Appendix 4. Windblown Dust Emission Estimation Methodology

Introduction

The production of windblown dust occurs through an intricate process where the force of wind initiates the movement of soil particles. As stated below,

> *This process has the distinct phases of particle entrainment, transport and deposition. It is a complex process because it is affected by many factors which include atmospheric conditions (e.g., wind, precipitation and temperature), soil properties (e.g., soil texture, composition and aggregation), land-surface characteristics (e.g., topography, moisture, aerodynamic roughness length, vegetation and non-erodible elements) and land-use practice (e.g., farming, grazing and mining). During a wind-erosion event, these factors interact with each other and, as erosion progresses, the properties of the eroded surface can be significantly modified.* (Shao, 2008a)

The development of an annual inventory of PM_{10} emissions from windblown dust focuses on quantifying the first phase of windblown dust production: particle entrainment. The phases of transport and deposition are typically explored during modeling exercises of specific windblown dust events and are not discussed here.

An assortment of dust emission schemes have been developed that attempt to quantify the entrainment of windblown dust (e.g., "Open Area Wind Erosion" chapter in *WRAP Fugitive Dust Handbook*, WGA, 2006). These schemes differ greatly depending on the geographic scale (local, regional or global) and theoretical constructs of the scheme (e.g., assessment of threshold wind speeds, the importance of soil properties and land uses, etc.). Published empirical data on windblown dust emissions varies widely as well, with dust emission rates for a given wind speed varying from 10^{-1} to 10^{5} µg $m^{-2}s^{-1}$ (Shao, 2008b). This suggests that the specific conditions and properties of subject soils greatly modify dust emission rates, and that the accuracy of a dust emission scheme is heavily dependent on the quality of the input data describing each of these controlling factors (e.g., surface roughness lengths, soil texture, moisture content, vegetation, etc.). Often, there is no reliable data available to account for a controlling factor (e.g., soil moisture or surface roughness lengths), forcing dust schemes to use surrogates or broad assumptions in an attempt to incorporate the effects of a controlling factor. Additionally, even when quality data on a relevant factor exists (e.g., soil texture), the role of that factor as it interacts with other factors is uncertain (Alfaro et al., 2004) or could change as atmospheric or soil conditions are altered throughout the year.

The inherent uncertainties involved with any windblown dust emission scheme require that the available input data for the region of interest be scrutinized to help inform the selection of an appropriate scheme. In choosing a dust emission scheme for this inventory, the focus was placed upon a theoretical model that best describes local, observed windblown dust events combined with empirical data from wind tunnel studies performed in the deserts of the southwest U.S.

Supply-Limited Windblown Dust Emission Scheme

The deserts of the southwest U.S., including Maricopa County, are characterized as supply-limited environments (Gillette and Chen, 2001; Zender and Kwon, 2005), where the potential for generating windblown dust is controlled primarily by the amount of surface material available for entrainment. In contrast, traditional dust emission schemes consider soils to be transport-limited, where windblown dust emissions are controlled solely by the force of wind (Bagnold, 1941; Greeley and Iverson, 1985). Traditional dust emission schemes perform best in areas where contiguous desert land with little vegetation exists (e.g., Sahara Desert). The Sonoran Desert, of which Maricopa County is a part of, contains a wide variety of vegetation, which can be quite dense in some areas, severely limiting the amount of exposed soil to be entrained by wind. Since the bulk of wind erosion research is rooted in the physics of transport-limited soils, most dust emission schemes (Gillette and Passi, 1988; Shao et al., 1993; Marticorena and Bergametti, 1995; Alfaro and Gomes, 2001) do not address many of the physical realities of supply-limited soils.

A major theoretical tenet of transport-limited schemes is that little or no dust emissions occur until wind speeds reach the threshold required for saltation to occur; the process by which the dynamic bombardment of sand particles blasts and breaks down aggregated soils to then be suspended as dust emissions. However, the supply-limited soils of the desert southwest have been shown to emit substantial quantities of dust, even the majority of dust emissions, in the absence of saltation (Macpherson et al., 2008). While the southwest deserts can experience high magnitude wind events where saltation dominates dust production (e.g., haboob), the majority of windblown dust emissions occur during lower intensity, higher frequency events (e.g., synoptic scale fronts, dust devils) (Koch and Renno, 2005; Macpherson et al., 2008). These events often do not reach the threshold wind speeds required for saltation to occur, yet monitoring data consistently record elevated ambient PM_{10} concentrations at these wind speeds (see further discussion in section on Threshold Friction Velocity). This suggests that significant quantities of dust emissions are generated primarily through direct aerodynamic entrainment of available surface material, before saltation occurs. Despite concerns that direct aerodynamic entrainment is limited due to the strong interactive cohesive forces between dust particles (Iverson and White, 1982), several studies have shown the importance of direct aerodynamic entrainment in the production of windblown dust (Loosmore and Hunt, 2000; Roney and White 2004; Kjelgaard et al., 2004; Macpherson et al., 2008; Harris and Davidson 2009). Consequently, the dust scheme chosen for the supply-limited environment of Maricopa County includes the process of direct aerodynamic entrainment as a major contributor to the production of windblown dust.

Another key limitation of transport-limited schemes concerns surface disturbance of soils. Disturbance levels of soils have been shown to be a key factor in controlling the intensity of dust emissions during a wind event (Tegen and Fung, 1995; Belnap and Gilliette, 1998; Gillette and Chen, 2001; Zender and Newman, 2003; Baddock et al., 2011). However, many transport-limited schemes do not have a direct mechanism to incorporate the effects of disturbed soil on dust production. Since dust emissions in a transport-limited scheme are dependent solely on saltation, a disturbed soil is often theoretically assumed to emit at the same rate as a stable soil since the texture, or particle size distribution of the soil is uniform in both disturbed and stable conditions (Alfaro et al., 2004). A common adjustment made to account for disturbance in traditional dust schemes is to assume that disturbed soils have lower threshold friction velocities than stable soils (WGA, 2006). This effect has been shown in relation to saltation (Gillette, 1980), but does not necessarily reflect the threshold friction velocities required for dust emissions, since supply-limited soils can show dust emissions in the absence of saltation on both disturbed and stable soils (Macpherson et al., 2008).

Instead of directly addressing surface disturbance, incorporation of the surface roughness length of the soil (which can provide an approximation for the non-erodible elements of the soil) is usually assumed to be the principal limiter of dust production, beyond friction velocities, in transport-limited schemes (Marticorena et al., 1997; Alfaro et al., 2004). Surface roughness lengths (the theoretical height at which the mean wind speed is assumed to be zero) are either calculated through direct measurement of wind speeds at varying heights or approximated through equations that estimate the roughness elements (e.g., rocks, vegetation, structures) associated with land cover or land uses. This produces wide variations in the estimation of surface roughness lengths for similar surfaces (MacKinnon et al., 2004). Surface roughness values have also been shown to change dynamically with effects from factors such as atmospheric conditions, past wind events, levels of disturbance and vegetation growth (Greeley et al., 1997). Attempts have been made recently to improve the database of available surface roughness lengths through satellite data, but incorporation of these data has not readily occurred and is largely focused on global scale dust emissions (Prigent et al., 2005). Because of the transient nature of surface roughness lengths and differing methodologies used to measure these lengths, a reliable local database does not exist that can incorporate their effects, especially when dealing with a large time period like an annual inventory (Marticorena et al., 2006).

While surface roughness lengths can eliminate rough surfaces as sources of dust production (i.e., many dust schemes assume no windblown dust emissions occur from surfaces with roughness lengths greater than 0.1 cm; Gillette, 1999) it cannot explain the difference in emissions seen between disturbed and stable soils at similar roughness lengths. In fact, the Owen Effect (Owen, 1964) demonstrates that surface roughness actually *increases* during saltation events. This positive feedback loop has the effect of simultaneously increasing friction velocities and saltation effects, which in turn increase vertical flux emissions (Gillette et al., 1998). Additionally, with supply-limited soils in particular, disturbed soils have been shown to produce orders of magnitude higher dust emissions than similar stable soils, despite having similar surface roughness lengths (Nickling and Gillies, 1989; Macpherson et al., 2008). This is because disturbance of the soil, through breaking of surface crusts and reorientation of surface grains, has the foremost effect of creating larger reservoirs of surface material available to be entrained as compared to stable soils. Since actual surface roughness lengths of subject soils are largely unknown and vary over time; and because surface roughness does not directly address the effects of disturbed soils, another variable is required to approximate disturbance levels. In this scheme, disturbance of soils is determined through use of site-specific inspection data of specific land uses gathered by Maricopa County Air Quality Department (MCAQD) personnel (further detail available in section on Threshold Friction Velocity).

In addition to the conceptual dust scheme associated with supply-limited soils, empirical wind tunnel data gathered in local supply-limited environments is utilized in the development of vertical dust fluxes. Three data sets of wind tunnel tests performed in the southwest U.S. (areas around Barstow, California; Las Vegas, Nevada and southern Arizona) present empirical data on windblown dust emission rates (Nickling and Gillies, 1989; Wacaser et al., 2006; Macpherson et al., 2008). These data confirm the initiation of dust emissions at wind speeds lower than thresholds required for saltation and that disturbed soils produce higher dust emissions than stable soils. These outcomes are expected in supply-limited environments and support the use of a dust scheme modeled around the characteristics of supply-limited environments. Specifically, the wind tunnel tests performed in southern Arizona (Nickling and Gillies, 1989) form the basis of the vertical fluxes (dust emission rates) used to quantify PM_{10} emissions from windblown dust in Maricopa County and the PM_{10} nonattainment area (see section on Vertical Emission Fluxes for further discussion).

As highlighted in the introduction, there are many factors that control the production of windblown dust beyond wind speed velocities and disturbance levels that cannot be directly accounted for in this dust scheme (e.g., soil texture, soil moisture, topography, land use, etc.).

Data for these factors can be limited, nonexistent or unreliable. It is also unknown what degree of importance each of these factors have when they combine in the processes that contribute to the production of windblown dust. In order to account for the role of these missing variables, windblown dust emissions developed here were standardized to match observed PM_{10} monitor concentrations when high winds were present. This sensitivity analysis puts the windblown dust emission estimates in context with other emissions sources and provides a reality check on dust emissions developed using only wind speed velocities and vertical flux equations. The analysis of PM_{10} concentrations under elevated wind speeds estimated that approximately 10% of annual PM_{10} emissions are linked to high wind speeds (see Standardized Windblown Dust Emissions section for more information). As such, windblown dust emissions have been limited to no more than 10% of the total annual inventory for Maricopa County and the PM_{10} nonattainment area.

Threshold Friction Velocity

An essential factor to any windblown dust scheme involves determining the threshold friction velocity (represented as u^*_t); the minimum wind speed at which windblown dust emissions are initiated at ground level. In reality, the threshold friction velocity will change based upon the individual properties of the subject soil during any given wind event. However, for the purposes of development of a windblown dust inventory, it is necessary to identify a minimum wind speed at which dust production can theoretically begin. The threshold friction velocity for this inventory was identified using the theoretical principles of aerodynamic entrainment observed on supply-limited soils (Macpherson et al., 2008) and empirical data from regional wind tunnel tests, local meteorological data, and local PM_{10} monitoring data.

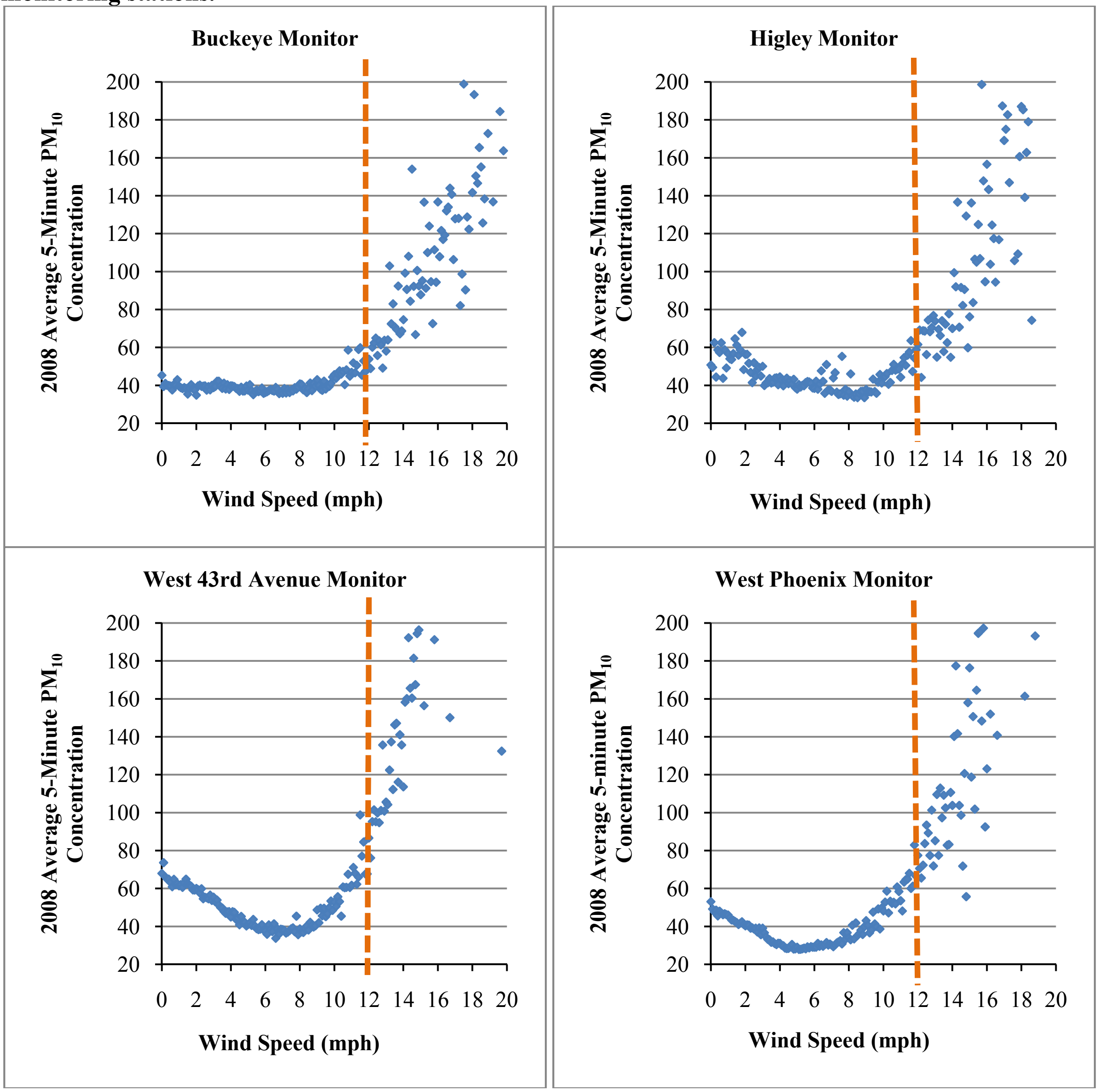
Many dust schemes set separate threshold velocities depending upon a measured or assumed set of soil properties. In the absence of, or augmentation to, local wind tunnel studies, soil texture and soil roughness lengths are common variables used to determine threshold friction velocities. In traditional transport-limited schemes, the physics of saltation dictate that loose, sandy soils will have lower threshold friction velocities than undisturbed clay- or silt-dominated soils (Gillette, 1999). However, the role of soil texture is unclear in the published literature, with recent studies finding that soil texture plays only a secondary role in dust production (Chatenet et al., 1996; Alfaro et al., 2004).

Wind tunnel studies done in the supply-limited deserts of the southwestern U.S. also show little connection between soil texture and threshold friction velocities. Wind tunnel studies in Las Vegas, Nevada (Wacaser et al., 2006) on nine different soil types (including both stable and disturbed soil conditions) found that all soil types emitted dust at the lowest available wind speed of the wind tunnel, approximately 11 mph, suggesting that soil texture plays no distinguishable role in setting threshold friction velocities. Studies in the deserts around Barstow, California found that dust emissions were initiated for three different soil textures (stable and disturbed) at ground-level wind speeds (u^*) between 16 to 26 cm/s. Depending on surface roughness values, these ground-level wind speeds translate into 10-meter wind speeds of approximately 10–15 mph. Wind tunnel studies performed in southern Arizona on mostly disturbed, sandy or sandy loam soils found saltation velocities to be between 13 to 30 mph. Roney and White (2004) found that direct aerodynamic entrainment threshold friction velocities are approximately 50 to 75% less than saltation thresholds, suggesting that the dust emission thresholds for southern Arizona could be as low as 7 mph. The measured wind tunnel data, combined with the conceptual ambiguity surrounding the role of soil texture, provide limited empirical rationale to set threshold friction velocities according to soil texture alone.

Large changes in surface roughness lengths have been clearly shown to affect threshold friction velocities of soils (Marticorena et al., 1997). However, there is no reliable data available to estimate surface roughness lengths throughout Maricopa County, especially on lands where frequent human activity is expected (e.g., agriculture, construction sites, urban vacant lots) (Marticorena et al., 2006). As mentioned earlier, these values are not static and change with atmospheric and anthropogenic activities. Surfaces that are known to have uniformly high surface roughness lengths (e.g., built-out urban areas and mountain ranges) have already been eliminated from the underlying land uses that are selected as possible sources of windblown dust. The land uses that remain (e.g., open and vacant areas, agriculture, construction sites) can have varying surface roughness lengths depending on the level of human and natural activity occurring on the soils. As such, tying threshold friction velocities to assumed surface roughness lengths is not a viable option.

Examination of local PM_{10} concentration and meteorological monitoring data in Maricopa County show that when wind speeds reach approximately 12 mph (measured as a 5-minute average), average PM_{10} concentrations are consistently higher than concentrations at lower wind speeds. Also, as wind speeds exceed 12 mph, average PM_{10} concentrations uniformly increase with increasing wind speeds. These monitoring stations are surrounded by a wide variety of land uses and differing surface roughness lengths, yet they all consistently display similar relationships between wind speeds and PM_{10} concentrations. Figure A4–1 displays the annual average relationship between wind speed and PM_{10} concentrations from four distinct monitoring locations which represent a variety of land uses, soil types and geographic conditions within Maricopa County. Although not shown in Figure A4-1, the remaining four monitoring stations that collected 5-minute PM_{10} concentration data in 2008 (Central Phoenix, Durango Complex, Greenwood and South Phoenix) show similar relationships between PM_{10} concentrations and wind speeds. This data, combined with the information developed from the wind tunnel studies performed in the southwest U.S., suggest that 12 mph is a valid approximation of the threshold friction velocity required for the initiation of windblown dust in Maricopa County.

Figure A4–1. 2008 average 5-minute PM_{10} concentration by wind speed at sample Maricopa County monitoring stations.



Vertical Emission Fluxes

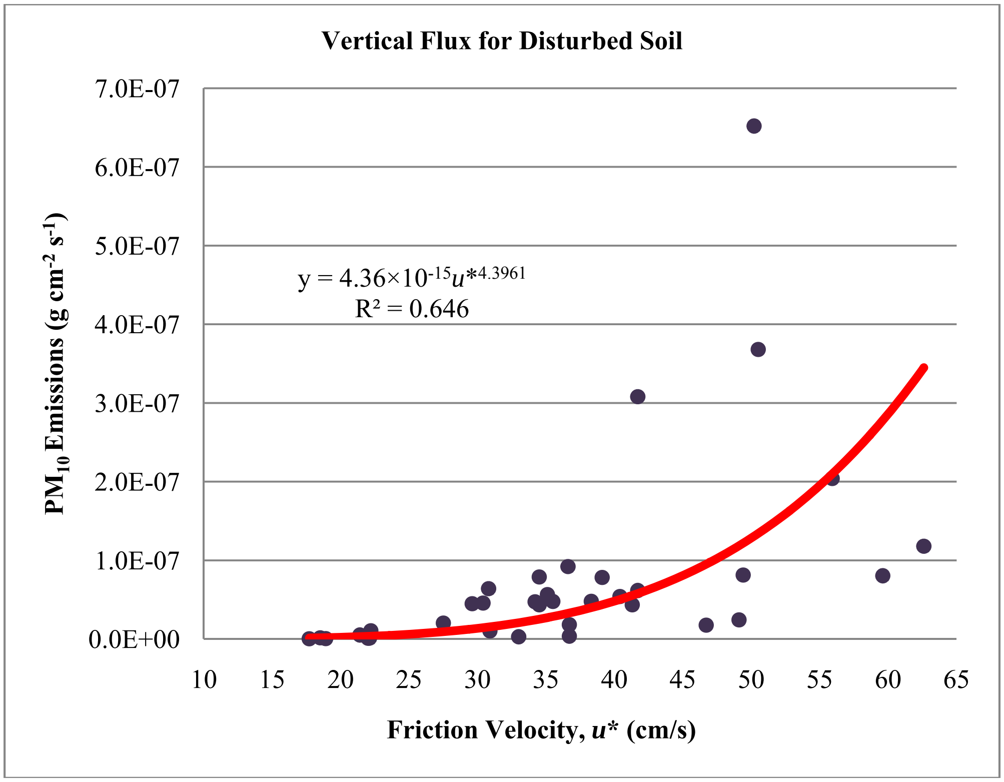
The rate at which windblown dust emissions are created and suspended in air is described as a vertical flux. Shao (2008a) describes three processes that contribute to the verical flux: (1) *Aerodynamic Entrainment* where dust particles are directly lifted off the surface; (2) *Saltation Bombardment* as sand grains or aggregates strike the surface and eject dust particles and (3) *Aggregate Disintegration* where dust particles attached to sand grains disintegrate under strong winds. A vertical flux rate can be developed through an equation that represents these processes, or empirically with the use of wind tunnel studies.

The vertical flux rate developed for this inventory uses wind tunnel studies performed in southern Arizona (Nickling and Gillies, 1989). These studies were performed under a variety of land uses (e.g., native desert, riverbeds, construction sites, agricultural land, mine tailings and dune flats) in soil textures that consisted of either sand or sandy loams. The studies were performed on thirteen sites that are described as disturbed by human activity, or having a strong potential to be disturbed because of the surface condition of the soil. The authors of the study provide vertical flux rates grouped by land use and by percent clay content. However, these grouping are not useful for this inventory given that recent research (Alfaro et al., 2004) and other wind tunnel studies (Wacaser et al., 2006) have shown that soil texture is not of primary importance in determining vertical fluxes. Fluxes based upon land use groupings provide limited information on soil condition and ignore other essential soil characteristics. Additionally, the wind tunnel studies performed in Barstow, California and Las Vegas, Nevada (Wacaser et al., 2006; Macpherson et al., 2008) show that soil disturbance is the largest factor affecting the vertical flux rate of a soil.

For the above reasons, applicable data from the southern Arizona studies (Nickling and Gillies, 1989) were grouped together to form an overall vertical flux for disturbed soils. Data from seven of the thirteen test sites was grouped together to form the disturbed soil vertical flux. These seven sites include the land uses of construction activities, abandoned agriculture, dry river beds and scrub desert. Six sites were excluded because the land uses or soil properties do not exist in Maricopa County (mine tailings, sand dunes) or because they were conducted on active agricultural fields. Dust emissions from active agricultural fields are calculated using a formula developed by the U.S. Department of Agriculture (see Active Agriculture section). Inactive agricultural land uses that are either fallow, abandoned or some other use (e.g., dairies) are represented by the vertical fluxes developed through the southern Arizona wind tunnel tests, as these land uses do not have active crop cover.

To create the disturbed soil vertical flux, a simple scatter plot of the data (frcition velocity against PM_{10} emissions) was made of the selected southern Arizona wind tunnel data. A power relationship is then developed from the data to produce the best fitting curve of the vertical flux. The assembled data performs reasonably well (R^2 of 0.646) in developing a statistically signifigant vertical flux ($4.36 \times 10^{-15} u*^{4.3961}$ g cm^{-2} s^{-1}) for disturbed soils, given the limited number of test sites and the lack of other variables describing the soil properties. There is significant scatter in the data seen at higher friction velocities. This phenomenon has been documented in other studies, and again highlights the fact that there are many other factors besides friction velocity that determine the vertical flux rates of soils (Houser and Nickling, 2001). Despite this short coming, friction velocity remains the primary variable with which to describe the magnitude of dust emissions; largely because it is one of the easiest variables to verify with quantitative data. The vertical flux developed through the southern Arizona wind tunnel data is in the same order of magnitude, and compares well with, other fluxes measured in similar wind tunnel tests in Barstow, California and Las Vegas, Nevada (Wacaser et al., 2006; Macpherson et al., 2008). Figure A4–2 graphs the data points from the wind tunnel studies used to develop the vertical flux for disturbed soil.

Figure A4–2. Vertical flux for disturbed soil.



Since the southern Arizona wind tunnel tests provided limited information on vertical fluxes from stable soils, a stable soil vertical flux could not be developed directly from the wind tunnel data. As a surrogate, the ratio of stable to disturbed vertical fluxes found in the wind tunnel studies performed in Barstow, California (Macpherson et al., 2008) was used to develop the vertical flux for stable land uses. The Barstow area study contained multiple tests done on stable and disturbed soils at the same test sites. This allows for a direct comparison of the windblown dust emission rates between stable and disturbed soils. Data from all of the Barstow wind tunnel tests were used except for the tests done on salt-crusted soils (dry lake beds), as this type of soil is rare in Maricopa County. The results of the Barstow studies indicate that the stable soil vertical flux was found to produce emissions at a rate of about 12 to 20% of the disturbed soil vertical flux.[1]

Determination of the amount of disturbed land in each land use category is accomplished through use of rule effectiveness rates developed by MCAQD (see Appendix 3 for details on rule effectiveness), since direct measurement of soil disturbance is not feasible (i.e., soil conditions are constantly changing) in an area as large as Maricopa County. Activities on land uses subject to windblown dust are regulated by MCAQD rules that require specific activity-related control measures that stabilize the soil. Compliance and inspection records provide an estimate of how often these measures are being implemented and the frequency of observed violations of the measures. By implied extension, this is also an estimate of how often a regulated land use soil is stabilized. Examination of compliance records for the period of July 2008 through June 2009 produced rule effectiveness rates of 90% for developing land uses (Rule 310), 65% for sand and

[1] For disturbed surfaces a flux of $2.35 \times 10^{-12} u^{*2.5604}$ g cm^{-2} s^{-1} was calculated using the Barstow wind tunnel data; likewise for stable surfaces, a flux of $2.96 \times 10^{-12} u^{*1.9744}$ g cm^{-2} s^{-1} was calculated. The ratio of these Barstow fluxes applied to the southern Arizona disturbed soil vertical flux (at the mean of each wind speed bin) allows for calculation of a vertical flux that can represent emissions from stable southern Arizona soils.

gravel processing and mining land uses (Rule 316), and 95% for vacant land uses (Rule 310.01). For the purposes of calculating windblown dust, these rule effectiveness percentages are used as surrogates for the percentage of a land use category that is assumed to be disturbed. Thus, the Rule 310 effectiveness rate of 90% serves as a surrogate for developing land uses (i.e., 90% of the land is stable, 10% is disturbed), the Rule 316 rate of 65% serves as a surrogate for sand and gravel processing and mining activities, and the Rule 310.01 rate of 95% serves as a surrogate for all open and vacant lands, landfills, automotive test tracks and inactive agricultural land uses. The rule effectiveness rate developed for agricultural operations (55%) applies only to active agricultural land uses and is incorporated in the equation used to estimate windblown dust from active agricultural fields (see section on Active Agricultural Emissions).

In order to utilize the disturbed soil and stable soil vertical fluxes for generating PM_{10} emission estimates, PM_{10} emission factors based upon these vertical fluxes are created. Initially, the units of the fluxes were converted (from g cm^{-2} s^{-1} to tons $acre^{-1}$ 5-minute^{-1}) to match available meteorological data on wind speeds and comparable units of mass with other sections of this inventory. Selection of a 5-minute average for the wind speed value was chosen because it is the shortest duration of wind speed available that is constantly measured. Windblown dust production has been shown to be more closely correlated with gusts than with averaged wind speeds (Cakmur et al., 2004; Engelstaedter and Washington, 2007). However, gusts (usually 1-second maximums) are not constantly measured which does not allow for their use in calculation of emissions in an annual inventory. Thus, the 5-minute average wind speed is selected as the input wind speed in both vertical fluxes (see Wind Speed Data section for more information).

These 5-minute average wind speeds are aggregated into five 10-meter wind speed bins (12-15 mph, 15-20 mph, 20-25 mph, 25-30 mph, and 30-35 mph) in order to develop a disturbed soil and stable soil emission factor per each wind speed bin. The midpoint of each wind speed bin (13.5 mph, 17.5 mph, 22.5 mph, 27.5 mph, and 32.5 mph) is converted via the Prandtl equation[2] to a $u*$ value (surface wind speed) for use in the disturbed soil vertical flux equation, resulting in a disturbed soil emission factor for each wind speed bin. After the disturbed soil emission factors are calculated, the ratio between disturbed and stable soil emissions observed at the Barstow tests is used to develop a stable soil emission factor for each wind speed bin. Table A4–1 shows the resulting stable soil and disturbed soil emission factors for each wind speed bin (by land use category) and the ratio of stable to disturbed soil emissions observed in the Barstow area wind tunnel studies.

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[2] The fluid dynamics Prandtl equation: $U = \frac{u^*}{k} ln \frac{z}{z_o}$, allows for the calculation of $u*$ at various 10-meter wind speeds by solving for $u*$: ($u^* = U \frac{k}{ln \frac{z}{z_o}}$), where U is wind speed at 10 meters, k is Von Karman's constant (0.4), z is 10 meters, and z_o is measured surface roughness value. An average value of 0.025cm (as measured during southern Arizona wind tunnel tests) was assumed for z_o Once $u*$ is calculated for each wind speed bin, that value is then inserted into the vertical flux rate to develop the emission factors seen in Table A4-1.

Table A4–1. PM_{10} emission factors for stable and disturbed land uses by wind speed bin.

Land Use Category	% of Land Use Category	PM_{10} Emission Factor (tons/acre-5-minute) by 10-Meter Wind Speed Bin (mph)				
		12-15	15-20	20-25	25-30	30-35
Agriculture (Active)		NA – Calculated Under Different Methodology				
Agriculture (Inactive) – Stable	95%	1.10×10^{-5}	2.93×10^{-5}	7.68×10^{-5}	1.64×10^{-4}	3.10×10^{-4}
Agriculture (Inactive) – Disturbed	5%	5.44×10^{-5}	1.69×10^{-4}	5.14×10^{-4}	1.24×10^{-3}	2.57×10^{-3}
Developing Land – Stable	90%	1.10×10^{-5}	2.93×10^{-5}	7.68×10^{-5}	1.64×10^{-4}	3.10×10^{-4}
Developing Land – Disturbed	10%	5.44×10^{-5}	1.69×10^{-4}	5.14×10^{-4}	1.24×10^{-3}	2.57×10^{-3}
Open Space, River Beds, Vacant, Landfill, Test Tracks – Stable	95%	1.10×10^{-5}	2.93×10^{-5}	7.68×10^{-5}	1.64×10^{-4}	3.10×10^{-4}
Open Space, River Beds, Vacant, Landfill, Test Tracks –Disturbed	5%	5.44×10^{-5}	1.69×10^{-4}	5.14×10^{-4}	1.24×10^{-3}	2.57×10^{-3}
Sand & Gravel, Mining – Stable	65%	1.10×10^{-5}	2.93×10^{-5}	7.68×10^{-5}	1.64×10^{-4}	3.10×10^{-4}
Sand & Gravel, Mining – Disturbed	35%	5.44×10^{-5}	1.69×10^{-4}	5.14×10^{-4}	1.24×10^{-3}	2.57×10^{-3}
Disturbed Soil Vertical Flux:		**Ratio of Barstow Stable to Disturbed Soil Emissions**				
$4.36 \times 10^{-15} u^{*4.3961}$ g cm^{-2} s^{-1}		20.16%	17.33%	14.94%	13.29%	12.06%

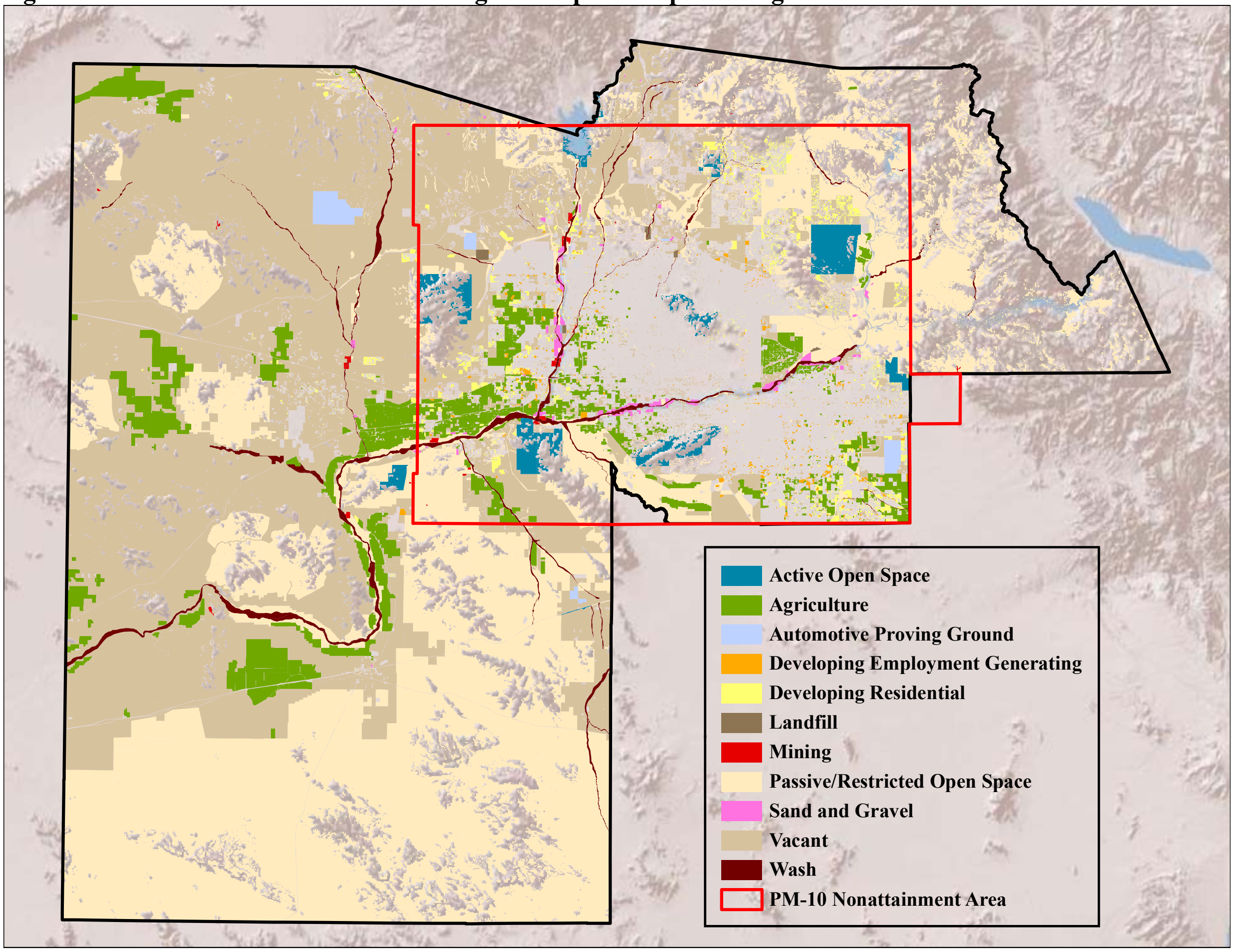
Land Use Data

The Maricopa Association of Governments (MAG) maintains GIS data on land use coverage in Maricopa County. The GIS data compiled by MAG represents land use coverage for the year 2009. A detailed explanation on how MAG assembles and maintains its GIS database is included as Attachment I of this Appendix. In addition to data provided by MAG, the Arizona Cotton Research and Protection Council (ACRPC) provided supplemental GIS information on agricultural field crops in portions of Area A in Maricopa County. Where appropriate, data from the ACRPC was used to update the agricultural land use category maintained by MAG. A total of nine individual land use categories were identified as having potential to emit windblown dust. These categories were selected due to an abundant presence of exposed soils and the possibility of periodic or frequent disturbance. Other land uses not selected may on occasion emit windblown dust, but the presence of structures or vegetated/paved surfaces associated with these land uses limits their ability to emit windblown dust on a consistent basis. Land uses on steeply sloped rocky terrain were also excluded as sources of windblown dust, as the large surface roughness lengths prohibits the production of windblown dust from this type of topography. Table A4–2 lists a description of, and the acreage associated with, the nine land use categories considered as sources of windblown dust. Figure A4–3 shows the extent and distribution of the land use categories determined to have the potential to emit windblown dust.

Table A4–2. Land use categories associated with the production of windblown dust.

MAG Land Use Category	Maricopa County Acreage	PM_{10} NAA Acreage	Description
Active Open Space	59,145	54,835	Natural desert community parks (e.g., White Tanks)
Agriculture	282,793	116,934	Active fields/orchards, dairies & inactive/abandoned
Auto Test Tracks	19,594	6,888	Unpaved automobile proving grounds
Developing	66,341	60,335	Vacant lands converting to built uses
Landfill	2,705	2,705	Community refuse disposal sites
Mining	3,329	2,004	Rock quarries/pits
Passive Open Space/Wash	1,861,493	341066	State/National parks, bombing range, dry rivers/washes
Sand & Gravel	11,112	10,350	Sand & Gravel processing facilities
Vacant	1,930,606	395,902	Developable/unprotected open spaces

Figure A4–3. Distribution of land use categories capable of producing windblown dust emissions.

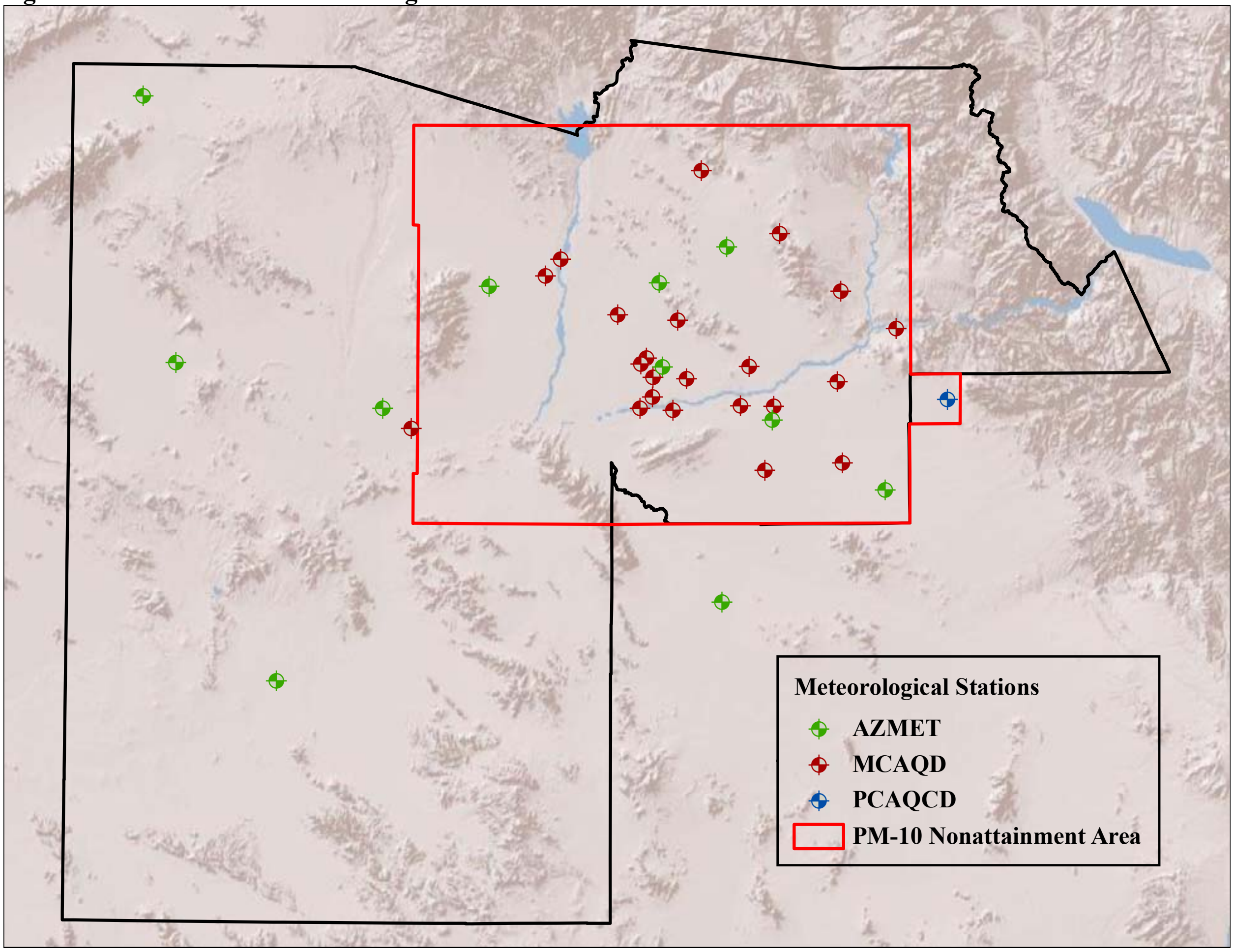


Meteorological Data

Thirty-four meteorological stations were used for source data to compile calendar year 2008 wind speed and precipitation for this inventory of windblown dust. This includes eleven stations operated by the Arizona Meteorological Network (AZMET), twenty-two stations operated by the Maricopa County Air Quality Department (MCAQD), and one station operated by the Pinal County Air Quality Control District (PCAQCD). Stations operated by the National Weather Service (NWS) in and around Maricopa County were not chosen for inclusion in this analysis due to differences in wind speed data collection methods that preclude "apples-to-apples" comparisons with data from the meteorological stations included in this work.[3] Figure A4–4 displays the location of the included meteorological stations.

[3] National Weather Service (NWS) stations report wind speeds in 2-minute averages at the time of posting, while AZMET, MCAQD and PCAQCD all report wind speed in hourly averages at the end of each hour or in 5-minute averages.

Figure A4–4. Location of meteorological stations.



Wind Speed Data

For this analysis, 5-minute average wind speeds form the basis of the wind data used in calculating windblown dust emissions. As mentioned earlier, windblown dust emissions have greater correlation with gusts than with averaged wind speeds (Cakmur et al., 2004; Engelstaedter and Washington, 2007). Data recorded as a 5-minute average provides finer time resolution (versus hourly average wind speeds) that can better capture the effects of gusts while still allowing for emission estimates to be developed. This approach also allows for any 5-minute time period over the threshold friction velocity (12 mph) to be counted and assigned into wind speed bins: 12–15 mph, 15–20 mph, 20–25 mph, 25–30 mph and 30–35 mph. Creating wind speed bins allows for the efficient calculation of emissions while still reflecting the change in magnitude of emissions as wind speeds rise. Outlined below are the steps necessary to prepare the wind speed data for inclusion in windblown dust emission calculations.

As an initial step, wind speed data from the selected meteorological stations were uniformly adjusted to speeds at 10 meters (to account for the difference in anemometer heights) through use of a standard wind profile power-law equation:

$$U_z = U_r(Z/Z_r)^p$$

where U_z is wind speed (in mph) at 10 meters, U_r is wind speed (in mph) at referenced anemometer height, Z is 10 meters, Z_r is the height (in meters) of the reference anemometer, and

p is the power-law exponent. Determination of p was made by comparing wind speeds at neighboring stations with different anemometer heights (e.g., AZMET's Buckeye station at 3 meters compared with MCAQD's Buckeye station at 10 meters) through a simple adaptation of the power-law equation:

$$p = \frac{\ln(U) - \ln(U_r)}{\ln(Z) - \ln(Z_r)}$$

The stations used in comparison were all assumed to have similar surface roughness lengths to each other as the stations were between 1–3 miles apart. Comparison of hourly average wind speeds yielded an average value for p of 0.06 for urban stations and 0.12 for rural stations (only those hours when atmospheric conditions are well mixed were used, as applying the approach described above for hours with calm winds tends to over-inflate the value of p).

In addition to correcting for height, adjustments to wind speed were performed to gap-fill missing data and interpolate 5-minute average values as necessary. All of the meteorological stations report hourly average wind speeds at the end of each hour. In addition, thirteen of the MCAQD stations also report 5-minute average wind speeds, with data completion rates of 75% or better. The data from these stations were: (1) counted and assigned to one of five wind speed bins of 12-15 mph, 15–20 mph, 20–25 mph, 25–30 mph, and 30–35 mph; and (2) "grown" to compensate for missing data, based upon the data completion rate of each station. Thus, a station that reported 124 5-minute periods assigned to a bin with a data completion rate of 90.63%, would result in a "grown" bin value of 137 (124 periods divided by 90.63%). Table A4–3 presents the recorded and grown 5-minute values by wind speed bin for the year 2008, for each of the thirteen MCAQD meteorological stations that were considered.

Table A4–3. Number of recorded and grown 5-minute average wind speeds for 2008, by wind speed bin and meteorological station.

	Recorded 5-Minute Averages						Grown 5-Minute Averages				
MCAQD Station	12-15 mph	15–20 mph	20–25 mph	25–30 mph	30–35 mph	% Data complete	12-15 mph	15–20 mph	20–25 mph	25–30 mph	30–35 mph
Buckeye	3030	1679	296	54	12	99.62%	3042	1685	297	54	12
Coyote Lakes	1846	840	77	1	0	98.71%	1870	851	78	1	0
Durango Complex	1776	618	33	10	1	96.39%	1843	641	34	10	1
Dysart	1782	784	92	6	0	78.16%	2280	1003	118	8	0
Falcon Field	2088	758	95	2	1	76.77%	2720	987	124	3	1
Greenwood	795	124	11	1	0	90.63%	877	137	12	1	0
Higley	1896	766	50	8	1	91.02%	2083	842	55	9	1
North Phoenix	376	80	8	2	0	77.59%	485	103	10	3	0
South Phoenix	696	169	9	0	1	99.19%	702	170	9	0	1
Tempe	54	5	0	0	0	86.38%	63	6	0	0	0
West Chandler	1637	515	42	3	1	99.09%	1652	520	42	3	1
West Forty-Third	2391	1042	83	13	6	98.44%	2429	1059	84	13	6
West Phoenix	892	111	8	1	0	92.47%	965	120	9	1	0

For the stations that do not record 5-minute average wind speeds[4], regression equations were developed (based upon those MCAQD stations that do report 5-minute average wind speeds) to interpolate counts of 5-minute average values. The equations were derived by regressing 5-minute average counts in each wind speed bin (dependent [y]) against a count of an hourly average wind speeds greater than a pre-determined wind speed (independent [x]). Since the

[4] AZMET and PCAQCD stations report average wind speed only on an hourly basis, and another nine MCAQD stations that measure wind speed on a 5-minute average had data completion rates less than 75% for 2008.

majority of wind speed counts exist in the lower wind speed bins (e.g., hourly average wind speeds over 25 mph were recorded only ten unique times in 2008), a count of hourly values greater than 15 mph was chosen as the independent variable (x). All of the regression equations proved to be statistically significant at the 95% confidence level. The results of the regression equations for each wind speed bin are shown in Table A4–4. The resulting 5-minute average wind speeds (by bin) for all meteorological stations in this study are shown in Table A4–5.

Table A4–4. Regression equation, *p*-value, and R^2 for interpolating 5-minute average wind speeds, by bin.

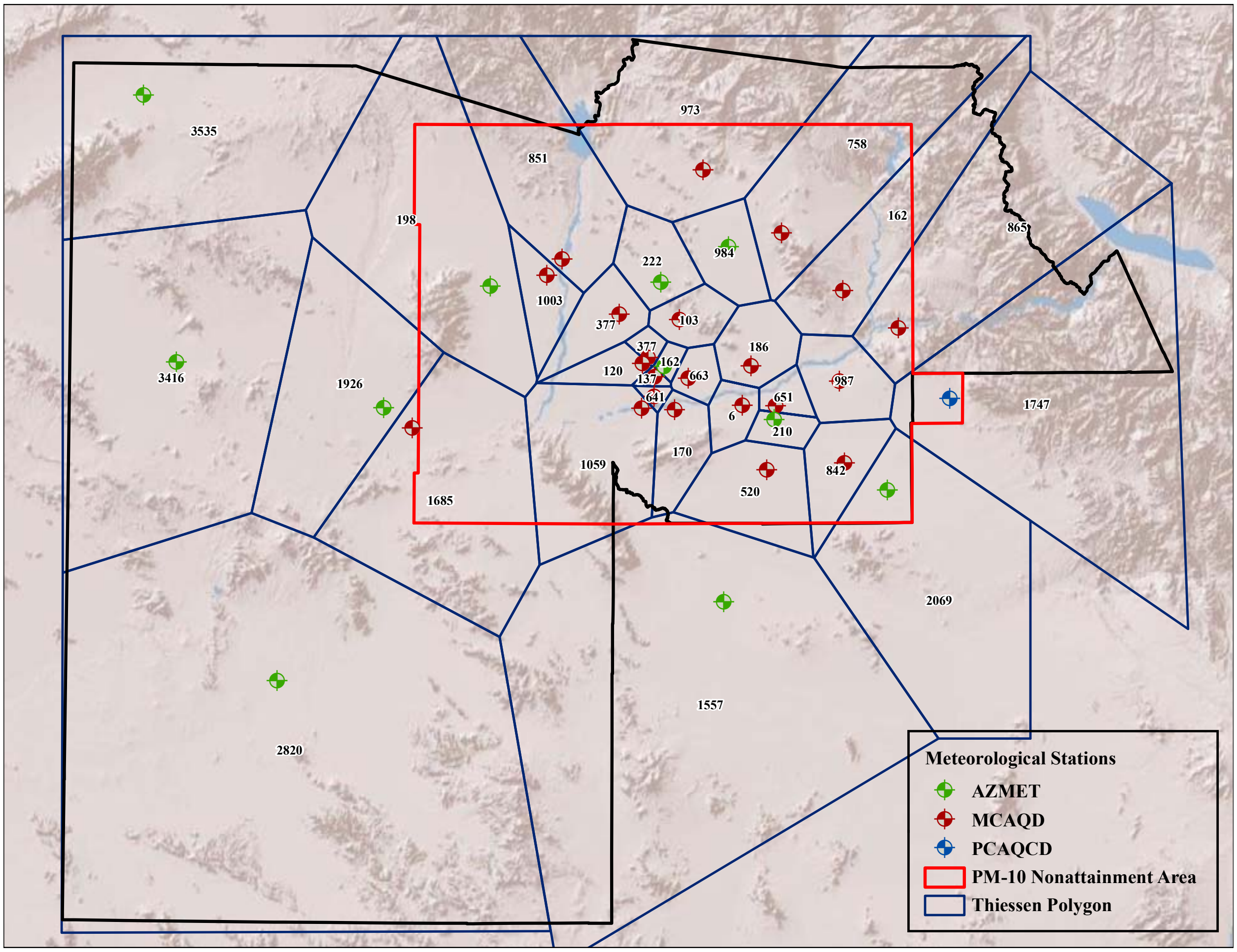
5-minute average wind speed bin	Regression equation	*p*-value (probability)	R^2
12-15 mph	$y = 827.00 + 19.80x$	0.00007056	77.55%
15–20 mph	$y = 150.05 + 11.92x$	0.00000006	93.77%
20–25 mph	$y = –8.34 + 1.39x$	0.00000021	92.09%
25–30 mph	$y = –4.20 + 0.31x$	0.00009300	76.42%
30–35 mph	$y = –0.99 + 0.07x$	0.00047000	68.57%

Table A4–5. Number of interpolated 5-minute average wind speeds, by station and wind speed bin. (Shaded cells denote interpolated values.)

Station Name	Number of hourly average values > 15 mph	Number of 5-minute average values between: 12-15 mph	15–20 mph	20–25 mph	25–30 mph	30–35 mph
AZMET Aguila	284	6450	3535	386	84	19
AZMET Buckeye	149	3777	1926	199	42	9
AZMET Desert Ridge	70	2213	984	89	18	4
AZMET Harquahala	274	6252	3416	373	81	18
AZMET Maricopa	118	3163	1557	156	32	7
AZMET Mesa	5	926	210	0	0	0
AZMET Paloma	224	5262	2820	303	65	15
AZMET Phoenix Encanto	1	847	162	0	0	0
AZMET Phoenix Greenway	6	946	222	0	0	0
AZMET Queen Creek	161	4015	2069	215	46	10
AZMET Waddell	4	906	198	0	0	0
MCAQD Blue Point	60	2015	865	75	14	3
MCAQD Buckeye	146	3042	1685	297	54	12
MCAQD Cave Creek	69	2193	973	88	17	4
MCAQD Central Phoenix	43	1678	663	51	9	2
MCAQD Coyote Lakes	54	1870	851	78	1	0
MCAQD Durango Complex	50	1843	641	34	10	1
MCAQD Dysart	64	2280	1003	118	8	0
MCAQD Falcon Field	58	2720	987	124	3	1
MCAQD Fountain Hills	1	847	162	0	0	0
MCAQD Glendale	19	1203	377	18	2	0
MCAQD Greenwood	1	877	137	12	1	0
MCAQD Higley	42	2083	842	55	9	1
MCAQD Mesa	42	1659	651	50	9	2
MCAQD North Phoenix	4	485	103	10	3	0
MCAQD Pinnacle Peak	51	1837	758	63	12	3
MCAQD South Phoenix	6	702	170	9	0	1
MCAQD South Scottsdale	3	886	186	0	0	0
MCAQD Tempe	0	63	6	0	0	0
MCAQD West Forty-Third	65	2429	1059	84	13	6
MCAQD West Chandler	23	1652	520	42	3	1
MCAQD West Indian School	19	1203	377	18	2	0
MCAQD West Phoenix	5	965	120	9	1	0
PCAQCD Apache Junction	134	3480	1747	178	37	8

Because wind speeds vary dramatically between different meteorological stations in Maricopa County (especially in the transition between rural and urban stations), it is important to represent those variations in space upon the land uses subject to windblown dust. This is accomplished by assigning the wind speed counts in Table A4–5 in GIS (spatial joining) to the land uses nearest each meteorological station through a series of Thiessen polygons[5] (Pulugurtha and James, 2006). This process allows for variations in wind speed counts to be representatively distributed in space across land uses subject to windblown dust, as opposed to "smearing" averaged wind speed counts across all of Maricopa County and the PM_{10} nonattainment area. As an example, Figure A4–5 shows the resulting Thiessen polygons for the 15-20 mph wind speed bin.

Figure A4–5. Thiessen polygon depiction displaying the number of values for the 15–20 mph wind speed bin.



Precipitation Data

During days with precipitation, windblown dust emissions are severely, if not completely, limited. Precipitation also increases overall soil moisture which acts as a control on the production of windblown dust after precipitation has ceased. To account for the role of precipitation, a simple formula used by the U.S. EPA when calculating the controlling role of precipitation on fugitive dust from unpaved roads can be adapted to windblown dust production (US EPA, 2006).

[5] A "Thiessen polygon" depicts an area whose boundaries define the region that is closest to a given point, relative to all other given points.

The adapted equation is represented as:

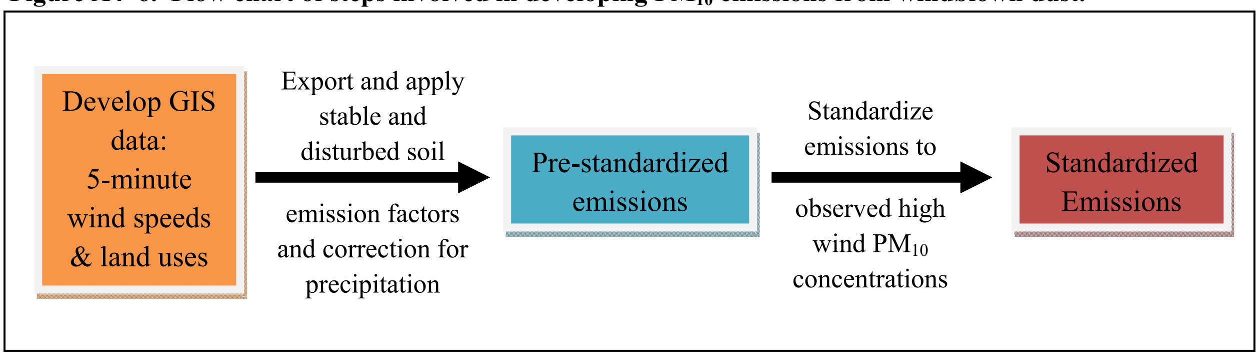
$$E = B \times (1 - P/N)$$

Where E equals emissions, B equals emissions before precipitation, P equals the annual number of "wet" days with at least 0.254 mm (0.01 in) of precipitation (39 days in 2008), and N equals the number of days in the year (366 in 2008). Using this formula equates to applying a 10.66% annual reduction in windblown dust due to precipitation.

Calculation of Windblown Dust Emissions

After developing the input data necessary to calculate windblown dust emissions (e.g., wind speed bin counts, disturbed and stable vertical flux equations, etc.), emission estimates of PM_{10} are calculated for both the PM_{10} nonattainment area and Maricopa County. These emission estimates represent the maximum potential emissions from each land use category since they are a product of only local wind speeds and emission factors developed from soils expected to emit high levels of dust. These emissions will be standardized (adjusted to match observed PM_{10} concentration under high winds) in the next section to account for a range of controlling factors (e.g., surface roughness lengths, soil moisture, vegetation, supply-limitation, etc.) where either adequate quantitative data does not exist or cannot be represented as a unique variable in an emission estimate equation (see section on Standardized Windblown Dust Emissions). Figure A4–6 contains a flow chart showing the steps involved in calculating PM_{10} emissions from windblown dust.

Figure A4–6. Flow chart of steps involved in developing PM_{10} emissions from windblown dust.



Calculation of pre-standardized emission estimates begins through the use of GIS to spatially assign the 5-minute wind speed bin counts to the underlying land use categories (as shown previously in Figure A4–5). These base data are exported from GIS as a spreadsheet, with each row of the spreadsheet representing a spatially unique land use category polygon with associated wind speed bin counts. The land use and wind speed specific emission factors for disturbed and stable soils listed in Table A4–1 are applied to each row of the spreadsheet to produce pre-standardized emissions. Since the specific geographic location of surface disturbance is unknown and varies throughout the year, each land use polygon is assumed to have the same proportion of disturbed and stable soils throughout the year as expressed by the percentages in Table A4–1 (i.e., all vacant parcels are assumed to be 95% stable and 5% disturbed). Base data and emissions from a sample vacant land use polygon are shown in Table A4–6. All pre-standardized emissions from land use categories except active agricultural fields are calculated per the methodology presented in Table A4–6.

Table A4–6. Base data and pre-standardized emissions from a sample vacant land use polygon.

	Polygon Acres	Count of 5-Minute Periods for 12 - 15 mph	Count of 5-Minute Periods for 15 - 20 mph	Count of 5-Minute Periods for 20 - 25 mph	Count of 5-Minute Periods for 25 - 30 mph	Count of 5-Minute Periods for 30 - 35 mph
Vacant Land Use Base Data	22.15	2280	1003	118	8	0
Emission Factors (tons/acre–5-min)		**12 - 15 mph**	**15 - 20 mph**	**20 - 25 mph**	**25 - 30 mph**	**30 - 35 mph**
Stable Soil Emission Factor		1.10×10^{-5}	2.93×10^{-5}	7.68×10^{-5}	1.64×10^{-4}	3.10×10^{-4}
Disturbed Soil Emission Factor		5.44×10^{-5}	1.69×10^{-4}	5.14×10^{-4}	1.24×10^{-3}	2.57×10^{-3}
Annual Emissions	**Acreage**	**12 - 15 mph Emissions (tons)**	**15- 20 mph Emissions (tons)**	**20 - 25 mph Emissions (tons)**	**25 - 30 mph Emissions (tons)**	**30 - 35 mph Emissions (tons)**
Stable Emissions (95% of acreage)[1]	21.04	0.53	0.62	0.19	0.03	0.00
Disturbed Emissions (5% of acreage)[2]	1.11	0.14	0.19	0.07	0.01	0.00
Total Emissions[3]	22.15	0.66	0.81	0.26	0.04	0.00

[1] Stable Emissions = Stable Acreage × Wind Speed Bin Count × Wind Speed Bin Emission Factor
[2] Disturbed Emissions = Disturbed Acreage × Wind Speed Bin Count × Wind Speed Bin Emission Factor
[3] Total (Pre-standardized) Emissions = Stable Emissions + Disturbed Emissions

Windblown Dust Emissions from Active Agricultural Areas

Since crop cover dramatically affects windblown dust production, windblown dust from active agricultural areas (fields or orchards with harvested or planted crops) cannot be calculated using the vertical fluxes developed for the other land use categories. Some crops, like alfalfa, maintain dense vegetative cover all year long and virtually eliminate the possibility of windblown dust from these types of fields. Thus, windblown dust from active agricultural fields is calculated using a soil erodibility formula developed by the U.S. Department of Agriculture (in US EPA, 1974):

$$E_s = a\ I\ C\ K\ L'\ V'$$

where E_s equals suspended PM in tons/acre-year, a is a constant (0.0125) representing the portion of PM as PM_{10}, I is soil erodibility, C is a climatic factor, K is surface roughness, L' is unsheltered field width and V' is vegetative cover.

The number of acres harvested in 2008 serves as a surrogate for the amount of active agricultural areas in Maricopa County. Data on the amount of acres harvested for 2008 is available through the Arizona Agricultural Statistics Bulletin and the U.S. Department of Agriculture National (USDA) Agricultural Statistics Service for 2008 (USDA, 2008; AASS, 2009). Data for the other variables in the equation is taken from the 1999 Serious Area PM-10 Plan (MAG, 2000). Table A4–7 lists the crop-specific values for each variable.

Table A4–7. Active Maricopa County agricultural acreage and default values for USDA equation variables, by crop type.

Crop	2008 Acreage	*a*	*I*	*C*	*K*	*L'*	*V'*	E_s
Cotton	18,800	0.0125	63.6	0.318	0.5	0.74	0.7	0.065
Alfalfa	83,000	0.0125	63.6	0.318	1	0.76	0	0
Other hay	4,500	0.0125	63.6	0.318	0.8	0.83	0	0
Wheat	30,100	0.0125	63.6	0.318	0.6	0.77	0	0
Barley	9,900	0.0125	63.6	0.318	0.6	0.77	0	0
Corn	700	0.0125	63.6	0.318	0.6	0.77	0.44	0.051
Potatoes	1,400	0.0125	63.6	0.318	0.8	0.70	0.6	0.085
Sorghum	2,200	0.0125	63.6	0.318	0.6	0.77	0	0
Other vegetables	16,072	0.0125	63.6	0.318	0.6	0.48	0.77	0.056
Citrus	2,124	0.0125	63.6	0.318	0.6	0.48	0.77	0.056

Application of the formula to develop annual PM_{10} emissions from active agricultural fields is achieved by multiplying crop type E_s by the number of acres in each crop type. In addition to applying the USDA formula, a control factor of 72.28% (1 – 27.72%) was applied to active agricultural emission estimates to reflect the effectiveness of the agricultural BMP program. This control factor is a combination of the rule effectiveness of the BMP program (55.33%; see Appendix 3) and the estimated control effectiveness of the BMP program (50.10%)[6], for an overall effectiveness of 27.72%. Emissions are allocated to the PM_{10} nonattainment area based upon the percentage (41.35%) of agricultural land use acres located with the nonattainment area.

Summary of Pre-standardized Windblown Dust Emission Calculations

To account for precipitation, pre-standardized emission estimates have been reduced by 10.66% (see section on Precipitation for more detail) for all land uses except active agricultural areas, as factor *C* in the USDA formula considers precipitation and the effects of soil moisture content. Annual pre-standardized PM_{10} emissions from active agricultural areas and all other land uses are listed in table A4–8 for Maricopa County and the PM_{10} nonattainment area.

Table A4–8. Annual pre-standardized PM_{10} emissions from windblown dust in Maricopa County and the PM_{10} nonattainment area.

	Annual emissions (tons/yr)	
Land use category	**Maricopa County**	**PM_{10} Nonattainment Area**
Active open space	3,191.63	2,660.86
Agriculture – active	1,739.06	719.10
Agriculture – inactive	16,711.81	3,686.87
Auto test tracks	2,192.92	534.01
Developing	5,897.93	4,863.19
Landfill	78.76	78.76
Mining	723.15	295.40
Passive open space/wash	268,122.10	22,669.38
Sand & gravel	1,511.72	1,341.04
Vacant	283,176.99	23,037.24
Totals:	**582,326.11**	**59,885.85**

[6] Derived from Table 4-2 of the Technical Support Document for Quantification of Agricultural Best Management Practices, prepared for ADEQ by URS and ERG, June 2001.

Standardized Windblown Dust Emissions

Pre-standardized windblown dust emission calculations represent maximum windblown dust emission rates from land uses that have the capability to emit windblown dust. This is largely due to the fact that the vertical fluxes used to calculate pre-standardized emissions are based upon wind tunnel tests done in areas selected *a priori* as areas suspected of generating large quantities of windblown dust (Nickling and Gillies, 1989). These are areas that are mostly free of vegetation, have low surface roughness, and have surfaces that are either disturbed or easily disturbed. Only a small percentage of the land use categories assumed to emit windblown dust have characteristics identical to the wind tunnel test sites. Many areas have much denser vegetation, higher surface roughness values, topography that shelters the wind, higher surface moisture, desert pavement crusts, etc. For those areas disturbed by anthropogenic activities, the role of active controls (e.g., applying water) is not represented in the vertical fluxes. The vertical fluxes also do not take into account the supply-limited nature of desert soils in Maricopa County, because the wind tunnel tests were only performed for a period of 10 to 30 minutes at most (ibid). During a sustained high-wind event, some soils will stop emitting before the wind speeds fall below the threshold friction velocity because the available reservoir of dust particles has been exhausted due to the supply-limitations of the soil. Because these windblown dust-limiting variables are not represented in the wind tunnel tests, they need to be accounted for outside the vertical flux equations. To account for this on an annual basis, a sensitivity analysis was performed by comparing windblown PM_{10} emission estimates against observed PM_{10} concentrations under high wind conditions.

In 2008, there were eight MCAQD PM_{10} monitors that recorded PM_{10} concentrations and associated wind speed in 5-minute averages. A simple test to see the impact of PM_{10} concentrations under high winds is to compare the measured PM_{10} mass associated with wind speeds below 12 mph (threshold friction velocity for windblown dust generation) against the mass associated with wind speeds at 12 mph or greater. While PM_{10} concentrations are not an exact surrogate for emissions since high wind PM_{10} concentrations can be the result of long distance transport from upwind sources in some cases, on an annual basis they are a rough approximation of the sources and magnitude of PM_{10} emissions in the area around the monitoring site. Table A4–9 shows the percentage of PM_{10} mass associated with wind speeds at or above 12 mph for eight MCAQD monitors with 5-minute data.

Table A4–9. Percentage of PM_{10} mass associated with wind speeds at or above 12 mph for eight MCAQD monitors in calendar year 2008.

Monitor	Sum of 5-min PM_{10} mass when 5-min winds ≥ 12mph (µg/m³)	Sum of all 5-min PM_{10} mass (µg/m³)	Percent PM_{10} mass associated with 5-min winds ≥ 12 mph
Buckeye	646,732	4,596,071	14.07%
Central Phoenix	96,398	2,014,492	4.79%
Durango Complex	361,223	5,023,592	7.19%
Greenwood	140,729	4,175,273	3.37%
Higley	293,153	4,468,163	6.56%
South Phoenix	204,019	4,753,036	4.29%
West Phoenix	133,834	3,698,296	3.62%
West Forty-Third	751,052	5,928,634	12.67%
All Monitors	2,627,139	34,657,557	7.58%

The analysis in Table A4–9 shows that as a weighted average, about 7.6% of annual PM_{10} emissions are associated with wind speeds greater than or equal to 12 mph. The monitors that are surrounded by land uses that are likely to produce windblown dust (e.g., Buckeye, West Forty-Third) have higher mass associated with winds ≥ 12 mph than do more urban monitors (e.g., Greenwood) where land uses have limited opportunity to produce windblown dust. A simple statistical analysis of the eight monitors produces a mean of about 7% and a standard deviation of 4%. Given that the monitors do not capture all emissions associated with high winds and that the limited numbers of monitors covering a large geographic area like Maricopa County do not represent all land use mixes, it is assumed that up to 10% (within one standard deviation of the monitor concentrations) of PM_{10} in an annual inventory of Maricopa County and the PM_{10} nonattainment area is windblown dust.

Annual PM_{10} emissions from sources other than windblown dust total 61,282.27 tons for Maricopa County and 43,333.20 tons for the PM_{10} nonattainment area. If windblown dust emissions are to represent 10% of an annual inventory, than PM_{10} emissions for the nonattainment area and Maricopa County should be standardized to 4,814.80 tons and 6,809.13 tons, respectively.[7]

Initial evaluation of the 10% standardized emission targets raises some questions. Despite the presence of significantly more acreage subject to windblown dust in the areas of Maricopa County outside the PM_{10} nonattainment area than within, the standardized emissions suggest that these areas emit at a lower rate than the PM_{10} nonattainment area. While this may seem counter-intuitive at first, given the disparity between acreages, there are theoretical reasons why these areas would emit less. It is important to point out initially that when high magnitude dust events do occur (wind speeds above saltation thresholds) the areas outside of the nonattainment area are going to be the dominant contributor of windblown dust during the event. This is because as saltation occurs, supply-limitation concerns are less important, and the potential for long-range transport increases. However, these events are rare, occurring only a handful of times in a year; while the majority of windblown dust generated on an annual basis occurs during higher frequency/lower intensity wind speeds where supply-limitations control dust production.

The following reasons therefore help to explain why the areas outside of the nonattainment area have greater supply-limitations (on an annual basis) during the more common lower magnitude/ higher frequency wind events, and thus lower dust emissions rates. First, the rates of soil disturbance are developed largely upon MCAQD inspections done only within the nonattainment area; it is very likely that areas outside the nonattainment area experience significantly fewer disturbances due to their isolation (e.g., Tonto National Forest, Goldwater Bombing Range). Second, vegetation in vacant areas outside the nonattainment area, both on the surface and just below the surface, is likely to be greater than vegetation existing on an area such as an urban vacant lot; this provides extra cohesion for the soil, limiting the reservoir of dust available to be entrained during a high wind event. Third, significantly large mountain ranges exist to the west and east of the nonattainment area, providing topographic protection from high winds and effectively funneling the winds to the valleys of the nonattainment area (Washington et al., 2006). Fourth, a recently installed temporary (March 2010 – February 2011) PM_{10} monitor located near Arlington, Arizona (approximately twelve miles west of the nonattainment border) indicated that approximately 8% of PM_{10} concentration are associated with wind speeds ≥ 12 mph. This is the only PM_{10} monitor that operated any significant distance outside the PM_{10}

[7] 43,333.20 tons ÷ 90% = 48,148.00 tons; 61,282.27 ÷ 90% = 68,091.30 tons. 10% of each represents standardized windblown dust emissions.

nonattainment area.[8] As such, PM_{10} concentrations associated with high winds in other areas of Maricopa County outside the nonattainment area are assumed to be similar to the Arlington monitor given the lack of monitoring data available. Given these observations, it is not unreasonable to assume that on an annual basis, areas outside of the nonattainment area will emit windblown dust at lower rates than areas inside the nonattainment area.

As a final note, it is critical to remember that an emissions inventory of windblown dust does not deal with the processes of transport and deposition. It seeks to quantify the amount of dust produced by the wind within a defined geographic area. Transport and deposition can consider sources of emissions hundreds or even thousands of miles away from the monitors during extreme high wind events (Prospero, 1999; VanCuren and Cahill, 2002). There are clearly sources of windblown dust immediately surrounding Maricopa County that will affect monitor concentrations during these high wind events. The purpose of air quality modeling is to combine all three stages of a dust event, particle entrainment, transport and deposition; while the purpose of this inventory is to quantify particle entrainment from sources within Maricopa County and the PM_{10} nonattainment area.

Functionally, pre-standardized emissions are scaled down to the standardized target emissions in two steps to account for the different emissions rates between Maricopa County and the nonattainment area. The first step simply takes the pre-standardized emissions of the nonattainment area and adjusts them to match the target emissions of 4,814.80 tons. This results in a uniform 91.96% reduction of the emissions in all land use categories. The second step assumes that the balance of emissions between the nonattainment area and the county standardized emission targets, 1,994.33 tons[9], originates in the "donut" area of Maricopa County outside the nonattainment area. Pre-standardized emissions from this "donut" area of the county were calculated using GIS and the methods described in previous sections; then standardized to the target of 1,994.33 tons, a 99.62% reduction of pre-standardized emissions.

Summary of Standardized Windblown Dust Emissions

Using the emission methodologies listed above, annual, standardized PM_{10} emissions for Maricopa County and the PM_{10} nonattainment area are calculated. $PM_{2.5}$ emissions are assumed to be 15% of PM_{10} emissions (WGA, 2006). Daily emissions are obtained by dividing annual emissions by the number of days in calendar year 2008 (366). Annual and daily standardized emissions for Maricopa County and the PM_{10} nonattainment area are shown in Tables A4–10 and A4–11, respectively.

[8] The Buckeye monitor is also located outside the nonattainment area, however at only a distance of 0.75 miles from the western border. In 2008 the Buckeye monitor had 14% of PM_{10} mass associated with wind speeds ≥ 12 mph, suggesting that the rural areas of Maricopa County outside of the nonattainment area may have more of their PM_{10} concentrations associated with high winds. However, when high wind PM_{10} concentrations of the Buckeye monitor are compared to the same time period of the temporary Arlington monitor (March 2010 – February 2011), the high wind percentage is reported to be approximately 7% of the PM_{10} mass, which is similar to the percentage reported by the Arlington monitor (8%).

[9] County standardized emission target of 6,809.13 tons – nonattainment area target of 4,814.80 tons = 1,994.33 tons.

Table A4–10. Standardized, annual and daily PM_{10} and $PM_{2.5}$ emissions from windblown dust in the Maricopa County, by land use category.

Land use category	Annual emissions (tons/yr) PM_{10}	Annual emissions (tons/yr) $PM_{2.5}$	Average daily emissions (lbs/day) PM_{10}	Average daily emissions (lbs/day) $PM_{2.5}$
Active open space	215.94	32.39	1,180.0	177.0
Agriculture – active	61.69	9.25	337.1	50.6
Agriculture – inactive	345.86	51.88	1,890.1	283.5
Auto test tracks	49.23	7.38	269.0	40.4
Developing	394.98	59.25	2,158.4	323.8
Landfill	6.33	0.95	34.6	5.2
Mining	25.37	3.81	138.7	20.8
Passive open space/wash	2,755.11	413.27	15,058.1	2,258.7
Sand & gravel	108.47	16.27	592.7	88.9
Vacant	2,846.15	426.92	15,555.8	2,333.4
Totals:	**6,809.13**	**1,021.37**	**37,214.6**	**5,582.2**

Table A4–11. Standardized, annual and daily PM_{10} and $PM_{2.5}$ emissions from windblown dust in the PM_{10} nonattainment area, by land use category.

Land use category	Annual emissions (tons/yr) PM_{10}	Annual emissions (tons/yr) $PM_{2.5}$	Average daily emissions (lbs/day) PM_{10}	Average daily emissions (lbs/day) $PM_{2.5}$
Active open space	213.93	32.09	1,169.0	175.4
Agriculture – active	57.82	8.67	315.9	47.4
Agriculture – inactive	296.42	44.46	1,619.8	243.0
Auto test tracks	42.93	6.44	234.6	35.2
Developing	391.00	58.65	2,136.6	320.5
Landfill	6.33	0.95	34.6	5.2
Mining	23.75	3.56	129.8	19.5
Passive open space/wash	1,822.61	273.39	9,959.6	1,493.9
Sand & gravel	107.82	16.17	589.2	88.4
Vacant	1,852.19	277.83	10,121.2	1,518.2
Totals:	**4,814.80**	**722.22**	**26,310.4**	**3,946.6**

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Attachment I

MAG 2009 GIS Existing Land Use Database Information

The following attachment exists in draft form, as the land use database is continually updated to reflect new source data and GIS methodologies. The draft as presented here was created on November 16, 2010.

Database Information

Database Name

EXISTING_LAND_USE_2009

Common Names

Existing Land Use, 2009
EXLU, 2009

Description

The Existing Land Use (EXLU) dataset was created as a joint effort of MAG and MAG member agency staff. This dataset serves as a land use inventory and is used for a variety of planning purposes including socioeconomic forecasting and air quality modeling.

This database has three components:

1. **MAG parcels:** Serves as the primary element of the land use inventory. The parcel base integrates Maricopa County Assessor's office (MCA) parcels, Arizona State Land Department (ASLD) land surface ownership and Bureau of Land Management (BLM) designated wilderness areas. Additional supplementary parcels have been created for areas not covered by the other datasets (e.g. within Tribal Lands) based on air photo interpretation and previous EXLU inventories. MCA parcels within the dataset have been modified in some cases to support data requirements for modeling efforts. In particular, groups of related or associated MCA parcels are often aggregated based on a MCA designated Economic Unit or Assessor Subdivision (MCRNUM). However, the majority of parcels retain the original geometry provided by the MCA. All parcels are assigned a detailed MAG land use code and can be related to original MCA parcels via a lookup table.

2. **Land use overlays:** Overrides the parcel base for cases in which the MCA parcels do not adequately distinguish changes in land use. Examples of this include areas encompassing public facilities and institutions, areas adjacent to water courses and major transportation corridors.

3. **Generalized EXLU:** Provides a *generalized* and *contiguous* representation of the land use inventory. Derived by integrating the MAG parcel based with the land use overlays and applying a series of GIS-based generalization procedures. The finest level of categorical detail provided is the MAG 'Long Display Code'.

Frequency of Update

Updates are made to this dataset on an annual basis.

Format

ArcSDE geodatabase feature classes

Projection

Coordinate System = State Plane
Zone = 3176 (Arizona Central)
Horizontal Datum = NAD83 HARN
Linear units = international feet

Data Sources

1. Maricopa County Assessor Office Parcels, February 2009
2. Maricopa County Assessor's Office Subdivisions, February 2009
3. Maricopa County Assessor's Office Secured Master File, February 2009
4. Maricopa County Assessor's Office Residential Master File, February 2009
5. Maricopa County Assessor's Office Commercial Master File, February 2009
6. Arizona State Land Department Land surface management
7. Arizona State Land Department Arizona Preserve Initiative lands
8. Arizona State Land Department Wilderness areas
9. Salt River Project canals
10. Central Arizona Project canals
11. MAG aerial imagery, 2009 (procured from Aerials Express)
12. MAG Existing Land Use, 2004
13. MAG Employer Database, 2008
14. MAG Residential Completions
15. Maricopa County Elections Department Streets
16. Kammrath property databases

Reference

MAG Land Use Codes

See Appendix A.

Assessor Property Use Codes

See http://www.maricopa.gov/assessor/gis/pdf/puc.pdf.

Database Standards and Structure

Naming Conventions and Update Schedule

The naming convention for the Existing Land Use feature class is as follows:

EXISTING_LAND_USE_20xx

Where xx represents the two digit year

File Location

The final version of this dataset is in an ArcSDE geodatabase. This includes the following feature classes:

- MAG_PARCELS: the detailed MAG parcel base
- EXLU_POLYGONS: the generalized EXLU
- CANALS_ROW: land use overlay for canals and surrounding areas
- PARCEL_ADJUNCTS: used to split or override parcel geometries
- FREEWAYS_ROW: land use overlay for freeways and surrounding areas
- PARKS: land use overlay for areas of significant active open space areas
- RAIL_ROW: land use overlay for railroads and surrounding areas
- WATER_COURSES: land use overlay for significant water areas such as residential lakes and stream beds

Update Schedule

Updates will be performed on this dataset on an annual basis. New secured data are released by the Assessor's Office in September of each year. Following acquisition of this data from the Assessor's Office, an incremental update to the Existing Land Use dataset will be undertaken.

Versioning

The Existing Land Use dataset is actively maintained on the *giswork* instance of ArcSDE. Editors create child versions of the database from the QA/QC version and perform all edits against the child version. Edits are reconciled and posted to the QA/QC version from the editor's child version. Edits are checked for completeness and correctness, and are then posted to the DEFAULT version on *giswork*.

At the end of each quarter, or on an as needed basis, the Existing Land Use data are replicated to the production database, *gismag*. The replicated feature class on the *gismag* instance is renamed with the naming convention described below. The fourth quarter iteration represents the final iteration for a calendar year.

Topological Relationships

None

Database Structure

Attributes of the generalized EXLU feature class are:

Field	Description	Format	Instance
OBJECTID	ESRI geodatabase unique identifier	ObjectID	giswork
LONG_DISPLAY_CODE	MAG generalized land use class	Text	giswork
ACRES	Area of the polygon	Double	giswork
MPA	MPA the polygon is within	Text	giswork
Shape	ESRI feature geometry	Geometry	giswork

Dependencies

1. Tabular data maintained in the form of the Parcel Information Table, Residential Information Table, and Non-Residential Information Table. These datasets provides input to the AZSMART model. These tables are a modified version of the Secured Master, Residential Master, and Commercial Master files acquired from the Maricopa County Assessor's Office. Work done to the existing land use dataset that modifies the land use also forces an update of the Parcel Information Table, Residential Information Table, and Non-Residential Information Table.
2. A feature class called MAG Parcels was constructed to serve as the basis for an Existing Land Use feature class. A MAG Parcel Number (MPN) was assigned to each feature in the dataset. In most cases the MPA is identical to the APN. In some cases, however, it was necessary to aggregate parcels together based on a shared Economic Unit (this was the case with large shopping centers and some buildings). The MPN, then, was edited to reflect this change. In these cases, the MPN was changed to reflect the Economic Unit value shared by the original parcels.

Database Creation

Summary

- Data are collected from various sources as outlined in this document.
- Assign a MAG Parcel Number (MPN) to each parcel.
- Merge parcels that fall within a single economic unit, as defined by the Maricopa County Assessor's Office. MPN is updated to reflect value of economic unit.
- Assign a property use code to the MAG Parcels by joining with the Secured Master File.
- Assign MAG land use codes based on a lookup table between property use codes and MAG land use codes.
- Locate parcels with null property uses are located and assigned a property use code and MAG land use code.
- Identify single family residential (SFR) land uses. Determine density of SFR parcels and assign a MAG land use code to these parcels.
- Identify parcels associated with airports, proving grounds, and public facilities and reviewed for assignment of correct MAG land use code.
- Compare MAG Parcels to Kammrath property databases.
- Visually inspect MAG Parcels with the aid of contextual datasets such as MAG aerial imagery, MAG employers database, and MAG residential completions database; recoding erroneous land uses.
- Construct Existing Land Use dataset for review by MAG member agencies.
- Incorporate comments from member agencies to Existing Land Use Parcels
- Construct final Existing Land Use dataset.

Ancillary Tables or Databases

MCA_MAG_LU_LOOKUP – a lookup table between Assessor property use codes and MAG land use codes.

APN_MPN_LOOKUP – a lookup table that maps MPN to APN

MAG_LU_CODES – a lookup table that provides additional information about the MAG land use codes and maps detailed land use codes to simple land use codes

Preliminary Steps

Data was collected from the Maricopa County Assessor's Office and the Arizona State Land Department. These datasets were loaded into the Enterprise geodatabase. A separate database for MAG Parcels was created. The purpose of the MAG parcel database was to aggregate parcels with shared economic units, thus aggregating multiple parcels into logical whole units. A MAG Parcel Number (MPN) was then assigned to each parcel remaining. For the majority of parcels, the MPN is the same as the APN. For parcels that were merged based on similar economic units, a new MPN was created. Following this, each parcel and property use file was checked for records with duplicate MPNs. The resulting MPN is the shared economic unit of the merged parcels or the MCR Number of the subdivision depending on if the percent ownership file is less than 100 in the Commercial Master File. The latter case was used in cases where an economic unit did not exist (i.e. condominiums) or where multiple economic units functioned as a logical whole.

Editing Steps

Initial Feature Class Construction

For each parcel and property use file, a field called FILE was added. This field was used calculate to the source of the parcels (e.g. ME for Mesa). The purpose of this was to provide a lineage back to the source file. Following this, all parcel files were merged into a single feature class, retaining the FILE, MPN, and shape fields. A new column, KEY, was added and calculated to the value of FILE + " " + MPN. The KEY field provides a unique identifier for cases in which MPN values exist in multiple files. Parcel property use tables were also merged into a single file, retaining the MPN and PROPERTY_USE fields. A similar KEY field was added to the property use table.

A PROPERTY_USE field was then added to the parcels feature class. The feature class and the property use table were then joined based on the KEY field and the PROPERTY_USE in the feature class was calculated based on the property use value in the joined table.

PROP_USE_COMMENT, REVIEW_PROP_USE, and MAG_LU fields were added to the feature class. PROP_USE_COMMENT was intended to detail problems or other information about property use codes. REVISE_PROP_USE stored changes made to the PROPERTY_USE field. Finally, MAG_LU stored the subsequent MAG land use code based on the MCA_MAG_LU lookup table.

Next, duplicate MPNs (most likely existing at the edges of merged regions) were dropped from the feature class. For parcels to be dropped, the REVISE_PROP_USE was set to -9999 and annotated using the PROP_USE_COMMENT field.

Addressing Null Property Uses

Next, null property uses were located in the feature class. Null property uses arose from one of two reasons: the parcel/MPN did not have a corresponding record in the property use table or the property use was null in the secured master file acquired from the Assessor's Office. This condition most likely arose due to the parcels and secured files being out of sync with one another, the secured files being more current than the parcels. Null values were reconciled by querying the Assessor's Office website. A script was written to scrape property uses from the Assessor's website. Most of the null values were resolved in this way, while the remainders were fixed manually.

Assigning densities to single family uses

When the 'default' MAG land use classes are assigned based on the MCA property use code, all single family residential (SFR) parcels are assigned a single class (e.g. 100). This class needs to be refined to provide additional detail about the density of the SFR parcel. Multiple definitions and approaches may be used to classify the SFR densities. The approach employed here is based on the assumption that (*a*.) MCA subdivisions provide a logical grouping of parcels within which to assess density since the subdivision boundaries likely reflect the original intents of the development and (*b.*) that SFR parcels falling outside of subdivisions may be grouped according to neighboring SFR parcels that are not separated by other land uses. This entails the following:

1. Assign each parcel to the subdivision it falls within:
    a. Obtain centroids for the parcel
    b. Perform a spatial join in which each parcel centroid is assigned to the subdivision it falls within
    c. Perform an attribute join (based on MPN) between the parcel polygons and their corresponding centroids to assign the subdivision to the parcel polygons. For parcel polygons falling outside of a centroid this value will be NULL

2. For SFR parcels falling outside a MCA subdivision, assign a pseudo subdivision based on a contiguous set of SFR parcels it falls within:
    a. Select a subset of SFR parcel polygons with NULL subdivisions
    b. Dissolve these parcels to obtain contiguous blocks: these blocks are pseudo subdivisions
    c. Assign a unique identity to each pseudo subdivision. The identity is assigned by concatenating the character 'b' with the OBJECTID of the pseudo subdivision
    d. Obtain centroids for the parcels identified in 2a.
    e. Perform a spatial join in which each centroid from 2b is assigned to the pseudo subdivision it falls within
    f. Perform an attribute join between the centroids resulting from 2e with the parcel polygons from 2b. Assign each parcel's subdivision field the values of the pseudo subdivision id of its corresponding centroid.

3. Assign a refined SFR land use based on the total number of units and the total number of SFR acres in its subdivision or pseudo subdivision.
    a. If it does not already exist, add a field called ACRES and use the Calculate Geometry tool to assign area in acres for each parcel
    b. Get a subset of SFR parcels
    c. Dissolve parcels on the subdivision field; retain the sum of ACRES field
    d. Join the parcels from 3b with the dissolved attribute table from 3c
    e. Use the following VBA code block to assign a density based SFR land use class to the parcels:

```
d = sumSubdivision Units/ sumSubdivisionAcres
if d <= 0.2 then
  lu = 110
elseif d > 0.2 and d <= 1 then
  lu = 120
elseif d > 1 and d <= 2 then
  lu = 130
elseif d > 2 and d <= 4 then
  lu = 140
elseif d > 4 and d <= 6 then
  lu = 150
elseif d > 6 then
  lu = 160
end if
```

Initial and Automated Land Use Checks

Areas in and around airports were checked. Parcels comprising the regional airports were flagged and recoded to an airport property use and MAG land use code. In most cases, the parcel configurations closely resembled the actual airport boundaries were kept as-is. However, overlays needed to be created for Sky Harbor, Buckeye, Gila Bend, and Pleasant Valley airports whose boundaries are distinctly different from the parcel boundaries.

Proving ground areas were also examined in detail. These areas typically consist of very large parcels that end up being coded as “industrial.” This tends to skew the acreage of industrial land in the county. These large parcels were sought out and recoded. Several landfills were also captured in this process.

Parcels representing large public facilities, prisons and jails, city halls, community centers, and religious institutions were also checked using aerial imagery, Google Street View, employer points, 2004 existing land use, and the values of neighboring parcels.

Kammrath property databases were also used during this process to check correctness of MAG land use code assignment. Property types addressed by this check were apartment complexes, mobile home and RV parks, and industrial parks in which the classification on warehousing versus light industrial use was not clear.

City by City Review

Having resolved a number of issues out of the gate, the next step was to perform a city by city review of the parcels. This was accomplished by the use of a tracking grid based on the PLSS to avoid duplication of effort. MAG GIS staff reviewed each city individually for assumed correctness of land use coding, to recode land uses or flag for exclusion sliver parcels. Parcels in which the land use was in question were primarily reviewed using aerial imagery, however the MAG employer database and MAG residential completions database were also used to provide supplementary information about the types of activities, and hence potential uses, taking place on individual parcels.

Overlay feature classes were also edited during this time. Since the underlying assumption in this editing process was that parcels could not be modified because they had to be tied back to an original parcel base for change tracking, overlays were used to approximate splits. For example, in many cases near water courses, property lines are not coincident with natural land use breaks. A parcel whose primary land use is agricultural may extend into the river bottom. The portion of the parcel in the river bottom is not agricultural, therefore a polygon is added to an overlay feature class representing that portion of the parcel that is in the river bottom and coded as “passive open space.” Layers used for this purpose include cultural features, freeway right-of-ways, railroad right-of-ways, parks, canals, and water courses and lakes.

Rules observed during the city by city review were:

1. As a general rule, parcel geometries were not changed. Significant non-road void areas were filled to account for public lands and State Trust not otherwise present in the Assessor’s data.
2. Developing residential parcels should be “parcelized” or broken into groups of parcels that look like a residential development. If this is not the case, these are recoded as vacant.
3. Developing residential and commercial parcels were generally recoded as vacant, unless it was demonstrable through review of aerial photos that the parcel in question was indeed developing.

4. Residential parcels that appeared to be connected with another already developed residential parcel were coded to match their associated parcel and flagged as "AZSMART EXCLUDE." The purpose of including this flag was so as not to change the total number of residential parcels.
5. Very small public facilities were excluded.
6. River bottoms and floodways are coded as Passive Open Space unless some other land use was evident. In most cases, this other land use would be sand and gravel operations.
7. For mobile homes or trailers sitting on large lots, as opposed to within mobile home/RV parks, the parcel was coded to match the adjacent residential parcels.
8. Parking lots and parking structures were coded to match adjacent commercial or office parcels if the parking feature was visibly associated with another parcel.

Some edits were made to the underlying parcels during this review. The Assessor's Parcels cover only those areas not occupied by State Trust or Federal public lands, including National Forests, BLM public lands, and Bureau of Reclamation sites. These were added as features to the Existing Land Use Parcels. These are identifiable by their lack of an MPN and being flagged in the comments field as being BLM, Bureau of Reclamation, Forest Service, Military or State Trust.

Once a MAG staff member had completed a review of a city, the MAG GIS Program Manager reviewed the city a second time to ensure consistency among editors and across cities.

Construction of Existing Land Use Feature Classes for Member Agency Review

Following these initial activities, the generalized existing land use for an individual city was constructed. Land use blocks were first generated using a selected subset of parcels (i.e. those parcels not flagged for exclusion). These were clipped to the MPA boundary of the individual city in question. The resulting clipped blocks were joined with a lookup table to assign generalized long display codes. The blocks were then dissolved on the long display code.

Next, land use blocks were integrated with Assessor Subdivisions. The intent in this operation was to identify subdivisions with homogenous residential land use and to remove most of the neighborhood active open space land use. These land uses were problematic because they tend to form long, continuous landscaping parcels that, in many cases, encircle a subdivision. These also include neighborhood parks of all sizes. Some parks were necessary to maintain because of their size, and the geometry of these were copied into the parks overlay.

The integration proceeded by first dividing the contiguous land use blocks into two sets: those contained within subdivisions and those falling outside of subdivisions. This was achieved by performing a union between the subdivisions and the land use blocks and then selected out the results based on the combinations of resulting values (more specifically, the FID values). Next, areas *within* subdivisions were further divided into areas within homogenous subdivisions and those falling within heterogeneous subdivisions. This classification was obtained by grouping the areas by subdivision (via the 'Summarize' tool in ArcGIS) and identifying those subdivisions that had a single long display code value. A minimum area threshold was also specified to eliminate slivers that are artifacts of the union process. Areas within homogenous subdivisions were replaced with a subdivision boundary. Areas within heterogeneous subdivisions were then independently fed into a cost allocation algorithm that assigned that land use at a given location based on the land use it was closest to (here distance was based on impedance rather than Euclidean distance). Following this, the land use outside of subdivisions, the homogenous subdivision boundaries and the results of the cost allocation algorithms were merged into a single dataset. The resulting dataset was then fed into another cost allocation to fill in the voids for areas falling outside of subdivisions.

The final step in this process was to integrate overlays via successive erases and merges. This began by integrating all the overlays into a single feature class. The overlays were integrated in the following order:

1. Open space
2. Parks
3. Water courses
4. Canal rows
5. Railroad rows
6. Freeways
7. Cultural adjuncts

Finally, the resulting integrated overlay feature class was combined with results of the final cost allocation. This was achieved by erasing the overlay areas from the allocated feature class and then merging the results of the erase with the integrated overlay class.

Database Update

Ancillary Tables or Databases

Parcels and secured master files from the previous year are used as a point of comparison with new data collected from the Assessor's Office.

MCA_MAG_LU_LOOKUP – a lookup table between Assessor property use codes and MAG land use codes

APN_MPN_LOOKUP – a lookup table that maps MPN to APN

MAG_LU_CODES – a lookup table that provides additional information about the MAG land use codes and maps detailed land use codes to simple land use codes

Preliminary Steps

Data is collected from the Maricopa County Assessor's Office and the Arizona State Land Department. These datasets are loaded into the Enterprise geodatabase.

Preparatory Steps

A determination of the extent of changes between data vintages is made. For the Land Department data, the changes will tend to be small. The likely impact of these changes will be removal of State Trust land into private ownership or to another government entity, the end result of either case being that Assessor parcels will be created from the transfer of ownership. For the Assessor data, the change will be more substantial and will include:

1. Parcels that have been retired through splits or merges
2. Parcels that have been added due to splits from a parent parcel or transfer from State or Federal ownership

3. Parcels that have new property uses assigned to them

These changes may be identified by comparing the APNs and property use codes among the parcels in the current year with those in the previous year. This can be handled via SQL queries:

Births

```
select * from dataloader.PARCELS_2010
where APN not in (
   select APN from dataloader.PARCELS_2009
)
```

Retirements/deaths

```
select * from dataloader.PARCELS_2009
where APN not in (
   Select APN from dataloader.PARCELS_2010
)
```

Transitions/changes

```
select a.APN, a.MAG_LU as MAG_LU_2010, b.MAG_LU as MAG_LU_2009
from (
   select a.APN, b.PropertyUseCode, c.MAG_Lucode as MAG_LU
   from dataloader.PARCELS_2010 a
   inner join dataloader.SECURED_MASTER_2010 b
   on a.APN = b.APN
   inner join GISWORK.dataloader.MCA_MAG_LU_LOOKUP c
   on b.PropertyUseCode = c.Property_Use_code
) a
inner join(
   select a.APN, b.PropertyUseCode, c.MAG_Lucode as MAG_LU
   from dataloader.PARCELS_2009 a
   inner join dataloader.SECURED_MASTER_2009 b
   on a.APN = b.APN
   inner join GISWORK.dataloader.MCA_MAG_LU_LOOKUP c
   on b.PropertyUseCode = c.Property_Use_code
) b
on a.APN = b.APN
where a.MAG_LU <> b.MAG_LU
```

<u>MAG Parcels Update Process</u>

1. For all parcels that have not changed, (i.e. they have the same property use code and their APN exists in both years) assign the MAG_LU based on the previous year

2. For parcels that have changed (i.e. their property use codes have changed) assign MAG_LU based on the default value provided in the MCA_MAG_LU_LOOKUP.

3. Re-build MAG Parcels for the parcels that have not changed. Note: this step is only necessary if the parcel geometries have shifted, otherwise the MAG Parcels from the

previous year can be used.

4. For all deaths/retiree parcels identify any MAG Parcels that will also need to be retired. It may also be necessary to identify related parcels that may or may not also be retired (e.g. a single parcel is retired but other parcels in the Economic Unit or subdivision remain unchanged).

5. Identify parcel births that will need to be aggregated to create new Existing Land Use Parcels:

```
select a.APN, count(*) as NUM_IMPROVEMENTS from (
   select APN
   from dataloader.PARCELS_2010
   where APN not in (
      select APN from dataloader.PARCELS_2009
   )
) a
inner join dataloader.COMMERCIAL_MASTER_2010 b
on a.APN = b.APN
where LTRIM(RTRIM(b.PercentOfOwnership)) <> '100'
group by a.APN
order by count(*) desc
```

6. Re-assign single family residential densities for parcel births and surrounding areas.

Generalized Existing Land Use Update Process

Determine if the parcels have shifted across years. If the parcels have shifted, re-build the generalized land use for the entire dataset per the process discussed for the initial construction. If the parcels have not shifted, identify regions surrounding births and transitions. These neighborhoods may simply involve generating minimum bounding rectangles (MBRs) or may be more complicated using something like a Voronoi diagram. Finally, re-build the generalized EXLU for each of the identified change regions.

Reporting

Report the number of changes that will be made to the database. This might include: the number of parcel births, deaths and transitions. Also, report the number of MAG Parcels that will consequently be retired or updated. It may also be worthwhile to report the types of transitions that are occurring, as well as the dominant land uses of the births and deaths.

For example, to report the types of land use transitions occurring:

```
select cast(b.MAG_LU as int) as MAG_LU_2009, cast(a.MAG_LU as
int) as MAG_LU_2010, count(*) as Parcel_Count from (
   select a.APN, b.PropertyUseCode, c.MAG_Lucode as MAG_LU from
   dataloader.PARCELS_2010 a inner join
   dataloader.SECURED_MASTER_2010 b
```

```
      on a.APN = b.APN
      inner join GISWORK.dataloader.MCA_MAG_LU_LOOKUP c
      on b.PropertyUseCode = c.Property_Use_code
   ) a
   inner join (
      select a.APN, b.PropertyUseCode, c.MAG_Lucode as MAG_LU from
      dataloader.PARCELS_2009 a inner join
      dataloader.SECURED_MASTER_2009 b
      on a.APN = b.APN
      inner join GISWORK.dataloader.MCA_MAG_LU_LOOKUP c
      on b.PropertyUseCode = c.Property_Use_code
   ) b
   on a.APN = b.APN
   where a.MAG_LU <> b.MAG_LU
   group by a.MAG_LU, b.MAG_LU
   order by count(*) desc, a.MAG_LU asc, b.MAG_LU asc
```

This will return the following:

2009 land use	2010 land use	Parcel count
910	100	6902
750	910	2567
910	710	1397
910	750	1310
900	910	1194
910	170	980
910	900	523
100	170	468
900	750	404
100	910	376
...	...	...

Review Process

Internal Review

Preliminary Steps

Perform the steps in the previous section. The resulting data should be in a versioned SDE database.

Review Steps

1. Perform QA/QC on births with "problematic" property use codes. For example most single family parcels will be fine, but parcels with a Property Use Code of 9000 will require additional review.

2. Examine problematic land use transitions. For example a transition from 910 (developing residential) to 100 (single family residential) is a reasonable transition. However, a transition, such as from 110 to 552 (public services), likely represents a problem in one of the base datasets and bears further investigation.

3. Generate acreages for all medium-level land use classes and compared against the previous existing land use acreages to determine if an error has occurred. The changes

between vintages should not be significant. Substantial changes in one land use class between vintages will be indicative of a problem in one of the underlying datasets, and will force a review of that land use class in the new data.

4. Perform point-in-polygon analysis between geocoded Kammrath data or other similar dataset and the MAG parcels. Check for parcels that contain points with incompatible uses (e.g. industrial point falling on a retail parcel) and make appropriate corrections as warranted with a secondary examination of aerial imagery for the area of interest.

Reporting

Report changes in acreages across the two years for the detailed MAG land use codes. Generate 'change maps' to highlight spatial trends in the land use transitions. Generate a semi-detailed report and dataset for the Air Quality division and Maricopa County using a course land use classification. The semi-detailed dataset contains parcel boundaries dissolved using the course classification and has overlays integrated but remaining voids are left alone and treated as 'Transportation' uses.

Member Agency Review

Preliminary Steps

The existing land use dataset is sent to members of the MAG POPTAC and GIS professionals who have been identified as key GIS contacts within the member agencies. A tracking database that includes a list of recipients and status of review material delivery and responses should be completed prior to sending any data out for review. It is also preferable to let members of the POPTAC know to expect the review materials within a certain period of time. This is best accomplished at a monthly MAG POPTAC meeting.

Review Steps

Notify members of the POPTAC that the existing land use dataset will be provided to them immediately. Members of the POPTAC will receive the low-detail dataset as a file geodatabase of their or as a paper map of their MPA, a summary table of existing land use classifications within their MPA at the low-detail level, and a lookup table of APN to MAG land use codes at the high-detail level. Data and maps will be mailed to members of the POPTAC. Members of the POPTAC will be instructed that they should provide feedback to MAG within six weeks. Feedback may be provided by individuals receiving paper maps may mark up the maps with any corrections or by individuals receiving geospatial data may provide a polygon feature class of recommended changes.

Comments received from member agencies shall be incorporated into the Existing Land Use as quickly as possible.

Reporting

Notify Members of the POPTAC that a final version of existing land use exists and that they will be provided with the dataset upon request.

Final Output

Metadata Update

Export the metadata from the current version of the Existing Land Use feature class to a local directory. This can then be imported to serve as the new feature class's metadata. Metadata fields that will then need to be updated are the citation name, publication date, and last update fields. Any additional changes to the feature class should be noted in the metadata at this time.

Export for Distribution

Export the current year's Existing Land Use feature classes from the *data* instance to I:\data\distribution\exlu. The frequency of export from ArcSDE is dependent on the frequency of replication from the *work* instance to the *data* instance.

Reporting

Report changes in acreages across the two years for the detailed MAG land use codes. Generate 'change maps' to highlight spatial trends in the land use transitions. It may also be worthwhile to generate ArcGIS server sites to deliver results and support land use queries.

Appendix A

MAG Land Use Codes

LUCODE	Land Use - Detailed	Land Use Description
110	Rural Residential	<= 1/5 du per acre (SF)
120	Estate Residential	1/5 du per acre to 1 du per acre (SF)
130	Large Lot Residential (SF)	1 du per acre to 2 du per acre (SF)
140	Medium Lot Residential (SF)	2-4 du per acre (SF)
150	Small Lot Residential (SF)	4-6 du per acre (SF)
160	Very Small Lot Residential (SF)	>6 du per acre (SF)
161	Very Small Lot Residential (SF-Mobile Homes)	Mobile home parks/RV Parks (>6 du per acre)
170	Medium Density Residential (MF)	5-10 du per acre (MF)
180	High Density Residential (MF)	10-15 du per acre (MF)
190	Very High Density Residential (MF)	15-50 DU/AC Residential (MF)
191	High Rise Residential	>50 DU/AC (MF)
210	Low Density Commercial	Movie Theatres, Skating Rinks, Amusement Facilities
220	Greenhouse Commercial	Nurseries, Greenhouses
230	Specialty Commercial	<=50,000 square feet
240	Neighborhood Commercial	50,000 to 100,000 square feet
250	Community Commercial	100,000 to 500,000 square feet
260	Regional Commercial	500,000 to 1,000,000 square feet
270	Super-Regional Commercial	>= 1,000,000 square feet
310	Storage Facilities	Storage Facilities
320	Warehouse	Warehouse/Distribution Centers
330	Light Industrial	Laboratory/Back Office
340	Heavy Industrial	Manufacturing
410	Office Low Rise	1-4 stories
420	Office Mid Rise	5-12 stories
430	Office High Rise	13 stories or more

510	Motels/Hotels	Motels/Hotels
511	Resorts	Resorts
520	Educational	Educational institutions where no detail available
521	Preschool/Daycare facilities	Preschool/Daycare facilities
522	Schools (K-12 grade)	Schools
523	Post High School Institutions	Including public and private colleges and technical training institutions
524	Arizona State University	ASU Main and Extended Campuses
525	Dormitories	Dormitories associated with educational institutions
530	Institutional	Institutions where no details are available
531	Religious Institutions	Churches/Religious Institutions
532	Medical Offices	Medical Offices
533	Hospitals/Medical Centers	Hospitals/Medical Centers
534	Nursing Homes/Assited Care Facilities	Nursing Homes/Assited Care Facilites (Group Quarter)
540	Cemeteries	Cemeteries, Mausoleums, Crematoriums
551	Public Offices	Includes city halls
552	Public Services	Includes community centers, libraries, police and fire stations, courts and other government services
553	Large Public Facilities	Includes power sub-stations, Work yards, Sewer and Water treatment plants
554	Military	Military Use
555	Prisons	Prisons and jails
560	Special Events	Includes stadiums, sports complexes, and fairgrounds
571	Landfill	Landfill
572	Sand and Gravel	Sand and Gravel
573	Automotive Proving Grounds	Automotive Proving Grounds
574	Mining	Mining

575	Solar Generating Stations	Solar generation stations not associated with other power facilities
610	Transportation	Freeways/Expressways/ Highways/ Major Roads/ Arterials/ ROWs where no detail available
611	Parking Lots	Parking Lots
612	Parking Structures	Parking Structures
613	Park and Ride lots	Park and Ride lots
614	Transit Center	Transit Center
615	Freeways/Expressways/ Highways	Freeways/Expressways/ Highways
616	Major Roads, Arterials	Major Roads, Arterials
617	Neighborhood roads	Neighborhood roads
618	Railroads	Railroads
620	Airports	Public use airports
621	Sky Harbor Airport	Sky Harbor Airport
622	Private airport	Private use airports
710	City/Regional Active Open Space	Includes city/regional parks, playgrounds/fields
711	Local/Neighborhood Active Open Space	Includes Local/Neighborhood common areas, parks, playgrounds
720	Golf courses	Golf Courses
730	Passive Open Space	Includes mountain preserves and washes
731	Restricted Open Space	Restricted Open Space (Including Firing Range)
732	Limited Use Public Facilities	Very small difficult to access parcels
733	Floodplain	Floodplain
740	Water	Reservoirs/Rivers/Lakes
741	Canal	Canal
742	Intermittant Water	Intermittant Water
743	Residential Lake	Residential Lake
750	Agriculture	General Agriculture
810	Business Park	Includes enclosed industrial, office or retail in a planned environment
820	Mixed Use	Jurisdiction defined
821	Mixed Use/Indian Community	Mixed Use/Indian Community
830	Planned Community	Planned Community

900	Vacant (existing land use database only)	Vacant
910	Developing Residential	Residential Under Construction
920	Developing Commercial	Commercial Under Construction
930	Developing Industrial	Industrial Under Construction
940	Developing Office	Office Under Construction
950	Developing Public/Other Employment	Employment Under Construction
960	Developing Transportation	Transportation Under Construction
970	Developing Open Space	Developing Open Space
980	Developing Multiple Use	Multiple Use Under Construction
999	Unknown	Unknown