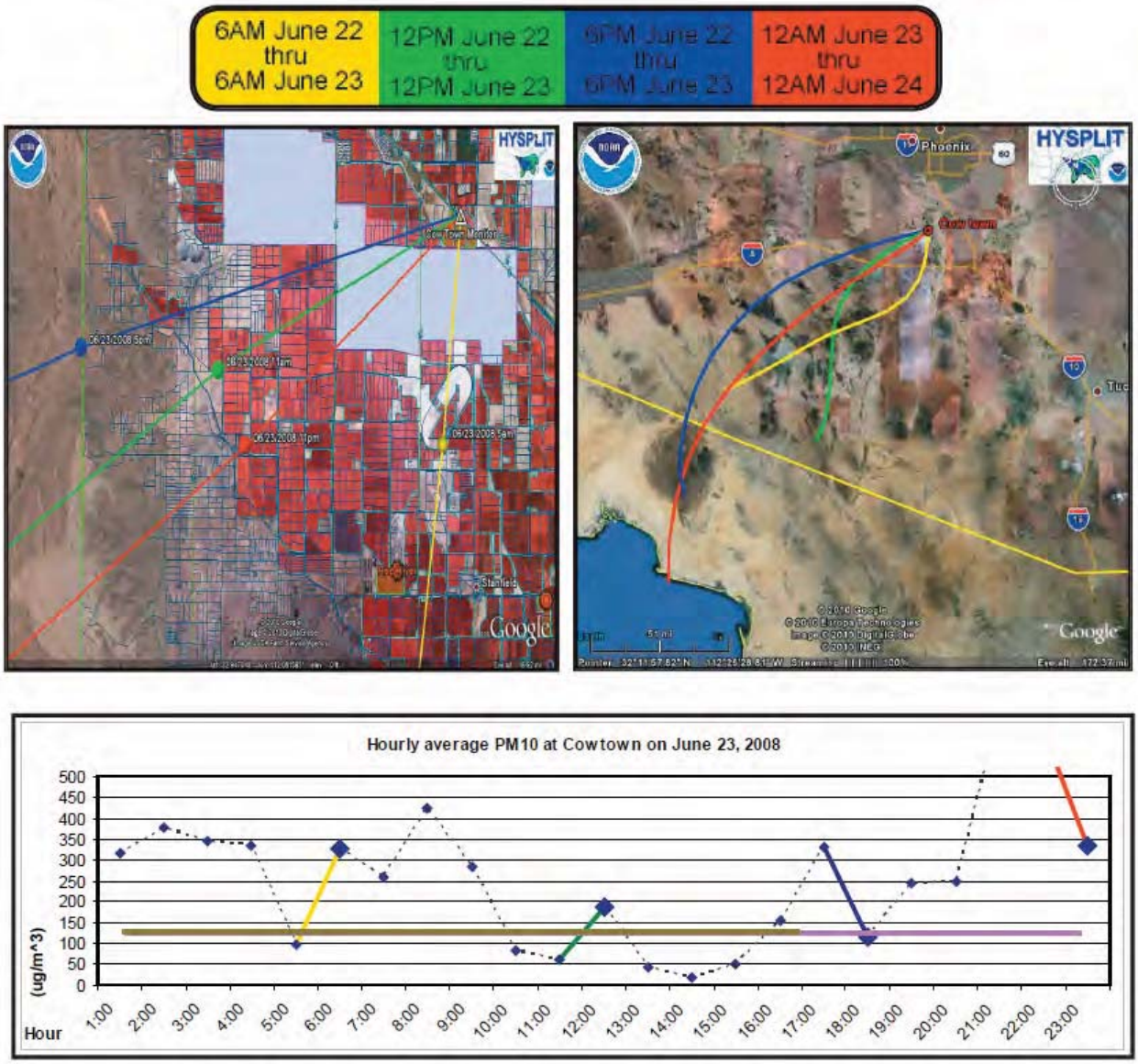


Figure 11g: June 23, 2008 (wind) modeled Cowtown back trajectories. On this date, a large area of high pressure over the region was competing with a trough of low pressure in the Pacific Northwest. Increased pressure gradients resulted in stronger surface winds during this period. The HYSPLIT 24-hour back trajectory model shows a classic southwesterly flow associated with an approaching trough of low pressure. It would appear that strong winds can be attributed to the exceedance at Cowtown on this date. The image on the left illustrates four color coded wind trajectories. The markers indicate the location of the air parcel, one hour before it reaches the Cowtown monitor. The red shaded areas are agricultural lands; the brown shaded areas are feedlots. The image to the right illustrates the long range 24-hour trajectory. The graph at bottom is the hourly PM10 data from the Cowtown monitor and is color coded the same as the trajectory maps to indicate the ambient PM10 concentration at the monitor one hour before the air parcel reaches the monitor. The brown and pink line at 150 μg/m³ indicates when the 24-hour PM10 standard was exceeded (17:00 hrs). Hourly PM2.5 data was not available, so hourly PM10 was used as a surrogate for PM2.5.

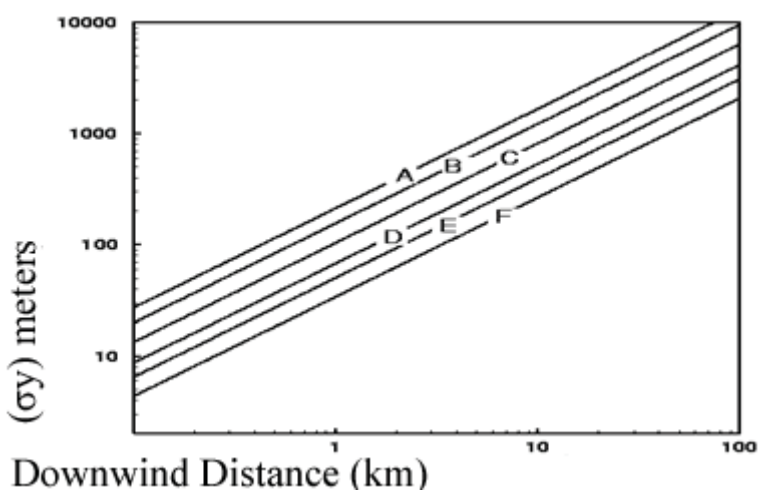


Data Analysis - Medium and long range transport is not occurring

Long and medium range transport of Primary PM generally creates region wide impacts due to down wind horizontal plume spreading. This is a well known component of dispersion and becomes particularly evident in ambient PM monitoring data for air pollution monitors which are located within the same airshed and in close proximity to each other. In Arizona, there are several $PM_{2.5}$ monitors in the state, including: Casa Grande, Apache Junction, Douglas, Orange Grove, Prescott Valley, and Yuma. Of these sites, Casa Grande is the nearest to Cowtown at approximately 24 km while Yuma is the farthest at 253 km. The Cowtown, Casa Grande and Apache Junction monitors are all in the same Gila River basin airshed and in terms of potential impacts from long range transport, would all likely to be impacted by the same plume.

The relative distance from the Cowtown monitor for Casa Grande and Apache Junction are 24 km and 64 km, respectively. If one were to assume Pasquill-Gifford rural horizontal dispersion (see figure 12) from a source 100 km from Cowtown and south-westerly winds, which is the predominant wind direction for each of the seven days modeled in the back trajectory analysis, it is easy to see that both Cowtown and Casa Grande should be equally impacted by the distant source. This is because the horizontal plume spread (σ_y) is expected to be large enough to impact both sites (figure 13). Based on each meteorological stability class, A-F, a source 100 km away from Cowtown is likely to produce a plume with a σ_y ranging from 20 km to 100 km. Since the Casa Grande monitor is only 24 km from the Cowtown monitor, one would estimate that long range transport from any direction would likely impact the two monitors. Of course, for the impacts to be equal at each site, one would need to assume a perpendicular incident angle of impact to the line drawn between Cowtown and Casa Grande, but varying the incident angle in either direction would only likely create marginal variations in relative impacts at each site, since the deposition rate of $PM_{2.5}$ is slow and the two monitors are close together.

Figure 12: Pasquill-Gifford σ_y, rural horizontal dispersion parameters. A-F are meteorological stability classes, where A is extremely unstable, B is moderately unstable, C is slightly unstable, D is neutral, E is slightly stable, F is moderately stable.



The Pasquill-Gifford dispersion parameters are theoretical and except for the use of stability classes, it does not include provisions for real world actions: like chemical conversion, deposition and removal, wind speed, surface roughness and a whole suite of meteorological variables which will directly influence the plume spread and PM concentrations downwind. Furthermore, the six stability classes do not represent the real atmosphere. Real dispersion varies continuously throughout the atmosphere, from stable to unstable and not stepwise as the A-F stability classes do. So, some variation in the relative PM impacts at each monitor is expected, but the general principal remains the same; distant sources from Cowtown will likely impact both Cowtown and Casa Grande, and on some occasions impact all three monitors, including Apache Junction.

If long or medium range transport is the source of the exceedances at Cowtown, a statistical analysis of the data collected from each of the three Pinal County monitoring sites should demonstrate that the ambient concentrations of the three sites are similar. The following analysis compares the ambient $PM_{2.5}$ concentrations from Cowtown to the ambient $PM_{2.5}$ concentrations from the nearby Casa Grande monitor, and as a supplement, to the more distant monitors at: Apache Junction, Douglas, Orange Grove, Prescott Valley, and Yuma for three years spanning from 2006 to 2008.

The comparison between the Casa Grande $PM_{2.5}$ Monitor and the Cowtown monitor reveals a significant difference in measured concentrations on both daily average and annual average $PM_{2.5}$. Over a period of three years from 2006 to 2008, the Cowtown monitor consistently measured more than double the ambient concentrations at Casa Grande, which implies that the impacts at that monitor are not from distant sources, but are from local sources of particulate pollution. Table 4 below illustrates the long term average differences between all of the $PM_{2.5}$ monitors in Arizona For all days in 2006, 2007 and 2008.

Table 4: Annual average ambient $PM_{2.5}$ concentrations at the Cowtown monitoring site and other $PM_{2.5}$ monitoring sites. In 2006 the annual average $PM_{2.5}$ concentration at Cowtown was 22.74 $\mu g/m^{3,}$ while the next highest annual average $PM_{2.5}$ concentration was 5.31 $\mu g/m^3$ from Apache Junction. This substantial difference in average ambient $PM_{2.5}$ concentrations continues through 2007 and 2008.

PM2.5 Measurements ($\mu g/m^3$)

Site	Site ID	2006	2007	2008	3 Yr Annual Avg
Cowtown	04-021-3013	22.74	22.5	19.63	21.62
Apache Junction	04-021-3002	5.31	6.96	7.52	6.60
Casa Grande	04-021-0001	7.55	10.25	10.61	9.47
Douglas	04-003-1005	6.78	6.79	6.84	6.80
Orange Grove	04-019-0011	5.8	5.84	5.57	5.74
Prescott Valley	04-025-2002	-	-	6.42	-
Yuma	04-027-0004	-	-	10.18	-

Close inspection of monitored $PM_{2.5}$ concentrations at Cowtown for days where the concentration exceeded the 35 µg/m^3 standard, again indicates highly localized $PM_{2.5}$ values at Cowtown independent of meteorological conditions. A comparative analysis of a sample of 30 days where the Cowtown monitor exhibits an exceedance for the three year period is shown Table 5 below.

Table 5: Daily ambient $PM_{2.5}$ concentrations at the Cowtown monitoring site and other Pinal county monitoring sites for the 30 exceedance days. For all $PM_{2.5}$ monitors in the state.

Sample of 30 Exceedance Days of PM2.5 (µg/m^3)

Site	Site ID	Sample Average	Observations*
Cowtown	04-021-3013	43.8	30
Apache Junction	04-021-3002	8.1	25
Casa Grande	04-021-0001	11.8	29
Douglas	04-003-1005	9.5	27
Orange Grove	04-019-0011	6.1	25
Prescott Valley	04-025-2002	7.2	7
Yuma	04-027-0004	13.8	5

*Not all monitors were in operation prior to 2008 and some monitors were flagged for invalid data on the day of the Cowtown monitor exceedance.

A statistical analysis was performed between the Pinal County ambient $PM_{2.5}$ monitored values: Cowtown, Casa Grande and Apache Junction. The average measured 24-hr averages are plotted in the Figure 13 below and indicate that the average 24-hour $PM_{2.5}$ concentrations are more than twice that of Casa Grande and Apache Junction.

Figure 13: A comparison of average 24-hour $PM_{2.5}$ concentrations between Cowtown, Apache Junction and Casa Grande.

Paired t-tests were performed to test the statistical significance of the difference between the measured concentrations at the three sites. The first set of three paired t-tests (Tables 6,7 and 7) use all available $PM_{2.5}$ data from 2006, 2007 and 2008, while the second set of three (Tables 9,10 and 11) are paired t-tests using only the $PM_{2.5}$ data from the 30 exceedance days. Results indicate the differences in the measured concentrations at Cowtown are statistically significant compared to Casa Grande and Apache Junction at the 95% confidence interval. The detailed results of the t-tests are:

Table 6: Paired t-test between Cowtown and Casa Grande, for all data 2006, 2007 and 2008.

	Cowtown	***Casa Grande***
Mean	21.65	9.34
Variance	167.99	20.30
Observations	159	159
Pearson Correlation	0.44	
Mean Difference	12.30	
Maximum Difference	55.26	
Minimum Difference	-6.80	
df	158	
t Stat	13.263	
P(T<=t) one-tail	9.25E-28	
t Critical one-tail	1.655	
P(T<=t) two-tail	1.85E-27	
t Critical two-tail	1.975	

Table 7: Paired t-test between Cowtown and Apache Junction, for all data 2006, 2007 and 2008.

	Cowtown	***Apache Junction***
Mean	21.05	6.65
Variance	153.69	9.94
Observations	150	150
Pearson Correlation	0.35	
Mean Difference	14.40	
Maximum Difference	55.70	
Minimum Difference	-6.00	
df	149	
t Stat	15.127	
P(T<=t) one-tail	3.28E-32	
t Critical one-tail	1.655	
P(T<=t) two-tail	6.55E-32	
t Critical two-tail	1.976	

Table 8: Paired t-test between Casa Grande and Apache Junction, for all data 2006, 2007 and 2008.

	Casa Grande	*Apache Junction*
Mean	9.41	6.75
Variance	21.39	9.97
Observations	144	144
Pearson Correlation	0.55	
Mean Difference	2.65	
Maximum Difference	22.60	
Minimum Difference	-6.50	
df	143	
t Stat	8.122	
P(T<=t) one-tail	9.70E-14	
t Critical one-tail	1.656	
P(T<=t) two-tail	1.94E-13	
t Critical two-tail	1.977	

Table 9: Paired t-test between Casa Grande and Apache Junction, for only the 30 exceedance days.

	Casa Grande	*Cowtown*
Mean	11.6034	44.0692
Variance	27.8040	57.3325
Observations	29	29
Pearson Correlation	-0.1982	
Mean Difference	32.4658	
Maximum Difference	55.2633	
Minimum Difference	19.2	
df	28	
t Stat	-17.4001	
P(T<=t) one-tail	7.55652E-17	
t Critical one-tail	1.7011	
P(T<=t) two-tail	1.5113E-16	
t Critical two-tail	2.0484	

Table 10: Paired t-test between Casa Grande and Apache Junction, for only the 30 exceedance days.

	Apache Junction	*Cowtown*
Mean	8.105	42.9657
Variance	9.1113	32.4848
Observations	25	25
Pearson Correlation	-0.3151	
Mean Difference	34.8607	
Maximum Difference	55.7	
Minimum Difference	21.6	
df	24	
t Stat	-24.0702	
P(T<=t) one-tail	1.28801E-18	
t Critical one-tail	1.7109	
P(T<=t) two-tail	2.57601E-18	
t Critical two-tail	2.0639	

Table 11: Paired t-test between Casa Grande and Apache Junction, for only the 30 exceedance days.

	Casa Grande	*Apache Junction*
Mean	11.78	8.1050
Variance	30.9350	9.1113
Observations	25	25
Pearson Correlation	0.6993	
Mean Difference	3.675	
Maximum Difference	11.7	
Minimum Difference	-5	
df	24	
t Stat	4.5147	
P(T<=t) one-tail	7.13287E-05	
t Critical one-tail	1.7109	
P(T<=t) two-tail	0.000142657	
t Critical two-tail	2.0639	

The data analysis makes a clear distinction between the three Pinal County $PM_{2.5}$ monitoring sites. If the assumption is made that long range transport is the source of the $PM_{2.5}$ exceedances in Pinal County, one would also need to assume that the exceedances would be more regional in nature, and therefore any statistical analysis on $PM_{2.5}$ monitor data from Pinal County would show considerable agreement among the monitors. The paired t-tests do not indicate that level of agreement, however. For all data, the paired t-test indicates that the Cowtown monitoring site is very different from both Casa Grande and Apache Junction, while the paired t-test for Casa Grande and Apache Junction show reasonable agreement. The same is true when looking at only the 30 exceedance days.

Data Analysis - $PM_{2.5}$ is a function of PM_{10}

The $PM_{2.5}$ problem in western Pinal County is relatively unique because, unlike virtually all other areas of the United States experiencing nonattainment of the $PM_{2.5}$ NAAQS, it does not

appear that primary combustion emissions and secondary particles are dominant for the site where the exceedances have been recorded. Both direct and statistical evidence suggests that $PM_{2.5}$ exceedances at the Cowtown monitor are largely the result of the numerous and extreme exceedances of the PM_{10} NAAQS.

First, with only one exception, all of the exceedances of the 24-hour average $PM_{2.5}$ NAAQS of 35 μg/m^3 occur only when there is also an exceedance of the PM_{10} NAAQS of 150 μg/m^3, as the following Table 9 illustrates:

Table 12: Comparison of PM_{10} and $PM_{2.5}$ Values for Valid $PM_{2.5}$ Exceedances for the Cowtown Monitor

		2006	***2007***	***2008***	***All Years***
Average	PM_{10} (μg/m^3)	380.5	353.6	322.6	358.2
	$PM_{2.5}$ (μg/m^3)	45.1	46.5	39.0	44.1
	Percent $PM_{2.5}$	12.6%	16.1%	12.8%	13.7%
Maximum	PM_{10} (μg/m^3)	606.0	759.3	465.0	759.3
	$PM_{2.5}$ (μg/m^3)	69.4	59.7	41.7	69.4
	Percent $PM_{2.5}$	20.4%	32.7%	18.2%	32.7%
Minimum	PM_{10} (μg/m^3)	249.0	182.6	217.0	182.6
	$PM_{2.5}$ (μg/m^3)	36.2	37.0	35.9	35.9
	Percent $PM_{2.5}$	6.9%	6.0%	9.0%	6.0%
Number of Samples		13	9	7	29

The one exception was for August 27, 2006, for which the $PM_{2.5}$ concentration was recorded as 35.8 μg/m^3 and PM_{10} was 86 μg/m^3. Closer examination of this sample revealed that the original filter weight was very likely erroneous. This value has been flagged in AQS as invalid. The supporting documentation for this is contained in Appendix A of this memorandum.

In addition to this assessment, linear regression analysis was performed to determine the degree to which PM_{10} concentrations and meteorological factors explained the variation in $PM_{2.5}$ concentrations. Data from calendar years 2006 through 2008 and January through June 2009 were included in this analysis. Meteorological data were taken from the AZMET Maricopa station because there was a complete record for that site, whereas the meteorological data set for the Cowtown monitor contains several data gaps. The AZMET Maricopa monitor (Latitude 33° 04' 07" N, Longitude 111° 58' 18" W) is located approximately 4 miles north of the Cowtown monitor (Latitude 33° 00' 38" N, Longitude 111° 58' 19" W). Meteorological variables evaluated included: average, maximum and minimum temperature; average and maximum relative

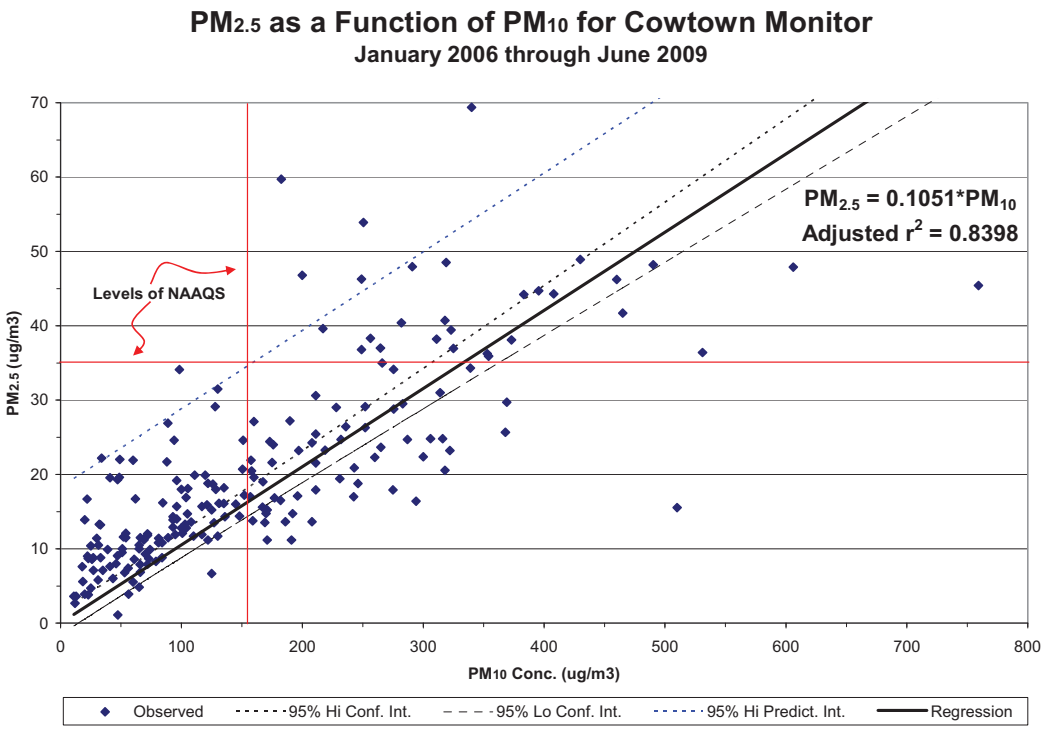
humidity; daily average, hourly average and hourly maximum wind speed; and daily average vector wind speed and direction, and wind direction during the maximum wind hour.

Multiple linear regression can be done either as a least-squares fit based on the averages of the dependent and independent variables, which includes calculating the estimate for a non-zero constant (y=ax+b), or through the origin (intercept of zero, or y=ax). Because $PM_{2.5}$ is a subset of PM_{10}, the potential that none of the particulate matter would be in the $PM_{2.5}$ fraction is highly unlikely; i.e., performing a linear regression with an intercept other than zero would be inappropriate. PM_{10} concentration and several meteorological variables were evaluated using scatter plots to determine if nonlinear relationships were evident (none were found), and then regressed with $PM_{2.5}$ as the dependent variable. PM_{10}, by far, explained more variation in $PM_{2.5}$ than any other variable. The only other variable that explained a significant amount of variation in $PM_{2.5}$ concentrations was relative humidity, and maximum relative humidity was a better predictor. This model, however, had a significant fault, in that the residuals (difference between the predicted and actual $PM_{2.5}$ concentrations) were significantly correlated with the actual $PM_{2.5}$ concentration. Consequently, the only reliable model that could be developed was for $PM_{2.5}$ as a function of PM_{10}. The results of that regression analysis are presented in Table 13:

Table 13: A linear regression analysis to determine the degree to which PM_{10} concentrations and meteorological factors explained the variation in $PM_{2.5}$ concentrations.

Regression Statistics					
Multiple R	0.9192				
R Square	0.8448				
Adjusted R Square	0.8398				
Standard Error	9.30858				
Observations	199				
ANOVA					
	df	SS	MS	F	Significance F
Regression	1	93417.61	93418	1078.11	7.92E-82
Residual	198	17156.62	86.65		
Total	199	110574.23			
	Coefficients	Standard Error	t Statistic	P-value	
Intercept	0	#N/A	#N/A	#N/A	
PM_{10}	0.1051	0.00320	32.83	4.7E-82	

Figure 14, below, presents a scatter plot with the regression line, the 95% confidence intervals for the regression line and the 95% one-tailed upper prediction interval.



This figure demonstrates that there is still a lot of variability that is not explained within this simple statistical model, especially for the outliers – where either the percentage of PM_{10} that is $PM_{2.5}$ is either much higher or much lower than the statistically estimated average of 10.5%. Many of these intervening factors likely include levels of activity at difference sources, wind direction and speed with respect to emissions from specific sources on certain days, and smoke from local fires (which would result in a much higher $PM_{2.5}$ proportion in that sample), to name a few. Regardless, this model indicates that, with 95% confidence, $PM_{2.5}$ concentrations are largely driven by the amount of PM_{10} in the atmosphere.

Conclusions

The Cowtown monitoring site lies within an irrigated desert plain, with active and retired agricultural operations to the north, northwest and east. Three cattle feedlot companies and a grain-processing complex operate to the south, southwest and southeast. Given the source mix near the Cowtown monitor, it is of little surprise that the major contributor from each of seven source categories (geologic soil, feedlot soil, motor vehicle emissions, vegetative burning, coal fired power plant, ammonium sulfate and ammonium nitrate) is from the feedlot source category, with geologic soil (including unpaved roads and agricultural soils) following second.

The following list presents the major findings of this research:

- The Cowtown monitor has a prominent chemical signature from nearby feedlots.
- The major source contributors to the $PM_{2.5}$ exceedances at Cowtown are from feedlots and geologic soil.
- When compared to other monitors in Pinal County, only Cowtown has feedlots as the major source contributor; other sites are geologic soil.
- Stagnation during the 2003 study produced high relative contributions from feedlot dust at Cowtown.
- Both stagnation and non-stagnation events created elevated $PM_{2.5}$ concentrations at Cowtown in 2006, 2007 and 2008, which indicate that fairly strong local sources can impact the monitor under any meteorological condition.
- The trajectory of winds for each of the 29 days in 2006, 2007 and 2008 can transport emissions from local sources to the Cowtown monitor.
- The trajectory of winds for each of the 29 days in 2006, 2007 and 2008 indicate that there are no distant sources along the back trajectory which would be expected to contribute to any of the $PM_{2.5}$ exceedances at Cowtown.
- On a daily and annual basis, Cowtown consistently measures higher $PM_{2.5}$ then any other monitor in Pinal County.
- $PM_{2.5}$ exceedances are always concurrent with PM_{10} exceedances.
- Any control measures that will achieve attainment of the PM_{10} NAAQS will also yield attainment of the $PM_{2.5}$ NAAQS.

REFERENCES

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Chow, J.C., Watson, J.G., Kuhns, H., Etyemezian, V., Lowenthal, D.H., & Crow, D., Kohl, S.D., Engelbrecht, J.P., Green, M.C., (2004). Source profiles for industrial, mobile, and area sources in the Big Bend regional Aerosol Visibility and Observational study.

APPENDIX A

Ken Buchanan
Assistant County Manager

Development Services

Don Gabrielson
Air Quality Director

PINAL • COUNTY
wide open opportunity

Terry Doolittle
County Manager

MEMORANDUM FROM AIR QUALITY

Date: December 7, 2009

To: File: S:\Word\Field Services\Ambient Monitors\QA Documents\QA Memos\Corrective Action

Cc:

From: Kale Walch

RE: Cowtown 8/27/2006 PM2.5 invalidation

Priority:

Below is summary of the actions that lead to the invalidation of the Cowtown August 27, 2006 PM2.5 filter being invalidated

During the course of reviewing data for the PM2.5 nonattainment boundary recommendation the original concentration listed for the Cowtown filter based PM2.5 sample taken on August 27, 2006 became suspect. Out of the thirty PM2.5 exceedance days reviewed for the 2006- July 2009 timeframe the only day on which a corresponding PM10 exceedance did not occur was August 27, 2006.

The internal review that was initiated resulted in the following conclusions

- The 8/27/2006 Cowtown PM2.5 filter was equilibrated and re-weighed on 10/20/09. The concentration value from the second weighing was 9 $\mu g/m^3$ versus the original concentration of 36 $\mu g/m^3$.
- The PM2.5 filters that were originally weighed before and after the Cowtown 8/27/2006 filter were also re-weighed. Unlike the Cowtown filter both of the second weights for these filters closely agreed with the first weighing.
- Pictures of several PM2.5 filters from 2006 were taken on 11/4/2009. While a colorimetric comparison of the filters did not lead to any quantifiable conclusion it did show the 8/27/2006 filter was lighter in color compared to other exceedance days.
- It is believed human error resulted in the original concentration that was entered into PCAQCD documents and AQS for the 8/27/2006 Cowtown sample. As a result this date has been invalidated in both PCAQCD documents and AQS as of 11/20/2009.

PCAQCD will resubmit a data certification to EPA Region 9 in April of 2010 that will include a request to certify the 2006 PCAQCD data set.

AIR QUALITY CONTROL DISTRICT

31 North Pinal Street, Building F, PO Box 987 Florence, AZ 85132 T 520-866-6929 FREE 888-431-1311 F 520-866-6967 www.pinalcountyaz.gov

Corrective Action Form

PART 1 – PROBLEM IDENTIFICATION

Submitted to: Don Gabrielson Date: October 30, 2009

Site/Location: Cowtown (CWTN) PM2.5 Date problem identified: October 28, 2009

Nature of problem:

The 8/27/09 PM2.5 filter value of 35.8 $\mu g/m^3$, an exceedance of the NAAQS, reported for CWTN appeared to be in error. Analysis conducted comparing PM10 and PM2.5 concentrations at CWTN demonstrated that the PM2.5 value reported for 8/27/2006 was approximately 42 percent of the total PM10 which is not consistent with other summertime values.

Recommended action:

Review the data point and determine validity

Signature of Requestor: _____ Date: 12/10/09

PART 2 PROBLEM RESOLUTION

Corrective action completed by: Mike Sundblom Date: October 30, 2009

Summary of corrective action:

CWTM PM2.5 sample filter collected on 8/27/2006 was equilibrated and re-weighed on 10/20/2009. The re-weighed mass value for the filter was 141.801mg. The original weight made on 9/13/2006 was 142.446mg. The revised concentration based upon the second weighing is 9$\mu g/m^3$. Based on this information and visiual observation of the filter color and loading I conclude that the original weight was erroneous. Because the filter was not stored at less that 25C the re-weighed value cannot be considered valid. The value has been invalidated in the PCAQCD datafile and was invalidated in AQS 11/20/2009 with code AR - Lab Error. The occurrence will be reported to EPA with July 2010 data certification.

Effectiveness of corrective action:

The action lead to a review of values reported before and after 8/27/06 and no related errors were discovered. Documentation located at: S:\Word\Field Services\Ambient Monitors\QA Documents\QA Memos\Corrective Action\CWTN PM2.5 08272006

If performance of monitoring equipment has been affected, provide last known date of proper performance and reason (audit, calibration, flow check, precision check, etc.):

No equipment effect was noted. The error was likely due to an operator oversight.

Signature of Unit Manager /Team Leader: _____ Date: 12/10/09

Part 3 – CORRECTIVE ACTION AND APPROVAL SIGNATURES

Could data be impacted (Y/N)? Y If yes, estimated date(s) of suspect/invalid data: 8/27/06

QA Staff _____ Date: 12/10/09

Monitoring Supervisor _____ Date: 12/10/09