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Guidance For Network Design and Optimum Site Exposure For $PM_{2.5}$ And PM_{10}

GUIDANCE FOR NETWORK DESIGN AND OPTIMUM SITE EXPOSURE FOR $PM_{2.5}$ AND PM_{10}

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ABSTRACT

This guidance provides a method and rationale for designing monitoring networks to determine compliance with newly enacted $PM_{2.5}$ and PM_{10} National Ambient Air Quality Standards. It defines concepts and terms of network design, presents a methodology for defining planning areas and community monitoring zones, identifies data resources and the uses of those resources for network design, and provides some practical examples of applying the guidance. $PM_{2.5}$ monitoring sites are to be population-oriented, measuring exposures where people live, work, and play. For comparison to the annual $PM_{2.5}$ standard, the locations must be community-oriented and as such, these do not necessarily correspond to the locations of highest PM concentrations in an area. Existing Metropolitan Statistical Areas are first examined to determine where the majority of the people live in each state. These are then broken down into smaller populated entities which may include county, zip code, census tract, or census block boundaries. Combinations of these population entities are combined to define Metropolitan Planning Areas. These may be further sub-divided into Community Monitoring Zones, based on examination of existing PM measurements, source locations, terrain, and meteorology. Finally, $PM_{2.5}$ monitors are located at specific sites that represent neighborhood or urban scales to determine compliance with the annual standard and at maximum, population oriented locations for comparison with the 24-hour standard. Transport and background sites are located between and away from planning areas to determine regional increments to PM measured within the planning area.

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1.0 INTRODUCTION

This document provides guidance for locating monitoring stations to measure compliance with national standards for Suspended Particulate Matter (PM) in the atmosphere. PM has been shown to adversely affect public health when susceptible populations are exposed to excessive concentrations (U.S. EPA, 1996; Vedal, 1997). National Ambient Air Quality Standards (NAAQS) for PM have been established to minimize the adverse effects of PM on the majority of U.S. residents. This guidance document is based on the new NAAQS (U.S. EPA, 1997). This document may be revised where necessary as it is further refined by actual application to network design during the implementation of the new monitoring program. The NAAQS apply to the mass concentrations of particulates with aerodynamic diameters lower than 10 µm (PM_{10}) and 2.5 µm ($PM_{2.5}$) and are described as follows (U.S. EPA, 1997):

- Twenty-four hour average $PM_{2.5}$ not to exceed 65 $\mu g/m^3$ for a three-year average of annual 98th percentiles at any population-oriented monitoring site in a monitoring area.

- Three-year annual average $PM_{2.5}$ not to exceed 15 $\mu g/m^3$ concentrations from a single community-oriented monitoring site or the spatial average of eligible community-oriented monitoring sites in a monitoring area.

- Twenty-four hour average PM_{10} not to exceed 150 $\mu g/m^3$ for a three-year average of annual 99th percentiles at any monitoring site in a monitoring area.

- Three-year average PM_{10} not to exceed 50 $\mu g/m^3$ for three annual average concentrations at any monitoring site in a monitoring area.

The $PM_{2.5}$ NAAQS are new. While the PM_{10} NAAQS retain the same values as the prior NAAQS (U.S. EPA, 1987), their form is new. Previously, the PM NAAQS applied to the highest 24-hour or annual averages found within a monitoring planning area, and monitoring networks were often designed to measure these highest values. These networks did not necessarily represent the overall exposure of populations to excessive PM concentrations. Some data from these networks were disregarded by epidemiologists as being unrelated to health indicators such as hospital admissions and death. Air quality districts may have been reluctant to locate source-oriented monitors that might assist in understanding source impacts because such monitors might cause a large area to be designated in non-attainment of NAAQS.

The new forms for these standards are intended to provide more robust measures for the PM indicator. While PM_{10} network design and siting criteria are unchanged, new $PM_{2.5}$ monitoring networks to determine compliance or non-compliance are intended to best represent the exposure of populations that might be affected by elevated $PM_{2.5}$ concentrations. As used in this document, the word compliance means attainment of a NAAQS. This involves new concepts of spatial averaging and the operation of some monitoring sites for $PM_{2.5}$ measurements that are not eligible for comparison to one or both of the $PM_{2.5}$ NAAQS.

Special Purpose Monitoring sites that help to understand the causes of non-compliance are encouraged by excluding their data from the compliance determination during the first two years of their operation. The number of monitors in the existing PM_{10} network will likely decrease as new $PM_{2.5}$ sites are established. The $PM_{2.5}$ sites may or may not be collocated with PM_{10} monitoring locations. This guidance for network design and optimum site exposure of PM_{10} and $PM_{2.5}$ monitors describes how particulate monitoring networks can comply with these intentions.

1.1 Objectives of Guidance

The objectives of the guidance specified here are to:

- Define concepts and terms of network design.
- Present a methodology for defining planning areas and selecting and evaluating monitoring sites in a network.
- Summarize the availability and usage of existing resources for network design.
- Demonstrate the methodology in practical applications.

This guidance builds upon the guidance specified by Koch and Rector (1987) for PM_{10} monitoring associated with the previous PM NAAQS. It also considers recent advances in sampling theory, the availability of different types of data over the Internet and on CD-ROM, and the practical experience of different air quality management districts.

Network design guidance must be more specific than in the past with respect to types of sites and what they represent. It should identify data available to make judgments on site selection and define methods to use these data for those judgments. It should provide methods to evaluate the extent to which these judgments were valid. This guidance intends to provide this specificity.

1.2 Schedule and Approvals for Network Design and Implementation

The implementation of network design, operation and evaluation for the revised PM NAAQS follows this schedule:

- **July 18, 1997:** Standards were promulgated.
- **September 16, 1997:** Standards became effective.
- **October–December, 1997:** Guidance is applied by state and local agencies in test areas and procedures are refined. Network deployment is completed.
- **January 1, 1998:** Network design guidance is finalized and the regulated requirement of $PM_{2.5}$ monitoring commences.

- **July 1, 1998:** Each state submits a PM monitoring network description to its EPA Regional Administrator describing its network.

- **September 16, 1998:** Commence operation of at least one core $PM_{2.5}$ SLAMS site in each MSA with population greater than 500,000, one site in each PAMS area, and two additional SLAMS sites per state. See footnote [1].

- **July 1, 1999, 2000, 2001, 2002, etc.:** State and local agencies submit annual monitoring reports and network evaluations, based on data from previous calendar year.

- **September 16, 1999:** Commence operation of other required SLAMS sites (including all required core SLAMS, required regional background and regional transport SLAMS, continuous PM monitors in areas with population greater than 1 million, and all additional required $PM_{2.5}$ SLAMS). See footnote [1].

- **September 16, 2000:** Commence operation of additional sites (e.g., sites classified as SLAMS/SPM to complete the mature network). See footnote.[1]

1.3 Related Documents

Other documents related to PM monitoring networks are:

- The Federal Register for July 18, 1997, pages 38652-38760 and 38764-38854, describe the proposed new PM standards, monitoring requirements, and designation of reference and equivalent methods for $PM_{2.5}$ (U.S. EPA, 1997).

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[1] Network deployment schedules as defined by 40 CFR part 58. Accelerated schedule may be dictated by additional guidance and EPA policy.

2.0 CONCEPTS OF NETWORK DESIGN

Several new concepts and definitions are embodied in the form of the revised air quality standards. A brief overview of these concepts and definitions is given in this section.

2.1 Particle Properties

A wide variety of suspended particles are found in a typical atmosphere. Size, chemical composition, concentration, and temporal variability all have the potential to affect public health and perception of pollution. Several of these same properties allow suspended particles to be attributed to their sources.

Friedlander (1970, 1971) proposes a size-composition probability density function (PDF) to describe the number of suspended particles at given times and points in space with specified chemical composition and particle size. While a useful theoretical concept, the exact PDF can never be obtained in practice with current technology. Since all sizes and every chemical component of particles cannot be measured everywhere at all times, the measurement problem must be narrowed in scope to identify those properties that are important for compliance.

Figure 2.1.1 shows the major features of the mass distribution of particle sizes found in the atmosphere. The "nucleation" range, also termed "ultrafine particles", consists of particles with diameters less than ~0.08 μm that are emitted directly from combustion sources or that condense from cooled gases soon after emission. The lifetimes of particles in the nucleation range are usually less than one hour because they rapidly coagulate with larger particles or serve as nuclei for cloud or fog droplets. This size range is detected only when fresh emissions sources are close to a measurement site or when new particles have been recently formed in the atmosphere.

The "accumulation" range consists of particles with diameters between 0.08 and ~2 μm. These particles result from the coagulation of smaller particles emitted from combustion sources, from condensation of volatile species, from gas-to-particle conversion, and from finely ground dust particles. The nucleation and accumulation ranges constitute the "fine particle size fraction", and the majority of sulfuric acid, ammonium bisulfate, ammonium sulfate, ammonium nitrate, organic carbon and elemental carbon is found in this size range. Particles larger than ~2 or 3 μm are called "coarse particles"; they result from grinding activities and are dominated by material of geological origin. Pollen and spores also inhabit the coarse particle size range, as do ground up trash, leaves, and tires. Coarse particles at the low end of the size range also occur when cloud and fog droplets form in a polluted environment, then dry out after having scavenged other particles and gases.

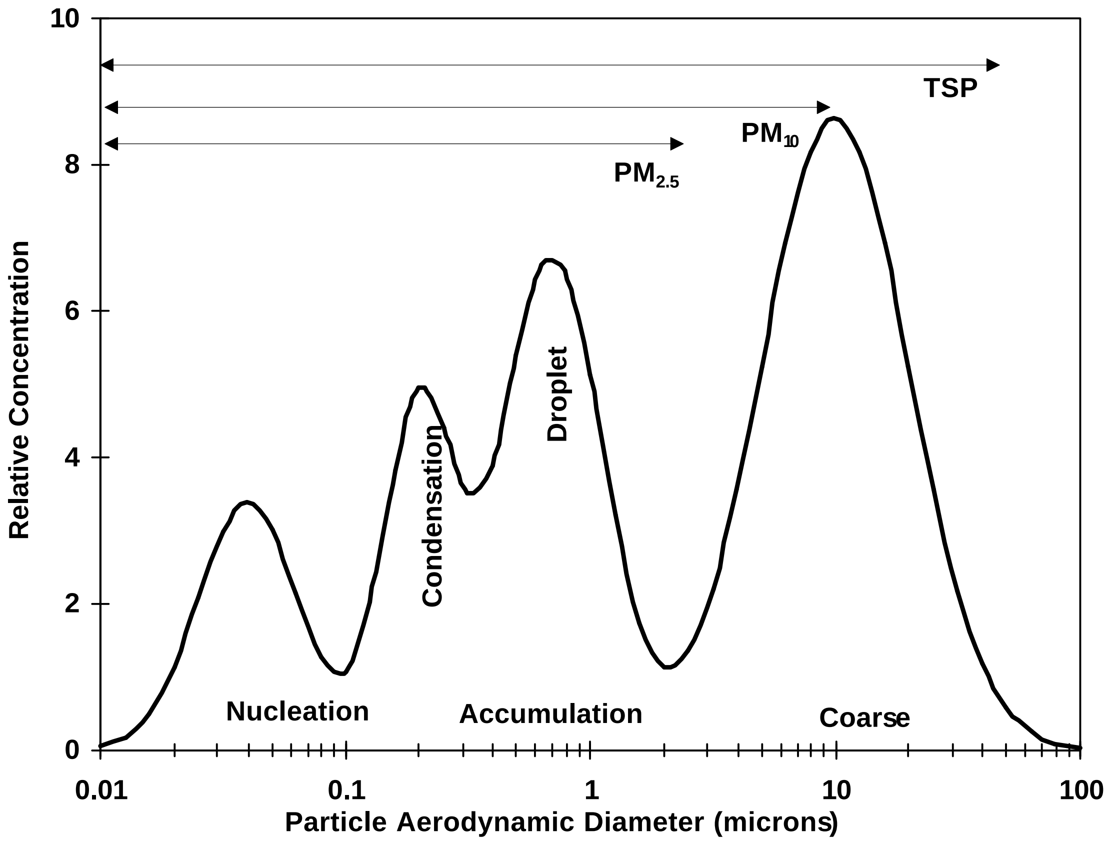


Figure 2.1.1. Idealized size distribution of particles in ambient air (Chow *et al.*, 1995).

Particle size fractions commonly measured by air quality monitors are identified in Figure 2.1.1 by the portion of the size spectrum that they occupy. The mass collected is proportional to the area under the distribution within each size range. The Total Suspended Particulate (TSP) size fraction ranges from 0 to ~40 µm, the PM_{10} fraction ranges from 0 to 10 µm, and the $PM_{2.5}$ size fraction ranges from 0 to 2.5 µm in aerodynamic diameter. No sampling device operates as a step function, passing 100% of all particles below a certain size and excluding 100% of the particles larger than that size. When sampled, each of these size ranges contains a certain abundance of particles above the upper size designation of each range.

Figure 2.1.2 shows typical residence times in the atmosphere for particle sizes within each size range, based on gravitational settling in mixed and stirred chambers (Hinds, 1982). Particles in the fine particle ($PM_{2.5}$) size fraction have substantially longer residence times, and therefore the potential to affect PM concentrations further distant from emissions sources, than particles with aerodynamic diameters exceeding 2 or 3 µm. In this regard, fine particles act more like gases than like coarse particles.

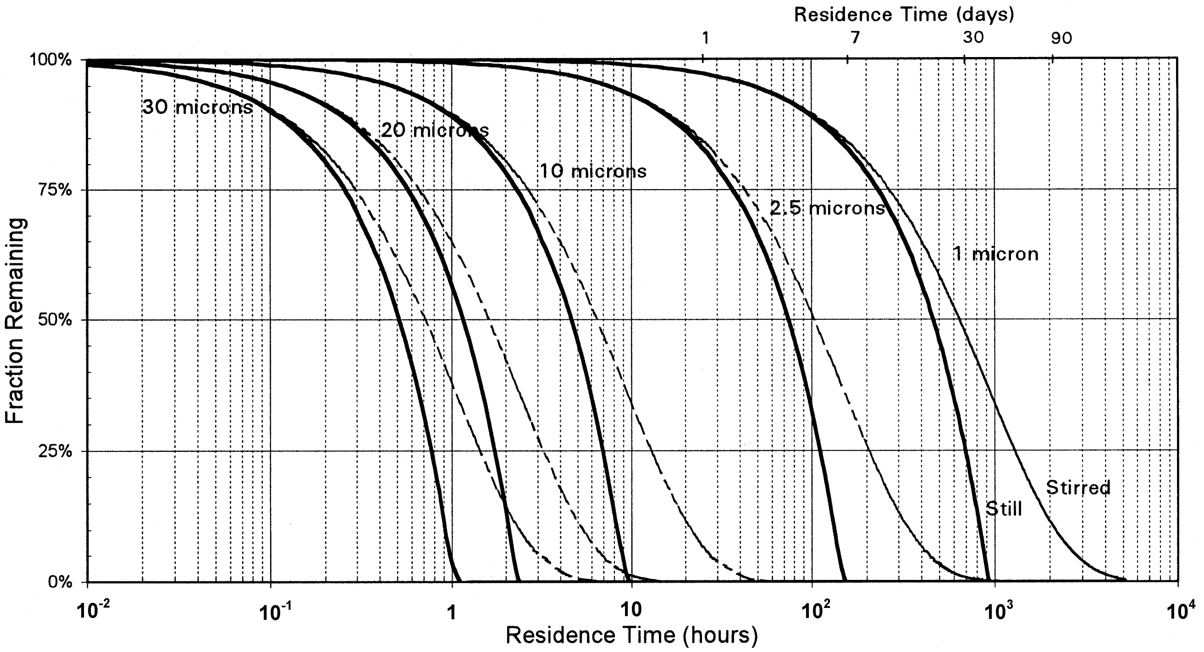


Figure 2.1.2. Residence times for homogeneously distributed particles of different aerodynamic diameters in a 100 m deep mixed layer. Gravitational settling is assumed for both still and stirred chamber models (Hinds, 1982).

Figure 2.1.1 shows the accumulation range to consist of at least two sub-modes, which is contrary to many other presentations that show only a single peak in this region. Recent measurements of chemically specific size distributions show these sub-modes in several different urban areas. John *et al.* (1990) interpreted the peak centered at ~0.2 μm as a "condensation" mode containing gas-phase reaction products. John *et al.* (1990) interpreted the ~0.7 μm peak as a "droplet" mode resulting from growth by nucleation of particles in the smaller size ranges and by reactions that take place in water droplets. The liquid water content of ammonium nitrate, ammonium sulfate, sodium chloride, and other soluble species increases with relative humidity, and this is especially important when relative humidity exceeds 70%. When these modes contain soluble particles, their peaks shift toward larger diameters as humidity increases.

The peak of the coarse mode may shift between ~6 and 25 μm. A small shift in the 50% cut-point of a PM_{10} sampler has a large influence on the mass collected because the coarse mode usually peaks near 10 μm. On the other hand, a similar shift in cut-point near 2.5 μm has a small effect on the mass collected owing to the low quantities of particles in the 1 to 3 μm size range.

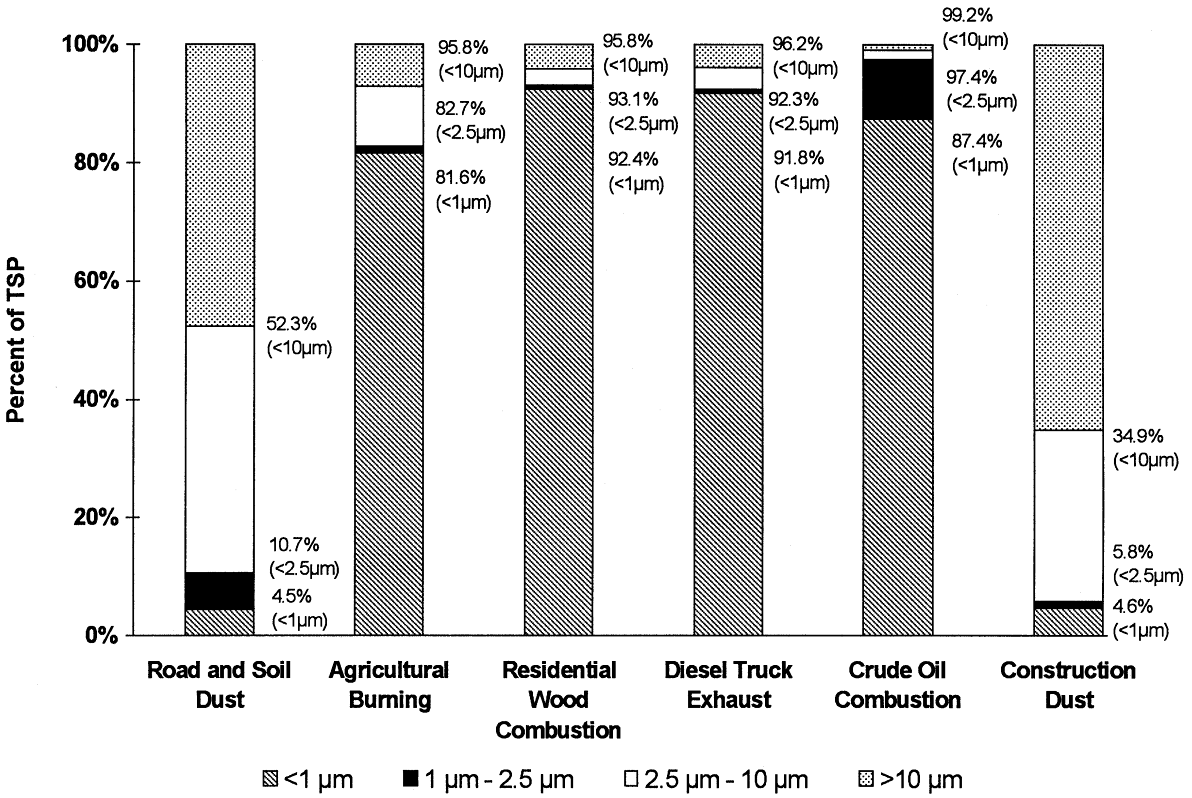


Figure 2.1.3. Size distributions of several particulate source emissions (Ahuja *et al.* 1989; Houck *et al.*, 1989, 1990).

Six major components account for nearly all of the PM_{10} mass in most urban areas: 1) geological material (oxides of aluminum, silicon, calcium, titanium, and iron); 2) organic carbon (consisting of hundreds of compounds); 3) elemental carbon; 4) sulfate; 5) nitrate; and 6) ammonium. Liquid water absorbed by soluble species is also a major component when the relative humidity exceeds ~70%, but much of this evaporates when filters are equilibrated prior to weighing. Water-soluble sodium and chloride are often found in coastal areas, and certain trace elements are found in areas highly influenced by industrial sources.

Although total mass measurements are somewhat dependent on the sampling and analysis methods (Chow, 1995), with reasonable assumptions regarding the chemical form of mineral oxides and organic species, the mass concentrations of PM_{10} and $PM_{2.5}$ can be reproduced within experimental precision (typically < ±10%) by summing the measured concentrations of these six chemical components. Comparison of the "reconstructed mass" from this method to measured total mass, when possible, is recommended as a data validation technique. Approximately half of PM_{10} is often composed of geological material. Geological material often constitutes less than ~10% of the $PM_{2.5}$ mass concentrations, however, as most of it is found in the coarse particle size fraction. As shown in Figure 2.1.3 (from Ahuja *et al.*, 1989; Houck *et al.*, 1989, 1990), most particles emitted by common sources, with the exception of fugitive dust sources, are in the $PM_{2.5}$ fraction.

Source Type	Dominant Particle size	Chemical Abundances in Percent Mass			
		< 0.1%	0.1 to 1 %	1 to 10 %	> 10 %
Paved Road Dust	Coarse	Cr, Sr, Pb, Zr	$SO_4^=$, Na^+, K^+, P, S, Cl, Mn, Zn, Ba, Ti	Elemental Carbon (EC), Al, K, Ca, Fe	Organic Carbon(OC), Si
Unpaved Road Dust	Coarse	NO_3^-, NH_4^+, P, Zn, Sr, Ba	$SO_4^=$, Na^+, K^+, P, S, Cl, Mn, Ba,Ti	OC, Al, K, Ca, Fe	Si
Construction	Coarse	Cr, Mn, Zn, Sr, Ba	$SO_4^=$, K^+, S, Ti	OC, Al, K, Ca, Fe	Si
Agricultural Soil	Coarse	NO_3, NH_4^+, Cr, Zn, Sr	$SO_4^=$, Na^+, K^+, S, Cl, Mn, Ba, Ti	OC, Al, K, Ca, Fe	Si
Natural Soil	Coarse	Cr, Mn, Sr, Zn, Ba	Cl^-, Na^+, EC, P, S, Cl, Ti	OC, Al, Mg, K, Ca, Fe	Si
Lake Bed	Coarse	Mn, Sr, Ba	K^+, Ti	$SO_4^=$, Na^+, OC, Al, S, Cl, K, Ca, Fe	Si
Motor Vehicle	Fine	Cr, Ni, Y	NH_4^+, Si, Cl, Al, Si, P, Ca, Mn, Fe, Zn, Br, Pb	Cl^-, NO_3^-, $SO_4^=$, NH_4^+, S	OC, EC
Vegetative Burning	Fine	Ca, Mn, Fe, Zn, Br, Rb, Pb	NO_3^-, $SO_4^=$, NH_4^+, Na^+, S	Cl^-, K^+, Cl, K	OC, EC
Residual Oil Combustion	Fine	K^+, OC, Cl, Ti, Cr, Co, Ga, Se	NH_4^+, Na^+, Zn, Fe, Si	V, OC, EC, Ni	S, $SO_4^=$
Incinerator	Fine	V, Mn, Cu, Ag, Sn	K^+, Al, Ti, Zn, Hg	NO_3^-, Na^+, EC, Si, S, Ca, Fe, Br, La, Pb	$SO_4^=$, NH_4^+, OC, Cl
Coal-Fired Boiler	Fine	Cl, Cr, Mn, Ga, As, Se, Br, Rb, Zr	NH_4^+, P, K, Ti, V, Ni, Zn, Sr, Ba, Pb	$SO_4^=$, OC, EC, Al, S, Ca, Fe	Si
Oil-Fired Power Plant	Fine	V, Ni, Se, As, Br, Ba	Al, Si, P, K, Zn	NH_4^+, OC, EC, Na, Ca, Pb	S, $SO_4^=$
Smelter Fine	Fine	V, Mn, Sb, Cr, Ti	Cd, Zn, Mg, Na, Ca, K, Se	Fe, Cu, As, Pb	S
Antimony Roaster	Fine	V, Cl, Ni, Mn	$SO_4^=$, Sb, Pb	S	None reported
Marine	Fine and Coarse	Ti, V, Ni, Sr, Zr, Pd, Ag, Sn, Sb, Pb	Al, Si, K, Ca, Fe, Cu, Zn, Ba, La	NO_3^-, $SO_4^=$, OC, EC	Cl^-, Na^+, Na, Cl

Table 2.1.1. Chemicals from particles in different emissions sources

The actual chemical components found in a given ambient sample have a strong correspondence to the chemical composition of the source emissions in the monitored airshed. Table 2.1.1 (from Chow, 1995) shows the relative abundance of several elements, inorganic compounds, and carbon from different source types. The most abundant species in air are also most abundant in source emissions, with the exception of sulfate, nitrate, and ammonium. Spatial gradients in the concentrations of one or more of these species dominated by a single source provide a good means of evaluating the zone of influence of that source.

Sulfate, nitrate, and ammonium abundances in directly emitted particles are not sufficient to account for the concentrations of these species measured in the atmosphere. Ambient mass concentrations contain both primary and secondary particles. Primary particles are directly emitted by sources and usually undergo few changes between source and receptor. Atmospheric concentrations of primary particles are, on average, proportional to the quantities that are emitted.

Secondary particles are those that form in the atmosphere from gases that are directly emitted by sources. Sulfur dioxide, ammonia, and oxides of nitrogen are the precursors for sulfuric acid, ammonium bisulfate, ammonium sulfate, and ammonium nitrate particles. "Heavy" volatile organic compounds (HVOC, those containing more than eight carbon atoms) may also change into particles; the majority of these transformations result from intense photochemical reactions that also create high ozone levels. Secondary particles usually form over several hours or days and attain aerodynamic diameters between 0.1 and 1 μm, as shown in Figure 2.1.1. Several of these particles, notably those containing ammonium nitrate, are volatile and transfer mass between the gas and particle phase to maintain a chemical equilibrium. This volatility has implications for ambient concentration measurements as well as for gas and particle concentrations in the atmosphere.

Ambient concentrations of secondary aerosols are not necessarily proportional to quantities of emissions since the rate at which they form may be limited by factors other than the concentration of the precursor gases. Secondary particulate ammonium nitrate concentrations depend on gaseous ammonia and nitric acid concentrations as well as temperature and relative humidity. A nearby source of ammonia may cause a localized increase in $PM_{2.5}$ concentrations by shifting the equilibrium from the gas to the particulate ammonium nitrate phase (Watson *et al.*, 1994). Ammonium sulfate may form rapidly from sulfur dioxide and ammonia gases in the presence of clouds and fogs, or slowly in dry air. Because fine particle deposition velocities are slower than those of the gaseous precursors, $PM_{2.5}$ may travel much farther than the precursors, and secondary particles precursors are often found far from their emissions sources and may extend over scales exceeding 1,000 km.

Compliance measurements are taken at fixed monitoring sites for specified time intervals, usually 24 hours. While fixed site monitoring is an effective surrogate for actual exposure, the air that people breathe depends on where they are, the most common locations being the home, the workplace, the automobile, and the outdoors. Most outdoor human exposure occurs during the daytime, so it is important to understand how particle concentrations differ between day and night.

Figure 2.1.4 shows a clear diurnal cycle of hourly $PM_{2.5}$ concentrations measured with a TEOM during the 26-day IMS95 Winter Study (Chow and Egami, 1997). This plot shows a distinct diurnal pattern for the 50th and 80th percentile concentrations which is consistent with emissions estimates and meteorological patterns during the winter in the southern San Joaquin Valley. Because much of the $PM_{2.5}$ is directly or indirectly related to emissions from motor vehicle exhaust, peaks of $PM_{2.5}$ concentrations during the morning and evening rush hours are expected at urban sites. The evening peak is suspected to be the accumulation of emissions from motor vehicle exhaust superimposed on domestic cooking and residential wood combustion contributions. Since transport and mixing are lowest during the cold evening hours, pollutant concentrations can build up rapidly after sunset and frequently carry over to the next morning.

Meyer *et al.* (1992) show a similar diurnal pattern during wintertime in a mountainous California community where wood is burned, with the evening peak remaining high well past

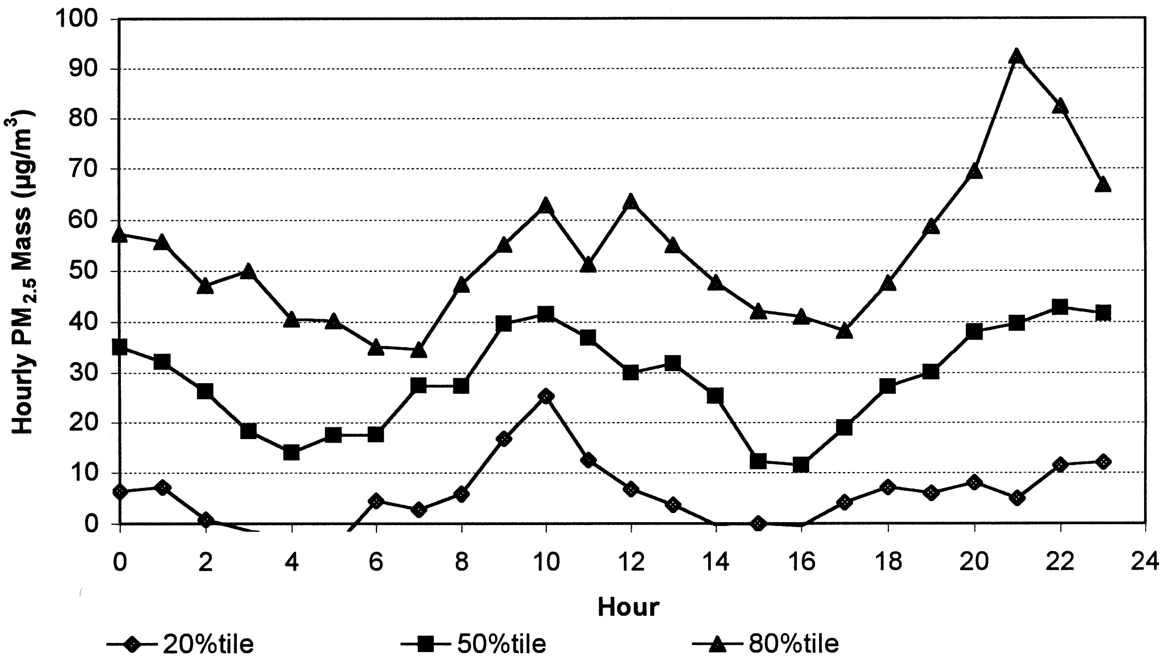


Figure 2.1.4. Hourly variations in the 20th, 50th, and 80th percentiles of $PM_{2.5}$ in Bakersfield, CA (Chow and Egami, 1997).

midnight. In some communities where fugitive dust is a major emitter, peak PM_{10} concentrations may occur during the afternoon when ventilation is good, but high winds raise the dust into the air. The data in Figure 2.1.4 imply that a person's maximum outdoor exposure to suspended particles near the measurement site occurs during morning and evening commuting periods.

A PM sampler location, especially its proximity to local sources, can play a large role in its ability to assess spatial variability and source contributions. Figure 2.1.5 illustrates the spatial variability of PM_{10} mass in a saturation monitoring network in California's San Joaquin Valley (Chow and Egami, 1997). During this study, most of the PM_{10} mass was in the $PM_{2.5}$ fraction. All scales of representation show the highly variable nature of fine particulate mass averaged over 24 hours. The variations are most noticeable in the urban areas where the variability was attributable to residential wood smoke and holiday driving patterns. Figure 2.1.6 shows the difference in PM_{10} chemical components in the same air basin. Sulfate, nitrate, and ammonium concentrations in these 24-hour samples are fairly uniform over each scale of representation. Organic carbon and crustal concentrations are more variable between measurement locations.

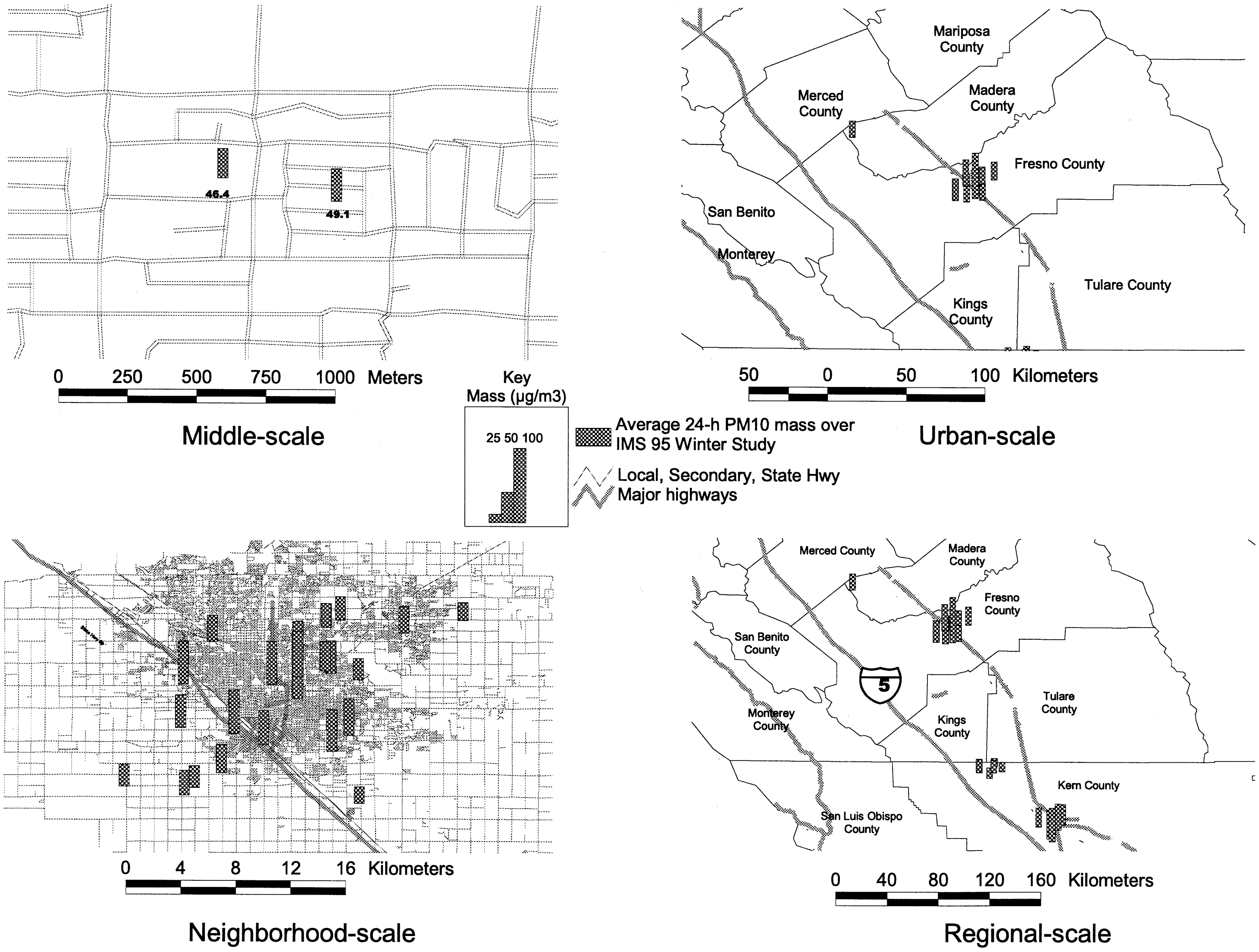


Figure 2.1.5. PM_{10} concentrations at different nearby sites centered around Fresno, CA.

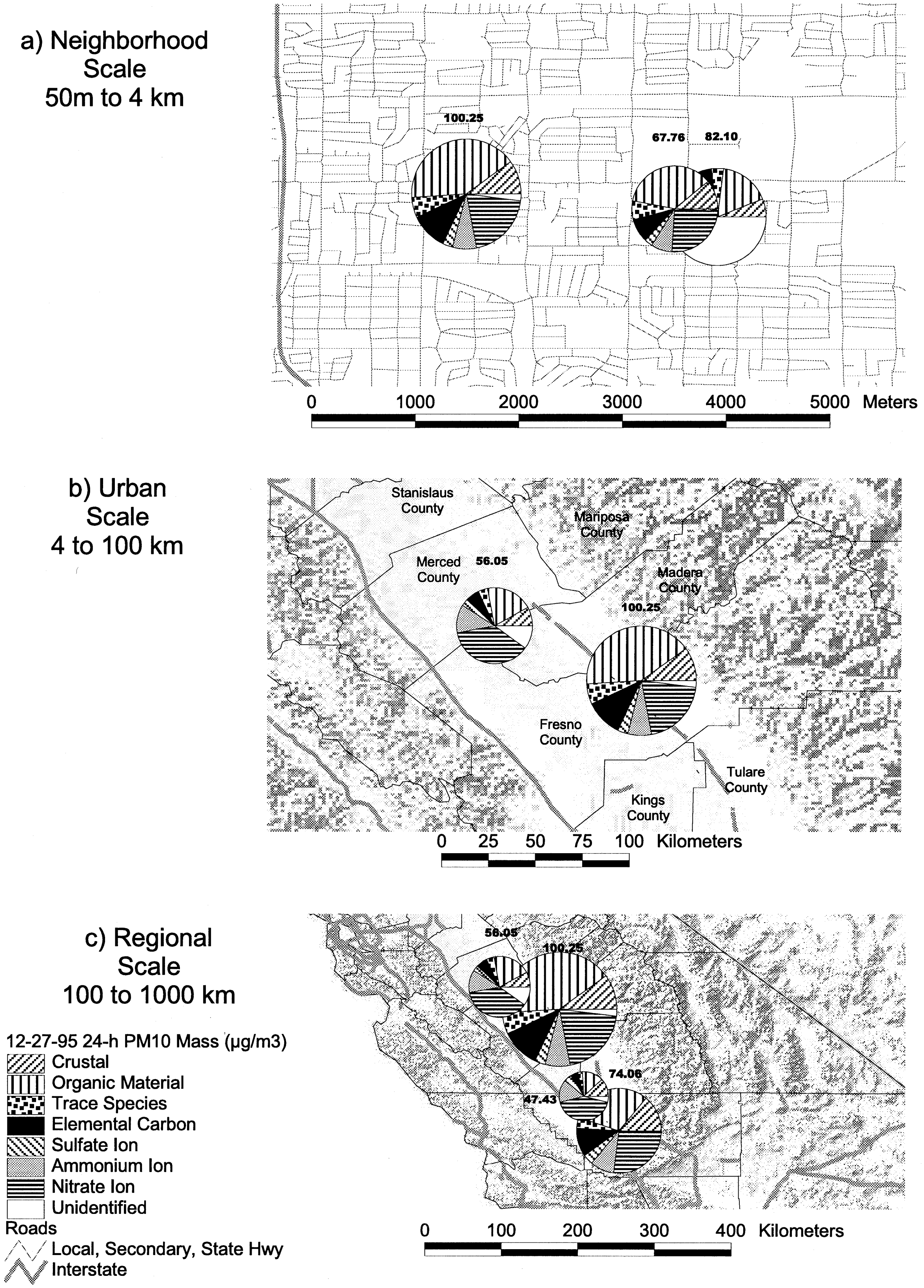


Figure 2.1.6. Spatial variation in 24-hour PM_{10} chemical compositions from the neighborhood to regional scale.

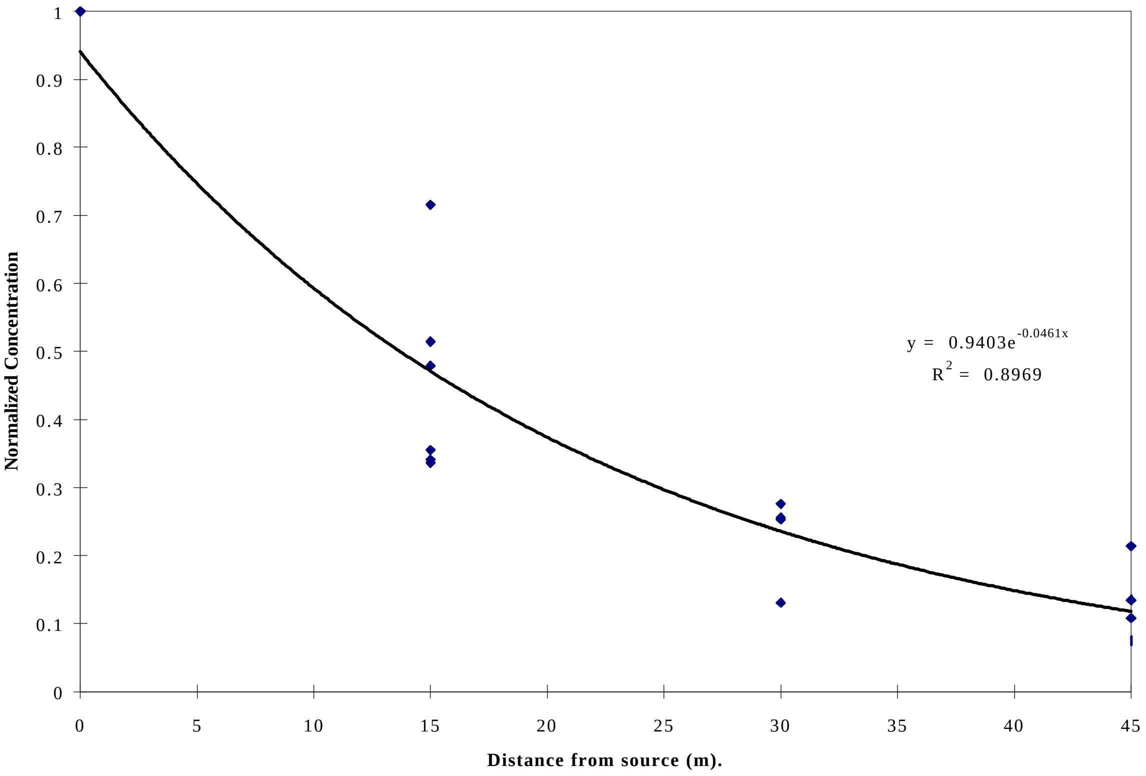


Figure 2.1.7. Normalized PM_{10} concentrations at increasing distances from an unpaved road (Watson *et al.*, 1996). Samples were taken at 2 m above ground level.

$PM_{2.5}$ concentrations are often more homogeneously distributed over space than are the contributions from coarse-mode, geological sources. There are exceptions, however, as shown by Chow *et al.* (1989) in comparing high wood smoke contributions between a residential and an urban sampling site separated by less than 10 km. The stagnant air conditions prevailing during high wintertime episodes caused the wood smoke to contribute nearly 50% of PM_{10} at the residential site, but to contribute less than 10% of PM_{10} at the urban-commercial site. This is also evident in the variability of organic carbon in Figure 2.1.6.

These spatial variations occur because particles deposit and disperse rapidly with distance from an emissions source. Figure 2.1.7 shows how PM_{10} caused by dust emitted by an unpaved road decreases with downwind distance from the edge of the road. Figure 2.1.2 indicates that deposition over time intervals required to traverse these distances is low, so that much of the decrease in concentration is probably due to vertical mixing and dispersion.

Outdoor particle mass concentrations, corresponding indoor measurements, and measurements from personal exposure monitors carried by test subjects are often poorly correlated. The correspondence between these three types of samples is much better for some chemical species, such as sulfate. When indoor concentrations were apportioned to sources in

Riverside, CA (Pellizari *et al*., 1993), particle loadings in outdoor air accounted for more than 60% of the indoor $PM_{2.5}$. Particles from smoking, cooking, house dust, and other indoor emissions constituted the remainder of indoor concentrations.

The lack of correlation between indoor and outdoor measurements does not mean that outdoor concentrations are unimportant. While residents can control indoor emissions through personal actions such as using filtered vacuum cleaners and exhausting cooking emissions, there is little that they can do to prevent the incursion of pollution from outdoor air. Smaller particles, such as $PM_{2.5}$, are more likely to penetrate indoors than are the coarse particles, which are more likely to deposit within the cracks and seams where air penetrates. Coarse particles also deposit to surfaces more rapidly due to gravitational settling in the stilled air of most indoor environments.

Most of the evidence relating ambient measurements of suspended particles taken in compliance networks to personal exposures shows that: 1) ambient concentrations, especially those for $PM_{2.5}$ particles, constitute a major fraction of the particles to which humans are exposed; and 2) ambient levels generally represent a lower bound on the concentrations to which people are commonly exposed.

2.2 Concepts

Several new concepts are explicit or implicit in the new standards and their implementation. These relate to how particle concentrations vary over a monitored area, how measurements correspond to population levels, and how nearby and distant sources affect measurement locations.

2.2.1 Spatial Uniformity

Spatial uniformity is the extent to which particle concentrations vary over a specified area. It is expressed as a spatial coefficient of variation of measured concentrations from many samplers in an area and as the deviation of measurements taken by a single sampler from the spatial average of all samplers. An annual coefficient of variation (standard deviation divided by the mean) of less than 10%, and a 20% maximum deviation of a single sampler from the mean, are desirable indicators of spatial uniformity for determining compliance with standards. This translates into an annual spatial standard deviation of no more than 1.5 $\mu g/m^3$, and maximum deviations of no more than 3 $\mu g/m^3$, at concentrations near the annual $PM_{2.5}$ standard of 15 $\mu g/m^3$.

2.2.2 Receptor Site Zone of Representation

PM_{10} and $PM_{2.5}$ concentrations measured at any receptor result from contributions of emissions from nearby and distant sources and the zone of representation of a monitoring site depends on the relative amounts contributed by sources on different spatial scales. The dimensions given below are nominal rather than exact and are presented as defined in 40 CFR part 58. They indicate the diameter of a circle, or the length and width of a grid square, with a monitor at its center.

- **Collocated Scale (1 to 10 m):** Collocated monitors are intended to measure the same air and involve separations of 1 to 5 m between samplers. Collocated measurements should not differ by more than the operational precision of the monitoring method. Monitors are operated on collocated scales to evaluate the equivalence of different measurement methods and procedures and to quantify the measurement accuracy and precision of the same measurement methods and procedures. The distance between collocated samplers should be large enough to preclude the air sampled by any of the devices from being affected by any of the other devices, but small enough so that all devices obtain air containing the same pollutant concentrations.

- **Microscale (10 to 100 m):** Microscale monitors show significant differences between $PM_{2.5}$ monitors separated by 10 to 50 m. This often occurs when monitors are located right next to a low-level emissions source, such as a busy roadway, construction site, wood stove chimney, or short stack. Compliance monitoring site exposure criteria intend to avoid microscale influences even for source-oriented monitoring sites. A microscale zone of representation is primarily useful for studying emissions rates and zones of influence, as illustrated in Figure 2.1.7.

- **Middle Scale (100 to 500 m):** Middle-scale monitors show significant differences between locations that are ~0.1 to 0.5 km apart. These differences may occur near large industrial areas with many different operations or near large construction sites. Monitors with middle-scale zones of representation are often source-oriented, used to determine the contributions from emitting activities with multiple, individual sources to nearby community exposure monitors.

- **Neighborhood Scale (500 m to 4 km):** Neighborhood-scale monitors do not show significant differences in particulate concentrations with spacing of a few kilometers. This dimension is often the size of emissions and modeling grids used in large urban areas for PM source assessment, so this zone of representation of a monitor is the only one that should be used to evaluate such models. Sources affecting neighborhood-scale sites typically consist of small individual emitters, such as clean, paved, curbed roads, uncongested traffic flow without a significant fraction of heavy-duty vehicles, or neighborhood use of residential heating devices such as fireplaces and wood stoves.

- **Urban Scale (4 to 100 km):** Urban-scale monitors show consistency among measurements with monitor separations of 10’s of km. These monitors represent a mixture of particles from many sources within the urban complex, including those from the smaller scales. PM measurements at urban-scale locations are not dominated by any particular neighborhood, however. Urban-scale sites are often located at higher elevations and away from highly traveled roads, industries, and residential heating. Monitors on the roofs of two- to four-story buildings, in the urban core area, are often good representatives of the urban scale.

- **Regional-Scale Background (100 to 1,000 km):** Regional-scale background monitors show consistency among measurements for monitor separations of a few hundred kilometers. Background concentrations are often more consistent for specific chemical compounds, such as sulfate or nitrate, than they are for PM mass concentrations. Regional-scale PM is a combination of naturally occurring aerosol from windblown dust and marine aerosol as well as particles generated in urban and industrial areas that may be more than 1,000 km distant. Regional-scale sites are best located in rural areas away from local sources, and at higher elevations. National parks, national wilderness areas, and many state and county parks and reserves are appropriate areas for regional-scale sites. Many of the IMPROVE sites characterize PM regional scale background in different regions of the U.S.

- **Continental-Scale Background (1,000 to 10,000 km):** Continental-scale background monitors show little variation even when they are separated by more than 1,000 km. They are hundreds of kilometers from the nearest significant emitters. Though these sites measure a mixture of natural and diluted manmade source contributions, the manmade component is at its minimum expected concentration. The Jarbidge Wilderness IMPROVE site in northern Nevada is a good example of a continental-scale background site for PM in North America.

- **Global-Scale Background(>10,000 km):** Global-scale background monitors are intended to quantify concentrations transported between different continents as well as naturally-emitted particles and precursors from sea spray, volcanoes, and windblown dust. Yellow sand from China has been detected at the Mauna Loa, HI, laboratory (Darzi and Winchester, 1982; Braaten and Cahill, 1986), and red dust from Africa's Sahara desert has been detected at Mt. Yunque, PR. Other global-scale sites include McMurdo, Palmer, and Ahmundson-Scott stations in Antarctica (Lowenthal *et al.*, 1996), Pt. Barrow, AK, and Mace Head, Ireland.

2.2.3 Community-Oriented Monitoring

Community-oriented (core) monitoring sites are beyond the zone of influence of a single source, and should have neighborhood- to urban- scale zones of representation. The principal purpose of community-oriented monitoring sites is to approximate the short-term and long-term exposures of large numbers of people where they live, work, and play. A monitor placed at the fence line of an emissions source would not be considered to represent community exposures, even though there might be residences abutting that fence line. A monitor placed in the middle of an area adjacent to a source would, however, be deemed a community exposure monitor for that neighborhood provided that the location represented a zone of at least 0.5 km in diameter. The fence line monitor might still be operated because it provides information on how much the nearby source contributes to the community-oriented site. The data from the fence line monitor would not be used to determine annual NAAQS compliance, though it might be used to make comparisons to the 24-hour standard or to design control strategies to bring the area into compliance with the annual NAAQS.

2.2.4 Background and Regional Transport Monitoring

Background and regional transport (or boundary) monitors are located outside of local air quality jurisdictions to determine how much of the PM at community-oriented sites derives from external sources. Background sites are intended to quantify regionally representative $PM_{2.5}$ for sites located away from populated areas and other significant emission sources. Transport sites are intended to measure fine particle contributions from upwind source areas, or mixtures of source areas, that move into a planning area.

Most planning areas contain at least one substantial metropolitan area. Several of these also include industrial sources, either concentrated in one or a few districts or dispersed throughout the planning area. Air quality planning areas also contain less developed areas that may be distant from the densely populated centers and industrial emitters. These may include agricultural areas, dormant lands, large parks, wildlife and nature preserves, large military bases, etc.

Transport sites should be located upwind of planning area boundaries, outside of the urban-scale zone of influence. For the most part, transport sites are between planning areas, or between districts containing large emitters (e.g., industrial complexes, isolated point sources) and a planning area. Measurements from transport sites represent transport into the planning area only during periods when the wind is from the direction of the external source area toward the planning area. During other periods, the transport site may also serve the purposes of a background site, or as a transport site for another planning area. For this reason, transport site locations are selected to achieve multiple purposes. Meteorological data needed to evaluate which purposes are being served should be available along with the $PM_{2.5}$ measurements.

Background monitors are intended to measure $PM_{2.5}$ concentrations that are not dependent on upwind sources, although the particles they quantify will be a mixture of natural and manmade source material. These stations should be distant from identified emitters, and may be at higher elevations than the urban-scale community exposure monitors. Current IMPROVE (Interagency Monitoring of Protected Visual Environments) $PM_{2.5}$ monitoring in National Parks and Wilderness Areas (Eldred *et al.*, 1990) provides the best examples of background monitoring sites, but there is a dearth of these sites in the non-western states. Table 2.2.1 lists the locations of IMPROVE sites and their current measurements.

Properly sited background stations should measure $PM_{2.5}$ typical of the lowest ambient concentrations in a state or region. These sites should not be along transport pathways, though in densely populated or industrialized regions (such as the northeast corridor) a given sample may or may not be along such a pathway depending on which way the wind is blowing.

Several background sites may be needed in large and geographically diverse states, such as California and others in the west, where terrain produces major barriers to

Name	Latitude	Longitude	Elev (m)	AT	EX	SC	A	B	C	D	RH	SO2	35
Acadia NP	44.3742	68.2622	122	X		X	X	X	X	X	X	X	
Badlands NP	43.7469	101.9411	730				X	X	X	X			
	43.8719	102.2308	960	X	X						X		
Bandelier NM, Rim Fire Tower	35.7817	106.2675	1981	X	X		X	X	X	X	X		
Big Bend NP	29.3053	103.1772	1052				X	X	X	X		X	
	29.3439	103.2067	1082	X	X						X		
Boundary Waters Canoe Area	47.9467	91.4958	515	X		X	X	X	X	X	X		
Bryce Canyon NP	37.6000	112.1667	2530				X	X	X	X			
	37.4667	112.2278	2710										X
Bridger Wilderness	42.9750	109.7583	2627				X	X	X	X			
	42.9281	109.7875	2390	X	X						X		
Canyonlands NP	38.4583	109.8217	1814	X	X		X	X	X	X	X		
Cape Romain NWR	0.0000	0.0000	34				X	X	X	X			X
Chassahowitzka NWR	28.7500	82.5667	0				X	X	X	X		X	
Chiricahua NM	32.0097	109.3883	1570	X	X		X	X	X	X	X		
Crater Lake NP	42.8958	122.1333	1981				X	X	X	X			
Craters of the Moon NM	43.4606	113.5622	1815										X
Denali NP	63.7233	148.9675	661				X	X	X	X		X	
Death Valley NP	36.5086	116.8478	125				X			X		X	
Dome Land	35.7000	118.2000	950				X	X					
Dolly Sods Wilderness	39.1047	79.4258	1175				X	X	X	X			
E.D. Forsythe NWR	39.4681	74.4536	5				X	X	X	X			X
Everglades NP	25.3883	0.0000	2				X					X	
Glacier NP	48.5103	113.9956	975				X	X	X	X			
	48.5581	113.9375	968	X	X						X		
Great Basin NP	39.0053	114.2158	2060	X	X		X	X	X	X	X		
Grand Canyon NP	36.0392	111.8300	2290										X
(Hopi Point Fire Tower)	36.0719	112.1550	2164				X	X	X	X		X	
	35.9964	111.9917	2256	X	X						X		
	36.0778	112.1289	1158	X	X		X	X	X	X	X	X	
Great Sand Dunes NM	37.7083	105.5172	2487				X	X	X	X			
Great Smokey Mountains NP	35.6314	83.9422	793	X		X	X	X	X	X	X	X	
Guadalupe Mountains NP	0.0000	104.8097	1658	X	X		X	X	X	X	X		
Haleakala NP	20.8039	156.2850	1097				X						
Jarbidge Wilderness	41.9583	115.0847	2400										X
	41.8925	115.4250	1889	X		X	X	X	X	X	X		
Lassen Volcanic NP	40.5369	121.5725	1756				X	X	X	X			
Lye Brook Wilderness	43.1444	73.1289	1010				X	X	X	X			
Mammoth Cave NP	37.2178	86.0736	219	X		X	X	X	X	X	X		X
Mesa Verde NP	37.1983	108.4903	2165				X	X	X	X			
Moosehorn NWR	0.0000	0.0000	40				X	X	X	X			
Mount Rainier NP	46.7614	122.1217	421	X		X	X	X	X	X	X		
National Capitol Central, D.C.	38.8950	77.0367	9				X	X	X	X			
Okefenoke NWR	30.7403	82.1286	38	X		X	X	X	X	X	X	X	
Petrified Forest NP	35.0772	109.7697	1755				X	X	X	X			
	34.8983	109.7958	1690	X	X						X		
Pinnacles NM	36.4850	121.1556	335				X	X	X	X			
Point Reyes NP	38.1231	122.9083	76				X	X	X	X			
Redwood National Seashore	41.5611	124.0828	235				X	X	X	X			
Rocky Mountain NP	40.2772	105.5450	2743				X	X	X	X			
	40.3606	105.5806	2536	X	X						X		
San Gorgonio Wilderness	34.1847	116.9019	1712	X	X		X	X	X	X	X		
Saguaro NM	32.1744	110.7364	938									X	
Sequoia NP	36.4936	118.8286	521				X	X	X	X		X	
Shenandoah NP, Big Meadows	38.5219	78.4361	1073	X	X		X	X	X	X	X	X	
Sipsey Wilderness	34.3431	87.3386	311				X	X	X	X			
Tonto NM	33.6339	111.1011	792				X	X	X	X			
Upper Buffalo Wilderness	35.8269	93.2056	701	X	X		X	X	X	X	X		
Virgin Islands NP	18.3333	64.7942	46				X						
Voyageurs NP	48.5878	93.1728	343				X					X	
Weminuche Wilderness Area	0.0000	0.0000	2758				X	X	X	X			
Yellowstone NP, Water Tank	44.5597	110.4000	2469				X	X	X	X		X	
Yosemite NP, Turtleback Dome	37.7114	119.7044	1605	X	X		X	X	X	X	X		

KEY

AT	ambient temperature (non-aspirated)	C	IMPROVE sampler module C
EX	extinction coefficient (transmissometer)	D	IMPROVE sampler module D
SC	scattering coefficient (nephelometer)	RH	relative humidity sensor
A	IMPROVE sampler module A	SO2	sulfur dioxide sampler
B	IMPROVE sampler module B	35	35 mm camera slides

Table 2.2.1. IMPROVE measurement sites.

atmospheric flow. Regions lacking IMPROVE monitors should determine the proximity of National Parks, Wilderness Areas, and State Preserves as candidates for background sites. Background monitors also contribute to regional visibility goals that are part of other air quality regulations.

2.2.5 Emissions Zone of Influence

The zone of influence of a source is the distance at which PM from that specific source contributes no more than 10% of the measured PM concentration. The zone of influence refers to a specific emitter, rather than to a source category. For example, though suspended road dust may contribute 50% of PM_{10} over a wide region, the majority of emissions from a specific road influence concentrations over a few tens of meters from the emissions point (see Figure 2.1.7).

The actual size of a zone of influence varies with meteorology, being larger downwind than upwind, and the nature of the source (point, elevated, area, line, etc.). Zones of influence are, therefore, expressed as orders of magnitude rather than as exact distances. The concept is useful for locating community exposure sites that are intended to represent concentrations for sources with large rather than small zones of influence. Actual zones of influence must be determined empirically, by spatially dense monitoring networks, or theoretically by applying air quality and meteorological models.

2.2.6 $PM_{2.5}$ Sampler Types

Measurement methods applied in PM networks are ground-based and are divided into three categories: Federal Reference Method (FRM) samplers, Federal Equivalent Method (FEM) samplers, and other samplers. The non-FRM samplers are distinguished by their level of similarity in design to Federal Reference Methods (FRM). The further from the FRMs in design, the more stringent are the requirements for designation of an instrument as an equivalent method.

- **Federal Reference Methods:** Federal Reference Methods for $PM_{2.5}$ are methods that have been designated as such under CFR 40 Chapter 1 Part 53, having met design and performance characteristics described in Part 50, Appendix L; Part 53, Subpart E; and Part 58, Appendix A. Reference method instruments acquire deposits over 24-hour periods on Teflon-membrane filters from air drawn at a controlled flow rate through a tested $PM_{2.5}$ inlet. The inlet and size separation components are specified by design, with drawings and manufacturing tolerances published in the Code of Federal Regulations. Most of the other measurement components and procedures are specified by performance characteristics, with specific test methods to assess that performance.

- **Class I Equivalent Methods:** Class I equivalent method instruments maintain the same measurement principles as reference method instruments, but with minor design changes. Class I instruments are intended to provide for sequential sampling without operator intervention at measurement sites that sample every day. Testing of design and performance characteristics for Class I instruments is given in Part 53, Subpart E.

- **Class II Equivalent Methods:** Class II equivalent method instruments include all other instruments based on a 24-hour integrated filter sample with subsequent moisture equilibration and gravimetric mass analysis, but differ substantially in design from the reference method instruments. More extensive performance testing is required for a Class II equivalent instrument than for reference or Class I equivalent instruments. Testing of design and performance characteristics for Class II methods is given in Part 53, Subpart F.

- **Class III Equivalent Methods:** Class III equivalent method instruments include any candidate instruments that cannot qualify as Class I or Class II instruments. These may either be filter-based integrated samplers not meeting Class I or Class II criteria, or filter or non-filter based continuous or semi-continuous samplers. Test procedures and performance requirements for Class III candidate method instruments will be determined on a case-by-case basis. The testing for these instruments will be the most stringent, because equivalency to reference methods must be demonstrated over a wide range of particle size distributions and aerosol compositions. Other methods include all non-FRM or non-equivalent measurement methods capable of characterizing fine particles that may not be or have not yet been classified as an equivalent method. Existing manual and continuous analyzers are in this category and potentially include the dichotomous sampler, IMPROVE samplers, nephelometers, beta attenuation monitors, and Tapered Element Oscillating Microbalances (TEOMs). Such instruments are not precluded from becoming equivalent on a site-specific, regional or national basis.

2.3 Definitions

Several terms and abbreviations are used throughout this guidance, and in the specification of the method for determining compliance with the revised standards. These terms are defined for: 1) theoretical concepts; 2) monitoring boundaries; 3) monitoring networks; and 4) site types.

2.3.1 Theoretical Concepts

As will be shown in Section 2.4, systematic sampling theory has seldom been applied to the design of air quality measurement networks. Since monitoring resources are always finite, trade-offs must be made off between numbers of sites, frequencies of samples, sample durations, and the quantities measured. As more experience is gained in the design of $PM_{2.5}$ monitoring networks, the theoretical and empirical basis for network design will become better established.

- **Cost Per Error (CPE) (Borgman *et al.*, 1996):** Total cost of sample collection and analysis divided by estimated error. There is a balance between the cost savings with fewer sites against the costs of having larger errors.

- **Error Per Cost (EPC) (Borgman *et al.*, 1996):** This is the reciprocal of CPE. It quantifies the statistical uncertainty associated with a given amount of monitoring resources.

2.3.2 Monitoring Boundaries

The new standards refer to several boundaries. Metropolitan Statistical Areas, Primary Metropolitan Statistical Areas, Consolidated Metropolitan Statistical Areas, and New England County Metropolitan Areas are defined by the U.S. Office of Management and Budget, and these are defined in Appendix B for the 1990 census. Metropolitan Planning Areas and Community Monitoring Zones are areas with boundaries corresponding to subdivisions of the statistical areas that are to be defined by each state according to these guidelines.

- **Metropolitan Statistical Area (MSA):** MSAs are designated by the U.S. Office of Management and Budget (OMB) as having a large population nucleus, together with adjacent communities having a high degree of economic and social integration with that nucleus. MSA boundaries correspond to portions of counties, single counties or groups of counties that often include urban and non-urban areas. MSAs are useful for identifying which parts of a state have sufficient populations to justify the installation of a compliance monitoring network. Their geographical extents may be too big for defining the boundaries of Metropolitan Planning Areas and Community Monitoring Zones.

- **Primary Metropolitan Statistical Area (PMSA):** PMSAs are single counties or groups of counties that are the component metropolitan portions of a mega-metropolitan area. PMSAs are similar to MSAs with the additional characteristic of having a degree of integration with surrounding metropolitan areas. A group of PMSAs having significant interaction with each other are termed a Consolidated Metropolitan Statistical Area (CMSA).

- **Consolidated Metropolitan Statistical Area (CMSA):** A Consolidated Metropolitan Statistical Area (CMSA) is a group of metropolitan areas (PMSAs) that have significant economic and social integration.

- **New England County Metropolitan Statistical Area (NECMSA):** The OMB defines NECMAs as a county-based alternative for the city- and town-based New England MSAs and CMSAs. The NECMA defined for an MSA or CMSA includes:
  - The county containing the first-named city in that MSA/CMSA title (this county may include the first-named cities of other MSAs/CMSAs as well), and
  - Each additional county having at least half its population in the MSAs/CMSAs whose first-named cities are in the previously identified county. NECMAs are not identified for individual PMSAs. There are twelve NECMAs, including one for the Boston-Worcester-Lawrence, MA-NH-ME-CT CMSA and one for

the Connecticut portion of the New York-Northern New Jersey-Long Island, NY-NJ-CT-PA CMSA.

- **Monitoring Planning Area (MPA):** MPAs are defined by the state implementation plan as the basic planning unit for $PM_{2.5}$ monitoring. A MPA is a contiguous geographic area with established, well-defined boundaries. MPAs may cross state lines and can be further subdivided into Community Monitoring Zones. A MPA does not necessarily correspond to the boundaries within which pollution control strategies will be applied. In fact, it is expected that emissions control regions will be much larger than the MPAs, owing to the superposition of regional-, urban-, and neighborhood-scale contributions to $PM_{2.5}$. MPAs may include aggregates of: 1) counties; 2) zip code regions; 3) census blocks and tracts; or 4) established air quality management districts. Counties are often much larger than the most densely populated areas they contain, and some large metropolitan areas may extend over several counties. Census blocks are very small and may be unwieldy to manipulate in some large areas. Zip code and census tract boundaries may be the most manageable units for many areas. These boundaries vary substantially in geography from one region to another. MPAs normally will contain at least 200,000 people, though portions of a state not associated with MSAs can be considered as a single MPA. Optional MPAs may be designated for other areas of a state. MPAs in MSAs are completely covered by one or more Community Monitoring Zones.

- **Community Monitoring Zone (CMZ):** When spatial averaging is utilized for making comparisons to the annual $PM_{2.5}$ NAAQS, Community Monitoring Zones must be defined in the monitoring network description. Otherwise, they may be used as a more informal manner, as a means to describe the communities surrounding one or more core monitoring sites. CMZs have dimensions of 4 to 50 km with boundaries defined by existing political demarcations (e.g., aggregates of zip codes, census tracts) with population attributes. They could be smaller in densely populated areas with large pollutant gradients. Each CMZ would ideally equal the collective zone of representation of one or more community-oriented monitors within that zone. The CMZ, applicable only to $PM_{2.5}$, is intended to represent the spatial uniformity of $PM_{2.5}$ concentrations. In practice, more than one monitor may be needed within each CMZ to evaluate the spatial uniformity of $PM_{2.5}$ concentrations and to accurately calculate the spatial average for comparison with the annual $PM_{2.5}$ NAAQS. When spatial averaging is used, each MPA would be completely covered by one or more contiguous CMZs.

2.3.3 Monitoring Networks

$PM_{2.5}$ monitoring networks may be new networks or part of existing networks. Additional sites may be added to existing networks according to this guidance.

- **State and Local Air Monitoring Stations (SLAMS):** SLAMS are designed and operated by local air pollution control districts to determine: 1) the highest concentrations expected to occur in each MPA; 2) representative concentrations in areas of high population density; 3) the impact on ambient pollution levels of significant sources or source categories; 4) general background concentration levels; 5) the extent of regional pollutant transport among populated areas, and 6) welfare-related impacts in rural and remote areas (i.e., visibility impairment and effects on vegetation). Only population-oriented SLAMS acquire data for determining compliance with PM $_{2.5}$ standards, and community-oriented (core) SLAMS acquire data for compliance with the annual $PM_{2.5}$ standard.

- **National Air Monitoring Stations (NAMS):** NAMS are long-term monitors to assess trends and support national assessments and decisions. The NAMS are intended to be part of a national trends network focusing on community exposure surveillance. NAMS is a subset of SLAMS, with the majority of sites being used to determine compliance or non-compliance with standards. Existing PM_{10} NAMS should generally be good candidates for $PM_{2.5}$ monitoring.

- **Photochemical Assessment Monitoring Stations (PAMS):** PAMS track trends in ozone precursor emissions, corroborate emission inventories, and support photochemical modeling. Ozone non-attainment areas classified as serious, severe, or extreme have PAMS sites that include enhanced monitoring of ozone, ozone precursors, and surface and upper-air meteorology. PAMS site type 2 represent the area of maximum O3 precursor concentration and should also represent good locations for core $PM_{2.5}$ sites. Though PAMS site type 1 and 4 are intended to be used for regional-scale ozone assessment, their siting and measurements also apply to secondary nitrate and organic aerosol formation and they should be considered as potential $PM_{2.5}$ monitoring sites, especially for transport and background monitoring. MPAs with existing PAMS are to install a $PM_{2.5}$ core site at a minimum of one PAMS location.

- **Interagency Monitoring of Protected Visual Environments (IMPROVE):** As noted above, the IMPROVE network provides long-term measurements of $PM_{2.5}$ and other visibility-related observables in National Parks and Wildernesses throughout the U.S. IMPROVE sites, and the data acquired at those sites, may qualify as background and/or transport sites for $PM_{2.5}$ networks.

2.3.4 Site Types

Several types of sampling sites, not all of which are designated for determining compliance with NAAQS, will be part of the $PM_{2.5}$ measurement networks.

- **Community-Oriented (Core) Sites:** Community-oriented sites are located where people live, work, and play rather than at the expected maximum impact point for specific source emissions. These sites are not located within the microscale or middle-scale zone of influence of a specific, nearby particle emitter. Community-oriented sites may be located in industrial areas as well as and in residential, commercial, recreational, and other areas where a substantial number of people may spend a significant fraction of their day.

A subset of the core sites are intended to acquire $PM_{2.5}$ concentrations every day. These include core SLAMS sites and sites collocated with PAMS sites. Two or more such core sites are to be operated in MSAs with population greater than 500,000, with at least one additional core site in each PAMS area.

Core sites are used to determine NAAQS compliance for both annual and 24-hour $PM_{2.5}$ standards. Because core sites are the only sites eligible for comparison to both the annual and 24-hour $PM_{2.5}$ NAAQS, they are the most important sites in the new $PM_{2.5}$ network. $PM_{2.5}$ concentrations may be spatially averaged among these sites within a CMZ when the annual average $PM_{2.5}$ at each core site is within ±20% of the spatial average on a yearly basis. Core sites should have a zone of representation of at least neighborhood scale (> 0.5 km). For a neighborhood scale, this means that the 24-hour concentrations should vary by no more than ±10 percent within an area whose diameter is between 0.5 and 4 km. For urban scale, the concentrations would be similar for distances greater than 4 km. In some monitoring areas, a site with a smaller spatially representative scale (microscale or middle scale) may be representative of many such small scale sites in the general area. This site is effectively representative of a larger scale and in accordance with Appendix D to 40 CFR 58 is also eligible to be called a core site. Sites representing source areas with small zones of influence (e.g., less than one-tenth the dimensions of the CMZ) do not qualify for spatial averaging.

The state can use one or more core monitoring sites to define community air quality for purposes of making comparisons to the annual $PM_{2.5}$ NAAQS. Multiple sites would exist within community monitoring zones and must each meet the eligibility requirements of Appendix D to 40 CFR 58. The elected community monitoring approach and the description of the CMZs would be contained in the state's network description.

- **Daily Compliance Sites:** Daily compliance sites are used to determine NAAQS compliance for the 24-hour (daily) $PM_{2.5}$ standard, but not for the annual standard. Because a daily compliance site does not necessarily represent community-oriented monitoring, it may be located near an emitter with a microscale or middle-scale zone of influence.

  The PM monitoring regulations state that any population-oriented site is eligible for comparison to the 24-hour $PM_{2.5}$ standard. If the monitoring stie is also representative of community-wide air quality, it is eligible for comparison to the annual $PM_{2.5}$ NAAQS. With a few anticipated exceptions, almost all sites in the new network will be population-oriented. A site may be population-oriented and at the same time be source oriented or reflective of maximum concentration. The same is true for the existing PM_{10} network.

Population-oriented sites may be located in hot spot locations and other portions of the above areas which are likely to invoke exposure to fine particles for at least part of a 24-hour sampling period. Hot spot locations have a micro or middle measurement scale of representativeness. Microscale means that the 24-hour measurements should vary by no more than ±10% within a circle of diameter 100 meters. Middle scale means that the 24-hour measurements should vary no more than ±10% within a circle of diameter 100-500 meters. These distances are the area around the monitor which may be different than the distance to the nearest major influencing source.

Limitations in resources dictate some tradeoffs in the selection of hot spot locations. Every potential hot spot may not be covered. In general, those maximum concentration locations most reflective of larger population impact should be given higher priority in the placement of permanent monitoring stations. Restrictions in the ability to site permanent monitors is also and important consideration. It may not be feasible to always establish stations adjacent to occupied buildings and within recreational settings, because we cannot obtain permission to use the property or the buildings obstruct the air flow. In such cases, alternate locations which are representative of population-oriented sites should be considered.

- **Special Purpose Monitors (SPM):** SPMs may or may not be used to determine compliance. Their purpose is to understand the nature and causes of excessive concentrations measured at compliance monitoring sites. SPMs do not necessarily use FRMs or FEM methods, and they may be operated over short periods of time at different locations. SPMs may be discontinued within their first two years of operation without prejudice when their purpose has been achieved. Typical SPMs might include: 1) portable saturation monitors operated at many locations around core sites to determine zones of representation, zones of influence, and spatial uniformity; 2) sequential samplers with Teflon and quartz filters or absorbing substrates to determine diurnal distributions of PM chemical components and precursor gases; and 3) short-time-resolution continuous monitors to determine diurnal mass concentration changes in response to changes in emission rates and meteorology. When SPMs use FRM or FEM samplers and satisfy other requirements of section 58.14a, then they may be used to judge compliance. However, non-attainment designations will not be based upon the SPM data for the first two years of their operation.

- **Transport Sites:** Transport sites are intended assess the effects of emissions within one MPA or isolated emission sources on other MPAs. To do this, they are typically located between MPAs, or between non-urban source areas and MPAs. Meteorological measurements will usually be associated with transport sites.

- **NAMS Sites:** Subsets of core and transport sites will be selected for long-term monitoring and will be designated as $PM_{2.5}$ NAMS for assessing trends and for performing future epidemiological studies.

- **Background Sites:** Background sites are intended to represent regional-scale $PM_{2.5}$ concentrations that may be a combination of contributions from several MPAs and non-urban source areas, as well as natural emissions. These are usually located in pristine areas, such as National Parks and Wilderness areas, and possibly at elevations higher than MPAs, but still within the typical mixed layer of the atmosphere.

2.4 Network Design Philosophies

The design of environmental sampling networks has been studied in hydrology (Andricevic, 1990; Kassim and Kottegoda, 1991; Woldt and Bogardi, 1992; Meyer *et al.*, 1994), meteorology (Gandin, 1970), and the geological sciences (Camisani-Calzolari, 1984; de Marsily *et al.*, 1984; Russo, 1984). Only a few of these concepts have been adapted to air quality networks. Some of the earliest work done in network design focused on meteorological observations (Gandin, 1970).

2.4.1 Network Design Objectives

Networks are designed to attain specific objectives. Objectives of the SLAMS $PM_{2.5}$ monitoring network are (U.S. EPA, 1997b):

- To determine representative concentrations in areas of high population density.

- To determine the impact on ambient pollution levels of significant sources or source categories.

- To determine general background concentration levels.

- To determine the extent of regional pollutant transport among populated areas; and in support of secondary standards.

- To determine the highest concentrations expected to occur in the area covered by the network.

- To determine the welfare-related impacts in more rural and remote areas such as visibility impairment and effects on vegetation.

Munn (1981) defines two basic methods of network design: 1) the statistical method, and 2) the modeling method. The statistical method assumes that existing data is available to extract meaningful statistical information for network design.

The statistical approach is based on the lognormal distribution followed by most air quality data (Larsen, 1969; Noll and Miller, 1977). Statistical methods take advantage of the fact that most air quality measurements are correlated either in time at the same location or in space with other monitors in a network. Networks are optimized by examining time series correlations from long measurement records or spatial correlations among measurements from many nearby monitors (Munn, 1975; Elsom, 1978; Handscombe and Elsom, 1982). Munn (1981) identifies four types of correlation analysis: 1) time correlation (autocorrelation) at one site; 2) cross-correlation of several pollutant concentrations at one site; 3) spatial correlations among simultaneous measurements at different sites; and 4) spatial correlations among different sites with time lags.

2.4.2 Random Sampling

Random sampling locates sites by chance, without taking into consideration the sources of pollutants (Nesbitt and Carter, 1996). Random placement is accomplished by specifying boundaries of a rectangular domain, generating x and y coordinates from a uniform-distribution random number generator truncated at the domain boundaries, and placing samplers as close to these coordinates as practical.

The advantages of random sampling designs are: 1) measurement bias is minimized; 2) implementation simplicity, with no knowledge assumed about the spatial and temporal distribution of concentrations; and 3) sampling locations are objectively chosen. The disadvantages are that: 1) many sampling locations must be allocated for an acceptable sampling error; 2) there is large potential for redundancy in a network with many locations; and 3) there is a large risk of poorly representing exposures in a network with few locations.

Borgman *et al.* (1996) cites an example of how many samplers are required for a certain confidence interval. If the 95% confidence interval is 1 $\mu g/m^3$ with a variance, σ^2, of 6.5 $(\mu g/m^3)^2$ the estimated number of samples is found to be

$$\frac{1.96s}{\sqrt{n}} = 1$$

and solving for n yields 25 samples. This large number of PM sampling sites would only be applicable to a very large urban area, or for a short-term special-study.

From a practical standpoint, random network siting is not a useful model for air quality monitoring. Prior knowledge, though sometimes incomplete, is always available concerning the sources and meteorology that affect PM concentrations in an area. Sampler siting constraints of power, security, and minimum separations from nearby emitters and obstructions impose logistical constraints that prevent a purely “random” selection of measurement locations. The community exposure monitoring philosophy of the new standards is not served by a random-sampling network design.

2.4.3 Systematic Sampling

Systematic sampling locates samplers on a grid system, with one sampler assigned to each grid cell. Noll and Miller (1977) call this type of sampling the “area method”. This method is most applicable in flat terrain with a few large point sources. Samplers are placed as close to the center of the cell as practical. This method minimizes sampling bias because of its regular spacing of sensor locations. However, systematic sampling requires a substantial number of samplers depending on the size of the MPA, and most of these samplers supply redundant information where $PM_{2.5}$ concentrations are spatially uniform.

Systematic sampling costs may be prohibitively high, even for small areas, except for short periods during which spatial uniformity is being evaluated. The positive characteristic of systematic sampling is that the network completely covers the planning area.

2.4.4 Judgmental Sampling

Judgmental sampling (Nesbitt and Carter, 1996) uses knowledge of source emissions and sensitive receptor locations, coupled with mechanisms for pollutant transport, to locate measurement sites. Noll and Miller (1977) call this the “source orientation method” and deem it most appropriate for monitoring point sources in uneven terrain. Air pollution models can be used to assist in this judgment, but this requires exceptional accuracy of the model formulation and the model input data. Few areas in the U.S. have good estimates of particle and precursor gas emissions, especially from mobile and area sources. Complex terrain and meteorology, as well as simulating secondary aerosol formation, also present challenges to currently available models for suspended particles.

Judgmental sampler locations may be determined by data from an existing monitoring network or by identifying the locations of pollutant sources and inferring pollutant transport from data analysis of emissions and wind measurements. Short-term experiments involving spatially dense measurements and modeling may assist in making or verifying judgments.

Monitoring networks for criteria pollutants always use judgmental sampling strategies that consider where source emissions are in relation to populations and which way the wind blows.

2.4.5 Heterogeneous Siting Strategies

Nesbitt and Carter (1996) combine judgmental and systematic sampling by applying the following steps: 1) identify potential sources of contamination or “hot spots” using existing measurements or models; 2) place a grid system over these areas; 3) perform sampling at these grid points; 4) define a systematic grid at points which yield positive contamination; 5) use the systematic grid to assess the remainder of the study area.

Figure 2.4.1 shows how a judgmental strategy compares with a combined judgmental and systematic strategy. The concentration isopleths can be interpolated from spatially dense measurements or produced by an air quality model. The judgmental strategy, by itself, missed areas of significant concentrations, while the combined judgmental and systematic strategy covered the areas of significant concentration that had not previously been monitored.

Another hybrid method for locating potential particulate matter samplers is based on geostatistical sampling (Journel, 1980; Russo, 1984; Kassim and Kottegoda, 1991; Trujillo-Ventura, 1991; Rouhani *et al.*, 1992; Borgman *et al.*, 1996). Kriging is a common method for interpolation to predict unknown values from existing spatial data (Volpi and Gambolati, 1978; Lefohn *et al.*, 1987; Venkatram, 1988). Kriging uses the correlation

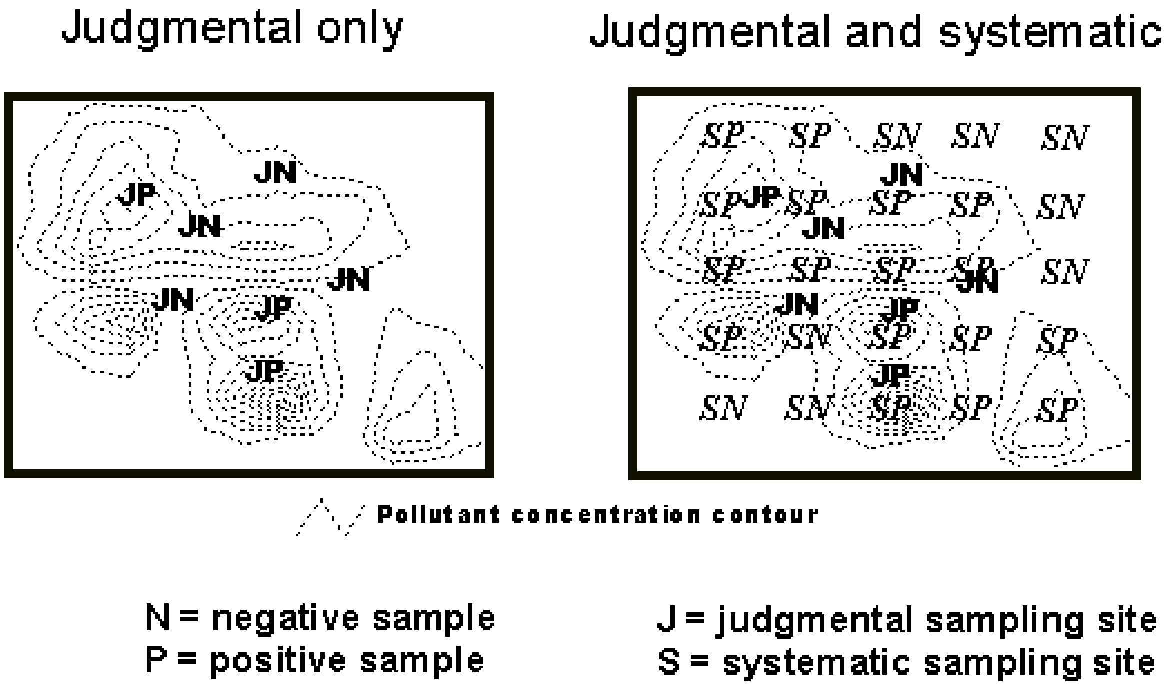


Figure 2.4.1. Examples of judgmental and hybrid sampling strategies.

structure to produce an estimator with the smallest possible mean square error and results in reduced sample size compared to other methods.

Most of this guidance is based on judgmental network design, though it is expected that networks will involve more of the hybrid approach as they are evaluated as future $PM_{2.5}$ measurements and improved aerosol modeling techniques are developed.

2.4.6 Other Siting Strategies

Other statistical tools to design air quality networks include: 1) the coefficient of geographic variation (Stalker and Dickerson, 1962; Stalker *et al.*, 1962); 2) structure functions (Goldstein *et al.*, 1974; Goldstein and Landovitz, 1977); 3) cluster analysis (Sabaton, 1976); 4) principal component analysis (Peterson, 1970; Sabaton, 1976); 5) the variational principle (Wilkins, 1971); and 6) linear programming (Darby et al., 1974; Hougland, 1977).

Modeling relies on a numerical or analytical model to estimate particulate concentrations in space and time. Because of its nature and sources, $PM_{2.5}$ is difficult to model over neighborhood- and urban-scales. As noted above, modeling requires a detailed emissions inventory over the entire domain. Efforts are being made to archive emissions data in geographical information systems (GIS).

Numerical source-oriented models are designed to simulate atmospheric diffusion or dispersion and estimate concentrations at defined receptors. Numerical source models can be grouped as kinematic, first-order closure, or second-order closure models (Bowne and Lundergan, 1983). Kinematic models are the simplest both mathematically and conceptually. These models simplify the non-linear equations of turbulent motion, thereby permitting a closed analytical approximation to describe pollutant concentration (Green *et al.,* 1980). First-order closure models are based on the assumption of an isotropic pollutant concentration field. Consequently, turbulent eddy fluxes are estimated as being proportional to the local spatial gradient of the transport quantities. The Eulerian grid models, Lagrangian particle models, and trajectory puff/plume models are included in this category. Second-order closure models involve a series of algorithm transformations of the equations of state, mass continuity, momentum, and energy by using the Boussinesque approximation and Reynold's decomposition theory (Holton, 1992; Stull, 1988).

For estimating $PM_{2.5}$ levels, Eulerian models that include aerosol modules simulating the physical and chemical processes governing particulate concentrations in the atmosphere are more suitable than Lagrangian models such as plume trajectory models. Eulerian three-dimensional models may use either a simplified treatment of atmospheric chemistry (usually used to address long-term particulate concentrations at urban sites) or include a more detailed atmospheric chemistry treatment (usually used to simulate only a few days of episodes due to their compositional cost).

Commonly used long-term Eulerian models with simplified atmospheric processes include (Seigneur *et al*., 1997):

- Urban Airshed Model Version V with Linear Chemistry (UAM-V).
- Regulatory Modeling System for Aerosol and Deposition (REMSAD).
- Visibility and Haze in the Western Atmosphere Model (VISHWA).

Commonly used short-term Eulerian models with complex atmospheric processes include:

- Urban Airshed Model Version V with Aerosols (UAM-AERO),
- Urban Airshed Model with Aerosol Inorganic Module (UAM-AIM).
- SARMAP Air Quality Model with Aerosols (SAQM-AERO).
- California Institute of Technology Model (CIT).
- Gas, Aerosol, Transport, Radiation Model (GATOR).
- Denver Air Quality Model (DAQM).
- Regional Particulate Model (RPM).

All of the above mentioned Eulerian models have been developed by various scientists from universities, federal and state agencies, and the private sector. These particulate air quality models provide a three-dimensional treatment to simulate the fate and transport of atmospheric contaminants. All of these Eulerian models include gas phase chemistry and aerosol dynamics and simulate atmospheric inorganics (such as sulfate, nitrate, and ammonium), but some of these models do not include the treatment of organics (i.e., REMSAD and UAM-LC).

In cases where secondary aerosols may not be a significant fraction of the $PM_{2.5}$ mass, the applicability of these Eulerian models needs to be investigated further. Less complex Gaussian plume dispersion models such as the Industrial Source Complex Model Version 3 (ISC3) and the Fugitive Dust Model (FDM) will continue to be useful in estimating impacts from particulate sources.

3.0 DEFINING STATE PLANNING AREAS

This section specifies the steps to define the boundaries of Monitoring Planning Areas (MPAs) for determining compliance with PM_{10} and $PM_{2.5}$ standards. This procedure requires the spatial examination of population statistics, topography, existing PM networks, past measurements, emissions densities, pollution transport patterns, and existing planning areas. The procedure gives preference to maintaining existing planning areas as MPAs for $PM_{2.5}$ and for adapting existing sites to $PM_{2.5}$ compliance monitoring. It also provides an objective means for identifying PM_{10} measurement locations that can be discontinued as PM_{10} compliance monitors.

Two examples, from Birmingham and Jefferson County, AL, and from California's San Joaquin Valley, are used to illustrate the application of the approach for selecting MPAs, optional CMZs, and sampling sites. These eastern and western areas show several examples of complications and solutions that might be encountered in following these guidelines. These examples are given for illustrative purposes only, using data from the public domain obtained from the sources identified in Appendix A. It is not intended that these examples should be used as the basis for re-design of existing PM networks in either of these areas.

The following steps define the MPAs:

1. **Identify Political Boundaries of Populated Areas:** Plot populated entities (MSAs, PMSAs, counties, zip code areas, census tracts, or census blocks). Identify where the majority of the people live. Identify a grouping of populated entities that define a contiguous area and designate this as an initial MPA. According to the new regulations, MPAs are required to correspond to all metropolitan statistical areas with populations greater than 200,000. The regulations also state that the MSA boundaries do not necessarily have to correspond to the proposed MPA, and that air planning district boundaries may be used.

2. **Identify Natural Air Basins:** Compare outer boundaries of the initial MPA on a topographic map showing terrain that might engender trapping, channeling, or separation of source emissions from populated areas. When terrain features are near the initial MPA boundary, add or subtract population entities to correspond as closely as possible to the terrain features. When terrain features are significant within the MPA boundary, identify potential Community Monitoring Zones (CMZ) that are separated by ridges, lakes, or valleys, or that are bounded on one edge by a seacoast.

3. **Locate Existing Air Quality Monitoring Sites:** Plot the locations of existing PM monitoring sites from NAMS, SLAMS, PAMS, IMPROVE, and special monitoring networks. Examine the extent to which these correspond to populated areas. Identify large distances between existing sites, and identify sites that appear to represent the same sizes of populated areas. Evaluate the justification for excluding existing sites outside of the initial MPA boundaries. If these are community oriented sites, extend the initial MPA boundaries with populated

entities to include these sites. Alternatively, evaluate these sites for potential as special monitoring, transport or background sites. If existing sites outside of the MPA do not qualify as any of these, designate these for potential discontinuation in favor of sites that better attain one of the monitoring objectives.

4. **Reconcile Boundaries with Existing Planning Areas:** Plot boundaries of existing planning areas, such as air quality management districts, urban master plan boundaries, and/or transportation planning regions. Make initial MPA boundaries correspond to existing planning boundaries. Add or subtract populated entities to define the MPA as closely as possible to the existing boundary. Where major adjustments are needed to accommodate existing planning boundaries, define initial CMZs or general areas for locating core sites within those boundaries according to the procedure in Section 4.

3.1 Identify Political Boundaries of Populated Areas

Appendix B lists Metropolitan Statistical Areas (MSA) and Primary Metropolitan Statistical Areas (PMSA) in the United States. Figures 3.1.1 and 3.1.2 show these statistical areas for the continental U.S. with shading for their populations in 1990 and 1995, respectively. The 1990 census values are to be used to determine population cut-offs, and in most cases these do not differ by more than ±10% from the 1995 estimates. Tables 3.1.1 and 3.1.2 are extracts from Appendix B for the states of Alabama and California, respectively. The MSAs and PMSAs are named after the most populated cities or counties and are intended to include the economic influence of a population center. Their boundaries may correspond to county or municipal borders.

In Alabama, the MSAs range from ~1,500 km^2 to 8,000 km^2, with population densities of ~40 to 100 people/km^2. This is typical of many eastern states, where the counties are relatively small compared to those of the west. In California, on the other hand, the MSAs range from ~1,000 km^2 to >20,000 km^2, with 1990 population densities from 25 people/km^2 to >1,100 people/km^2. The most extreme cases in Appendix B are: 1) the Las Vegas MSA that covers more than 100,000 km^2 and includes Nye, Clark, and Mohave Counties, among the largest counties in the U.S.; and 2) the Jersey City PMSA that includes only 120 km^2 of Hudson County with one of the highest U.S. population densities (>4,500 people/km^2). More than 95% of the population in the Las Vegas MSA lives in the southern portion of Clark County, occupying less than 5% of the MSA land area, while the Jersey City PSMA has high population density throughout. While the majority of the MSAs remained in the same categories from 1990 to 1995, there are several that exceeded 200,000 in population by the year 1995. The Las Vegas MSA continued to grow and changed from a >500,000 category to a >1 million category by 1995.

Countywide population maps and MSA designations are most useful for identifying those parts of a state that are not required to perform community exposure monitoring. MSAs are not useful for defining the boundaries of MPAs in most cases. Figure 3.1.1 and Appendix B show a wide variation in populations among the MSAs. A large number of these had less than 500,000 people in them during 1990, and these are mostly in the non-coastal western states. There are many small but highly populated MSAs along the east

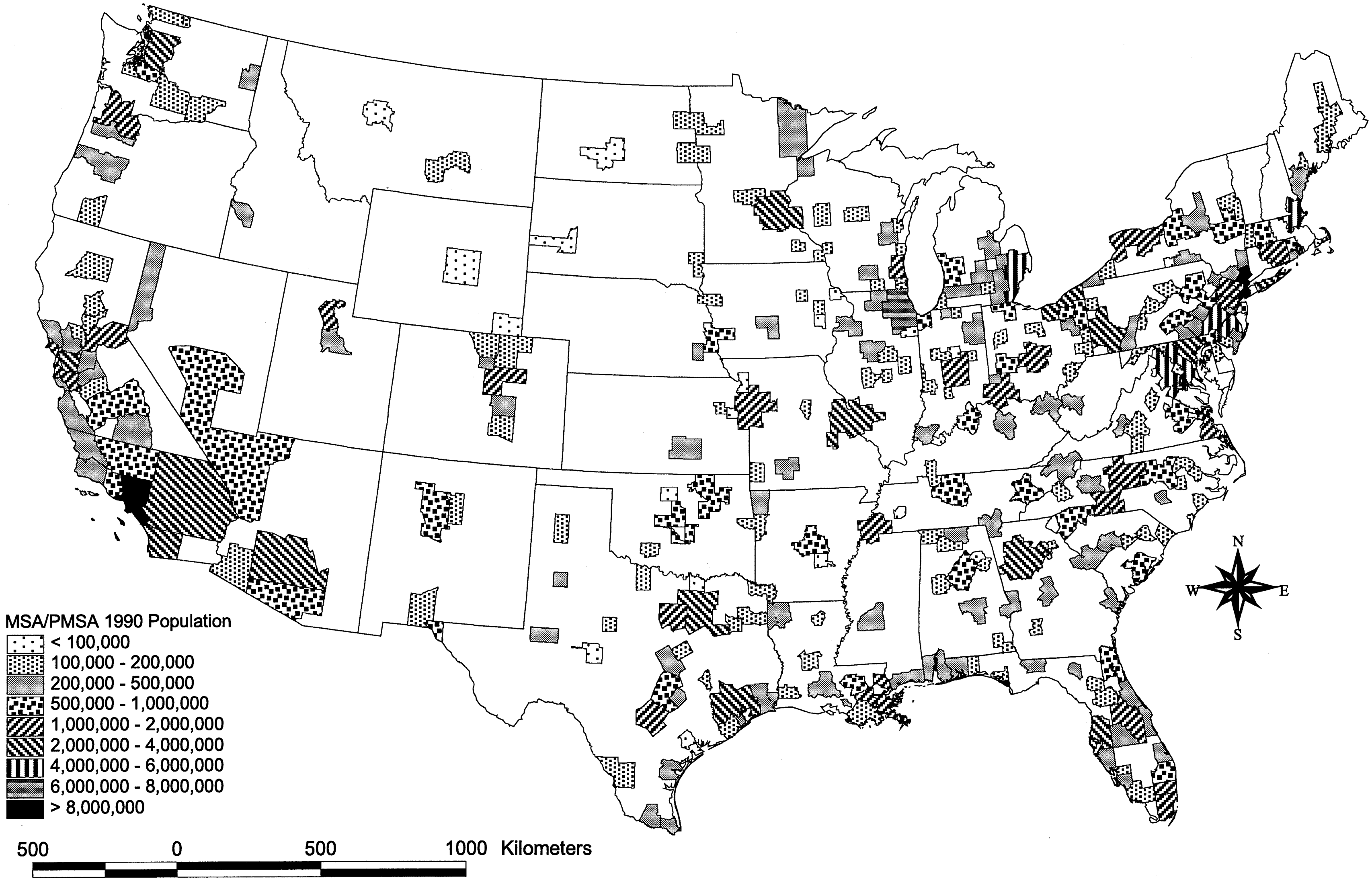


Figure 3.1.1. Metropolitan Statistical Areas and Primary Metropolitan Statistical Areas in the continental U.S. with 1990 populations.

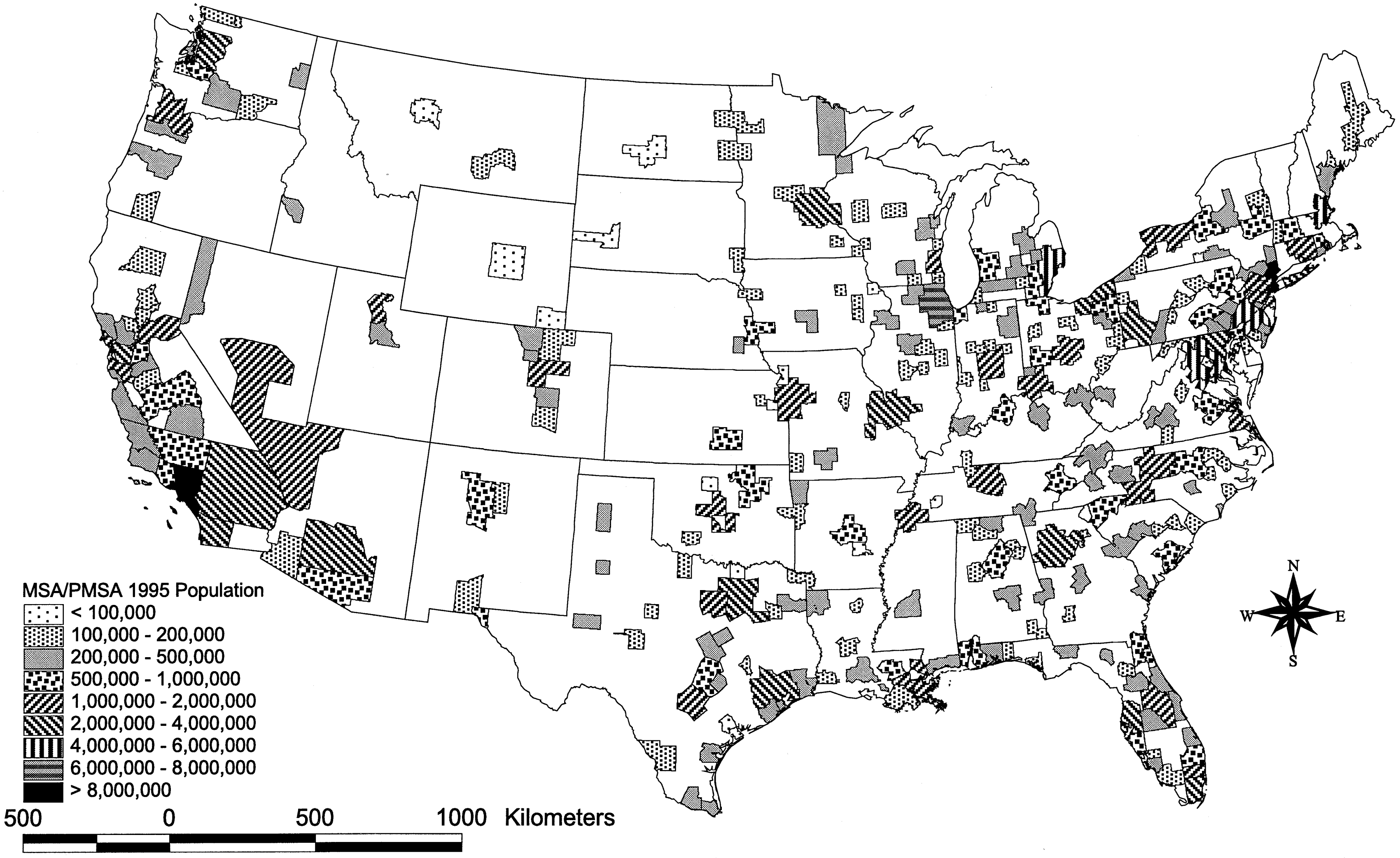


Figure 3.1.2. Metropolitan Statistical Areas and Primary Metropolitan Statistical Areas in the continental U.S. with 1995 populations.

State	Metropolitan Area	TYPE	Counties	1990 Population	1995 Est. Population	1995 pop density (km^{-2})	Area (km^2)
AL	Anniston, AL	MSA	Calhoun County	116,034	117,263	74.4	1576.0
AL	Birmingham, AL	MSA	Blount County Jefferson County St. Clair County Shelby County	840,140	881,761	106.8	8,255.0
AL	Decatur, AL	MSA	Lawrence County Morgan County	131,556	139,837	42.3	3304.0
AL	Dothan, AL	MSA	Dale County Houston County	130,964	134,368	45.4	2956.6
AL	Florence, AL	MSA	Colbert County Lauderdale County	131,327	136,184	41.6	3274.0
AL	Gadsden, AL	MSA	Etowah County	99,840	100,259	72.4	1385.2
AL	Huntsville, AL	MSA	Limestone County Madison County	293,047	317,684	89.3	3556.2
AL	Mobile, AL	MSA	Baldwin County Mobile County	476,923	517,611	70.6	7329.4
AL	Montgomery, AL	MSA	Autauga County Elmore County Montgomery County	292,517	315,332	60.6	5199.3
AL	Tuscaloosa, AL	MSA	Tuscaloosa County	150,522	158,732	46.2	3432.4

Table 3.1.1. Alabama Metropolitan Statistical Areas and Primary Metropolitan Statistical Areas.

State	Metropolitan Area	TYPE	Counties	1990 Population	1995 Est. Population	1995 pop density (km^{-2})	Area (km^2)
CA	Bakersfield, CA	MSA	Kern County	543,477	617,528	29.3	21086.7
CA	Chico-Paradise, CA	MSA	Butte County	182,120	192,880	45.4	4246.6
CA	Fresno, CA	MSA	Fresno County Madera County	755,580	844,293	40.2	20983.3
CA	Los Angeles-Long Beach, CA	PMSA	Los Angeles County	8,863,164	9,138,789	869.1	10515.3
CA	Los Angeles-Riverside-Orange County, CA	CMSA	Los Angeles County Orange County Riverside County San Bernardino County Ventura County	14,531,529	15,362,165	174.4	88080.4
CA	Orange County, CA	PMSA	Orange County	2,410,556	2,563,971	1253.6	2045.3
CA	Riverside-San Bernardino, CA	PMSA	Riverside County San Bernardino County	2,588,793	2,949,387	41.8	70629.2
CA	Ventura, CA	PMSA	Ventura County	669,016	710,018	148.5	4781.0
CA	Merced, CA	MSA	Merced County	178,403	194,407	38.9	4995.8
CA	Modesto, CA	MSA	Stanislaus County	370,522	410,870	106.1	3870.9
CA	Redding, CA	MSA	Shasta County	147,036	160,940	16.4	9804.8
CA	Sacramento, CA	PMSA	El Dorado County Placer County Sacramento County	1,340,010	1,456,955	137.8	10571.3
CA	Yolo, CA	PMSA	Yolo County	141,092	147,769	56.4	2622.2
CA	Salinas, CA	MSA	Monterey County	355,660	348,841	40.5	8603.8
CA	San Diego, CA	MSA	San Diego County	2,498,016	2,644,132	242.8	10889.6
CA	Oakland, CA	PMSA	Alameda County Contra Costa County	2,082,914	2,195,411	581.5	3775.7
CA	Sacramento-Yolo, CA	CMSA	El Dorado County Placer County Sacramento County Yolo County	1,481,220	1,604,724	121.1	13250.4

Table 3.1.2. California Metropolitan Statistical Areas and Primary Metropolitan Statistical Areas.

State	Metropolitan Area	TYPE	Counties	1990 Population	1995 Est. Population	1995 pop density (km^{-2})	Area (km^2)
CA	San Francisco, CA	PMSA	Marin County San Francisco County San Mateo County	1,603,678	1,645,815	625.7	2630.4
CA	San Francisco-Oakland-San Jose, CA	CMSA	Alameda County Contra Costa County Marin County San Francisco County San Mateo County Santa Clara County Santa Cruz County Sonoma County Napa County Solano County	6,249,881	6,539,602	341.1	19173.7
CA	San Jose, CA	PMSA	Santa Clara County	1,497,577	1,565,253	468.0	3344.3
CA	Santa Cruz-Watsonville, CA	PMSA	Santa Cruz County	229,734	236,669	205.0	1154.6
CA	Santa Rosa, CA	PMSA	Sonoma County	388,222	414,569	101.6	4082.4
CA	Vallejo-Fairfield-Napa, CA	PMSA	Napa County Solano County	451,186	481,885	117.6	4097.5
CA	San Luis Obispo-Atascadero-Paso Robles, CA	MSA	San Luis Obispo County	217,162	226,071	26.4	8558.6
CA	Santa Barbara-Santa Maria-Lompoc, CA	MSA	Santa Barbara County	369,608	381,401	53.8	7092.6
CA	Stockton-Lodi, CA	MSA	San Joaquin County	480,628	523,969	144.6	3624.5
CA	Visalia-Tulare-Porterville, CA	MSA	Tulare County	311,921	346,843	27.8	12495.0
CA	Yuba City, CA	MSA	Sutter County Yuba County	122,643	136,104	42.6	3193.9

Table 3.1.2 (continued). California Metropolitan Statistical Areas and Primary Metropolitan Statistical Areas.

coast, in the upper midwest, and along the gulf coast. California dominates the west coast with the largest number of and most populated MSAs.

Figure 3.1.3 shows a continental U.S. map of federal lands that are generally low in population. While these are not of interest for community-oriented monitoring, many of them are good candidates for background monitoring sites. Currently operating stations from the IMPROVE network are plotted on this map, and these provide the first preference for background sites. While the western states have an abundance of these pristine areas, and a long history of IMPROVE background monitoring, the coverage in midwestern, eastern, and southern states is sparse.

Counties, zip code areas, census tracts, and census blocks have population attributes that qualify them as populated entities. These boundaries are available from the 1990 U.S. census that also contains 1990 and 1995/1996 population estimates associated with each entity. Population estimates and 1990 census data are available from the U.S. Census Bureau in electronic and paper formats. See Appendix A for sources of population data. Figure 3.1.4 shows these populated entities in the Birmingham, AL MSA. This MSA consists of four counties, but Blount and St. Clair counties in the upper right of the MSA have no principal cities and small populations. More than 80% of the people in the MSA live in Jefferson County, in and around the principal cities noted in Figure 3.1.4a. The largest and most central of these cities is Birmingham, the largest city in Alabama.

Figure 3.1.4b shows zip code boundaries in Jefferson and Shelby counties; these are more dense and of smaller size in and around the city of Birmingham. Five-digit zip codes may be associated with a few hundred people in rural areas, or with tens of thousands of people in urban areas. Figure 3.1.4c shows census tracts, each containing from 1,000 to 8,000 people, for both counties. These are very small, and often highly populated, in the urban area of south-central Jefferson County, but they become larger and less densely populated toward the north, east, and west edges of the county. Finally, Figure 3.1.4d shows the boundaries for census blocks. Census blocks are subsets of the census tracts, and may contain from 500 to 5,000 people. Their small sizes in the populated area, and their comparable sizes to the census tracts in the less populated periphery of Jefferson County, makes census blocks less desirable than census tracts for defining MPAs, CMZs or general areas for community-oriented monitoring in this MSA.

From these figures, it appears that census blocks provide more population detail than is needed for defining an MPA. Zip code boundaries provide reasonable distributions except at the edges of a potential MPA. Census tracts are probably the most practical units of population to define political boundaries for the Birmingham MPA. In Birmingham, AL, the Jefferson County boundaries provide the first estimate of the MPA, with some of northern parts of Shelby County that abut the Birmingham metropolitan area. As will be seen below, county boundaries are not good starting points for California's San Joaquin Valley.

3.2 Identify Natural Air Basins

In many states, including Alabama and California, political boundaries do not necessarily correspond to terrain features that may trap or channel source emissions or

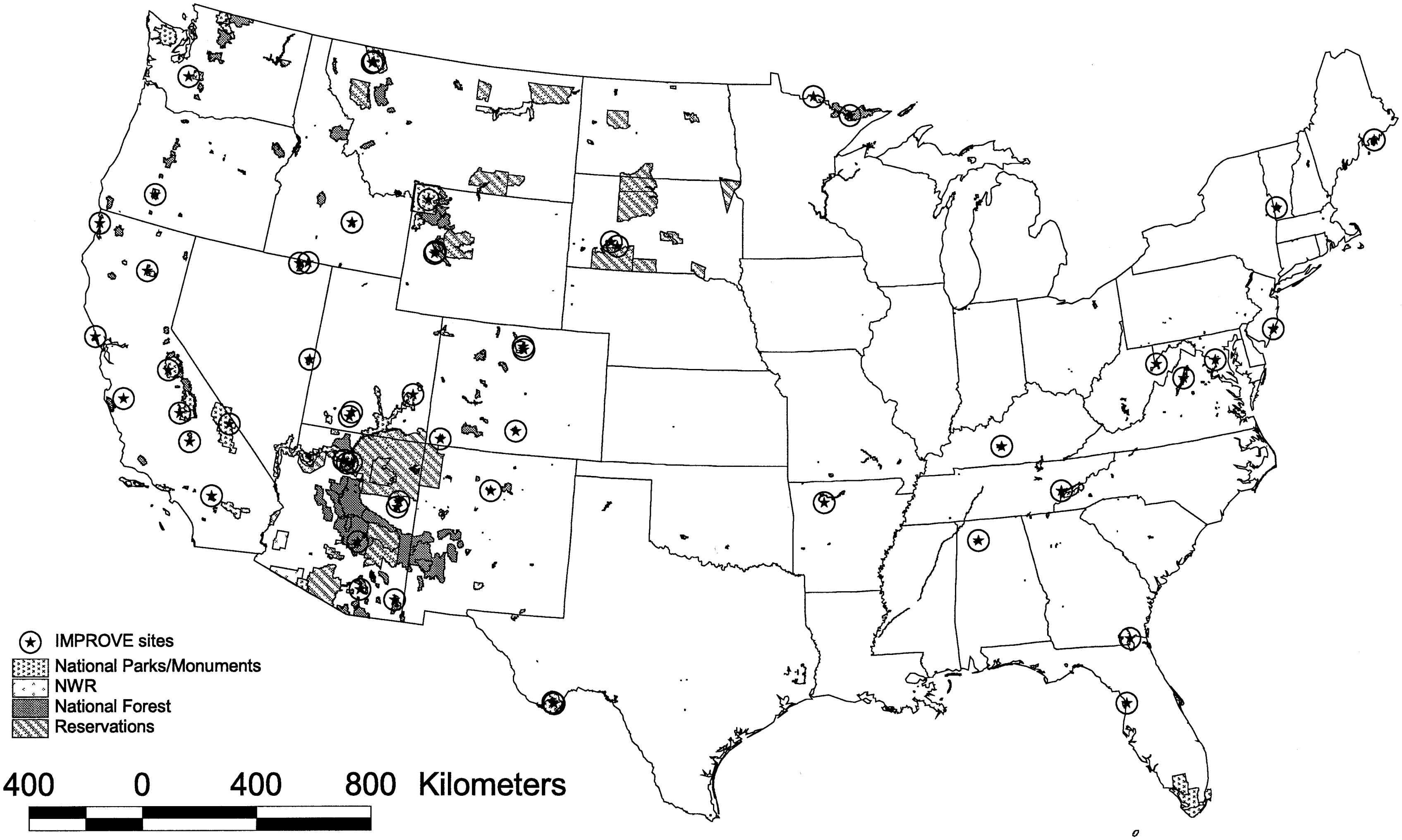
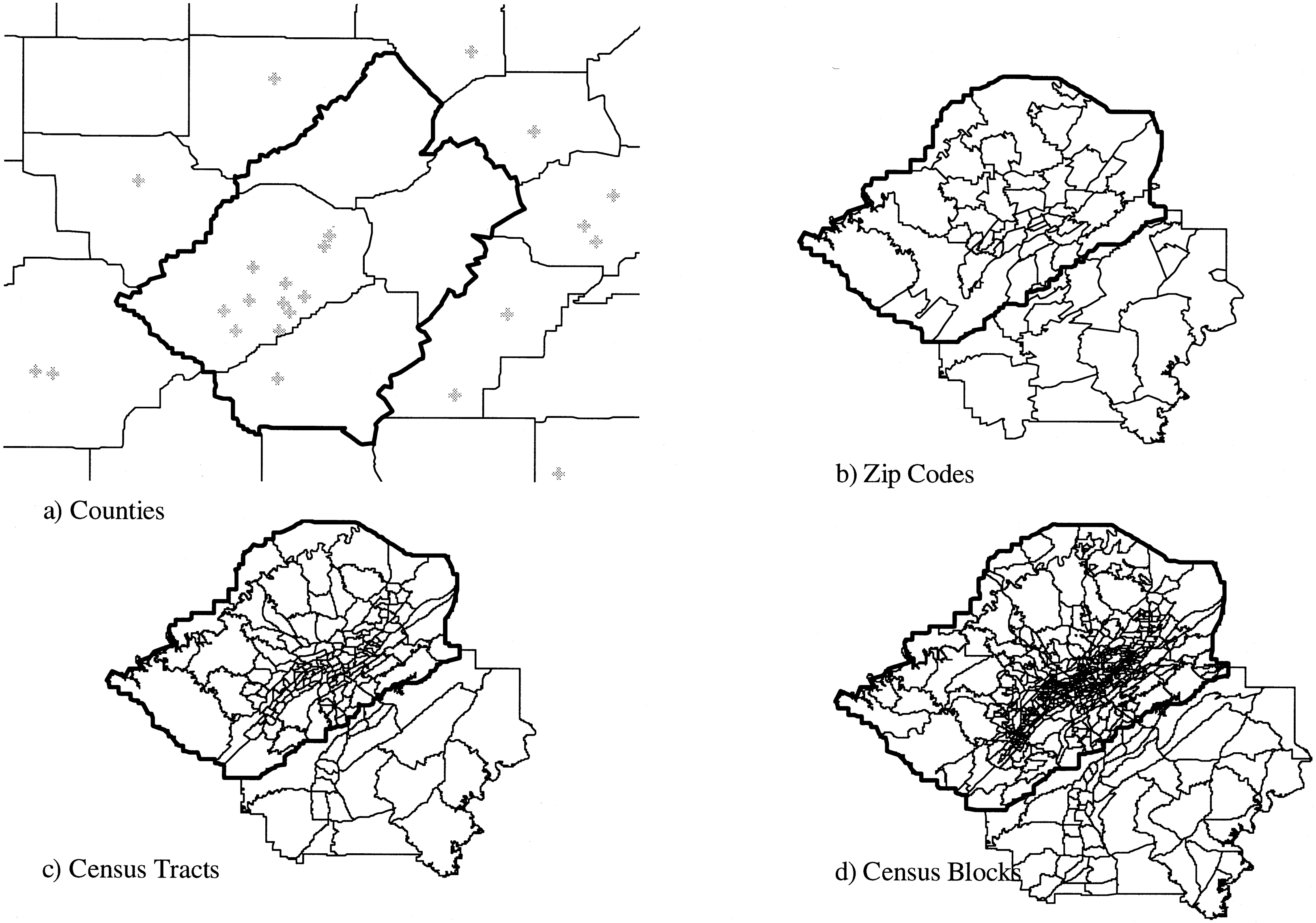


Figure 3.1.3. National parks and monuments, national wildlife refuges, national forests, Indian reservations, and IMPROVE background monitoring sites.



a) Counties

b) Zip Codes

c) Census Tracts

d) Census Blocks

Figure 3.1.4. Populated entities in the Birmingham MSA: a) counties, b) zip codes, c) census tracts, and d) census blocks.

separate emissions from populations. These terrain features may be larger than the single populated area that represents an MPA, or there may be several terrain features that affect concentrations within an MPA. USGS maps with scales of 1:250000, 1:50000 and 1:24000 are useful defining these boundaries. Smaller scale (1:250,000) maps are readily available in electronic format. See Appendix A for sources. This scale is marginally adequate for identifying Monitoring Planning Areas.

Figure 3.2.1 shows the Birmingham MSA in relation to the terrain of the state of Alabama. Alabama is relatively flat toward the south, with the southwestern end of the Appalachian mountain range penetrating into its northeast corner as far as Jefferson County. Birmingham and its neighboring cities are situated along the narrow valleys that constitute the end of this range. These northwest to southeast valleys are separated by ridges that barely attain 300 m in height above the valley floors, and people live and work both within the valleys, on the hillsides, and on the ridges. The populated entities in Figure 3.1.3 can be seen to follow this terrain, as do the major transportation corridors.

The Opossum Valley, just to the north of downtown Birmingham, contains a large industrial complex that extends nearly 40 km to the northeast and southwest from the most densely populated entities. These industries are interspersed with residences in the Opossum Valley, and lie just north of low ridges that separate Opossum from the valleys to the south. The hills are low enough that they probably do not channel local flows, except possibly during night or morning when temperature inversions might induce shallow mixed layers. Table 3.1.1 shows few other highly populated areas in Alabama. Mobile, AL, is on the gulf coast and it is unlikely to have a major influence on pollution in Birmingham. Huntsville to the north and Montgomery to the south have ~300,000 people in their MSAs and little heavy industry. Much of the area between cities is forested or occupied by small farms. Precipitation is abundant, and there is little bare land within the state. The Birmingham MSA may be affected by a superposition of contributions from regional-scale emitters in the southeastern U.S. and urban-scale and neighborhood-scale sources within the MPA.

The San Joaquin Valley (SJV) in central California, shown in Figure 3.2.2, is a significant contrast to Birmingham, AL. This is a complex region, from an air quality and meteorological perspective, owing to its proximity to the Pacific Ocean, its surrounding terrain that affects air flows, its diversity of climates, and its large population centers separated by vast areas of intensively cultivated farmland. Central California contains nearly half of the state's 32 million people.

The SJV encompasses nearly 64,000 square kilometers and contains a population in excess of 3 million people. The majority of this population is centered in the large urban areas of Bakersfield, Fresno, Modesto, and Stockton, though there are nearly 100 smaller communities in the region. The San Francisco Bay area, with more than 6 million people, and a much higher population density than that of the SJV, is generally upwind during non-winter months.

The SJV is bordered on the west by the Coast Mountain range, rising to 1,530 meters (m) above sea level (ASL), and on the east by the Sierra Nevada range with peaks exceeding

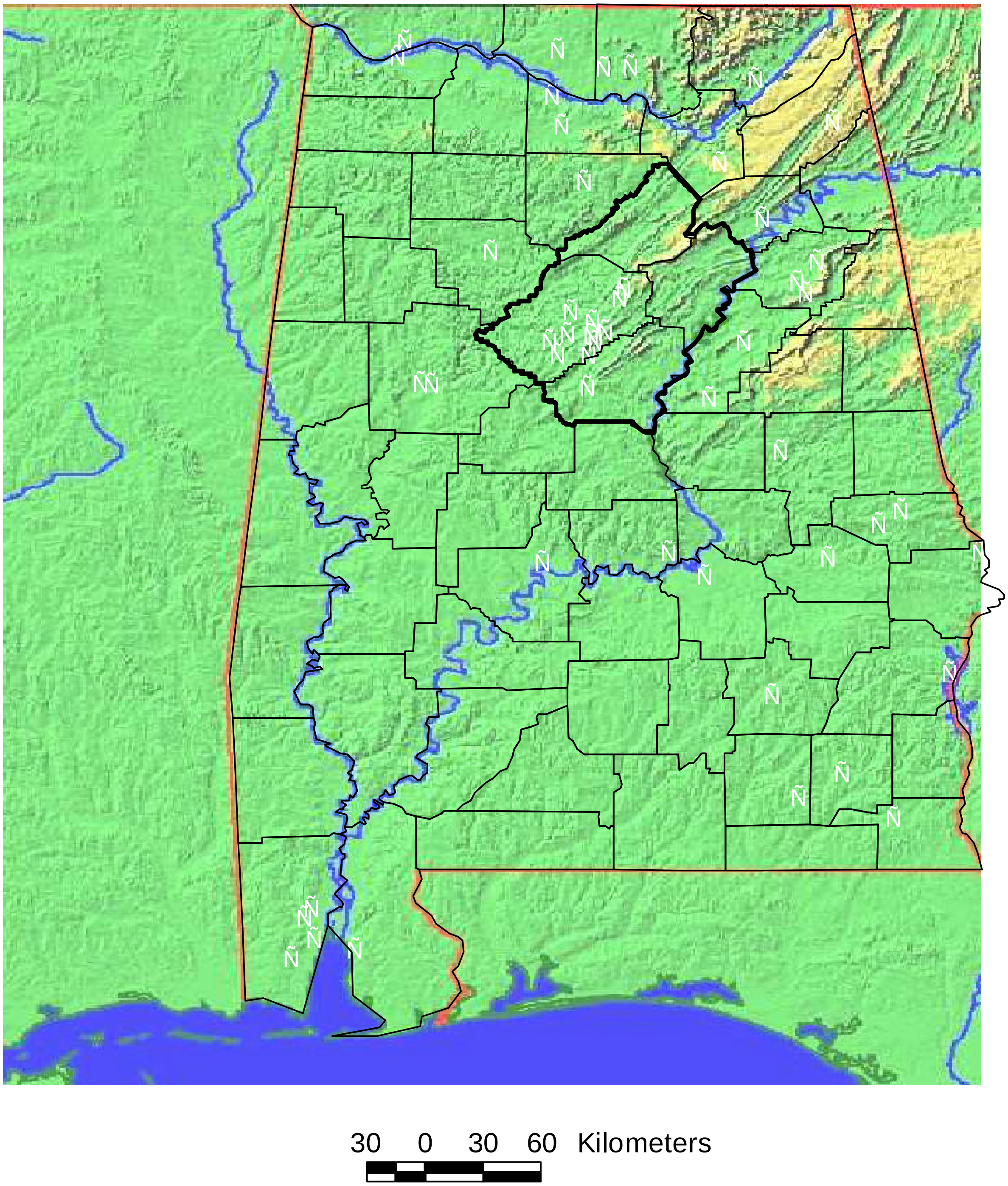


Figure 3.2.1. The Birmingham MSA in relation to counties, principal cities (+), and terrain in Alabama.

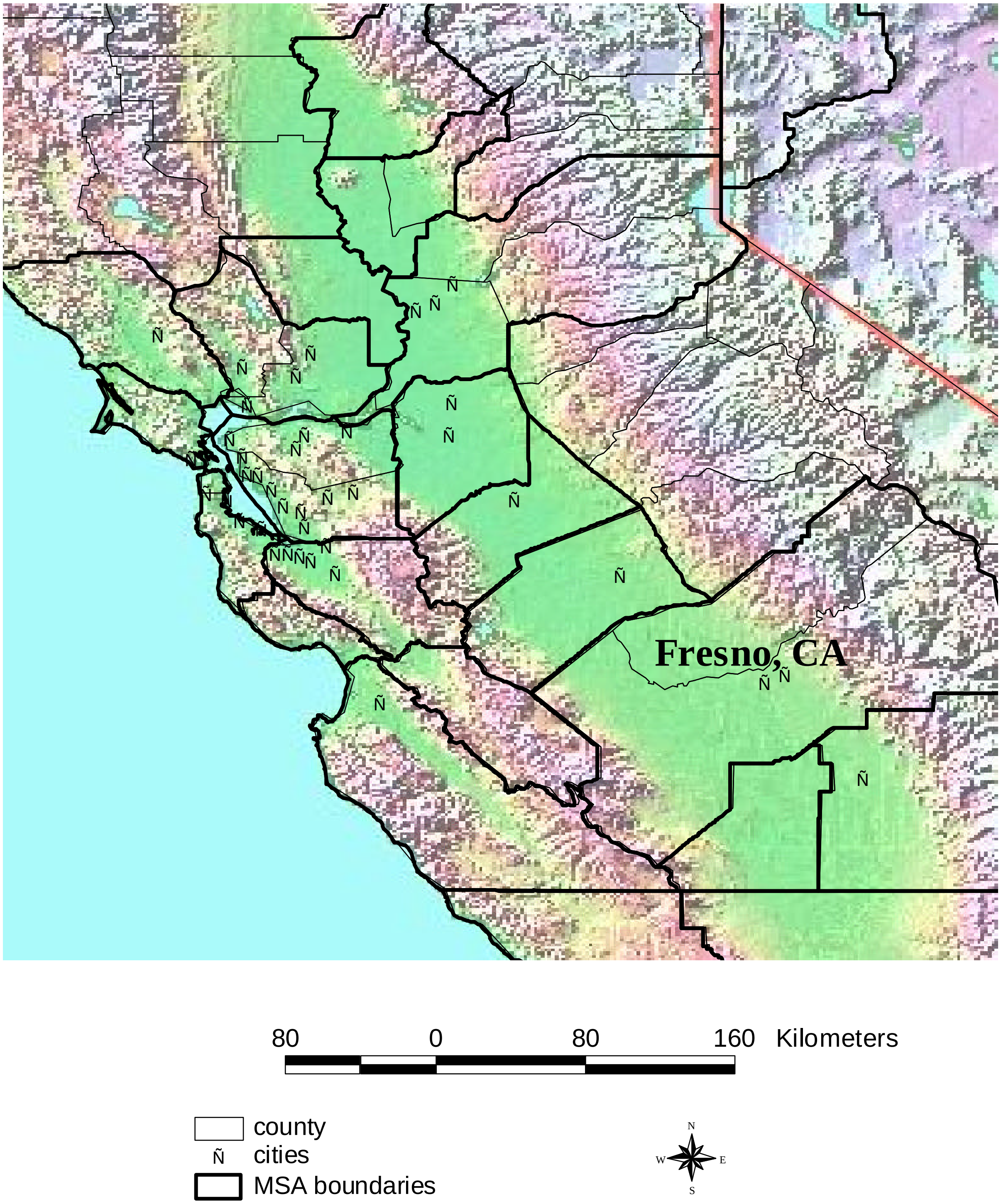


Figure 3.2.2. Central California MSAs in relation to counties, principal cities (+), and terrain.

4,300 m ASL. These ranges converge at the Tehachapi Mountains in the southernmost end of the valley with mountain passes to the Los Angeles basin (Tejon Pass, 1,256 m ASL) and to the Mojave Desert (Tehachapi Pass, 1,225 m ASL). These are significant orographic barriers that can channel flow. There is little heavy industry in the SJV. Agriculture of all types is the major industry, with oil and gas production and refining, waste incineration, electrical co-generation, transportation, commerce, and light manufacturing constituting the remainder of the economy. The climate is arid, with precipitation only in the winter. Bare land is prevalent throughout the region, especially after harvests and prior to re-planting. There is much potential for transport between populated areas within the SJV, from outside of the SJV into the Valley, and from the rural areas to the populated areas.

The populated entities in the SJV are large and extend into the coastal mountains and the Sierra Nevadas. The most populated areas are on the flat terrain between the two ranges, and these are in a line following SR 99 on the eastern side of the Valley.

3.3 Identify Existing Air Quality Monitoring Sites

Figures 3.3.1 shows particle monitoring sites that are currently operated, or were operated in the past, by the Jefferson County Department of Health. Some of these have been discontinued, but their data should still be evaluated along with the cause for their termination. The Jefferson County network corresponds well to the populated entities. Sites are located both within the Opossum Valley, as well as in the southern valleys. The measurements at the Inglenook site, which is furthest north, and the Leeds Elementary School site, which is furthest east, are in areas with lower population, and they might be evaluated as potential background or transport locations, or as monitors in a separate CMZ.

Figure 3.3.2 shows census tracts with past and current PM monitoring sites in the San Joaquin Valley. The areas with the densest concentrations of tracts have one to three monitors apiece. There are also several monitoring sites along the southwestern side of the Valley, in the Sierra Nevadas to the east, and in the Mojave Desert (eastern Kern County). Several of these sites may be appropriate as source-oriented SPMs, background sites, or transport sites.

Figures 3.3.3 and 3.3.4 show potential MPAs determine by census tracts for Jefferson County and the San Joaquin Valley, respectively. Notice that the MPA for Jefferson County also includes a few of the more densely populated tracts in Shelby County, as this appears to be an area of growth in residential housing. Notice that three separate MPAs are identified for the San Joaquin Valley, each corresponding to the most highly populated portions of an MSA and including existing community-oriented monitoring sites.

3.4 Reconcile Boundaries with Existing Planning Areas

Population entities can be added or subtracted at the edges of initial MPAs to correspond to existing boundaries, but the MPAs should still correspond to populated areas. Air pollution control agencies such as the San Joaquin Valley Unified Air Pollution Control District (SJVUAPCD) are responsible for large geographic areas, several MSAs and several initial MPAs. These areas have two options for reconciling the MPAs with their boundaries:

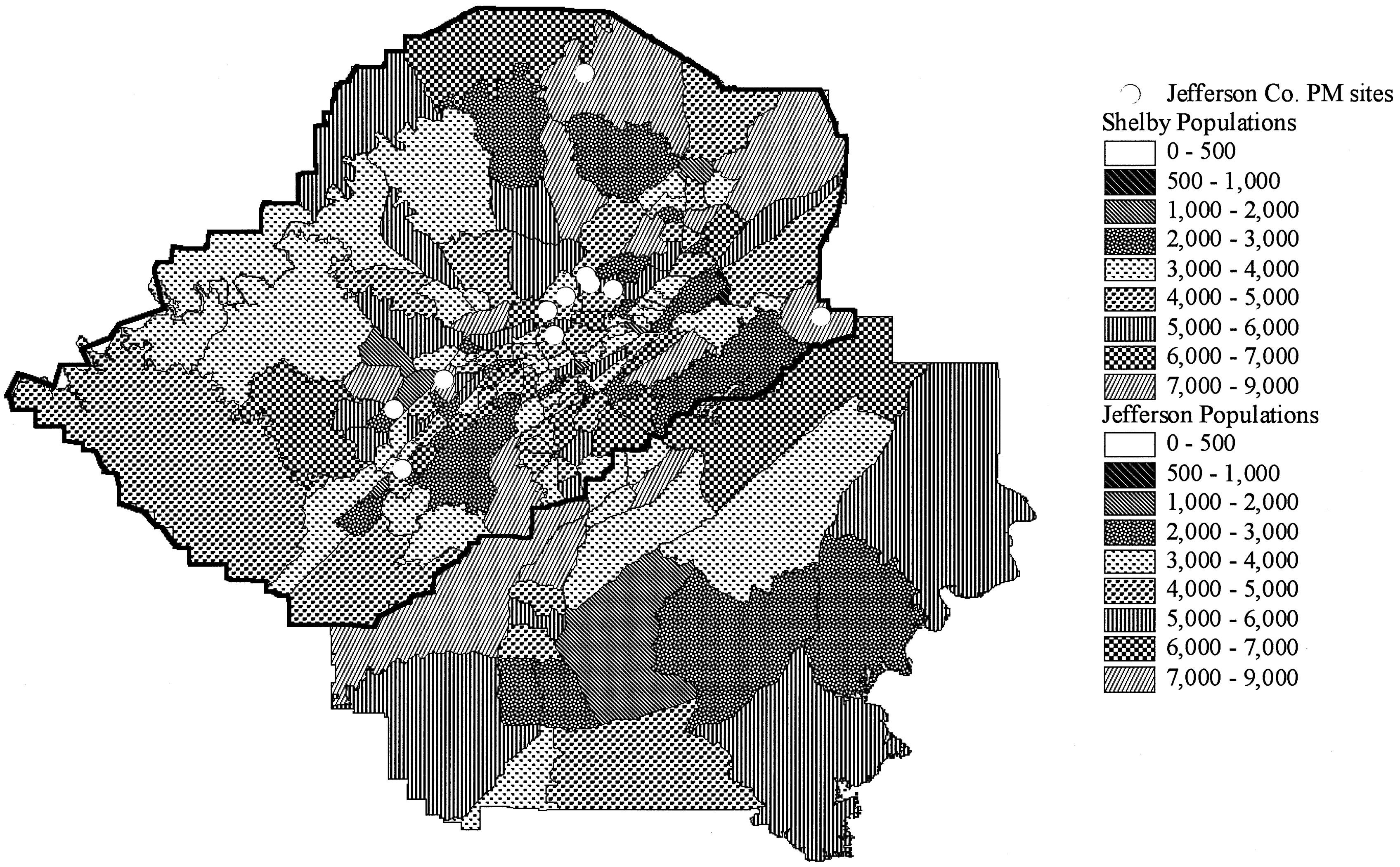


Figure 3.3.1. Populations in Jefferson and Shelby county census tracts. Jefferson County Health Department PM monitoring sites are shown.

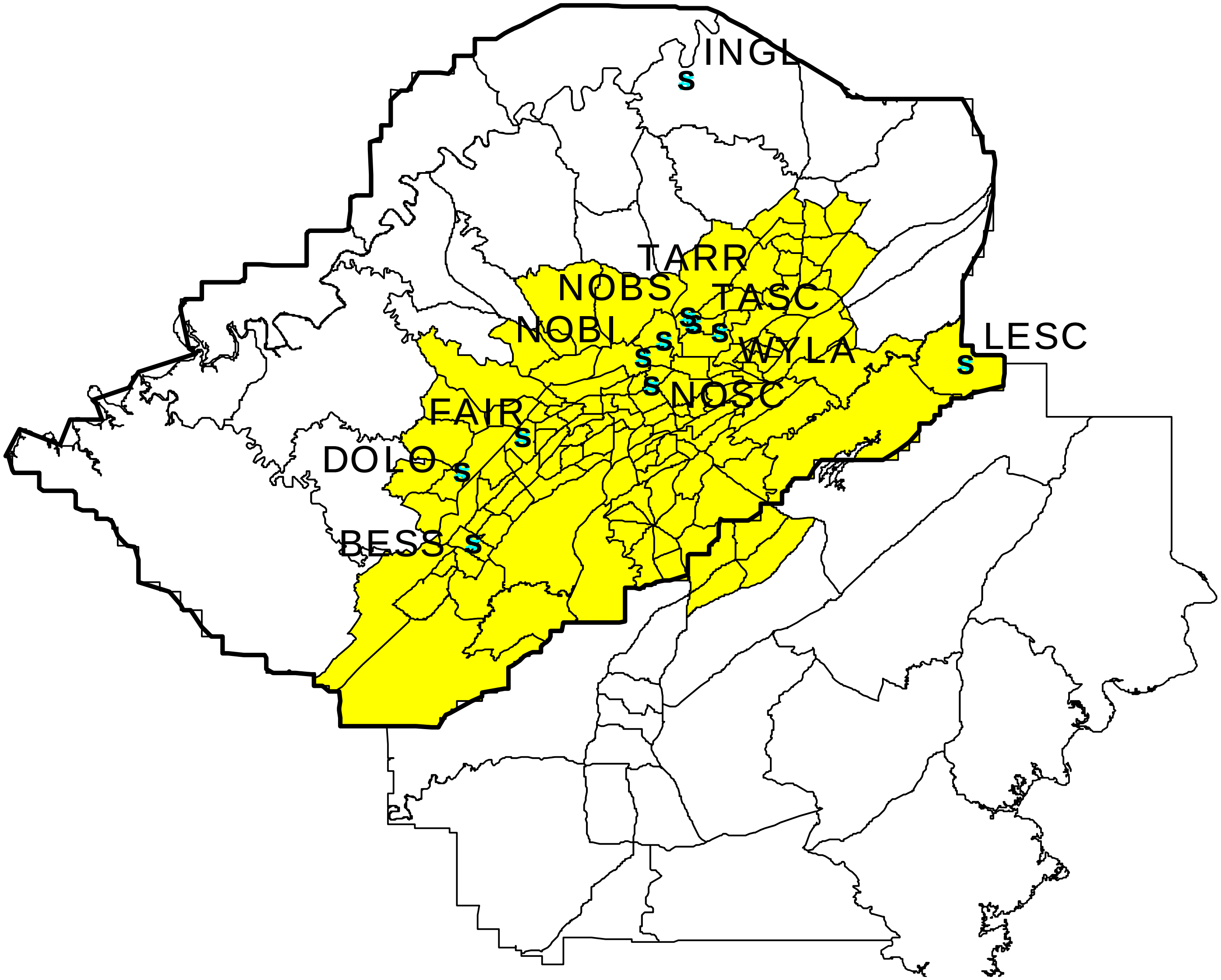


Figure 3.3.2. Potential Monitoring Planning Area for the Birmingham MSA. Dots represent monitoring sites.

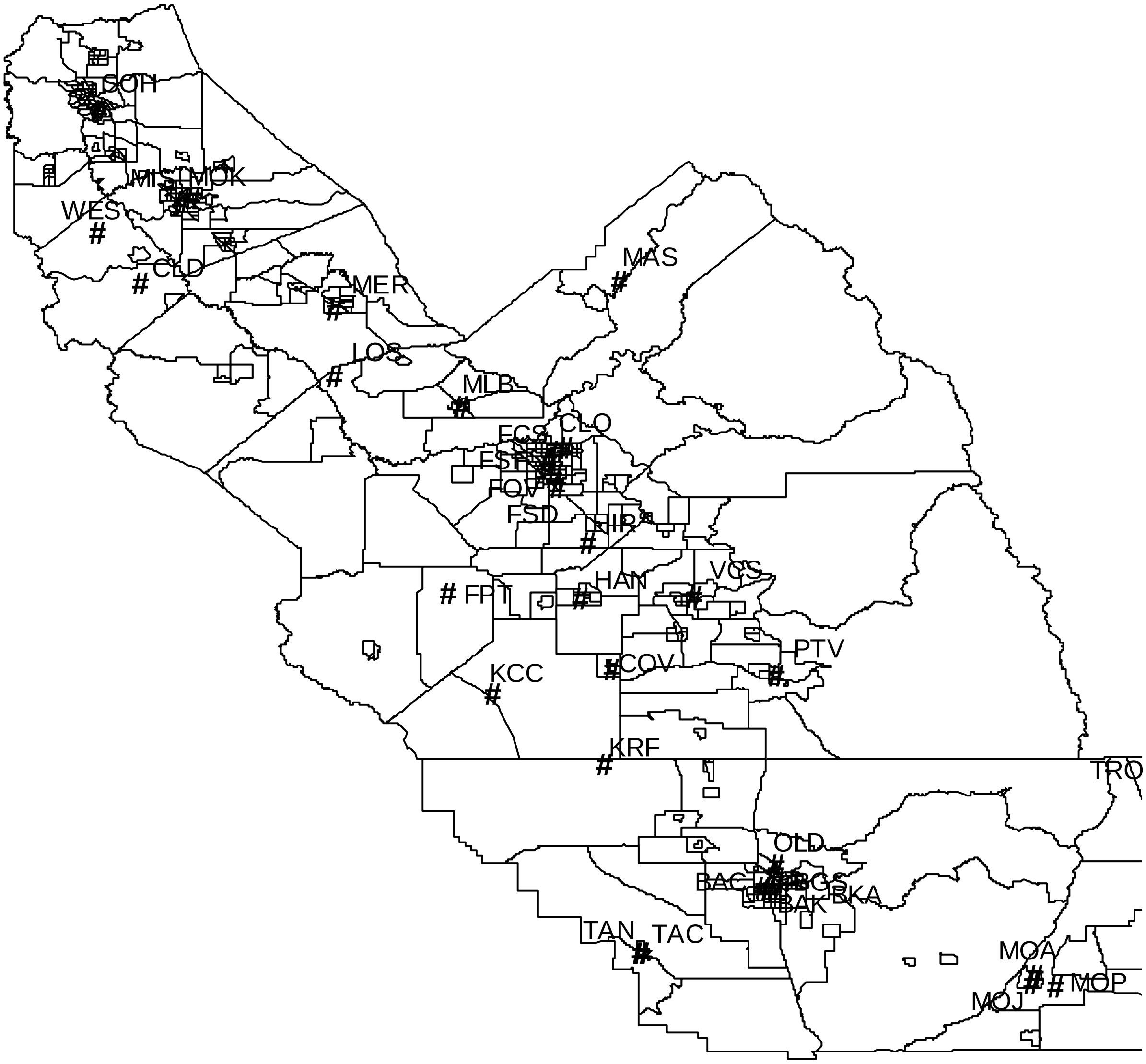
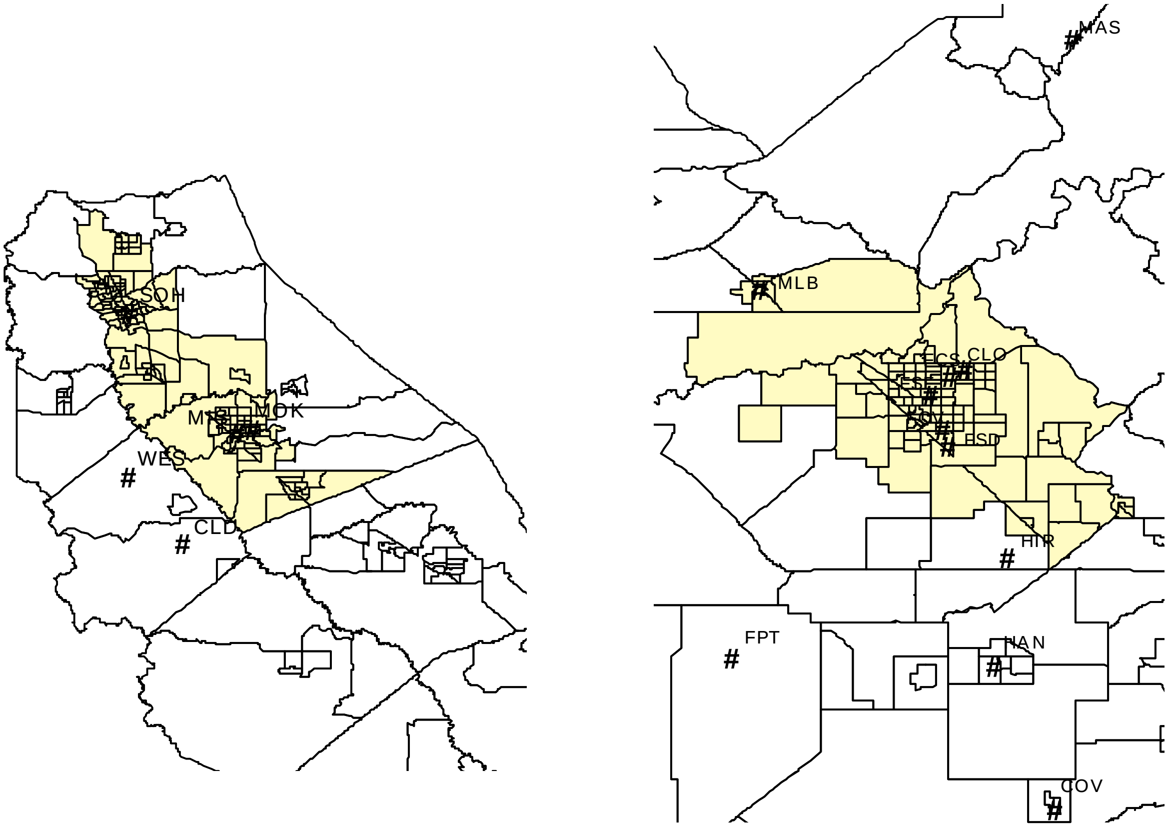
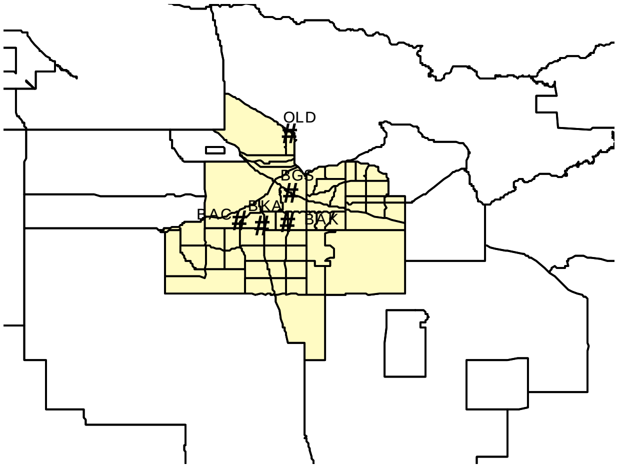


Figure 3.3.3. Census tract boundaries and past and present PM monitoring sites in California's San Joaquin Valley.



a) Stockton/Modesto

b) Fresno/Madera/Clovis/Selma



c) Bakersfield

Figure 3.3.4. Potential San Joaquin Valley MPAs: a) Stockton/Modesto, b) Fresno/Madera/Clovis/Selma, and c) Bakersfield.

- Several MPAs can be designated within the existing jurisdiction, as shown in Figure 3.3.4. Areas between or along the edges of these MPAs become target areas for transport and background monitors, or as SPMs if they are intended to determine specific source influences.

- The MPA can be defined as identical to the existing jurisdictional boundaries. The initial MPAs, such as those in Figure 3.3.4, can be designated as one or more CMZ within the MPA.

In the first option, compliance is determined from SLAMS and other compliance sites within the MPA portions of the jurisdiction, where the most people are exposed to $PM_{2.5}$. Special purpose monitoring between and around these MPAs may be used for source assessment, and may result in emission reduction requirements outside of the MPAs. Alternatively, special purpose transport monitors between the MPAs might be appropriate. In both instances, the data from these SPMs are not necessarily needed for compliance assessments. In the second option, all areas within the jurisdiction are part of an MPA, and measurements from any part may be used for determining compliance.

In other cases, the MPA may extend outside of the current boundaries of the air quality control agency, as for the Birmingham metropolitan area that extends south into Shelby County, AL. There are two options in this case:

- Designate two adjacent MPAs, with the dividing line at jurisdictional lines. This has the advantage of making a clean break between the two administrative agencies, but the disadvantage of complicated coordinated emissions reduction strategies should the $PM_{2.5}$ standards be exceeded.

- Designate one MPA, but with separate CMZs (or core monitoring sites) divided by the jurisdictional line. This has the advantage of allowing monitoring networks to be administered by the existing air pollution control agencies, while allowing for more coordinated planning with respect to needed emissions reductions should the standards be exceeded within different jurisdictions.

The Jefferson County Department of Health has jurisdiction over all air quality monitoring in the county, but none in Shelby County. Shelby County conducts no PM monitoring, and it does not maintain an infrastructure for air quality monitoring and emissions control. These functions are handled by the state for most of the lightly populated counties in Alabama. In this case, the few northern Shelby tracts in Figure 3.3.2 might be eliminated from the MPA to keep the MPA entirely within the jurisdiction of Jefferson County. It is possible that measurements entirely within Jefferson County adequately represent population exposures just south of the Jefferson County border. This hypothesis could be tested by short-term SPMs in Shelby County.

3.5 Summary

Figures 3.3.3 and 3.3.4 show potential MPAs for Birmingham, AL, and for portions of California's San Joaquin Valley that can be used as examples for other areas. In the Birmingham case, the potential MPA is smaller than the entire county and corresponds to the ~100 km long by ~20 km wide swath that cuts through Jefferson County, and extends partially into Shelby County to the south. It corresponds on its edges to terrain features, but it also includes several valleys.

In the San Joaquin Valley portion of Central California, three MPAs are defined within the existing boundaries of the SJVUAPCD for Stockton/Modesto, Fresno/Madera/Clovis/Selma, and Bakersfield, the most highly populated regions of the Valley. The detailed population maps of these areas show that there is substantial difference in population density within the Valley, and even within the proposed MPAs.

4.0 DEFINING $PM_{2.5}$ COMMUNITY MONITORING ZONES

Community-oriented monitors and optional Community Monitoring Zones (CMZ) within MPAs are intended to quantify neighborhood-scale exposures that are added to underlying urban and regional PM contributions. In this discussion, the term CMZ is used to represent the specifically defined area required by the regulations when spatial averaging is intended for making comparisons to the annual $PM_{2.5}$ NAAQS or a more general area only used for description of the communities represented by one or more core sites. CMZs are defined based on terrain, sources, and prior monitoring within and upwind of an MPA. Core sites and optional CMZs should be reviewed annually to determine whether or not additional core sites or CMZs are needed or changes to CMZ boundaries are appropriate. General locations for core sites and CMZs are defined by the following steps:

1. **Locate Emissions Sources and Population:** Plot major land use within the populated entities within the categories of commercial, residential, industrial, or agricultural and the major roadways. Plot emissions from major point sources for primary PM, sulfur dioxide, and oxides of nitrogen. Use a gridded emissions inventory or maps of source type and density, if available. Each monitoring site in the CMZ will principally be affected by similar emission sources. Determine which populated areas coincide with or are in close proximity to areas of high source density and which are in areas of low source density. When evaluating community exposures to emissions, consider populations at work and leisure activities, as well as at home. Population density is important both for determining exposure and for estimating emissions from vehicles, cooking, woodburning, etc. Modify initial CMZ boundaries identified when defining MPAs to better represent exposure to nearby source emissions from commercial, residential, industrial, and agricultural emissions.

2. **Identify Meteorological Patterns:** Plot wind directions and speeds, vertical temperature structure, and frequencies of fogs by season. Determine how these vary within and around the initial MPA and CMZs. Extend the dimensions of CMZs that include large source emissions in the downwind direction, using terrain as a guide for potential channeling.

3. **Compare PM concentrations:** Determine the spatial homogeneity of average and maximum concentrations from previous measurements or model calculations within the potential CMZ for annual, seasonal, and maximum PM concentrations. Use measurements of $PM_{2.5}$ or visibility if available; if not, use PM_{10} or other air pollutant measurements. Combine potential CMZs where these concentrations are similar. When existing $PM_{2.5}$ measurements are available, the CMZ should be chosen such that the average concentrations at individual sites does not exceed the spatial average by more than ±20 percent on a year-by-year basis. Lastly, the CMZ is defined such that each site is generally well correlated with other sites in the CMZ on a day-to-day basis ($r>0.6$).

4. **Adjust CMZs to jurisdictional boundaries:** Where air quality management jurisdictional boundaries are within a natural CMZ, divide the CMZ along these lines so that a separate CMZ resides within each jurisdiction.

5. **Locate Sites:** Where existing sites are within each CMZ, give them first priority of $PM_{2.5}$ monitoring when they meet the siting criteria in Section 5. Where CMZs do not contain existing sites, apply the criteria of Section 5 to select new sites.

4.1 Locate Emissions Sources

As noted in Section 3, Jefferson County is highly industrialized in the Opossum Valley, but contains less industry in the other, adjacent valleys. Several different types of heavy industries are located in various clusters in the Opossum Valley, so two potential CMZs might be defined for each end of the MPA in Figure 3.3.2. The commercial central city also indicates another source area, but it is so close to the Opossum Valley that emissions are very likely to mix over the low ridges separating them. A third CMZ might be considered for the downtown area.

In contrast, California's San Joaquin Valley has little heavy industry. While crude oil combustion in Kern County to the south was associated with elevated sulfate levels in the past, this fuel source has been replaced with natural gas that brings countywide sulfur dioxide emissions down to levels comparable with those of other parts of the Valley. The initial CMZs are set equal to the MPAs illustrated in Figure 3.3.4, since each consists of mostly urban source emissions such as road dust, vehicle exhaust, residential wood burning, and oxides of nitrogen and sulfur dioxide from gasoline and diesel fuel combustion.

The AIRS-AFS database is a useful source for locating local emissions sources. A downloaded AFS database is usable with a GIS. There may be special cases where the TRIS inventory may provide species information. The local transit authority may be consulted for data on diesel fuel usage and bus routing. State Department of Transportation data on heavy truck registration (especially short haul bulk haulers) can be consulted.

4.2 Identify Meteorological Patterns

Figures 4.2.1 and 4.2.2 show examples of wind transport directions and distances for different seasons and different times of the day for National Weather Service wind data from the Birmingham, AL, and Fresno, CA, airports. The vertical axes of these plots represent distance in the north/south direction while the horizontal axes represent distances in the east/west direction. The plotted points are the distances and directions that emitted particles or precursors would travel if they were transported by the measured surface winds.

In Figure 4.2.1, the denser concentration of points in the southwest corner of the morning and nighttime plots indicates some, but not dominant, channeling through the valleys. Transport sites should definitely be located to the northeast. The afternoon plots in all seasons show a greater frequency of large transport distances and no special preference for transport direction. Wind speeds and transport distances are lowest at night during the

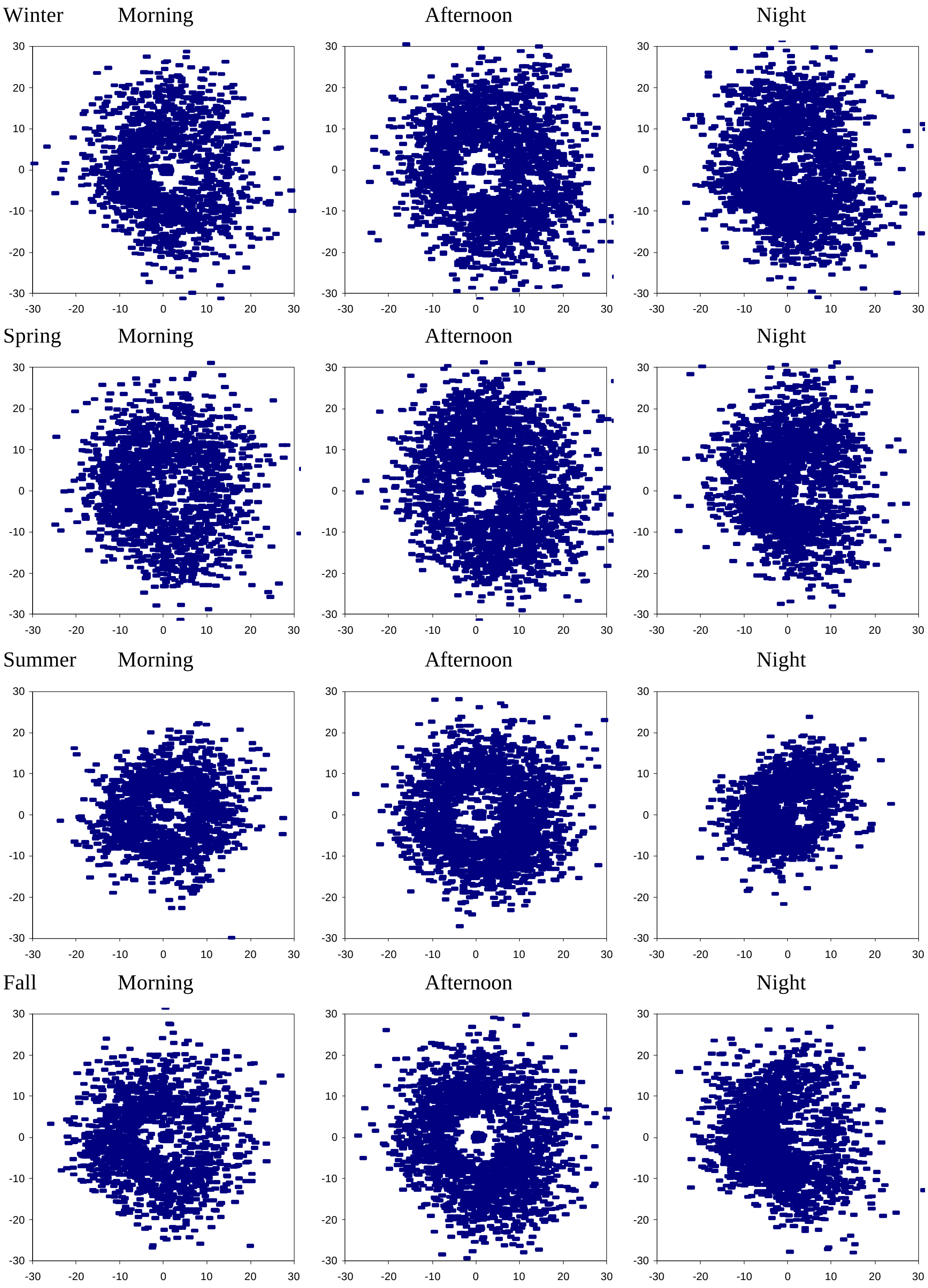


Figure 4.2.1. Hourly wind transport directions (from N) and distances (km). 1988-92 Birmingham airport winds for winter (Dec-Feb), spring (Mar-May), summer (Jun-Aug), and fall (Sep-Nov) during morning (0700-1000 CST), afternoon (1200-1600 CST), and night (2200-0500 CST).

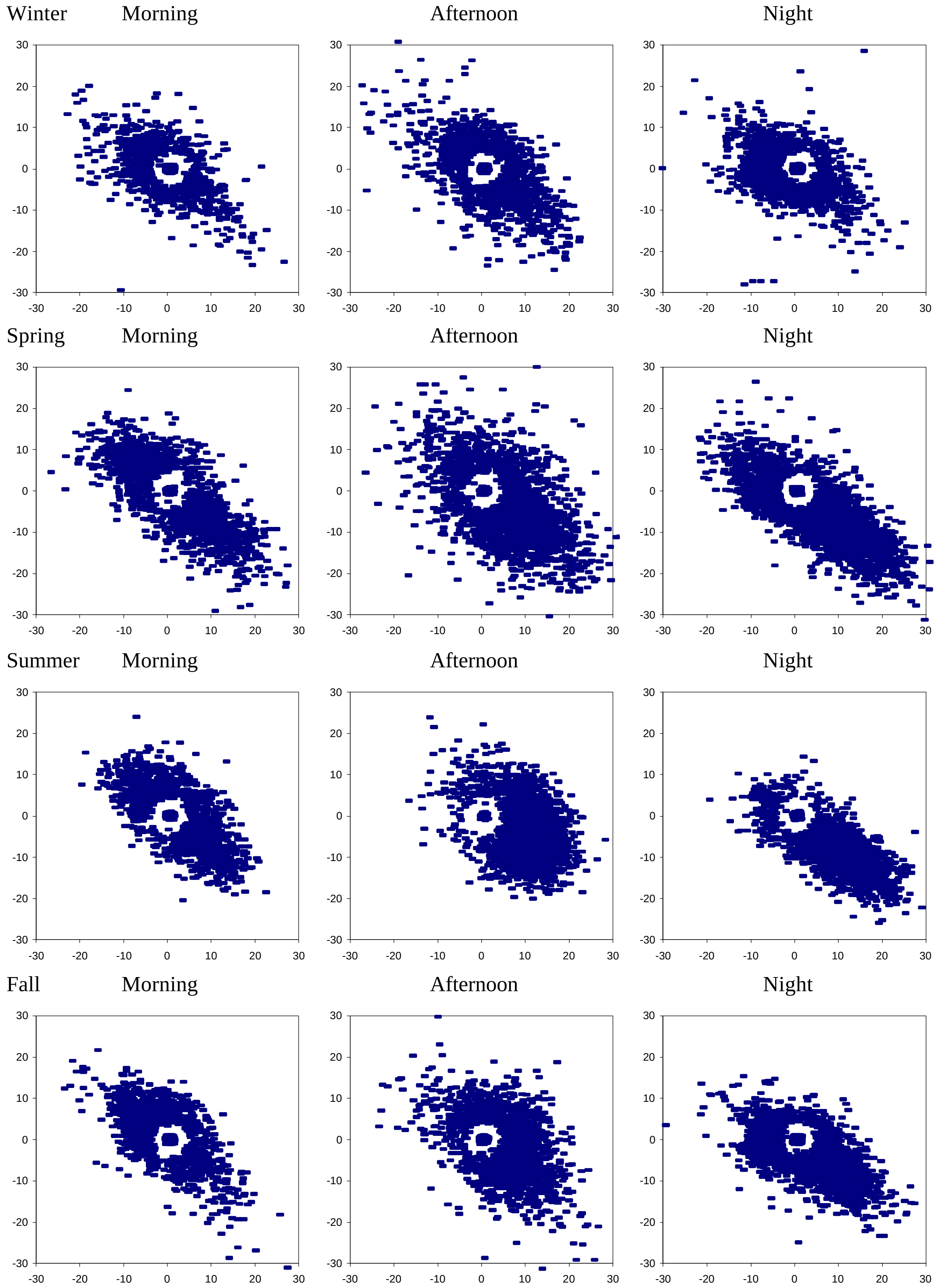


Figure 4.2.2. Hourly wind transport directions (from N) and distances (km). 1988-92 Fresno airport winds for winter (Dec-Feb), spring (Mar-May), summer (Jun-Aug), and fall (Sep-Nov) during morning (0700-1000 PST), afternoon (1200-1600 PST), and night (2200-0500 PST).

summer in Jefferson County. The implication of this brief meteorological analysis is that emissions can be transported in many directions, with a slight tendency toward the southwest. There is no reason to change the dimensions or orientations of the initial CMZs owing to transport.

Figure 4.2.2 from the San Joaquin Valley shows substantial channeling along the northwest to southeast axis of the Valley. The frequency and magnitude of transport is definitely from the northwest to the southeast, except possibly during winter when there are nearly equal densities of northwest and southeast transport.

These plots show that CMZs might be longer in the southeastern direction, downwind of source areas such as population centers, than in the northwestern direction.

Other useful displays of meteorological variables relevant to PM transport and formation are:

- **Annual and Seasonal Wind Roses:** Wind roses are compass-type plots of the frequencies of wind speeds and directions over a specified period. They are another method of representing the transport patterns shown in Figures 4.2.1 and 4.2.2. Wind roses show the dominant direction of near-surface transport. The directions often correspond to terrain-channeling in mountainous or hilly areas. These vary with season and time of day.

- **Time Series of Hourly Wind Directions and Speeds Corresponding to High Concentrations:** These plots show the magnitudes of hourly wind speeds and directions as a function of time throughout a day. Since there are many hourly wind measurements, these are only practical for selected 24-hour periods, usually those corresponding to high PM concentrations. Very low wind speeds with variable directions might correspond to a multi-day pollutant build-up in stagnant air. PM levels under these conditions are often dominated by neighborhood- and urban-scale emitters. Moderately high wind speeds that only correspond to a high PM level at one site may indicate contributions from a nearby upwind source. High wind speeds often dilute pollutant concentrations, but may engender suspension of fine particle fugitive dust. This dust may remain suspended for a long time and result in regional scale contributions.

- **Vertical Temperature Plots Corresponding to High Concentrations:** Where upper air soundings are available, temperatures as a function of height may be examined to estimate the depth of the mixed layer. During the winter, especially when snow is on the ground, intense temperature inversions may persist for several days in areas that are surrounded by elevated terrain. This allows the accumulation of urban and neighborhood scale emissions.

- **Frequencies of Fogs:** Plots of the number of hours during which fog is observed during the day, which are available from many National Weather Service summaries, indicate the potential for aqueous-phase conversion of sulfur dioxide to sulfate. Reactions in fogs are the only mechanisms by which nearby sulfur dioxide emissions can transform into significant quantities of sulfate. Much of the sulfate observed in most locations without frequent fogs results from regional-scale transport during which slower non-aqueous reactions or reactions in elevated clouds occur.

4.3 Compare PM Concentrations

Few areas possess sufficient $PM_{2.5}$ measurements to permit comparisons for the first selection of CMZs. PM_{10} measurements are often available, and where these show acceptable spatial uniformity, it is likely that the $PM_{2.5}$ would also show homogeneity if it had been measured at the same locations. When the PM_{10} measurements are non-uniform among different sites, however, it may be the case that $PM_{2.5}$ concentrations are still spatially homogeneous, owing to the substantial differences in atmospheric residence times and zones of influence of emissions sources discussed in Section 2.

Several MPAs may have undergone an air quality modeling exercise to estimate PM_{10} and possibly $PM_{2.5}$ concentrations for a year or for high PM episodes. These modeled estimates can also be used in place of or in addition to measurements to further refine CMZs. As shown in Section 2, $PM_{2.5}$ is a complex combination of chemical compounds that is difficult to accurately represent in mathematical models. Emissions rates from area and mobile sources are often inaccurate, as these often are episodic and based on unknown fuels and operating conditions. Secondary particle formation depends on many factors that are often unknown. Transport under low-wind-speed conditions, that often accompany high PM levels, is not well measured or modeled. Modeling results need to be extensively evaluated against chemical- and size-specific $PM_{2.5}$ measurements to establish confidence that they accurately represent the applicable emissions, meteorological, and transformation processes. Once the validity of the modeling results has been established, $PM_{2.5}$ concentration isopleths can be compared with the initial CMZ boundaries to further improve the homogeneity of the CMZ.

Table 4.3.1 shows several uniformity measures from the seven PM_{10} measurement sites in Jefferson County: 1) Bessemer (BESS) in the southwest corner; 2) North Birmingham (NOBI) in the Opossum Valley ~0.5 km southwest of a steel-pipe forming plant; 3) Inglenook (INGL) in the northeast portion of the county; 4) Northside School (NOSC) in downtown Birmingham; 5) Leeds Elementary School (LESC) in the eastern-most corner of the county; 6) Wyland (WYLA) just northeast of Northside School; and 7) Tarrant Elementary School which is a few kilometers northeast of the North Birmingham site, but >1 km distant from a large industrial source complex. These seven sites, for which data are listed in EPA's AIRS data base, are fewer than the number of sites listed in the AIRS site log. Several source-oriented SPMs have been operated over several years in Jefferson County, and these data should be included in this type of analysis.

Annual Averages (µg/m^3)

Year	BESS	NOBI	INGL	NOSC	LESC	WYLA	TASC
1990	33.5	47.6	34.6	40.3	30.7	38.1	37.3
1991	31.9	41.0	30.6	36.7	30.6	33.1	32.0
1992	28.4	38.6	28.5	31.2	27.7	31.4	30.1
1993	28.4	32.7	26.5	29.3	25.3	29.6	27.0
1994	24.8		24.7	27.2	23.7		25.6
1995	27.2			27.6	24.6		27.7

98th Percentile 24-Hour Averages (µg/m^3)

Year	BESS	NOBI	INGL	NOSC	LESC	WYLA	TASC
1990	62	111	72	77	61	85	76
1991	79	100	75	80	70	78	76
1992	52	91	52	66	52	70	55
1993	58	81	62	69	61	64	58
1994	50		47	58	48		50
1995	56			52	50		57

Spatial Average Statistics (µg/m^3)

Year	Spatial Average	Spatial Std	Spatial COV	Max Average	Min Average	Average +20%	Average –20%	Average +10%	Average –10%
1990	37.4	5.1	13.6	47.6	30.7	44.9	30.0	41.2	33.7
1991	33.7	3.5	10.5	41.0	30.6	40.4	26.9	37.0	30.3
1992	30.9	3.4	11.1	38.6	27.7	37.0	24.7	33.9	27.8
1993	28.4	2.2	7.9	32.7	25.3	34.1	22.7	31.2	25.6
1994	25.2	1.2	4.7	27.2	23.7	30.2	20.2	27.7	22.7
1995	26.8	1.2	4.7	27.7	24.6	32.1	21.4	29.4	24.1

Intersite PM_{10} Correlation Coefficients (1990-1993, n=226)

	BESS	NOBI	INGL	NOSC	LESC	WYLA	TASC
BESS	1.000						
NOBI	0.848	1.000					
INGL	0.872	0.786	1.000				
NOSC	0.916	0.909	0.855	1.000			
LESC	0.873	0.809	0.885	0.856	1.000		
WYLA	0.811	0.879	0.822	0.834	0.846	1.000	
TASC	0.844	0.794	0.933	0.837	0.833	0.799	1.000

Table 4.3.1. Uniformity measures for PM_{10} in Birmingham.

The first two sub-sections of Table 4.3.1 show the annual arithmetic averages and 98th percentile (second highest 24-hour maximum with sixth-day sampling) for these sites. Note that the North Birmingham, Inglenook, and Wyland sites have no data after 1993. The North Birmingham hivol size-selective inlet (SSI) monitor was replaced by a continuous TEOM monitor that acquires hourly PM_{10} concentrations daily, but this appears under a different AIRS code and was not extracted with this data set. There are known differences between TEOM and SSI PM monitors in areas with volatizable aerosol (Chow, 1995). Sudden changes in year-to-year concentrations might be due to changes in measurement method rather than as a result of emissions reductions. Only data from the same type of PM_{10} samplers should be used in the analysis of prior data to select CMZs.

There are also changes in past data owing to emissions reductions. The Jefferson County data in Table 4.3.1 clearly shows the effects of stringent regulations on industrial emissions since 1990. The NOBI source-oriented site PM_{10} concentrations were very different from the annual average and 98th percentile concentrations at other sites during 1990, but by 1993 they were much more similar to those at the other sites. In 1994, the INGL site in the northeast corner of Jefferson County, and the LESC site in eastern Jefferson County had similar average and 98th percentile PM_{10} levels. In 1995, the BESS, NOSC, and TASC stations near the center of the MPA show almost identical annual averages, and 98th percentile PM_{10} concentrations that differ by no more than 6 $\mu g/m^3$. The LESC site shows ~3 $\mu g/m^3$ lower annual PM_{10} average, and a separate CMZ could be defined around this site. Alternatively, the MPA might be defined to be smaller than that represented in Section 3 for the Birmingham MSA, and the LESC site might be considered as a background or transport site.

The third segment of Table 4.3.1 shows how spatial averages of annual averages at the different Jefferson County sites vary from year to year. Notice that the spatial standard deviation decreased from 5.1 $\mu g/m^3$ in 1990 to 1.2 $\mu g/m^3$ in 1994. This resulted from the decrease in concentrations at the NOBI source-oriented site, and its elimination after 1993. Even in 1993, however, the spatial coefficient of variation (COV) was less than 10% when the NOBI site was included in the average.

The final panel of Table 4.3.1 shows the spatial correlation coefficients among the different sites for the 1990 through 1993 periods when data were available from each one. Each of these exceeds 0.8, with the exception of the NOBI site. This shows that the information content of the different monitoring locations is similar, and that some PM_{10} sites can be sacrificed in favor of collocated $PM_{2.5}$ sites at most of the Jefferson County sites.

Other analyses of historical PM_{10} and $PM_{2.5}$ that provide a basis for selecting CMZs, and also serve as a justification for de-commissioning PM_{10} sites in favor of $PM_{2.5}$ sites are:

- **Spatial Plots of Maximum, Annual and Seasonal Average PM:** These consist of pies or bars with areas or heights corresponding to PM concentration on a map. They can be displayed on the maps of source emissions in conjunction with the meteorological plots to gain a better understanding of source Zones of Influence and receptor Zones of Representation.

- **Time Series Plots of PM Mass and Selected Chemical Concentrations:** These consist of single or stacked bars of concentrations for each day. The chemical concentrations provide an indication of the types of regional, urban, or local sources that might be contributing.

- **Pollution Roses for Hourly PM Concentrations:** Pollution roses show the average concentration associated with a specific wind direction. These are only practical and useful when hourly data are available from an hourly PM monitor. Bias toward a specific direction may indicate an overwhelming influence from a nearby source. The sampling site may be judged as unrepresentative of the CMZ.

The CMZ boundaries are adjusted to include locations that show PM_{10} concentrations varying together. Sampling sites that show substantial deviations from other sites in the area are identified and reasons for their deviation is sought. These sites are excluded from consideration as core sites if they do not have neighborhood- or urban-scale zones of representation.

CMZ boundaries are adjusted to include contiguous groups of measurements that show a reasonable degree of spatial homogeneity, as indicated by the various homogeneity measures in the analyses above.

4.4 Adjust CMZs to Jurisdictional Boundaries

Just as the MPAs give preference to existing jurisdictional boundaries, the CMZ definitions may also conform to these boundaries as long as they consist of defined populated entities. These may include municipal borders or planning districts. An example has already been given in Section 3. A single MPA might include portions of Jefferson and Shelby Counties with two CMZs. The Jefferson County CMZ would be monitored by the Jefferson County Health Department. The Shelby County CMZ would be monitored by the State of Alabama. On the other hand, a special monitoring study might show that measurements in Jefferson County also apply to population exposures in the more densely populated portion of Shelby County, thereby eliminating the need for an additional CMZ.

4.5 Locate Sites

There are two options for the community-oriented monitoring approach for making comparisons to the annual $PM_{2.5}$ NAAQS. The network can either be constructed in terms of using: 1) individual community-oriented core sites; or 2) taking the spatial average of two or more eligible core sites in a well defined community monitoring zone. Existing sites within a CMZ are evaluated against the PM siting criteria in Section 5. Sites that do not meet those criteria for neighborhood or urban zones of representation are eliminated as potential compliance monitoring sites for comparison to annual standards, though they may be designated as daily compliance sites or SPM sites. Core $PM_{2.5}$ sites should include: 1) a population-oriented site with the highest expected community-oriented concentrations; 2) a site with high population density with poor air quality (high population exposure); and 3) a site collocated at a PAMS site, if the MPA is a PAMS area.

MSA Population	Number of Core $PM_{2.5}$ SLAMS
200,000 to 500,000	1
500,000 to 1 million	2
1 million to 2 million	3
2 million to 4 million	4
4 million to 6 million	6
6 million to 8 million	8
> 8 million	10

Table 4.5.1. Number of required core $PM_{2.5}$ SLAMS monitors per MSA.

If a PAMS station is located in an CMZ and attains the neighborhood or urban criteria, this is selected as the first monitor in the CMZ. The preference is a PAMS site type #2 which is representative of the area of maximum ozone precursor concentrations. If there is no PAMS site within the CMZ, the existing site with the highest PM measurements or modeled concentrations that is determined to have a neighborhood or urban zone of representation in a populated area is selected.

The next site to be added is one in an area with high population and poor air quality. For these selections, existing PM_{10} NAMS sites should be given prime consideration. In addition, each state should have at least one core site for regional transport monitoring and one site for regional background monitoring. For each MSA or PMSA with a population over 1 million, a continuous fine particle analyzer (e.g., beta attenuation analyzer, nephelometer, transmissometer, or inertial microbalance TEOM) must be located at a core $PM_{2.5}$ site. With these criteria, neither the Jefferson County or San Joaquin Valley examples cited here would require continuous monitors, since neither one contains an MSA with more than 1 million inhabitants. However, continuous monitors should be considered in all areas with population greater than 200,000 to assist with public reporting of real-time data.

The selection of the known or anticipated community-oriented monitoring site with the highest concentration as the first site in the CMZ serves two purposes. First, it allows the site to be used for determination of the 24-hour and annual $PM_{2.5}$ standards. Second, it encourages the location of other sites within the CMZ boundaries to give a more representative $PM_{2.5}$ spatial average.

The number of required monitors in an MPA is a function of the MPA's population. Table 4.5.1 shows the minimum number of these core monitors for a given MSA population.

5.0 MONITOR SITING

$PM_{2.5}$ monitors are situated to meet requirements as core sites, community averaging sites, or daily compliance sites. Internal requirements are those for operating the needed instruments, while external criteria address site surroundings to achieve specific monitoring purposes.

5.1 Internal Siting Criteria

Internal criteria refer to the logistics of locating and service instruments for multi-year monitoring. These include:

- **Long-term Site Commitment:** NAMS sites are meant to measure trends as well as compliance, and a long-term commitment from the property owner for continued monitoring is required. Public buildings such as schools, fire stations, police stations, recreation halls, and hospitals often have more stability and a motive for public service than do private or commercial buildings.

- **Sufficient Operating Space:** A large, flat space, elevated at least 1 m but no more than 14 m above ground level, is needed to place monitors and monitoring probes. The space available for samplers should be at least 5 m distant and upwind (most common wind direction) from building exhausts and intakes and at least 2 m from walls, parapets, or penthouses that might influence air flow. Buildings housing large emitters, such as coal-, waste-, or oil-burning boilers, furnaces or incinerators, should be avoided.

- **Access and Security**: Access to the sampling platform should be controlled by fencing or elevation above ground level. Sampler inlets should be sufficiently distant (>10 m) from public access to preclude purposeful contamination from reaching them in sufficient quantities to bias samples. Access should be controlled by a locked door, gate, or ladder with documentation of site visitations and the purposes of those visits.

- **Safety**: Wiring, access steps, sampler spacing, and platform railings should comply with all relevant codes and workplace regulations, as well as common sense, to minimize potential for injury to personnel or equipment.

- **Power**: Power should be sufficient for the samplers to be operated on a long-term basis, as well as for special study and audit samplers to be located at a site. Where possible, a separate circuit breaker should be provided for each instrument to prevent an electrical malfunction in one monitor from shutting off power to the other monitors at the site.

- **Environmental Control:** Environments surrounding monitoring instruments should be maintained within the manufacturers specifications for proper instrument function. Most FRM filter-based samplers are designed to operate under a wide range of environmental conditions and can be located outdoors in most types of weather. Several continuous monitoring methods may require environmental shelters with temperature and humidity controls to protect their electronic sensing and data acquisition mechanisms.

These criteria may be tightened or relaxed for special purpose, transport, and background monitors. For example, battery-powered saturation monitors may be located on utility poles at various elevations to assess the zone of influence and zones of representation for sources and receptors.

5.2 External Siting Criteria

External siting criteria refer to the environs surrounding a measurement location, and these differ depending on the zone of representation intended for a specific monitoring site.

- **Exposure:** Large nearby buildings and trees extending above the height of the monitor may present barriers or deposition surfaces for PM. Certain trees may also be sources of PM in the form of detritus, pollen, or insect parts. These can be avoided by locating samplers by placing them >20 m from nearby trees, and twice the difference in elevation difference from nearby buildings or other obstacles.

- **Distance from Nearby Emitters:** The monitor should be outside the zone of influence of sources located within the designated zone of representation for the monitoring site. Neighborhood and urban zones of representation are needed for community-oriented compliance monitors. These should generally be at least 1 km from very large, visibly identifiable source areas occupied by major industries such as cement and steel production or ore processing. Regarding exhaust and road dust emissions from paved roads, Figure 5.2.1 provides guidance on the recommended monitoring distances from paved roads with different levels of average daily traffic for neighborhood- and urban-scale sites. A minimum distance of ~50 m from busy paved highways is usually outside the road's immediate zone of influence for a rooftop monitor. These siting criteria were established for PM_{10} monitoring siting (U.S. EPA, 1987), and they have proven their validity in PM_{10} network design. For larger than middle-scale monitoring, no unpaved roads with significant traffic or residential wood-burning appliances should be located within 100 m of the monitoring location. Background monitoring sites should be located >100 km from large population centers, and >100 m from roads and wood burning (burning is common, though often intermittent, in camping, forested, and agricultural areas).

- **Proximity to Other Measurements:** Other air quality and meteorological measurements can aid in the interpretation of high PM levels, and with all other considerations being equal, $PM_{2.5}$ sites should give preference to existing sites that make other measurements. For example, high local wind gusts may

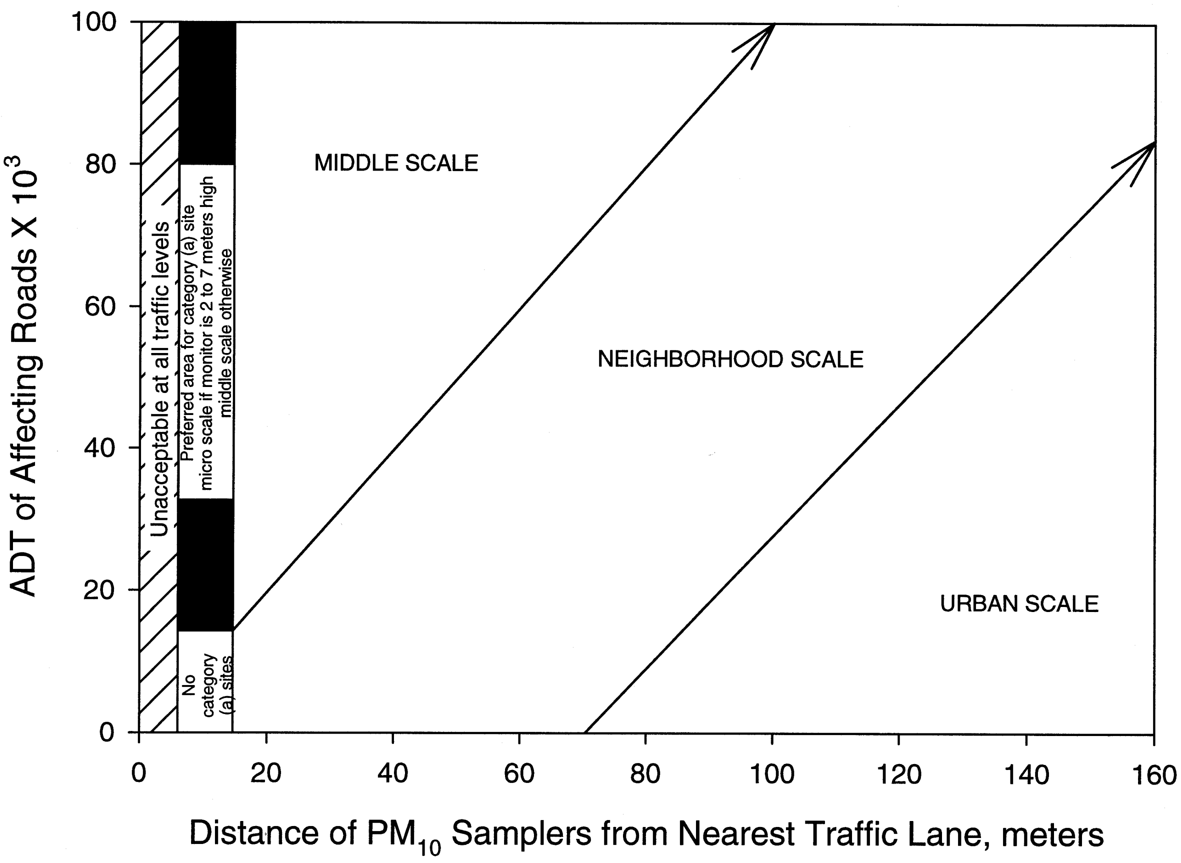


Figure 5.2.1. Recommended distances and elevations of PM sampler inlets from heavily traveled roadways.

explain high PM readings as caused by wind blown dust. These gusts are often localized, and would not be detected on a more distant monitor. Similarly, a strong correspondence between hourly CO and PM readings would indicate that locally emitted vehicle exhaust is a large contributor at that site. This conclusion would be more tenuous if the CO measurements were not collocated. In particular, collocating PM_{10} and $PM_{2.5}$ monitors will provide information on the size distribution of suspended particles.

5.3 Evaluating Zones of Representation

A site originally selected to represent community exposure (generally on a neighborhood or urban scale) may have its zone of representation change owing to long-term changes in land use or short term events that affect that particular site.

- **Annual Site Surveys:** The land use and sources around a monitoring site may change from year to year, especially in high growth areas. Maps should be updated as part of the annual measurement network summary, and the setbacks from emissions sources and obstructions should be re-evaluated to ascertain that they are still met.

- **Records of Intermittent Events**: High $PM_{2.5}$ or PM_{10} concentrations may have corresponded to a specific event, such as construction or a fire, occurring near the measurement location. Visual events should be recorded as part of the measurement network maintenance, and these should be summarized at the end of each year for inclusion in the annual network evaluation report.

- **Saturation Monitoring Studies:** To evaluate the zone of representation of sites, many monitors may be located at different distances around and between monitors in a CMZ. Spatial uniformity measures can be determined for these temporary locations and compared to those from the sites within the CMZ to evaluate how well the long-term sites represent population exposures to PM.

5.4 Evaluating Siting Redundancy

The spatial uniformity measures specified in Section 4 to can be applied to $PM_{2.5}$ concentrations at the sites within a CMZ to determine the extent to which each one supplies additional information concerning exposure. When information content is redundant, recommendations can be justified for the transfer of sites within a CMZ to other parts of the CMZ or to other CMZs.

5.5 Evaluating Network Adequacy for Spatial Averaging

Appendix D of 40 CFR 58 lays out several specific requirements for $PM_{2.5}$ monitoring sites to be eligible for spatial averaging: (1) they each represent a neighborhood or larger spatial measurement scale and (2) their community monitoring zone represents homogeneous air quality. To satisfy the latter, the sites' annual averages must be within ±20% of the CMZ-wide average on an annual basis, be influenced by similar sources and be reasonably correlated on a daily basis ($r > 0.6$). This assessment can be made in a preliminary manner with one year of data, but will require three years of $PM_{2.5}$ air quality data before final evaluation of site eligibility and comparisons to the NAAQS can be made.

EPA recommends that the State follow additional design criteria to ensure that the air quality in a community monitoring zone is spatially homogeneous. This should include an evaluation of several factors including the year-to-year variability of each individual site, the effect of changing emissions over time, the relative distribution of concentrations among the sites, the spatial patterns within the CMZ, similarities and differences in speciated $PM_{2.5}$, and the relationship between population density and air quality patterns.

5.5.1 Temporal Behavior

The evaluation of ±20% year-to-year variability should support spatially homogeneous air quality during 3-year period.

One location should not be consistently and substantially higher (e.g., 30% higher) than all the other sites. The variation among annual means should reflect sampling and meteorological variation and should not characterize consistent differences in air quality within the community monitoring zone. The left hand graph in Figure 5.5.1 supports homogeneity while the right hand diagram does not. Accordingly, it may not be sufficient that individual means be ±20%.

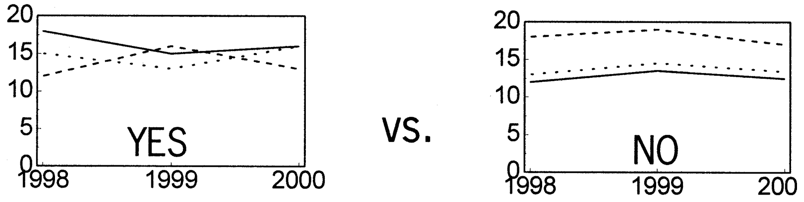


Figure 5.5.1. Example of spatial homogeneity over a three-year period.

5.5.2 Consistent trends

The variation among the eligible core monitors should be stable over time. Changes in emissions can differently affect individual monitoring locations. This can cause site eligibility to change over time. Although the sites can be within ±20 % during the first year, they can be ±30% or more after changes in emissions have occurred. This is depicted in Figure 5.5.2. Therefore the initial set of annual means should be well within ±20 % (e.g. 10-15%) to allow for potential changes over time.

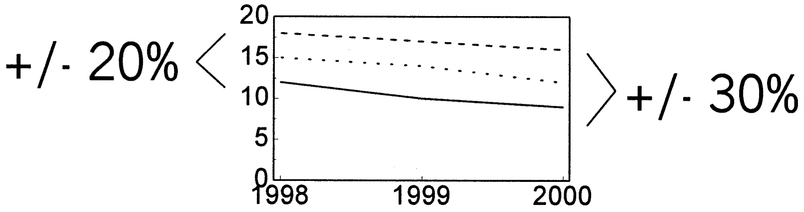


Figure 5.5.2. Example of temporal trends.

5.5.3 Spatial Placement of Monitors

The core monitoring sites should adequately reflect area-wide average air quality. With the help from modeling or spatial interpolation, the site average can be compared to other estimates of the area-wide average. An example of this is shown in Figure 5.5.3. If there are significant discrepancies between the different area-wide estimates, the placement of the monitors within the zone can be questioned.

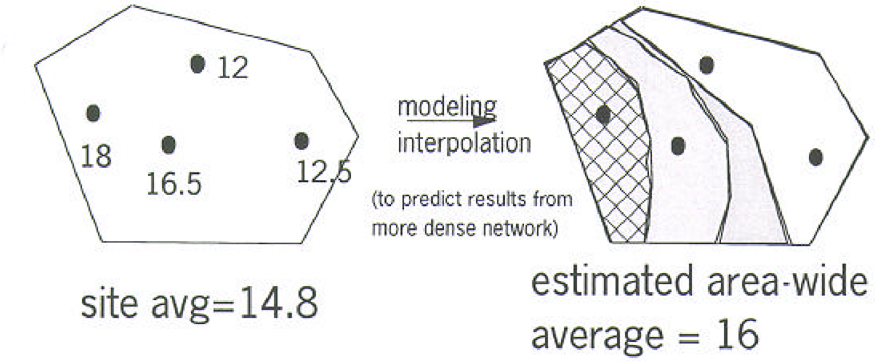


Figure 5.5.3. Example of spatial averaging.

5.5.4 Chemical Composition of $PM_{2.5}$

To satisfy the requirement that the sites are influenced by similar sources, the aerosol for all eligible sites in the CMZ should have similar chemical composition on an annual basis. Moreover, for more sensitive evaluation, this should also be true on seasonal basis. Although chemical analysis to determine eligibility for spatial averaging is not required, the use of chemical speciation data, when available, can provide important insights into the relative differences among monitoring sites. Appropriate chemical species can be used (e.g., carbon, metals) for making this assessment.

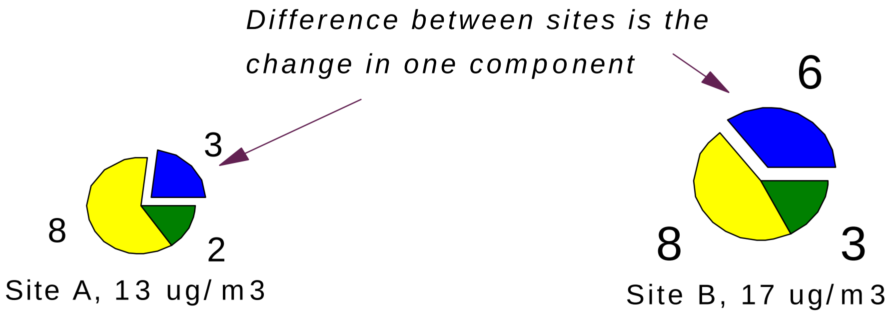


Figure 5.5.4. Example of differences in chemical composition between two sites.

5.5.5 Population Density and Air Quality Patterns (additional supporting evidence)

To further justify the placement of monitoring sites within the community monitoring zones, the estimated air quality pattern and population density should support the placement of core monitors. This is illustrated in the following figure which presents a case where average air quality is or is not representative of potential population exposure.

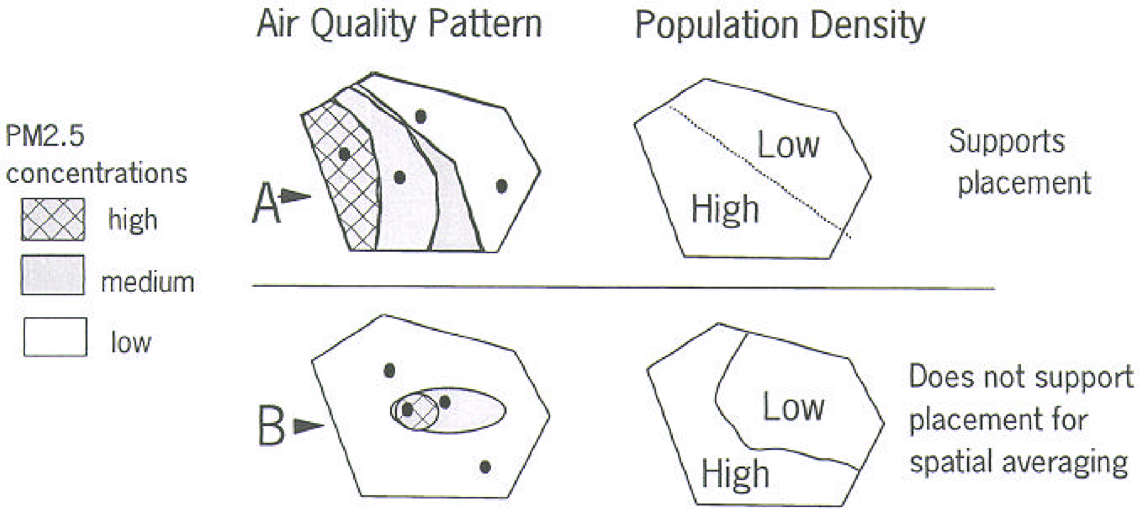


Figure 5.5.5. Example of using population density for monitor placement.

6.0 STATE PM MONITORING NETWORK DESCRIPTIONS, ANNUAL REPORTS, AND NETWORK EVALUATIONS

As implied by this guidance, monitoring network configurations are likely to change from year to year. NAMS sites will remain fixed to the extent allowed by such considerations as leasing arrangements, urban renewal projects, and loss of monitoring locations due to other construction, fires, or natural disasters. NAMS will include some of the current NAMS network for PM_{10} and the current PAMS network for ozone to maintain continuity with long-term data sets acquired at these sites. PAMS with $PM_{2.5}$ monitors will be a subset of the core SLAMS as well as selected regional transport sites.

Non-NAMS SLAMS sites may change their locations from year to year, however, if they are shown to provide the same information for determining attainment as NAMS sites. SPMs will surely change location from year to year, and may even be discontinued without major review once they have provided the data for their intended purposes. This section outlines the elements of state network descriptions, annual reports, and network evaluations that will document and justify changes in the monitoring network.

6.1 State PM Monitoring Network Descriptions

The State PM Monitoring Network Description should describe the PM monitoring strategy based on the use of SLAMS (including NAMS and PAMS) and SPMs for PM_{10} and $PM_{2.5}$. The phase-in of $PM_{2.5}$ monitors and changes in the existing PM_{10} and TSP network should be specified and justified. These descriptions should document the application of this guidance to the selection of MPAs within each state, the definition of MPA and CMZ boundaries, and transport and background sites within each state. Specific definitions for CMZs are only needed for spatial averaging, otherwise more general descriptions of community monitoring areas are appropriate. The description should be a single summary report that documents monitoring for the entire state, with a separate appendix for each of the designated MPAs. The network description should consist of the following sections.

1. **Introduction**: Describe the state's physical setting, major metropolitan areas, economic activity and industry. Show those MSAs within the state having populations levels requiring MPAs. Identify other areas with lower populations that the state chooses to define as MPAs and specify the reasons for these additional MPAs.

2. **Monitoring Planning Areas**: Show the MPAs that have been defined for the state and summarize the justification for these MPAs, based on the steps in Section 3. USGS (1:125000) maps and census data are available in electronic formats (see Appendix A).

3. **Community Monitoring Approach**: Indicate the extent to which spatial averaging is intended and provide maps showing boundaries for the CMZs. These maps need not be as detailed as those shown in the appendices to justify the CMZs.

4. **Transport and Background Areas**: Show the areas where transport between or upwind of MPAs is expected to occur and explain why that transport is expected. Locate monitors distant from source areas and explain why these should represent background levels within the state or selected portions of the state.

5. **Schedule and Responsibilities for Network Change:** Show the planned start-up date for each new $PM_{2.5}$ monitoring site, with its MPA and CMZ (where appropriate) designation, its type (community-exposure, daily compliance, SPM, transport, or background), its anticipated monitoring methods (e.g., FRM, Class I, II, and/or III equivalent or other non-reference/equivalent methods), and its measurement frequency. Show which PM_{10} monitoring sites will be modified by discontinuation or reduction in measurement frequency. Network changes are to be phased in between 1998 and 1999 for $PM_{2.5}$ and between 1998 and 2000 for PM_{10}.

A separate appendix for each MPA should present the following detailed information:

1. **Introduction**: Describe the physical setting of the MPA, population characteristics, climate and weather, dominant economic activities, and emissions sources. Much of this information can be concisely and efficiently summarized on maps such as USGS (1:50000 or 1:2400), aerial photographic, or commercial maps available on CD-ROM (Appendix A identifies several options).

2. **Community Monitoring Areas or Zones:** Show maps of the selected community monitoring areas or community monitoring zones, if appropriate, and justify them based on the procedures in Section 4. Document modeling and data analysis activities that were conducted to determine these zones. These maps should include, where available and appropriate: 1) populated entity boundaries (e.g. census tracts or blocks), 2) relevant jurisdictional boundaries; 3) commercial, residential, agricultural, and industrial land uses; 4) suspected area source emissions hot spots (e.g. wood burning communities, diesel emissions hot spots identified from bus transfer locations, railyards, marine terminals, waste recycling, land preparation, unpaved roads, etc.). Include tables of spatial uniformity measures (spatial averages, spatial coefficients of variation, 98th percentile concentrations, and spatial correlations) using existing data to determine the zone of representation of existing monitors. Use wind roses and trajectories to identify potential transport pathways and terrain maps to identify potential barriers to transport.

3. **Sampling Site Descriptions**: Provide site descriptions, including maps showing surrounding sources as well as verbal descriptions of activities surrounding the site. Define the variables measured at each site in terms of observables measured (e.g., PM_{10} mass, $PM_{2.5}$ mass, chemical composition), sample duration, frequency, and measurement method.

4. **Sites Intended for Comparison with NAAQS**: Specify those sites that acquire measurements to be compared with the NAAQS, with their designation as community-oriented, daily compliance, or other sites. Identify sampling methods that acquire compliance data at these sites.

5. **Special Purpose Monitoring Projects**: Where there is doubt concerning the validity of the CMZs, the zone of representation of a sampling site, or the influence on PM from different sources, define special purpose monitoring projects to resolve these concerns.

6. **Phase-In and Responsibilities:** Estimate costs of hardware, operation, and maintenance for the number of stations and measurement frequencies required, and reconcile these costs with current resources. Justify trade-offs between additions of $PM_{2.5}$ monitors at the expense of PM_{10} monitors. Specify responsibilities of local and state monitoring authorities, and determine a schedule for changes.

6.2 Annual Measurement Reports

The annual measurement report should include the following information for each MPA:

1. **Annual Site Data Summaries**: Include tables of PM_{10} and $PM_{2.5}$ annual averages, maximum concentrations, and 98th and 99th percentile concentrations for each monitoring site for each year. For most situations these data can be obtained from EPA's AIRS database. This will include data from non-compliance monitors, including SPMs, as well as for compliance monitors.

2. **Spatial Averages:** When spatial averaging is utilized, include tables of spatially averaged annual-average $PM_{2.5}$ concentrations for each CMZ for each year. Identify sites with annual averages differing by more than ±20% from the spatial average, and remove them from the average.

3. **Compliance Statistics:** Include three-year-average annual averages for each core site (and when appropriate for each CMZ) and three-year-average 98th and 99th percentile averages for each eligible site.

4. **Compliance Determination**: Compare the compliance statistics with standards, and discuss the compliance or non-compliance of each site and/or CMZ in the MPA. Compare measurements at background and transport sites with those at core sites to estimate the extent to which urban-scale (within the MPA) or regional-scale (within and outside of the MPA) sources contribute to the excess concentrations. Discuss the comparison of concentrations at background and transport sites with the core sites.

6.3 Annual Network Evaluation

The annual network evaluation should include the following information for each MPA:

1. **Changes in Site Characteristics:** Document changes in site exposure owing to construction or demolition of nearby buildings or the growth of foliage, the presence of temporary (e.g., building construction, road repair) or permanent (e.g., an industrial facility or a new highway) emitters within 1 km of the site, or special events (e.g., accidental fires, major wind storms). Record the magnitude, location, and duration of these changes. Examine PM measurements in conjunction with these changes to evaluate the continued population-orientation of the site.

2. **Concentration Uniformity Measures:** Evaluate spatial time-series plots, spatial correlation coefficients, differences between site-specific averages and 98th percentile values, and spatial coefficients of variation within and between CMZs within an MPA. These measures are especially important for evaluating the spatial average used to determine compliance with the annual $PM_{2.5}$ standard. The annual average at each site within a CMZ should not differ by more than ±20% from the CMZ average. If one or more of these site-specific averages exceeds this tolerance, it may be necessary to re-define the CMZs to better represent community exposure, or to re-evaluate the site exposure. On the other hand, high correlations among measurements, low spatial coefficients of variation, and annual averages and 98th and 99th percentiles that do not differ by more than ±5% within a CMZ indicate that some stations are redundant. Justification can be made for moving one or more of the non-NAMS trend stations to another location where it might better represent population exposure. Similar results for measurements in different CMZs within the MPA indicate that the adjacent CMZs with similar concentrations might be combined into a larger CMZ, with a consequent reduction in the number of monitors needed to represent the spatial average.

3. **Monitoring Site Additions and Deletions**: When sites are determined to no longer represent population exposure, or when spatial uniformity measures show that they provide consistently redundant information, recommendations and justifications for deletion may be submitted to the EPA regional office for approval. When spatial uniformity measures show high variability within a CMZ, when a populated area expands beyond its original boundaries, or when special monitoring sites are deemed necessary, measurement locations may need to be added. These, too, should be justified. The intent of this annual evaluation is to continually re-define the network, within available monitoring resource constraints, to best represent population exposures. This section of the evaluation allows substantial flexibility for networks to evolve to attain this end.

4. **Changes to CMZ and MPA Boundaries and Site Designations**: SLAMS with $PM_{2.5}$ standard exceedances should be considered for re-designation as core sites. SPM sites showing NAAQS violations should be considered for designation as

SLAMS sites. Changes in population or emissions may require changes in MPA or CMZ boundaries, including the creation of additional MPAs or CMZs. The evaluation of spatial uniformity measures may also justify recommendations for changes in MPA or CMZ boundaries. In particular, the 2000 census will provide more current information on population distributions, and when these data become available in 2001 or 2002, the MPA and CMZ boundaries will need to be re-assessed. Locally generated land-use patterns in rapidly growing areas can also be used to determine the extent to which the boundaries of planning areas and averaging zones should be expanded.

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APPENDIX A

Sources of Data Used for Network Design and Evaluation

Appendix A (continued)
Sources of Data Used for Network Design and Evaluation

Database	Description	Access	Format(s)	Relevant Data Fields	Reference or Internet Address
U.S. Geological Service Digital Elevation Model database	This site contains 1 minute or 1:250,000-scale Digital Elevation Models of the US arranged by USGS quadrants.	WWW and ftp	USGS DEM format (ASCII)	Digital elevation data are read into ARC/INFO, ArcView, other GIS packages as data layers. They are also used in dispersion models.	http://edcftp.cr.usgs.gov:80/pub/data/DEM/250/
U.S. Geological Service North American Digital Elevation Models	30 arc second (approximately 1 km resolution) DCW Digital Elevation Models of North America are provided here. These maps are supplied in four equal pieces over the US.	WWW and ftp	compressed BIL (band interleaved by line) format that can be read into GIS software	Digital elevation data are read into ARC/INFO, ArcView, other GIS packages as data layers. They are also used in dispersion models.	http://edcwww.cr.usgs.gov/landdaac/gtopo30/gtopo30.html
U.S. Geological Survey Topographic, Image and Related Maps	The USGS offers standard topographic quadrangle maps. Scales are 7.5 minute (1:24,000, 1:25,000 and 1:20,000), 7.5x15 minute (1:25,000) and 15 minute (1:50,000 and 1:63,360). County maps are available in 1:50,000 and 1:100,000.	These maps can be obtained at local map dealers as well as from the USGS	paper maps	Topographic maps may be useful in defining MPAs, CMZs and general mapping at the microscale to urban scale.	Other maps are available from the USGS at http://mapping.usgs.gov/esic/mapprice.html. Commercial dealers may be located on the web at http://mapping.usgs.gov/esic/usimage/dealers.html or the local phone book. Maps may be ordered from the USGS directly by calling (800) USA-MAPS or by mail at: USGS Information Services, Box 25286, Denver, CO 80225.
The USGS Geographic Names Information System (GNIS)	The GNIS contains name and location information for approximately 2 million physical and cultural features located throughout the U.S. and it's territories.	FTP	Formatted ASCII text file	This database provides location (latitude and longitude) for populated entities as well as geographic features.	http://mapping.usgs.gov/www/gnis/gnisftp.html
Johns Hopkins Univ/Applied Physics Laboratory Digital Elevation Model images	This site provides excellent 5 x 5 degree color shaded relief maps of the lower 48 states.	WWW	Digital GIF format	These images can be easily printed out or imported into ArcView as a terrain layer.	http://fermi.jhuapl.edu/states/states.html
U.S. EPA Forest Land Distribution Data of the United States	Full U.S. forest GIS coverages and GIF images are available for forest type and forest density	WWW	Digital GIF, ARC/INFO grid formats	This data set may be useful in defining natural air basins by showing forest cover & tree type coverages as land-use.	http://www.epa.gov/docs/grd/forest_inventory/
U.S. Bureau of the Census TIGER Mapping Service	In this web site one can create maps on-line using several of the attributes in the TIGER/Line database such as MSA, census tracts, citiesm streets, etc.	WWW	Digital GIF format	This web site produces quick turn-around, user-defined US maps zoomed in on any region of the U.S.	http://tiger.census.gov/
U.S. Bureau of Census U.S. Gazetteer	This gazetteer is used to identify places to view with the Tiger Map Server and obtain census data from the 1990 Census Lookup server. You can search for places, counties or MCDs by entering the name and state abbreviation (optional), or 5-digit zip code.	WWW	Census data is provided in HTML, tab delimited or CODATA formats. The map images are in the digital GIF format.	This web site allows custom map creation which can be used to identify planning areas and population. Census tracts, MSA, PMSA are options in the map making process.	http://www.census.gov/cgi-bin/gazetteer
Temporal Urban Mapping at USGS	This site includes several digital satellite and geographic images of the SF Bay area (data limited to Bay area & Baltimore/Washington area)	WWW	Digital GIF format	population growth maps, satellite orthophoto images and Lansat of San Francisco	http://edcwww2.cr.usgs.gov/umap/umap.html
USGS Geologic Information	This site mainly contains digital geologic maps for the central and western US, national geologic map database but has some useful base maps.	WWW	MapInfo, ARC/INFO format	geologic GIS and US base maps	http://geology.usgs.gov/maps.html

Appendix A (continued)
Sources of Data Used for Network Design and Evaluation

Bay Area Digital Geo Reource (BADGER)	The Bay Area Shared Information Consortium makes available maps, images and data on the San Francisco Bay area.	WWW	Several digital formats including GIF satellite images	10 meter satellite imagery over SF Bay area	http://www.svi.org/badger.html
National Park Service boundary database	National Park Service boundaries and regions are distributed in ARC/INFO GIS export format at this site. An ARC/INFO coverage of U.S. States is also available at this site.	WWW	ARC/INFO export format	park boundaries in GIS	ftp://ftp.its.nps.gov/pub/park_boundaries/
US TIGER/Line databases	These disks contain a multitude of geographic information such as state,county,census block , census tract, etc. boundary databases.	CD-ROM	ASCII (in TIGER/Line database format)	US boundary databases which includes some land-use information	Customer Services, Bureau of Census, 301-457-4100
U.S. Census Summary Tape Files (STF)	These disks contain US population & socioeconomic data taken during the 1990 census	CD-ROM	ASCII	US population databases	Customer Services, Bureau of Census, 301-457-4100
U.S. Census metropolitan area population estimates	1990 to 1995 MSA/PMSA/CMSA/NECMA population estimates by the U.S. Bureau of Census	WWW	ASCII text files that are easily importable into spreadsheet programs	US MSA, CMSA, PMSA, NECMA population estimates	http://www.census.gov/population/www/estimates/metropop.html
Landview II software	Landview is a display software for TIGER/Line, STF data. Currently a DOS application with limited exportability.	CD-ROM	Reads ASCII TIGER and census data	DOS based text and graphical display and provides quick hard copies	Customer Services, Bureau of Census, 301-457-4100
Voyager and Voyager Viewer mapping software	Voyager is a multidimensional data browser for browsing Voyager data files.	WWW	Reads Voyager data files.	This software package is useful as a visualization tool for temporal and spatial air quality databases.	http://capita.wustl.edu/CAPITA/utilities/utilities.html
ESRI ARC/INFO and ArcView GIS software	ArcView is a commercially available desktop GIS software for PC, Mac and UNIX systems. ARC/INFO is also a commercial GIS package with extensive spatal analysis tools for network design.	Through ESRI	CD-ROM	These software tools can be used to simply display cartographic data or provide spatial data analysis of the data sets in this appendix.	The software is available from Envrionmental Systems Research Institute, Inc. (ESRI). They may be contacted by e-mail at info@esri.com or on the WWW at http://www.esri.com or (800) 447-9778.
Western Regional Climate Center	This climate center serves CA, NV, OR, WA, ID, MT, UT, AZ, NM; meteorological data	WWW	various formats	climate data	http://wrcc.sage.dri.edu
High Plains Climate Center	This climate center serves ND, SD, NE, KS, CO, WY data; meteorological data	WWW	various formats	climate data	http://hpccsun.unl.edu
Midwestern Climate Center	This climate center serves MN, IA, MO, WI, IL, IN, KY, MI, OH; meteorological data	WWW	various formats	climate data	http://mcc.wsw.uiuc.edu
Northeast Regional Climate Center	This climate center serves ME, NH, VT, NY, MA, RI, CT, PA, NJ, DE, MD, WV; meteorological data	WWW	various formats	climate data	http://met-www.cit.cornell.edu/
Southern Regional Climate Center	This climate center serves LA, TX, OK, AR, MS, TN; meteorological data	WWW	various formats	climate data	http://www.srcc.lsu.edu/srcc.html
Southeastern Climate Center	This climate center serves SC, NC, VA, AL, FL, GA, Puerto Rico, Virgin Islands; meteorological	WWW	various formats	climate data	http://water.dnr.state.sc.us/climate/sercc
National Climatic Data Center	The NCDC provides a wealth of climate data, publications, databases, images related to climate in the US and world-wide. Some data is available on-line.	WWW and ftp	various formats	climate data world-wide but mainly for the United States	http://www.ncdc.noaa.gov/
IMPROVE network data	Data is available for the IMPROVE network (visibility in National Parks & wilderness areas).	listserve via e-mail to subscribe	ASCII text files	aerosol and visibility data	LISTSERVE@caesar.ucdavis.edu; "SUBSCRIBE IMPROVE-DATA-USERS"
U.S. EPA SCRAM Meteorological Data	Airport Surface & Upper Air Meteorological data for slected US airports	internet (web, telnet, ftp), phone dial-up	ASCII text files	surface meteorology and mixing height	http://www.epa.gov/scram001/t25.htm

Appendix A (continued)
Sources of Data Used for Network Design and Evaluation

U.S. EPA Aerometric Information Retrieval System (AIRS)	Aerometric Information Retrieval System -- primary data source for air quality and meteorological data from the EPA	phone dial-up	ASCII reports	air quality and emissions data such as TSP, PM_{10}, $PM_{2.5}$,O_3, NO, CO data	http://www.epa.gov/docs/airs/airs.html or US EPA OAQPS at (919) 541-5454
U.S. EPA Region 3 GIS data	The region 3 web site gives access to the EPA Region III Land Cover Data Set and GIS coverages of watersheds, forests, ecoregions, TRI sites, CERCLIS, hydrology, roads, railroads, NPL and USGS DEM.	WWW	GIS coverages are in ARC/INFO export format with GIF preview images. The land cover data set an ERDAS image readable in ARC/INFO.	The data provided at this web site may be useful in determining state planning areas and CMZs by showing land use and possible biogenic emission sources.	http://www.epa.gov/reg3giss/libraryp.htm
U.S. EPA Region 7 GIS data	The Quad100 GIS data library contains 1:100,000-scale base data for Region 7 and is tiled by United States Geological Survey (USGS) 1:100,000-scale (30 X 60 arc minutes) quadrangle boundaries.	WWW	This site provides ARC/INFO GIS coverages.	The data provided at this web site may be useful in determining state planning areas and CMZs by showing streams, lakes, transportation routes, wetlands and county boundaries.	http://www.epa.gov/region07/envdata/gis/q100lib.html
U.S. EPA Region 8 GIS data	This site contains Region VIII Environmental ARC/INFO GIS Data covering natural and man-made boundaries.	WWW	The data files are in Unix GZIPed Arc/Info 7.02 export format.	Country Boundaries,Census Tract Boundaries,Dams,Ecoregions,Federal Land Boundary,Hydrologic Unit Codes,Linear Hydrology (streams, rivers, etc),Polygonal Hydrology,Mines,National Pollution Discharge,Historic & Current Place Names,Railroads,Seismic Activity,State Boundary,Tribal Land,Toxic Release Inventory,Treatment,Storage & Disposal Facilities,Zip Codes	http://www.epa.gov/region08/data.html
U.S. EPA Region 9 Nonattainment Maps	This site provides O_3, CO, NO_2,PM_{10},class 1, tribal land maps in EPA's region 9	WWW	Digital GIF format	nonattainment maps	http://www.epa.gov/region09/air/maps/maps_top.html
STATSGO data (U.S. Department of Agriculture Soil Conservation Service Geographic Database)	This US soil geographic database is arranged according to state.	WWW	ARC/INFO, DLG-3	GIS soil coverages for ARC/INFO and ArcView	ftp://ftp.ftw.nrcs.usda.gov/pub/statsgo/
Oregon digital map library	This site contains Oregon 1:2,000,000 to 1:24,000 digital maps of agriculture land, cities, geology, highways, population, soils, etc.	WWW	ARC/INFO	many GIS useful coverages for land-use but only for Oregon	http://www.sscgis.state.or.us/data/data.html
U.S. GeoData DEM and DLG files from the EROS Data Center	The EROS data center offers U.S. DEM, Land Use Land Cover (LULC) and Digital Line Graph (DLG) databases in scales from 1:100,000 to 1:2,000,000.	WWW	These digital files can be imported into ARC/INFO and other GIS packages.	DEM provides elevation & boundary data for use with a GIS. The DLG provide boundary, streets and topographic data for a GIS.	http://edcwww.cr.usgs.gov/doc/edchome/ndcdb/ndcdb.html

APPENDIX B

Metropolitan Statistical Areas, Primary Metropolitan Statistical Areas, Consolidated Metropolitan Statistical Areas, and New England County Metropolitan Statistical Areas in the United States

Appendix B (continued)
Metropolitan Statistical Areas, Primary Metropolitan Statistical Areas, Consolidated Metropolitan Statistical Areas, and New England County Metropolitan Statistical Areas in the United States

State	Metropolitan Area	TYPE	Counties	1990 Population	1995 Est. Population	1995 pop density (km^{-2})	Area (km^2)
AK	Anchorage, AK	MSA	Anchorage Borough	226,338	251,335	57.2	4396.9
AL	Anniston, AL	MSA	Calhoun County	116,034	117,263	74.4	1576.0
AL	Birmingham, AL	MSA	Blount County Jefferson County St. Clair County Shelby County	840,140	881,761	106.8	8,255.0
AL	Decatur, AL	MSA	Lawrence County Morgan County	131,556	139,837	42.3	3304.0
AL	Dothan, AL	MSA	Dale County Houston County	130,964	134,368	45.4	2956.6
AL	Florence, AL	MSA	Colbert County Lauderdale County	131,327	136,184	41.6	3274.0
AL	Gadsden, AL	MSA	Etowah County	99,840	100,259	72.4	1385.2
AL	Huntsville, AL	MSA	Limestone County Madison County	293,047	317,684	89.3	3556.2
AL	Mobile, AL	MSA	Baldwin County Mobile County	476,923	517,611	70.6	7329.4
AL	Montgomery, AL	MSA	Autauga County Elmore County Montgomery County	292,517	315,332	60.6	5199.3
AL	Tuscaloosa, AL	MSA	Tuscaloosa County	150,522	158,732	46.2	3432.4
AR	Fayetteville-Springdale-Rogers, AR	MSA	Benton County Washington County	210,908	252,640	54.4	4645.3
AR	Jonesboro, AR	MSA					
AR	Little Rock-North Little Rock, AR	MSA	Faulkner County Lonoke County Pulaski County Saline County	513,117	543,568	72.2	7533.2
AR	Pine Bluff, AR	MSA	Jefferson County	85,487	84,042	36.7	2291.6
AR-OK	Fort Smith, AR-OK	MSA	Crawford County Sebastian County Sequoyah County	175,911	188,572	40.3	4676.9
AZ	Phoenix-Mesa, AZ	MSA	Maricopa County Pinal County	2,238,480	2,563,582	67.9	37746.7
AZ	Tucson, AZ	MSA	Pima County	666,880	752,428	31.6	23794.4
AZ	Yuma, AZ	MSA	Yuma County	106,895	132,869	9.3	14282.4
AZ-UT	Flagstaff, AZ-UT	MSA	Coconino County Kane County	101,760	116,498		
CA	Bakersfield, CA	MSA	Kern County	543,477	617,528	29.3	21086.7
CA	Chico-Paradise, CA	MSA	Butte County	182,120	192,880	45.4	4246.6
CA	Fresno, CA	MSA	Fresno County Madera County	755,580	844,293	40.2	20983.3
CA	Los Angeles-Long Beach, CA	PMSA	Los Angeles County	8,863,164	9,138,789	869.1	10515.3
CA	Los Angeles-Riverside-Orange County, CA	CMSA	Los Angeles County Orange County Riverside County San Bernardino County Ventura County	14,531,529	15,362,165	174.4	88080.4
CA	Orange County, CA	PMSA	Orange County	2,410,556	2,563,971	1253.6	2045.3
CA	Riverside-San Bernardino, CA	PMSA	Riverside County San Bernardino County	2,588,793	2,949,387	41.8	70629.2
CA	Ventura, CA	PMSA	Ventura County	669,016	710,018	148.5	4781.0
CA	Merced, CA	MSA	Merced County	178,403	194,407	38.9	4995.8
CA	Modesto, CA	MSA	Stanislaus County	370,522	410,870	106.1	3870.9
CA	Redding, CA	MSA	Shasta County	147,036	160,940	16.4	9804.8
CA	Sacramento, CA	PMSA	El Dorado County Placer County Sacramento County	1,340,010	1,456,955	137.8	10571.3
CA	Yolo, CA	PMSA	Yolo County	141,092	147,769	56.4	2622.2
CA	Salinas, CA	MSA	Monterey County	355,660	348,841	40.5	8603.8
CA	San Diego, CA	MSA	San Diego County	2,498,016	2,644,132	242.8	10889.6
CA	Oakland, CA	PMSA	Alameda County Contra Costa County	2,082,914	2,195,411	581.5	3775.7
CA	Sacramento-Yolo, CA	CMSA	El Dorado County Placer County Sacramento County Yolo County	1,481,220	1,604,724	121.1	13250.4
CA	San Francisco, CA	PMSA	Marin County San Francisco County	1,603,678	1,645,815	625.7	2630.4

Appendix B (continued)

Metropolitan Statistical Areas, Primary Metropolitan Statistical Areas, Consolidated Metropolitan Statistical Areas, and New England County Metropolitan Statistical Areas in the United States

State	Metropolitan Area	TYPE	Counties	1990 Population	1995 Est. Population	1995 pop density (km^{-2})	Area (km^2)
			San Mateo County				
CA	San Francisco-Oakland-San Jose, CA	CMSA	Alameda County Contra Costa County Marin County San Francisco County San Mateo County Santa Clara County Santa Cruz County Sonoma County Napa County Solano County	6,249,881	6,539,602	341.1	19173.7
CA	San Jose, CA	PMSA	Santa Clara County	1,497,577	1,565,253	468.0	3344.3
CA	Santa Cruz-Watsonville, CA	PMSA	Santa Cruz County	229,734	236,669	205.0	1154.6
CA	Santa Rosa, CA	PMSA	Sonoma County	388,222	414,569	101.6	4082.4
CA	Vallejo-Fairfield-Napa, CA	PMSA	Napa County Solano County	451,186	481,885	117.6	4097.5
CA	San Luis Obispo-Atascadero-Paso Robles, CA	MSA	San Luis Obispo County	217,162	226,071	26.4	8558.6
CA	Santa Barbara-Santa Maria-Lompoc, CA	MSA	Santa Barbara County	369,608	381,401	53.8	7092.6
CA	Stockton-Lodi, CA	MSA	San Joaquin County	480,628	523,969	144.6	3624.5
CA	Visalia-Tulare-Porterville, CA	MSA	Tulare County	311,921	346,843	27.8	12495.0
CA	Yuba City, CA	MSA	Sutter County Yuba County	122,643	136,104	42.6	3193.9
CO	Colorado Springs, CO	MSA	El Paso County	397,014	465,800	84.6	5508.1
CO	Boulder-Longmont, CO	PMSA	Boulder County	225,339	253,850	132.0	1923.0
CO	Denver, CO	PMSA	Adams County Arapahoe County Denver County Douglas County Jefferson County	1,622,980	1,831,308	188.0	9740.6
CO	Denver-Boulder-Greeley, CO	CMSA	Boulder County Adams County Arapahoe County Denver County Douglas County Jefferson County Weld County	1,980,140	2,233,172	101.6	21981.2
CO	Greeley, CO	PMSA	Weld County	131,821	148,014	14.3	10341.3
CO	Fort Collins-Loveland, CO	MSA	Larimer County	186,136	217,215	32.2	6737.7
CO	Grand Junction, CO	MSA	Mesa County	93,145	106,548		
CO	Pueblo, CO	MSA	Pueblo County	123,051	129,759	21.0	6187.0
CT	Hartford, CT	NECMA	Hartford County (pt.) Litchfield County (pt.) Middlesex County (pt.) Tolland County (pt.)	1,123,678	1,115,223	282.5	3947.1
CT	Bridgeport, CT	PMSA	Fairfield County (pt.) New Haven County (pt.)	1,631,864			3190.0
CT	Danbury, CT	PMSA	Fairfield County (pt.) Litchfield County (pt.)	1,001,737			4003.8
CT	New Haven-Bridgeport-Stamford-Waterbury-Danbury, CT	NECMA	Middlesex County (pt.) New Haven County (pt.) Fairfield County (pt.)	1,631,864	1,625,513	505.3	3216.8
CT	Stamford-Norwalk, CT	PMSA	Fairfield County (pt.)	827,645			1621.0
CT	Waterbury, CT	PMSA	Litchfield County (pt.) New Haven County (pt.)	978,311			3951.8
CT-RI	New London-Norwich, CT-RI	NECMA	New London County, CT (pt.)	254,957	250,404		
DC-MD-VA-WV	Washington, DC-MD-VA-WV	PMSA	District of Columbia Calvert County, MD Charles County, MD Frederick County, MD Montgomery County, MD Prince George's County, MD Arlington County, VA Clarke County, VA Culpeper County, VA Fairfax County, VA Fauquier County, VA King George County, VA Loudoun County, VA Prince William County, VA	4,223,485	4,509,932	267.5	16862.7

Appendix B (continued)

Metropolitan Statistical Areas, Primary Metropolitan Statistical Areas, Consolidated Metropolitan Statistical Areas, and New England County Metropolitan Statistical Areas in the United States

State	Metropolitan Area	TYPE	Counties	1990 Population	1995 Est. Population	1995 pop density (km^{-2})	Area (km^2)
			Spotsylvania County, VA Stafford County, VA Warren County, VA Berkeley County, WV Jefferson County, WV				
DC-MD-VA-WV	Washington-Baltimore, DC-MD-VA-WV	CMSA	Anne Arundel County Baltimore County Carroll County Harford County Howard County Queen Anne's County Washington County District of Columbia Calvert County Charles County Frederick County Montgomery County Prince George's County Arlington County Clarke County Culpeper County Fairfax County Fauquier County King George County Loudoun County Prince William County Spotsylvania County Stafford County Warren County Berkeley County Jefferson County	6,726,395	7,107,116	286.5	24809.5
DE	Dover, DE	MSA	Kent County	110,993	121,725	79.6	1529.8
DE-MD	Wilmington-Newark, DE-MD	PMSA	New Castle County Cecil County	513,293	546,063	272.2	2005.9
FL	Daytona Beach, FL	MSA	Flagler County Volusia County	399,413	448,904	108.9	4120.4
FL	Fort Myers-Cape Coral, FL	MSA	Lee County	335,113	375,381	180.4	2081.3
FL	Fort Pierce-Port St. Lucie, FL	MSA	Martin County St. Lucie County	251,071	283,552	97.0	2921.9
FL	Fort Walton Beach, FL	MSA	Okaloosa County	143,776	163,707	67.5	2423.7
FL	Gainesville, FL	MSA	Alachua County	181,596	196,106	86.6	2264.4
FL	Jacksonville, FL	MSA	Clay County Duval County Nassau County St. Johns County	906,727	979,045	143.4	6826.3
FL	Lakeland-Winter Haven, FL	MSA	Polk County	405,382	436,701	89.9	4856.1
FL	Melbourne-Titusville-Palm Bay, FL	MSA	Brevard County	398,978	450,646	170.8	2637.9
FL	Fort Lauderdale, FL	PMSA	Broward County	1,255,488	1,412,165	451.0	3131.0
FL	Miami, FL	PMSA	Dade County	1,937,094	2,031,336	403.4	5036.2
FL	Miami-Fort Lauderdale, FL	CMSA	Broward County Dade County	3,192,725	3,443,501		
FL	Naples, FL	MSA	Collier County	152,099	181,381	34.6	5245.9
FL	Ocala, FL	MSA	Marion County	194,833	226,678	55.4	4089.6
FL	Orlando, FL	MSA	Lake County Orange County Osceola County Seminole County	1,224,852	1,390,574	153.8	9041.6
FL	Panama City, FL	MSA	Bay County	126,994	142,690	72.1	1978.1
FL	Pensacola, FL	MSA	Escambia County Santa Rosa County	344,406	377,914	86.9	4349.8
FL	Punta Gorda, FL	MSA	Charlotte County	110,975	129,381	72.0	1796.6
FL	Sarasota-Bradenton, FL	MSA	Manatee County Sarasota County	489,483	525,806	154.6	3400.6
FL	Tallahassee, FL	MSA	Gadsden County Leon County	233,598	257,295	84.0	3063.8
FL	Tampa-St. Petersburg-Clearwater, FL	MSA	Hernando County Hillsborough County Pasco County Pinellas County	2,067,959	2,180,484	329.6	6616.1

Appendix B (continued)
Metropolitan Statistical Areas, Primary Metropolitan Statistical Areas, Consolidated Metropolitan Statistical Areas, and New England County Metropolitan Statistical Areas in the United States

State	Metropolitan Area	TYPE	Counties	1990 Population	1995 Est. Population	1995 pop density (km^{-2})	Area (km^2)
FL	West Palm Beach-Boca Raton, FL	MSA	Palm Beach County	863,518	972,093	184.5	5268.9
GA	Albany, GA	MSA	Dougherty County Lee County	112,571	117,433	66.1	1775.4
GA	Athens, GA	MSA	Clarke County Madison County Oconee County	126,262	134,793	88.1	1530.8
GA	Atlanta, GA	MSA	Barrow County Bartow County Carroll County Cherokee County Clayton County Cobb County Coweta County DeKalb County Douglas County Fayette County Forsyth County Fulton County Gwinnett County Henry County Newton County Paulding County Pickens County Rockdale County Spalding County Walton County	2,959,950	3,431,983	216.3	15866.8
GA	Macon, GA	MSA	Bibb County Houston County Jones County Peach County Twiggs County	290,909	309,756	78.1	3967.9
GA	Savannah, GA	MSA	Bryan County Chatham County Effingham County	258,060	279,468	79.2	3526.6
GA-AL	Columbus, GA-AL	MSA	Russell County, AL Chattahoochee County, GA Harris County, GA Muscogee County, GA	260,860	272,380	67.0	4066.3
GA-SC	Augusta-Aiken, GA-SC	MSA	Columbia County, GA McDuffie County, GA Richmond County, GA Aiken County, SC Edgefield County, SC	415,220	453,209	52.4	8643.7
HI	Honolulu, HI	MSA	Honolulu County	836,231	877,198	564.3	1554.5
IA	Cedar Rapids, IA	MSA	Linn County	168,767	178,559	96.1	1858.4
IA	Des Moines, IA	MSA	Dallas County Polk County Warren County	392,928	421,447	94.2	4474.7
IA	Dubuque, IA	MSA	Dubuque County	86,403	88,566	56.2	1575.3
IA	Iowa City, IA	MSA	Johnson County	96,119	101,291	63.6	1591.7
IA	Waterloo-Cedar Falls, IA	MSA	Black Hawk County	123,798	123,077	83.8	1469.5
IA-IL	Davenport-Moline-Rock Island, IA-IL	MSA	Henry County, IL Rock Island County, IL Scott County, IA	350,861	358,243	81.0	4423.6
IA-NE	Sioux City, IA-NE	MSA	Woodbury County, IA Dakota County, NE	115,018	120,033	40.8	2943.8
ID	Boise City, ID	MSA	Ada County Canyon County	295,851	360,341	84.6	4260.0
IL	Bloomington-Normal, IL	MSA	McLean County	129,180	139,274	45.4	3065.6
IL	Champaign-Urbana, IL	MSA	Champaign County	173,025	169,096	65.5	2582.7
IL	Chicago, IL	PMSA	Cook County DeKalb County DuPage County Grundy County Kane County Kendall County Lake County McHenry County Will County	7,410,858	7,724,770	588.9	13118.3

Appendix B (continued)
Metropolitan Statistical Areas, Primary Metropolitan Statistical Areas, Consolidated Metropolitan Statistical Areas, and New England County Metropolitan Statistical Areas in the United States

State	Metropolitan Area	TYPE	Counties	1990 Population	1995 Est. Population	1995 pop density (km^{-2})	Area (km^2)
IL-IN-WI	Chicago-Gary-Kenosha, IL-IN-WI	CMSA	Cook County DeKalb County DuPage County Grundy County Kane County Kendall County Lake County McHenry County Will County Lake County Porter County Kankakee County Kenosha County	8,239,820	8,589,913	475.6	18060.0
IL	Kankakee, IL	PMSA	Kankakee County	96,255	102,046	58.2	1754.7
IL	Decatur, IL	MSA	Macon County	117,206	116,414	77.4	1503.6
IL	Peoria-Pekin, IL	MSA	Peoria County Tazewell County Woodford County	339,172	345,555	74.3	4653.0
IL	Rockford, IL	MSA	Boone County Ogle County Winnebago County	329,676	350,538	87.1	4025.2
IL	Springfield, IL	MSA	Menard County Sangamon County	189,550	197,015	64.3	3062.8
IN	Bloomington, IN	MSA	Monroe County	108,978	115,208	112.8	1021.4
IN	Gary, IN	PMSA	Lake County Porter County	604,526	623,159	262.9	2370.5
IN	Elkhart-Goshen, IN	MSA	Elkhart County	156,198	166,994	139.0	1201.3
IN	Fort Wayne, IN	MSA	Adams County Allen County DeKalb County Huntington County Wells County Whitley County	456,281	471,508	74.4	6339.5
IN	Indianapolis, IN	MSA	Boone County Hamilton County Hancock County Hendricks County Johnson County Madison County Marion County Morgan County Shelby County	1,380,491	1,476,865	161.8	9125.4
IN	Kokomo, IN	MSA	Howard County Tipton County	96,946	100,226	69.9	1433.5
IN	Lafayette, IN	MSA	Clinton County Tippecanoe County	161,572	167,879	71.6	2343.9
IN	Muncie, IN	MSA	Delaware County	119,659	118,577	116.4	1018.7
IN	South Bend, IN	MSA	St. Joseph County	247,052	258,083	217.9	1184.5
IN	Terre Haute, IN	MSA	Clay County Vermillion County Vigo County	147,585	149,769	56.8	2636.3
IN-KY	Evansville-Henderson, IN-KY	MSA	Posey County, IN Vanderburgh County, IN Warrick County, IN Henderson County, KY	278,990	288,369	75.9	3800.4
KS	Lawrence, KS	MSA	Douglas County	81,798	88,206	74.5	1183.5
KS	Topeka, KS	MSA	Shawnee County	160,976	165,062	115.9	1424.1
KS	Wichita, KS	MSA	Butler County Harvey County Sedgwick County	485,270	508,224	66.1	7686.7
KY	Lexington, KY	MSA	Bourbon County Clark County Fayette County Jessamine County Madison County Scott County Woodford County	405,936	435,736	87.6	4973.0
KY	Owensboro, KY	MSA	Daviess County	87,189	90,662	75.7	1197.7
KY-IN	Louisville, KY-IN	MSA	Clark County, IN	948,829	987,102	183.9	5367.2

Appendix B (continued)

Metropolitan Statistical Areas, Primary Metropolitan Statistical Areas, Consolidated Metropolitan Statistical Areas, and New England County Metropolitan Statistical Areas in the United States

State	Metropolitan Area	TYPE	Counties	1990 Population	1995 Est. Population	1995 pop density (km^{-2})	Area (km^2)
			Floyd County, IN Harrison County, IN Scott County, IN Bullitt County, KY Jefferson County, KY Oldham County, KY				
LA	Alexandria, LA	MSA	Rapides Parish	131,556	127,167	37.1	3425.7
LA	Baton Rouge, LA	MSA	Ascension Parish East Baton Rouge Parish Livingston Parish West Baton Rouge Parish	528,264	563,994	137.3	4109.1
LA	Houma, LA	MSA	Lafourche Parish Terrebonne Parish	182,842	188,757	31.1	6060.3
LA	Lafayette, LA	MSA	Acadia Parish Lafayette Parish St. Landry Parish St. Martin Parish	344,953	365,857	54.5	6717.9
LA	Lake Charles, LA	MSA	Calcasieu Parish	168,134	175,868	63.4	2774.4
LA	Monroe, LA	MSA	Ouachita Parish	142,191	146,826	92.8	1582.5
LA	New Orleans, LA	MSA	Jefferson Parish Orleans Parish Plaquemines Parish St. Bernard Parish St. Charles Parish St. James Parish St. John the Baptist Parish St. Tammany Parish	1,285,270	1,315,294	149.4	8804.8
LA	Shreveport-Bossier City, LA	MSA	Bossier Parish Caddo Parish Webster Parish	376,330	379,778	63.3	5999.7
MA	Barnstable-Yarmouth, MA	NECMA	Barnstable County (pt.)	186,605	199,804	194.9	1025.0
MA	Brockton, MA	PMSA	Bristol County (pt.) Norfolk County (pt.) Plymouth County (pt.)	1,557,688			4186.0
MA	Fitchburg-Leominster, MA	PMSA	Middlesex County (pt.) Worcester County (pt.)	2,108,173			6052.1
MA	New Bedford, MA	PMSA	Bristol County (pt.) Plymouth County (pt.)	941,601			3151.1
MA	Pittsfield, MA	NECMA	Berkshire County (pt.)	139,352	135,743	56.3	2412.3
MA	Springfield, MA	NECMA	Hampden County (pt.) Hampshire County (pt.)	602,878	592,587	199.6	2968.1
MA-CT	Worcester, MA-CT	PMSA	Windham County, CT (pt.) Hampden County, MA (pt.) Worcester County, MA (pt.)	1,268,540			6849.2
MA-NH	Boston-Worcester-Lawrence-Lowell-Brockton, MA-NH	NECMA	Bristol County, MA (pt.) Essex County, MA (pt.) Middlesex County, MA (pt.) Norfolk County, MA (pt.) Plymouth County, MA (pt.) Suffolk County, MA Worcester County, MA (pt.) Rockingham County, NH (pt.) Hillsborough County, NH Strafford County, NH	5,685,763	5,768,968	345.7	16689.9
MA-NH	Lawrence, MA-NH	PMSA	Essex County, MA (pt.) Rockingham County, NH (pt.)	915,925			3090.7
MA-NH	Lowell, MA-NH	PMSA	Middlesex County, MA (pt.) Hillsborough County, NH (pt.)	1,734,541			4403.1
MA-WI	Duluth-Superior, MN-WI	MSA	St. Louis County, MN Douglas County, WI	239,971			19515.4
MD	Baltimore, MD	PMSA	Anne Arundel County Baltimore County Carroll County Harford County Howard County Queen Anne's County	2,382,172	2,469,985	365.5	6758.1
MD	Hagerstown, MD	PMSA	Washington County	121,393	127,199	107.2	1186.6
MD-WV	Cumberland, MD-WV	MSA	Allegany County, MD	101,643	101,275	51.9	1950.6

Appendix B (continued)
Metropolitan Statistical Areas, Primary Metropolitan Statistical Areas, Consolidated Metropolitan Statistical Areas, and New England County Metropolitan Statistical Areas in the United States

State	Metropolitan Area	TYPE	Counties	1990 Population	1995 Est. Population	1995 pop density (km^{-2})	Area (km^2)
			Mineral County, WV				
ME	Bangor, ME	NECMA	Penobscot County (pt.)	146,601	145,905	13.7	10685.9
ME	Lewiston-Auburn, ME	NECMA	Androscoggin County (pt.)	105,259	103,751	85.2	1218.1
ME	Portland, ME	NECMA	Cumberland County (pt.)	243,135	248,526	52.5	4730.8
MI	Benton Harbor, MI	MSA	Berrien County	161,378	162,623	110.0	1479.0
MI	Ann Arbor, MI	PMSA	Lenawee County Livingston County Washtenaw County	490,058	522,916	99.5	5255.2
MI	Detroit, MI	PMSA	Lapeer County Macomb County Monroe County Oakland County St. Clair County Wayne County	4,266,654	4,320,203	428.0	10093.7
MI	Detroit-Ann Arbor-Flint, MI	CMSA	Lenawee County Livingston County Washtenaw County LaPeer County Macomb County Monroe County Oakland County St. Clair County Wayne County Genesee County	5,187,171	5,279,500	308.9	17093.9
MI	Flint, MI	PMSA	Genesee County	430,459	436,381	263.4	1656.7
MI	Grand Rapids-Muskegon-Holland, MI	MSA	Allegan County Kent County Muskegon County Ottawa County	937,891	997,895	139.7	7145.0
MI	Jackson, MI	MSA	Jackson County	149,756	154,010	84.1	1830.2
MI	Kalamazoo-Battle Creek, MI	MSA	Calhoun County Kalamazoo County Van Buren County	429,453	443,253	90.9	4873.8
MI	Lansing-East Lansing, MI	MSA	Clinton County Eaton County Ingham County	432,674	437,633	99.0	4421.8
MI	Saginaw-Bay City-Midland, MI	MSA	Bay County Midland County Saginaw County	399,320	403,572	87.8	4595.8
MN-WI	Duluth-Superior, MN-WI	MSA	St. Louis County Douglas County	239,971	239,921		
MN	Rochester, MN	MSA	Olmsted County	106,470	112,619	66.6	1691.4
MN	St. Cloud, MN	MSA	Benton County Stearns County	148,976	158,802	35.0	4540.0
MN-WI	Minneapolis-St. Paul, MN-WI	MSA	Anoka County, MN Carver County, MN Chisago County, MN Dakota County, MN Hennepin County, MN Isanti County, MN Ramsey County, MN Scott County, MN Sherburne County, MN Washington County, MN Wright County, MN Pierce County, WI St. Croix County, WI	2,538,834	2,723,137	173.4	15706.9
MO	Columbia, MO	MSA	Boone County	112,379	123,742	69.7	1775.1
MO	Joplin, MO	MSA	Jasper County Newton County	134,910	143,804	43.8	3279.7
MO	St. Joseph, MO	MSA	Andrew County Buchanan County	97,715	97,679	44.6	2188.5
MO	Springfield, MO	MSA	Christian County Greene County Webster County	264,346	294,526	62.1	4743.9
MO-IL	St. Louis, MO-IL	MSA	Clinton County, IL Jersey County, IL Madison County, IL Monroe County, IL	2,511,698	2,547,686	137.9	18481.2

Appendix B (continued)

Metropolitan Statistical Areas, Primary Metropolitan Statistical Areas, Consolidated Metropolitan Statistical Areas, and New England County Metropolitan Statistical Areas in the United States

State	Metropolitan Area	TYPE	Counties	1990 Population	1995 Est. Population	1995 pop density (km^{-2})	Area (km^2)
			St. Clair County, IL Franklin County, MO Jefferson County, MO Lincoln County, MO St. Charles County, MO St. Louis County, MO Warren County, MO				
MO-KS	Kansas City, MO-KS	MSA	Johnson County, KS Leavenworth County, KS Miami County, KS Wyandotte County, KS Cass County, MO Clay County, MO Clinton County, MO Jackson County, MO Lafayette County, MO Platte County, MO Ray County, MO	1,582,875	1,663,453	118.8	14003.3
MS	Biloxi-Gulfport-Pascagoula, MS	MSA	Hancock County Harrison County Jackson County	312,368	341,548	73.9	4622.0
MS	Hattiesburg, MS	MSA	Forrest County Lamar County	98,738	106,195		
MS	Jackson, MS	MSA	Hinds County Madison County Rankin County	395,396	416,297	68.0	6120.2
MT	Billings, MT	MSA	Yellowstone County	113,419	124,655	18.3	6825.2
MT	Great Falls, MT	MSA	Cascade County	77,691	81,091	11.6	6987.9
MY	Casper, WY	MSA	Natrona County	61,226	64,025	4.6	13830.8
NC	Asheville, NC	MSA	Buncombe County Madison County	191,774	207,448	72.4	2863.8
NC	Fayetteville, NC	MSA	Cumberland County	274,566	285,869	169.0	1691.6
NC	Goldsboro, NC	MSA	Wayne County	104,666	110,174	77.0	1431.2
NC	Greensboro--Winston-Salem--High Point, NC	MSA	Alamance County Davidson County Davie County Forsyth County Guilford County Randolph County Stokes County Yadkin County	1,050,304	1,123,840	111.8	10056.6
NC	Greenville, NC	MSA	Pitt County	107,924	117,740	69.8	1687.7
NC	Hickory-Morganton-Lenoir, NC	MSA	Alexander County Burke County Caldwell County Catawba County	292,409	310,236	73.1	4244.3
NC	Jacksonville, NC	MSA	Onslow County	149,838	143,324	72.2	1986.2
NC	Raleigh-Durham-Chapel Hill, NC	MSA	Chatham County Durham County Franklin County Johnston County Orange County Wake County	855,545	995,256	110.1	9041.7
NC	Rocky Mount, NC	MSA	Edgecombe County Nash County	133,235	141,932	52.4	2707.6
NC	Wilmington, NC	MSA	Brunswick County New Hanover County	171,269	200,610	389.3	515.3
NC-SC	Charlotte-Gastonia-Rock Hill, NC-SC	MSA	Cabarrus County, NC Gaston County, NC Lincoln County, NC Mecklenburg County, NC Rowan County, NC Union County, NC York County, SC	1,162,140	1,289,177	147.3	8750.5
ND	Bismarck, ND	MSA	Burleigh County Morton County	83,831	89,440	9.7	9219.4
ND-MN	Fargo-Moorhead, ND-MN	MSA	Clay County Cass County	153,296	163,618	22.5	7280.6
ND-MN	Grand Forks, ND-MN	MSA	Polk County	103,181	104,571	11.8	8827.7

Appendix B (continued)
Metropolitan Statistical Areas, Primary Metropolitan Statistical Areas, Consolidated Metropolitan Statistical Areas, and New England County Metropolitan Statistical Areas in the United States

State	Metropolitan Area	TYPE	Counties	1990 Population	1995 Est. Population	1995 pop density (km^{-2})	Area (km^2)
			Grand Forks County				
NE	Lincoln, NE	MSA	Lancaster County	213,641	228,638	105.2	2172.7
NE-IA	Omaha, NE-IA	MSA	Pottawattamie County, IA Cass County, NE Douglas County, NE Sarpy County, NE Washington County, NE	639,580	670,322	104.5	6412.4
NH	Manchester, NH	PMSA	Hillsborough County (pt.) Merrimack County (pt.) Rockingham County (pt.)	701,923			6491.2
NH	Nashua, NH	PMSA	Hillsborough County	581,918			4070.7
NH-ME	Portsmouth-Rochester, NH-ME	PMSA	York County, ME (pt.) Rockingham County, NH (pt.) Strafford County, NH (pt.)	514,665			5322.6
NJ	Bergen-Passaic, NJ	PMSA	Bergen County Passaic County	1,278,440	1,308,655	1205.2	1085.9
NJ	Jersey City, NJ	PMSA	Hudson County	553,099	550,183	4553.2	120.8
NJ	Middlesex-Somerset-Hunterdon, NJ	PMSA	Hunterdon County Middlesex County Somerset County	1,019,835	1,080,450	399.0	2707.7
NJ	Monmouth-Ocean, NJ	PMSA	Monmouth County Ocean County	986,327	1,050,052	365.8	2870.3
NJ	Newark, NJ	PMSA	Essex County Morris County Sussex County Union County Warren County	1,915,928	1,936,096	473.8	4086.5
NJ	Trenton, NJ	PMSA	Mercer County	325,824	330,305	564.4	585.2
NJ	Atlantic-Cape May, NJ	PMSA	Atlantic County Cape May County	319,416	332,336	157.2	2114.4
NJ	Vineland-Millville-Bridgeton, NJ	PMSA	Cumberland County	138,053	138,058	108.9	1267.3
NM	Albuquerque, NM	MSA	Bernalillo County Sandoval County Valencia County	589,131	659,855	42.9	15393.6
NM	Las Cruces, NM	MSA	Dona Ana County	135,510	158,849	16.1	9861.3
NM	Santa Fe, NM	MSA	Los Alamos County Santa Fe County	117,043	135,018	25.8	5228.5
NV	Reno, NV	MSA	Washoe County	254,667	290,833	17.7	16426.9
NV-AZ	Las Vegas, NV-AZ	MSA	Mohave County Clark County Nye County	852,737	1,138,758	11.2	101969.1
NY	Albany-Schenectady-Troy, NY	MSA	Albany County Montgomery County Rensselaer County Saratoga County Schenectady County Schoharie County	861,623	873,361	104.6	8346.3
NY	Binghamton, NY	MSA	Broome County Tioga County	264,497	257,403	81.1	3174.3
NY	Buffalo-Niagara Falls, NY	MSA	Erie County Niagara County	1,189,288	1,184,052	291.6	4060.2
NY	Elmira, NY	MSA	Chemung County	95,195	94,082	89.0	1057.2
NY	Glens Falls, NY	MSA	Warren County Washington County	118,539	122,559	27.7	4416.6
NY	Jamestown, NY	MSA	Chautauqua County	141,895	141,677	51.5	2751.0
NY	Dutchess County, NY	PMSA	Dutchess County	259,462	262,062	126.2	2076.3
NY	Nassau-Suffolk, NY	PMSA	Nassau County Suffolk County	1,321,864	2,659,476	1126.9	2360.1
NY	New York, NY	PMSA	Bronx County Kings County New York County Putnam County Queens County Richmond County Rockland County Westchester County	8,546,846	8,570,212	2883.4	2972.3
NY-NJ-CT-PA	New York-No. New Jersey-Long Island, NY-NJ-CT-PA	CMSA	Bergen County Passaic County Fairfield County	17,830,586	18,107,235	779.7	23221.9

Appendix B (continued)

Metropolitan Statistical Areas, Primary Metropolitan Statistical Areas, Consolidated Metropolitan Statistical Areas, and New England County Metropolitan Statistical Areas in the United States

State	Metropolitan Area	TYPE	Counties	1990 Population	1995 Est. Population	1995 pop density (km^{-2})	Area (km^{2})
			New Haven County Litchfield County Dutchess County Hudson County Hunterdon County Middlesex County Somerset County Monmouth County Ocean County Nassau County Suffolk County Middlesex County Bronx County Kings County New York County Putnam County Queens County Richmond County Rockland County Westchester County Essex County Morris County Sussex County Union County Warren County Orange County Pike County Mercer County				
NY	Rochester, NY	MSA	Genesee County Livingston County Monroe County Ontario County Orleans County Wayne County	1,062,470	1,088,516	122.7	8872.5
NY	Syracuse, NY	MSA	Cayuga County Madison County Onondaga County Oswego County	742,177	750,090	93.9	7984.5
NY	Utica-Rome, NY	MSA	Herkimer County Oneida County	316,633	308,562	45.4	6797.7
NY-PA	Newburgh, NY-PA	PMSA	Orange County, NY Pike County, PA	335,613	359,744	101.9	3531.3
OH	Canton-Massillon, OH	MSA	Carroll County Stark County	394,106	403,695	160.5	2514.5
OH	Hamilton-Middletown, OH	PMSA	Butler County	291,479	315,601	260.8	1210.3
OH	Akron, OH	PMSA	Portage County Summit County	657,575	678,834	289.5	2344.5
OH-KY-IN	Cincinnati-Hamilton, OH-KY-IN	CMSA	Dearborn County Ohio County Boone County Campbell County Gallatin County Grant County Kenton County Pendleton County Brown County Clermont County Hamilton County Warren County Butler County	1,817,569	1,907,438	192.4	9914.5
OH	Cleveland-Akron, OH	CMSA	Portage County Summit County Ashtabula Caounty Cuyahoga County Geauga County Lake County Lorain County Medina County	2,859,644	2,903,808	309.5	9383.5
OH	Cleveland-Lorain-Elyria, OH	PMSA	Ashtabula County	2,202,069	2,224,974	317.3	7012.4

Appendix B (continued)

Metropolitan Statistical Areas, Primary Metropolitan Statistical Areas, Consolidated Metropolitan Statistical Areas, and New England County Metropolitan Statistical Areas in the United States

State	Metropolitan Area	TYPE	Counties	1990 Population	1995 Est. Population	1995 pop density (km^{-2})	Area (km^2)
			Cuyahoga County Geauga County Lake County Lorain County Medina County				
OH	Columbus, OH	MSA	Delaware County Fairfield County Franklin County Licking County Madison County Pickaway County	1,345,450	1,437,512	176.6	8138.2
OH	Dayton-Springfield, OH	MSA	Clark County Greene County Miami County Montgomery County	951,270	956,412	219.3	4360.7
OH	Lima, OH	MSA	Allen County Auglaize County	154,340	156,276	74.9	2086.8
OH	Mansfield, OH	MSA	Crawford County Richland County	174,007	176,154	75.6	2329.4
OH	Toledo, OH	MSA	Fulton County Lucas County Wood County	614,128	612,798	173.4	3534.3
OH	Youngstown-Warren, OH	MSA	Columbiana County Mahoning County Trumbull County	600,895	602,608	148.8	4049.8
OH-KY-IN	Cincinnati, OH-KY-IN	PMSA	Dearborn County, IN Ohio County, IN Boone County, KY Campbell County, KY Gallatin County, KY Grant County, KY Kenton County, KY Pendleton County, KY Brown County, OH Clermont County, OH Hamilton County, OH Warren County, OH	1,526,092	1,591,837	183.9	8656.5
OH-WV	Steubenville-Weirton, OH-WV	MSA	Jefferson County, OH Brooke County, WV Hancock County, WV	142,523	139,862	92.9	1506.2
OK	Enid, OK	MSA	Garfield County	56,735	57,330	20.9	2741.5
OK	Lawton, OK	MSA	Comanche County	111,486	115,672	41.8	2769.8
OK	Oklahoma City, OK	MSA	Canadian County Cleveland County Logan County McClain County Oklahoma County Pottawatomie County	958,839	1,015,174	92.3	11000.8
OK	Tulsa, OK	MSA	Creek County Osage County Rogers County Tulsa County Wagoner County	708,954	746,500	57.5	12988.7
OR	Eugene-Springfield, OR	MSA	Lane County	282,912	303,426	25.7	11795.3
OR	Medford-Ashland, OR	MSA	Jackson County	146,389	166,060	23.0	7214.1
OR	Salem, OR	PMSA	Marion County Polk County	278,024	311,722	62.5	4988.5
OR-WA	Portland-Salem, OR-WA	CMSA	Clackamas County Columbia County Multnomah County Washington County Yamhill County Clark County Marion County Polk County	1,793,476	2,021,982	112.4	17984.9
OR-WA	Portland-Vancouver, OR-WA	PMSA	Clackamas County Columbia County Multnomah County Washington County	1,515,452	1,710,260	131.3	13021.6

Appendix B (continued)
Metropolitan Statistical Areas, Primary Metropolitan Statistical Areas, Consolidated Metropolitan Statistical Areas, and New England County Metropolitan Statistical Areas in the United States

State	Metropolitan Area	TYPE	Counties	1990 Population	1995 Est. Population	1995 pop density (km^{-2})	Area (km^2)
			Yamhill County Clark County				
PA	Allentown-Bethlehem-Easton, PA	MSA	Carbon County Lehigh County Northampton County	595,208	613,466	214.7	2857.0
PA	Altoona, PA	MSA	Blair County	130,542	131,647	96.7	1362.0
PA	Erie, PA	MSA	Erie County	275,572	280,460	135.0	2077.2
PA	Harrisburg-Lebanon-Carlisle, PA	MSA	Cumberland County Dauphin County Lebanon County Perry County	587,986	612,617	118.8	5156.4
PA	Johnstown, PA	MSA	Cambria County Somerset County	241,247	240,644	52.7	4565.8
PA	Lancaster, PA	MSA	Lancaster County	422,822	447,521	182.0	2458.2
PA-NJ-DE-MD	Philadelphia-Wilmington-Atlantic City, PA-NJ-DE-MD	CMSA	Atlantic County Cape May County Burlington County Camden County Gloucester County Salem County Bucks County Chester County Delaware County Montgomery County Philadelphia County Cumberland County New Castle County Cecil County	5,893,019	5,967,323	386.9	15423.4
PA	Pittsburgh, PA	MSA	Allegheny County Beaver County Butler County Fayette County Washington County Westmoreland County	2,394,811	2,394,702	200.0	11975.9
PA	Reading, PA	MSA	Berks County	336,523	349,583	157.1	2225.4
PA	Scranton--Wilkes-Barre--Hazleton, PA	MSA	Columbia County Lackawanna County Luzerne County Wyoming County	638,466	635,559	109.9	5782.3
PA	Sharon, PA	MSA	Mercer County	121,003	122,254	70.3	1740.1
PA	State College, PA	MSA	Centre County	123,786	131,968	46.0	2868.7
PA	Williamsport, PA	MSA	Lycoming County	118,710	120,194	37.6	3198.5
PA	York, PA	MSA	York County	339,574	362,793	154.8	2343.0
PA-NJ	Philadelphia, PA-NJ	PMSA	Burlington County, NJ Camden County, NJ Gloucester County, NJ Salem County, NJ Bucks County, PA Chester County, PA Delaware County, PA Montgomery County, PA Philadelphia County, PA	4,922,257	4,950,866		
RI-MA	Providence-Warwick-Pawtucket, RI-MA	NECMA	Bristol County, MA (pt.) Bristol County, RI Kent County, RI Newport County, RI (pt.) Providence County, RI Washington County, RI (pt.)	916,270	907,801	370.1	2452.7
SC	Charleston-North Charleston, SC	MSA	Berkeley County Charleston County Dorchester County	506,875	506,420	75.4	6712.7
SC	Columbia, SC	MSA	Lexington County Richland County	453,331	481,718	127.6	3774.5
SC	Florence, SC	MSA	Florence County	114,344	122,769	59.3	2070.0
SC	Greenville-Spartanburg-Anderson, SC	MSA	Anderson County Cherokee County Greenville County Pickens County Spartanburg County	830,563	884,306	106.3	8315.8

Appendix B (continued)
Metropolitan Statistical Areas, Primary Metropolitan Statistical Areas, Consolidated Metropolitan Statistical Areas, and New England County Metropolitan Statistical Areas in the United States

State	Metropolitan Area	TYPE	Counties	1990 Population	1995 Est. Population	1995 pop density (km^{-2})	Area (km^2)
SC	Myrtle Beach, SC	MSA	Horry County	144,053	157,902	53.8	2936.3
SC	Sumter, SC	MSA	Sumter County	102,637	106,823	62.0	1723.5
SD	Rapid City, SD	MSA	Pennington County	81,343	87,304	12.1	7190.8
SD	Sioux Falls, SD	MSA	Lincoln County Minnehaha County	139,236	153,307	42.7	3593.2
TN	Jackson, TN	MSA	Chester County Madison County	77,982	83,715	58.0	1442.9
TN	Knoxville, TN	MSA	Anderson County Blount County Knox County Loudon County Sevier County Union County	585,960	640,700	101.0	6343.2
TN	Nashville, TN	MSA	Cheatham County Davidson County Dickson County Robertson County Rutherford County Sumner County Williamson County Wilson County	985,026	1,093,836	103.7	10549.2
TN-AR-MS	Memphis, TN-AR-MS	MSA	Crittenden County, AR DeSoto County, MS Fayette County, TN Shelby County, TN Tipton County, TN	1,007,306	1,068,891	137.2	7789.6
TN-GA	Chattanooga, TN-GA	MSA	Catoosa County, GA Dade County, GA Walker County, GA Hamilton County, TN Marion County, TN	424,347	443,060	93.7	4726.2
TN-KY	Clarksville-Hopkinsville, TN-KY	MSA	Christian County, KY Montgomery County, TN	169,439	189,477	58.0	3264.8
TN-VA	Johnson City-Kingsport-Bristol, TN-VA	MSA	Carter County, TN Hawkins County, TN Sullivan County, TN Unicoi County, TN Washington County, TN Scott County, VA Washington County, VA	436,047	454,056	61.2	7421.8
TX	Abilene, TX	MSA	Taylor County	119,655	122,791	51.8	2371.7
TX	Amarillo, TX	MSA	Potter County Randall County	187,514	201,012	42.6	4723.9
TX	Austin-San Marcos, TX	MSA	Bastrop County Caldwell County Hays County Travis County Williamson County	807,964	999,936	115.7	8644.1
TX	Beaumont-Port Arthur, TX	MSA	Hardin County Jefferson County Orange County	361,226	374,637	67.1	5579.9
TX	Brownsville-Harlingen-San Benito, TX	MSA	Cameron County	260,120	309,578	132.0	2345.4
TX	Bryan-College Station, TX	MSA	Brazos County	121,862	130,486	86.0	1517.3
TX	Corpus Christi, TX	MSA	Nueces County San Patricio County	349,894	378,936	95.8	3956.6
TX	Dallas, TX	PMSA	Collin County Dallas County Denton County Ellis County Henderson County Hunt County Kaufman County Rockwall County	2,676,248	2,957,910	184.6	16023.3
TX	Dallas-Fort Worth, TX	CMSA	Collin County Dallas County Denton County Ellis County Henderson County Hunt County	4,037,282	4,449,875	277.7	16023.3

Appendix B (continued)

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State	Metropolitan Area	TYPE	Counties	1990 Population	1995 Est. Population	1995 pop density (km^{-2})	Area (km^2)
			Kaufman County Rockwall County				
TX	Fort Worth-Arlington, TX	PMSA	Hood County Johnson County Parker County Tarrant County	1,361,034	1,491,965	197.4	7557.9
TX	El Paso, TX	MSA	El Paso County	591,610	678,313	258.5	2623.9
TX	Brazoria, TX	PMSA	Brazoria County	191,707	216,016	60.1	3592.0
TX	Galveston-Texas City, TX	PMSA	Galveston County	217,399	237,533	230.0	1032.6
TX	Houston, TX	PMSA	Chambers County Fort Bend County Harris County Liberty County Montgomery County Waller County	3,322,025	3,710,844	242.0	15335.8
TX	Houston-Galveston-Brazoria, TX	CMSA	Brazoria County Galveston County Chambers County Fort Bend County Harris County Liberty County Montgomery County Waller County	3,731,029	4,164,393	207.0	20116.5
TX	Killeen-Temple, TX	MSA	Bell County Coryell County	255,301	289,903	53.0	5467.1
TX	Laredo, TX	MSA	Webb County	133,239	170,863	19.7	8694.6
TX	Longview-Marshall, TX	MSA	Gregg County Harrison County Upshur County	193,801	203,949	44.7	4560.0
TX	Lubbock, TX	MSA	Lubbock County	222,636	232,276	99.7	2330.0
TX	McAllen-Edinburg-Mission, TX	MSA	Hidalgo County	383,545	479,783	118.1	4063.9
TX	Odessa-Midland, TX	MSA	Ector County Midland County	225,545	239,245	51.3	4665.8
TX	San Angelo, TX	MSA	Tom Green County	98,458	101,555	25.8	3942.5
TX	San Antonio, TX	MSA	Bexar County Comal County Guadalupe County Wilson County	1,324,749	1,460,809	169.5	8616.4
TX	Sherman-Denison, TX	MSA	Grayson County	95,021	98,336	40.7	2418.2
TX	Tyler, TX	MSA	Smith County	151,309	161,986	67.4	2404.8
TX	Victoria, TX	MSA	Victoria County	74,361	79,992	35.0	2285.9
TX	Waco, TX	MSA	McLennan County	189,123	200,111	74.2	2698.6
TX	Wichita Falls, TX	MSA	Archer County Wichita County	130,351	133,386	33.5	3982.0
TX-AR	Texarkana, TX-Texarkana, AR	MSA	Miller County, AR Bowie County, TX	120,132	122,991	31.4	3916.1
UT	Provo-Orem, UT	MSA	Utah County	263,590	298,789	57.7	5175.9
UT	Salt Lake City-Ogden, UT	MSA	Davis County Salt Lake County Weber County	1,072,227	1,199,323	286.3	4189.3
VA	Charlottesville, VA	MSA	Albemarle County Fluvanna County Greene County	131,107	142,148	46.6	3048.6
VA	Danville, VA	MSA	Pittsylvania County	108,711	109,890	41.8	2626.0
VA	Lynchburg, VA	MSA	Amherst County Bedford County Campbell County	193,928	204,212	44.0	4638.3
VA	Richmond-Petersburg, VA	MSA	Charles City County Chesterfield County Dinwiddie County Goochland County Hanover County Henrico County New Kent County Powhatan County Prince George County	865,640	927,435	121.6	7626.9
VA	Roanoke, VA	MSA	Botetourt County Roanoke County	224,477	228,895	103.9	2203.6
VA-NC	Norfolk-Virginia Beach-Newport News, VA-NC	MSA	Currituck County, NC	1,443,244	1,540,446	253.2	6083.1

Appendix B (continued)
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State	Metropolitan Area	TYPE	Counties	1990 Population	1995 Est. Population	1995 pop density (km^{-2})	Area (km^2)
			Gloucester County, VA Isle of Wight County, VA James City County, VA Mathews County, VA York County, VA				
VT	Burlington, VT	NECMA	Chittenden County (pt.) Franklin County (pt.) Grand Isle County (pt.)	177,059	188,175	57.7	3259.9
WA	Bellingham, WA	MSA	Whatcom County	127,780	148,929	27.1	5490.9
WA	Richland-Kennewick-Pasco, WA	MSA	Benton County Franklin County	150,033	177,529	23.3	7628.3
WA	Bremerton, WA	PMSA	Kitsap County	189,731	226,720	221.1	1025.6
WA	Olympia, WA	PMSA	Thurston County	161,238	191,974	101.9	1883.1
WA	Seattle-Bellevue-Everett, WA	PMSA	Island County King County Snohomish County	2,033,156	2,197,451	191.7	11460.5
WA	Seattle-Tacoma-Bremerton, WA	CMSA	Kitsap County Thurston County Island County King County Snohomish County Pierce County	2,970,300	3,265,139	174.3	18733.4
WA	Tacoma, WA	PMSA	Pierce County	586,203	648,994	149.5	4339.7
WA	Spokane, WA	MSA	Spokane County	361,364	401,205	87.8	4568.3
WA	Yakima, WA	MSA	Yakima County	188,823	212,035	19.1	11126.9
WI	Appleton-Oshkosh-Neenah, WI	MSA	Calumet County Outagamie County Winnebago County	336,073	336,073	92.8	3623.1
WI	Kenosha, WI	PMSA	Kenosha County	128,181	139,938	198.0	706.6
WI	Eau Claire, WI	MSA	Chippewa County Eau Claire County	137,543	142,663	33.4	4268.7
WI	Green Bay, WI	MSA	Brown County	194,594	210,303	153.6	1369.4
WI	Janesville-Beloit, WI	MSA	Rock County	139,510	148,349	79.5	1866.2
WI	Madison, WI	MSA	Dane County	367,085	393,296	126.3	3113.6
WI	Milwaukee-Waukesha, WI	PMSA	Milwaukee County Ozaukee County Washington County Waukesha County	1,432,149	1,457,939	385.6	3781.3
WI	Milwaukee-Racine, WI	CMSA	Milwaukee County Ozaukee County Washington County Waukesha County Racine County	1,607,183	1,640,831	352.9	4649.0
WI	Racine, WI	PMSA	Racine County	175,034	182,892	212.0	862.8
WI	Sheboygan, WI	MSA	Sheboygan County	103,877	108,326	81.4	1330.4
WI	Wausau, WI	MSA	Marathon County	115,400	120,776	30.2	4001.7
WI-MN	La Crosse, WI-MN	MSA	Houston County, MN La Crosse County, WI	116,401	121,005	46.2	2619.1
WV	Charleston, WV	MSA	Kanawha County Putnam County	250,454	255,139	78.8	3236.0
WV-KY-OH	Huntington-Ashland, WV-KY-OH	MSA	Boyd County, KY Carter County, KY Greenup County, KY Lawrence County, OH Cabell County, WV Wayne County, WV	312,529	317,489	56.8	5594.1
WV-OH	Parkersburg-Marietta, WV-OH	MSA	Washington County, OH Wood County, WV	149,169	152,131	58.6	2596.7
WV-OH	Wheeling, WV-OH	MSA	Belmont County, OH Marshall County, WV Ohio County, WV	159,301	157,349	63.9	2461.8
WY	Cheyenne, WY	MSA	Laramie County	73,142	78,444	11.3	6957.4

TECHNICAL REPORT DATA

(PLEASE READ INSTRUCTIONS ON THE REVERSE BEFORE COMPLETING)

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2.

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16. ABSTRACT

This guidance provides a method and rationale for designing monitoring networks to determine compliance with newly enacted PM 2.5 and PM 10 national ambient air quality standards. It defines concepts and terms of network design, presents a methodology for defining planning areas and community monitoring zones, identifies data resources and the uses of those resources for network design, and provides some practical examples of applying the guidance. PM 2.5 monitoring sites are to be population-oriented, measuring exposures where people live, work, and play. For comparison to the annual PM 2.5 standard, the locations must be community-oriented and as such, these do not necessarily correspond to the locations of highest PM concentrations in an area. Existing metropolitan statistical aras are first examined to determine where the majority of the people live in each state. These are then broken down into smaller populated entities which may include county, zip code, census tract, or census block boundaries. Combinations of these population entities are combined to define metropilitan planning areas. These may be further sub-divided into community monitoring zones, based on examination of existing PM measurements, source locations, terrain, and meteorology. Finally, PM 2.5 monitors are located at specific sites that represent neighborhood or urban scales to determine compliance with the annual standard and at maximum, population oriented locations for comparison with the 24-hour standard. Transport and background sites are located between and away from planning areas to determine regional increments to PM measured within the planning area.

17. KEY WORDS AND DOCUMENT ANALYSIS

a. DESCRIPTORS
PM 2.5, National Ambient Air Quality Standards, Monitors, Monitoring Network, Network Design,

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