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Optimum Sampling Site Exposure Criteria For Lead

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Optimum Sampling Site Exposure Criteria for Lead

by

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SECTION 1

INTRODUCTION

The primary purpose of this document is to guide Federal, state, and local agencies in selecting sites for monitoring lead in the atmosphere. This guideline provides more details on site-selection procedures than do the Part 58 Regulations. Should any conflicts occur between the guideline and the regulations, however, the regulations take precedence. In addition, this guideline should not be used as a basis for rejecting data from existing monitors sited prior to the publication of this guideline.

For monitoring networks to provide a representative sampling of air quality in an area of concern, the number and locations of monitors must be selected with care. This document emphasizes the concept of spatial representativeness in selecting optimum monitoring sites to meet monitoring objectives. A number of guidelines are given that can be used to identify the types of representative sites that characterize exposure to lead in any area of concern. Using these rules and knowing the objectives of a specific monitoring group, the user of this document can select the number and locations of sites that best meet monitoring needs. Specific steps are recommended for selecting monitoring sites with respect to each representative type of site.

The contents of this document include the following subjects:

- Monitoring objectives and Federal requirements
- Characteristics of lead air pollution including airborne forms, sources, distribution patterns, meteorological influences, and topographical influences
- Methods of site selection
- Site selection criteria.

This document extends and updates an earlier document prepared by PEDCo Environmental, Inc. (PEDCo 1981a), which was published only in draft form.

SECTION 2

MONITORING OBJECTIVES FOR LEAD

GENERAL

Monitoring objectives are established to fulfill authoritative requests or provide information relevant to certain interests. The data obtained from a planned ambient air monitoring network are examined to determine how well the objectives are being met, and to revise the monitoring plan when necessary. Air quality monitoring data are collected for the ultimate objective of ensuring the protection of public health, but more immediate application of the data may be intended for one or more of the following uses:

- Evaluation of ambient air quality
- Enforcement of source-specific regulations
- Evaluation/development of control plans
- Air quality maintenance planning
- Development and testing of models
- Research.

Further refinement and rationale of the objectives and data uses can easily be established by the user. Table 1 lists a variety of uses for lead monitoring data that are applicable to the six categories listed above. More extensive discussions of these uses can be found in other guideline documents such as those by Koch and Rector (1983); Ball and Anderson (1977); Ludwig and Kealoha (1975); Ludwig, Kealoha, and Shelar (1977); Ludwig and Shelar (1978), etc.

Once the objectives and data uses are determined, the monitoring network and siting criteria are designed to accommodate the intended use.

REQUIREMENTS FOR MONITORING LEAD

National Ambient Air Quality Standard

The National Ambient Air Quality Standard (NAAQS) for lead, published in the Federal Register (43 FR 46245, October 5, 1978), is 1.5 $\mu g/m^3$, maximum arithmetic mean averaged over a calendar quarter. The Federal reference method for measuring atmospheric lead concentrations (given in Appendix G to 40 CFR 50) is by atomic absorption spectrophotometry analysis of particulate matter collected on high-volume air sampler filters. Sampling every sixth day will satisfy the monitoring requirements for an acceptable data base if at

TABLE 1. PRINCIPAL USES FOR LEAD MONITORING DATA

1. Evaluate Ambient Air Quality
   - Judge Attainment of NAAQS
   - Establish Progress in Achieving/Maintaining NAAQS
   - Establish Long-Term Trends
   - Air Quality Indices
   - Population Exposures Documentation
   - Respond to Unique Citizen Complaints
   - Develop/Revise Standards

2. Enforce Source-Specific Regulations
   - Categorical Sources (New Source Review (NSR), Supplementary Control Systems (SCS), Prevention of Significant Deterioration (PSD))
   - Individual Sources
   - Enforcement Actions

3. Evaluate/Develop Control Plans
   - State Implementation Plan (SIP) Provisions
   - Evaluate/Develop/Revise Local Control Strategies

4. Air Quality Maintenance Planning
   - Establish Baseline Conditions
   - Project Future Air Quality

5. Develop and Test Models
   - Input for Receptor Models
   - Validation and Refinement
   - Assess Representativeness of Monitoring Networks

6. Research
   - Effects on Humans, Plants, Animals, and Environment
   - Characterize Source, Transport, Transformation, and Fate for Anthropogenic and Natural Emissions
   - Develop/Test New Instrumentation

least 75 percent of the scheduled samples meet quality assurance guidelines. A rigorous quality assurance program requires that all sources of sample contamination be minimized, including surfaces of collection containers and devices, hands and clothing of personnel, chemical reagents, laboratory atmosphere, and labware and tools.

The monitors must be operated on a minimum sampling frequency of one 24-hour sample every 6 days, but the analysis of the 24-hour samples may be performed for either individual samples or composites of the samples collected over a month or quarter of a year.

Planning and Maintaining Control of Ambient Lead

Determination that an area is meeting the ambient air standard for lead will depend heavily upon the selection of sites for monitoring lead. As a minimum, SIPs are required to provide two lead monitoring sites (per Appendix D of 40 CFR 58) in each urbanized area that has a 1970 population greater than 500,000, or where lead air quality levels (measured since January 1, 1974) exceed or have exceeded the lead standard. One of the two monitoring sites must be located near a roadway in the area of expected maximum concentration, and one site must be representative of a neighborhood scale (see definition at end of Section 3). In addition, Subpart E (Control Strategy--Lead) of Section 51.80 requires each SIP to demonstrate that the NAAQS for lead will be attained and maintained in the following areas:

1. Areas in the vicinity of the following point sources of lead:

   Primary lead smelters
   Secondary lead smelters
   Primary copper smelters
   Lead gasoline additive plants
   Lead-acid storage battery manufacturing plants that produce 2,000 or more batteries per day
   Any other stationary source that actually emits 25 or more tons per year of lead or lead compounds measured as elemental lead.

2. Any other area that has lead air concentrations in excess of the national standard concentration for lead, measured since January 1, 1974. States may be allowed to limit the time period to the last 3 years or since January 1, 1978, when adequately justified (U.S. EPA 1983).

For lead SIPs, EPA has defined point sources differently than for other pollutants. Point sources for lead are any stationary source causing emissions in excess of 4.54 metric tons (5 tons) per year of lead or lead compounds measured as elemental lead. This definition is important to remember in planning monitoring sites.

Many areas have no significant stationary sources of lead emissions. Table 2 shows that most lead emissions come from gasoline consumption by motor vehicles. Thus, lead concentrations near areas of heavy traffic and on the downwind edge of dense urban developments are of major concern in planning control measures. Ambient monitoring data are needed to confirm that the SIP controls of motor vehicle emissions are adequate and working.

TABLE 2. ESTIMATED 1981 ATMOSPHERIC LEAD EMISSIONS FOR THE UNITED STATES

Source category	Annual U.S. emissions (metric tons/yr)	Percentage of U.S. total emissions
Gasoline combustion*	31,815	85.9
Waste oil combustion	754	2.0
Solid waste disposal	290	0.8
Coal combustion	863	2.3
Oil combustion	205	0.6
Gray iron production	268	0.7
Iron and steel production	484	1.3
Secondary lead smelting	573	1.5
Primary copper smelting	27	0.1
Ore crushing and grinding	296	0.8
Primary lead smelting	837	2.3
Other metallurgical processes	49	0.1
Lead alkyl manufacture	223	0.6
Type metal	77	0.2
Portland cement production	65	0.2
Miscellaneous	218	0.5
Total	37,032#	100

* Organolead vapors emitted to the atmosphere during the manufacture, transport, and handling of leaded gasoline are not included in this inventory. In the October 1983 review draft of Air Quality Criteria for Lead, it is estimated that these emissions contribute less than 10 percent of the total lead present in the atmosphere.

\# Inventory does not include emissions from exhausting of workroom air, burning of lead-painted surfaces, welding of lead-painted steel structures, or weathering of painted surfaces.

Source: U.S. Environmental Protection Agency, Environmental Criteria and Assessment Office, Research Triangle Park, N.C.

SECTION 3

CHARACTERISTICS OF LEAD AIR POLLUTION

AIRBORNE FORMS

The lead compound that is emitted is dictated by the type of source (e.g., alkyl lead compounds from petroleum refineries, lead salts from automotive exhaust, elemental lead from smelters). However, automotive exhaust accounts for 80 to 90 percent of lead emissions (see Table 2). Most research on the forms of lead in the atmosphere has been directed toward characterizing the fate of lead emitted from automobiles.

The chemical and physical form of lead emissions have important implications with regard to the sampling method used to measure atmospheric lead concentrations. Not more than 10 percent of the airborne lead is associated with particles exceeding about 2 μm diameter (Little and Wiffen 1978). Cars driven at normal speeds emit aerosols mainly in submicron sizes. For a vehicle operating on leaded fuel at idle, 20 mph, or 30 mph, the mode of the particle size distribution occurs between 0.03 and 0.05 μm. At 50 mph, the particles are slightly smaller. Although secondary aerosol formation causes a significant change in the size distribution, the size distribution from auto emissions is in close agreement with the size distribution of particles collected near a freeway (Miller et al. 1976). Additional findings regarding lead emissions to the atmosphere are summarized in Appendix A.

SOURCES OF EMISSIONS

Development of a monitoring strategy requires recognition of the emission sources. Procedures for preparing source inventories are described in various other EPA guideline documents, e.g., Development of an Example Control Strategy for Lead (EPA-450/2-79-002, OAQPS No. 1.2.123) and Supplementary Guidelines for Lead Implementation Plans (EPA 450/2-78-038). An updated revision to the latter document, Supplementary Guidelines for Lead Implementation Plans--Updated Projections for Motor Vehicle Lead Emissions (EPA-450/2-83-002), should also be noted. Emission inventories will be useful to identify the lead sources that must be included in the surveillance plan.

The primary sources of lead to the atmosphere are automotive emissions and waste oil incineration (see Table 2). An estimated 86 percent of lead emissions to the atmosphere were due to automotive emissions from combustion of leaded gasoline, based on 1981 data. The relative amount of lead emitted to the atmosphere due to automotive emissions will decrease as unleaded gasoline becomes the predominant fuel for automobiles. Coal combustion and primary lead smelting contributed 2.3 percent each. Waste oil combustion contributed 2.0 percent of the atmospheric emissions. All other categories of stationary sources contribute 1.5 percent or less.

Although highways are the main sources of lead emissions, major facilities for lead production and refining and major industrial consumers of lead can also be important local sources. Domestic ore, produced from eight mines in Missouri, accounts for 87 percent of the domestic production. Mines in Idaho and Colorado contributed 12 percent of the 1981 ore production. Of the five primary lead smelters operating in 1981, the largest smelter is located in Herculaneum, Missouri. Other primary lead smelters are located at Boss, Missouri; East Helena, Montana; El Paso, Texas; and Glover, Missouri.

Consumption or uses of lead in the United States for 1981 are shown in Table 3. Manufacture of storage batteries consumes the overwhelming share of lead production. The use of lead in petroleum refining (nearly 10 percent of the amount produced) is of concern to atmospheric concentrations of lead, because most of the lead emitted to the atmosphere is from automotive emissions. Lead emissions from automotive exhaust may be diminished by the reduced use of leaded gasoline in conformance with the phasedown regulations established by EPA in 40 CFR Part 80 and by the decrease in the number of automobiles being driven that may use leaded gasoline. The use of unleaded gasoline is projected to increase from 50 percent of the total gasoline sold in 1980 to 81 percent of the gasoline sold in 1990 (see Table 4). Additional data on lead production and consumption trends and the location of lead producers and refineries in the United States are given in Appendix B.

METEOROLOGICAL INFLUENCES

The meteorological influences that need to be considered in selecting monitoring sites can be described by a dispersion climatology that encompasses those atmospheric parameters that affect the distribution of ambient concentration. The parameters of primary concern are wind advection, horizontal dispersion, and vertical mixing. With the exception of advection (i.e., surface winds), direct measures of these parameters are not routinely made in most areas. The important fine structure needed to characterize significant air pollution transport is generally not observed and must be inferred indirectly (e.g., Hewson 1976, Holzworth 1974, and McCormick and Holzworth 1976). It is important to consider what regular data are available and what additional parameters are needed.

Wind direction is the most obvious meteorological parameter influencing the concentrations that will be observed. Wind speed influences the observed concentrations by the rate of dilution of the emissions as well as rate of transport while undergoing dispersion. Seasonal changes in wind patterns are frequently observed at most U.S. cities. Changes in seasonal wind patterns, apparent from climatological wind roses, are an important consideration in selecting lead monitoring sites because the lead standard is based on a quarterly average.

TABLE 3. USES OF LEAD--U.S. DATA, 1981

Lead consumption--1981	Metric tons	Percent of total
Metal Products		
Ammunition	49,514	4.2
Bearing metals	6,922	0.6
Casting metals	18,582	1.6
Pipes extruded products	8,829	0.8
Sheet lead	19,355	1.7
Solder	29,705	2.5
Storage batteries	770,152	66.0
Other metal products	50,648	4.3
Pigments		
Paints	16,316	1.4
Glass and ceramic products	44,339	3.8
Other pigments	19,510	1.7
Chemicals		
Petroleum refining	111,367	9.5
Miscellaneous uses	21,862	1.9
TOTAL	1,167,101	100.0

Source: Bureau of Mines Yearbook, 1981.

TABLE 4. PROJECTED U.S. USE OF LEADED AND UNLEADED GASOLINE

Year	Percent of total gasoline sold	
	Leaded	Unleaded
1975*	85	15
1980*	50	50
1985†	33	67
1990†	19	81

* Source: Chemical & Engineering News, No. 27, p. 12, 1980.

† Source: Federal Register, Vol. 47, No. 210, p. 49329.

Monitoring sites may be selected by reviewing the frequency of wind directions. River valley locations tend to have a high frequency of up-and-down-valley air flow patterns due to channeling of the air along the valley, especially during times when stable atmospheric conditions exist. Wind patterns influenced by topographic features show a high frequency of wind directions determined by the terrain-dominated circulation pattern. The high frequency of the terrain-dominated wind directions will influence the long-term average concentration.

The mixing height is frequently considered a seasonable variable, with lower mixing heights occurring in the fall and winter when the atmosphere is more stable than during the spring and summer. Low mixing heights caused by atmospheric temperature inversions frequently occur in low-lying areas and valleys. A sampling site placed in a locality with a high frequency of low mixing heights may, over a period of months, result in a higher pollutant concentration than would be observed from a site located on a hill or level terrain.

Advection

For most monitoring objectives, advection is adequately defined by the near-surface wind (speed and direction) measured at or adjusted to a reference height of 10 m above ground. Routinely available observations from the National Weather Service consist of short-term averages taken hourly or every 3 hours. Although these are useful, vector averages based on continuous recordings over 1-hour periods are more desirable where they are available.

The frequency of air flow directions is an intuitively appealing siting tool. One of the most useful summary depictions of wind flow shows the frequency of occurrence of wind directions, with a breakdown of wind speed by classes within each directional interval and is known as a wind rose (see Figure 1). By convention, wind directions are denoted by the sector from which wind is blowing. Wind roses may be constructed on an 8-sector basis, a 16-sector basis, or a 36-sector basis. Wind roses are commonly constructed for annual, seasonal, or monthly distributions. Under some circumstances, wind roses are devised to study winds under critical conditions. For example, STAR* summaries offer a joint frequency distribution of winds and atmospheric stability. These are available from the National Climatic Center# and may be compared for various time periods (e.g., see Figure 2). Additional categories

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* STability ARray, a broad-based algorithm for determining stability in the Tower atmosphere using estimates based on winds and cloudiness. See Doty, Wallace, and Holzworth (1976).

\# U.S. Department of Commerce, National Oceanic and Atmospheric Administration, Environmental Data Services, National Climatic Center, Federal Building, Asheville, N.C. 22801.

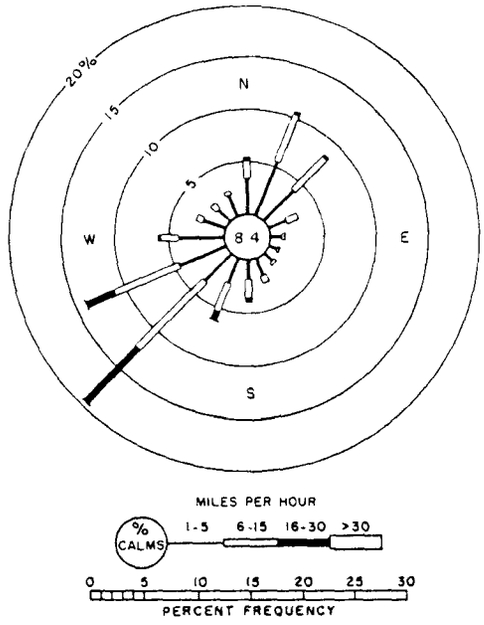

Figure 1. A typical wind rose with wind speed information (Slade 1968).

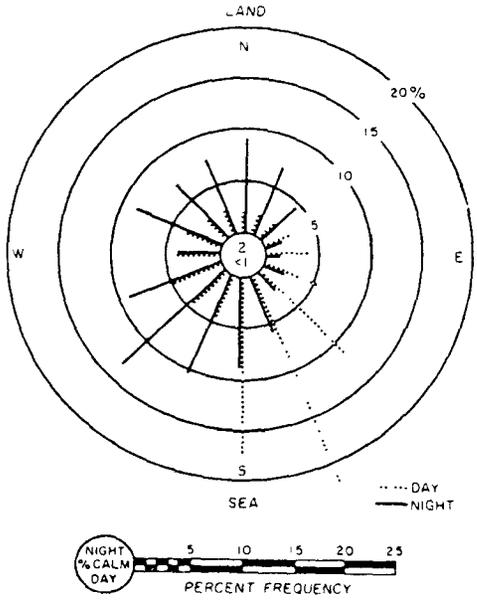

Figure 2. A day-night wind rose showing, in this case, the diurnal effect of the sea breeze (Slade 1968).

of wind roses include winds under important pollutant index levels, distribution of persistent 24-hour winds, and distributions within key parts of the day (i.e., morning versus afternoon).

Dispersion

Dispersion is the resultant effect of atmospheric turbulence to actively dilute source material. Direct measurements of the three-dimensional wind fluctuations that manifest turbulence are rarely made. Instead, various methods of characterizing turbulence based on theoretical and empirical relationships are employed. The most common system is based upon associations among wind speed, solar insolation, and cloud cover. Many operational models accept this type of data directly, and manual techniques have evolved to treat these as well (see Turner 1970).

Mixing Height

Mixing height defines the vertical extent of mixing. Ground-based and low-level inversions are the principal limiting factors. Mixing height is determined from a thermodynamic analysis of vertical temperature soundings. These soundings are routinely performed at 0000 GMT* and 1200 GMT each day at a number of locations throughout the country.

Other Parameters

Additional parameters that may be useful are listed below:

- Precipitation--to relate to scavenging processes
- Air temperature--to be applied to plume rise estimates.

TOPOGRAPHICAL INFLUENCES

Uncomplicated (e.g., level, uniform terrain) settings for sampling are rarely encountered. Distortions of the normal flow of air from the sources to the monitor are caused by irregularities in the terrain and other physiographic features. Two major factors in this regard are:

- Aerodynamic diversion--flow around and over obstacles. Distortion of the flow field may be severe during moderate to strong synoptic winds.

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* GMT means Greenwich Mean Time. The relation of GMT to U.S. standard times can be determined by noting that 0000 GMT = 1900 EST = 1800 CST = 1700 MST = 1600 PST.

- Local circulations--mountain-valley winds, land-sea breezes, and the like that may prevail when synoptic influences are sufficiently weak. Under these conditions, flow patterns within the scene may "wall off" subareas. Transport and dispersion estimates at one place are unlikely to reflect air motions elsewhere.

These factors will always influence the monitoring site selection. However, because the standard for lead is based on average concentrations measured over a calendar quarter, many of the terrain-induced influences may be averaged over the sample period when the primary objective is to compare air quality with the Federal standards. The influence of terrain and physiographic features will be more critical when sampling for shorter periods (especially less than 24 hours) and for source-oriented monitoring. Some of the more salient considerations regarding terrain and physiographic influences are described briefly in the following paragraphs.

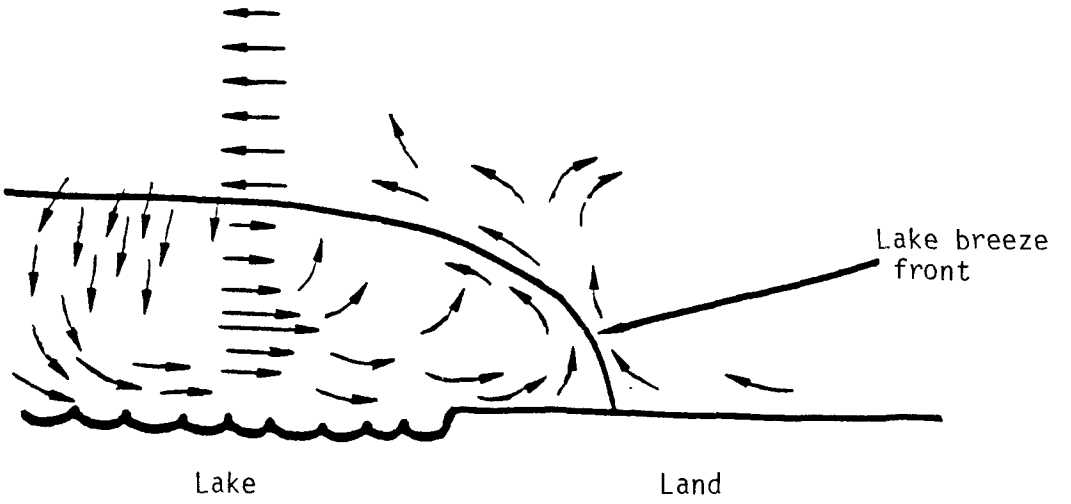
Topographic Elements

Topographic elements become a factor when their influences extend into the neighborhood scale (horizontal size order of kilometers). Because the ratio of downstream aerodynamic effect to obstacle height is on the size order of 10 to 1, obstacles on the order of 100 m will influence horizontal sizes of the order of 1 km. The central problem that terrain introduces is the added detail impressed upon the advection/dispersion field. That is, a simple pattern that may be replicated consistently over level terrain becomes distorted by three-dimensional perturbations in the presence of substantial terrain relief. The principal types of flow distortion that occur include separation flow on the downwind side of ridges when the flow is perpendicular to the ridge, channeling of air flow by valleys, and local circulations caused by differential heating of adjacent terrain slopes.

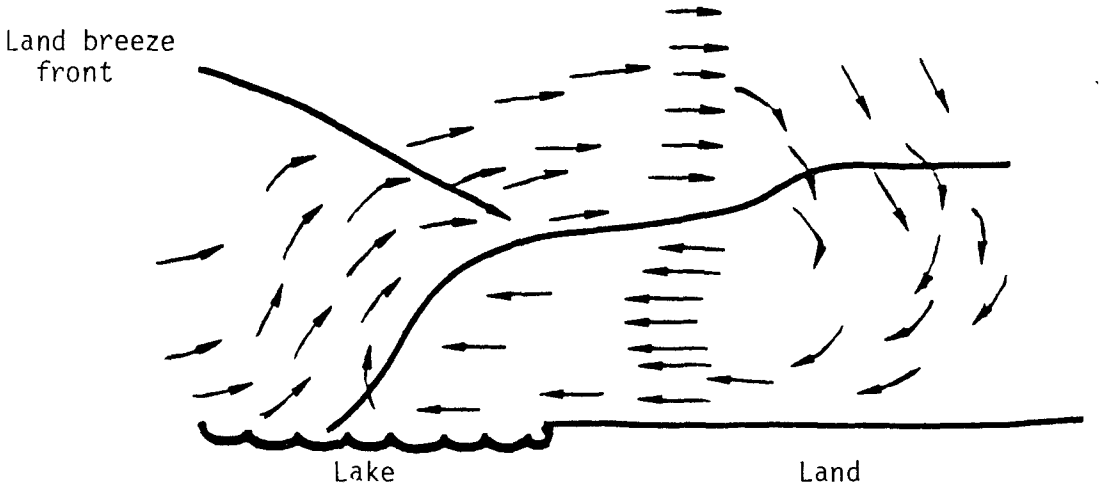
Coastal Settings

In coastal settings, during periods of light synoptic winds accompanied by a sufficiently strong thermal contrast between water temperatures and land temperatures, a land/sea breeze circulation (or land/lake breeze) will control air motions in the vicinity of the shoreline.

Figure 3 displays the characteristic circulation patterns associated with a lake (or sea) breeze (3a) and a land breeze (3b). This circulation system is not static. As shown in Figure 4, the convergence zone migrates inland as the land surface heats up. The intensity of the sea breeze may increase through midafternoon, but dies out after sunset as the land surface rapidly cools. At night, the land breeze sets up, but is generally less vigorous because thermal contrasts are smaller.



a. Lake breeze



b. Land breeze

Figure 3. Characteristics of lake coast air flow.

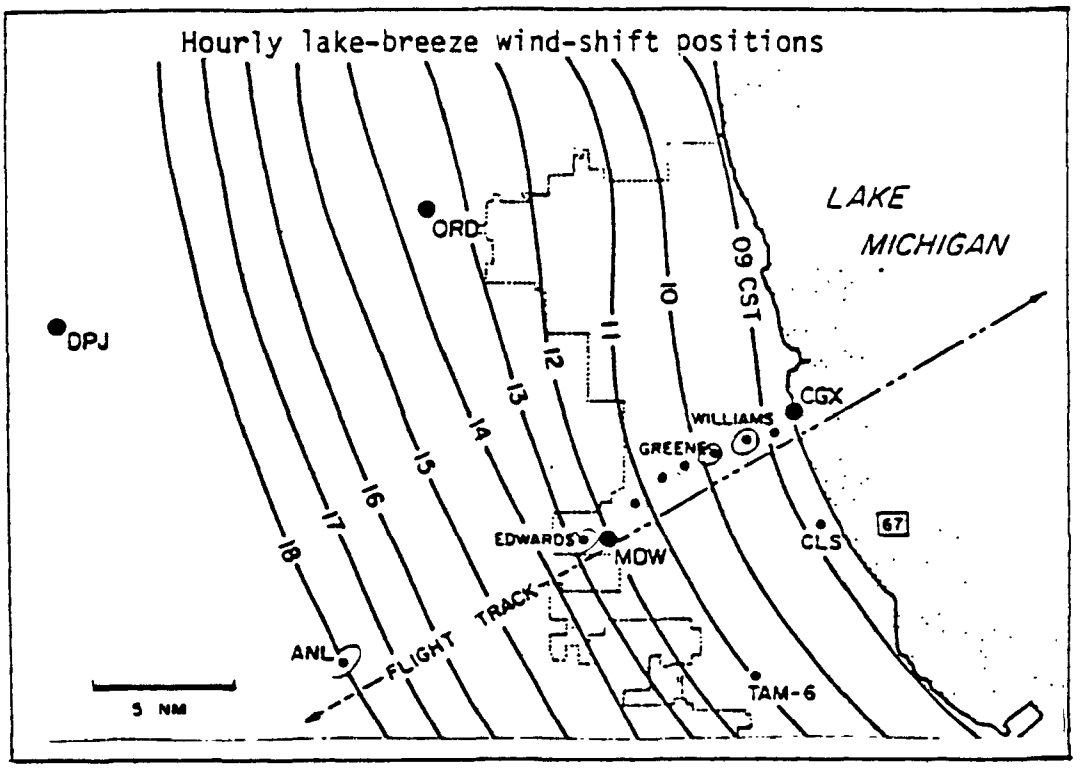


Figure 4. Hourly positions of lake breeze front of August 13, 1967 (Lyons and Olsson 1972).

The primary impact of this system is to recompose a coastal monitoring scene into at least two siting domains: one area subject to the land/sea breeze effects, another outside of this influence. The size and extent of the land/sea breeze-affected subarea can be assessed in a number of ways. An obvious factor of contrast is the horizontal distribution of wind directions on appropriate days; however, few areas have sufficiently detailed meteorological networks to define the horizontal extent of the area and the change in size of the affected area with time. A more reasonable approach is to use air temperature and relative humidity patterns to identify sites that are affected. A distinctive signature will be observed in hygrothermograph recordings that define the passage of the lake/sea breeze front.

Small-Scale Obstacles

Wind deflection around and over obstacles is a concern in selecting specific sites in an urban area, because the effects occur on the microscale. As shown in Figure 5, air does not simply slip past an isolated structure. There are three distinguishable zones of air around a building:

1. Displacement zone--where streamlines are deflected upwind and outward, remaining so for some distance

2. Wake zone--where streamlines gradually recover original configuration

3. Cavity zone--return flow in the immediate vicinity of the downwind side.

In terms of site selection, this effect is of obvious importance if an intervening obstacle contains a strong enough source to generate a ground-level impact that would be assigned to a source further upstream--particularly if monitoring were to unwittingly take place in the cavity zone. This effect is further complicated when many such obstacles are placed together, as shown in Figure 6.

Urban Effects

In addition to the effects of individual buildings, a city induces large-scale modifications to the local wind field. These modifications have a bearing on site selection, due to the heat island circulation.

When a heat island circulation exists, there is a convergence zone over the center of the city and a return flow into outlying areas, as illustrated in Figure 7. This circulation pattern is most pronounced at night when differential radiative cooling rates favor higher temperatures in the urban center. The circulation pattern is generally weaker during the day when urban/rural thermal contrasts are not as strong.

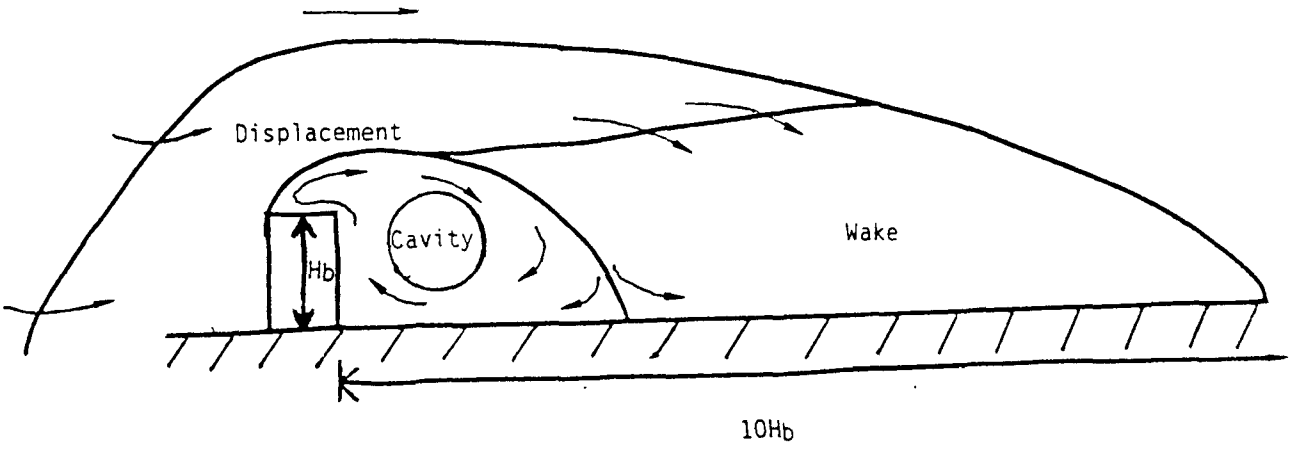


Figure 5. Flow zones around a building.

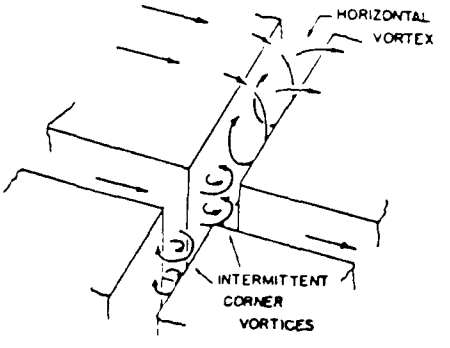


Figure 6. Flow characteristics among multiple buildings.

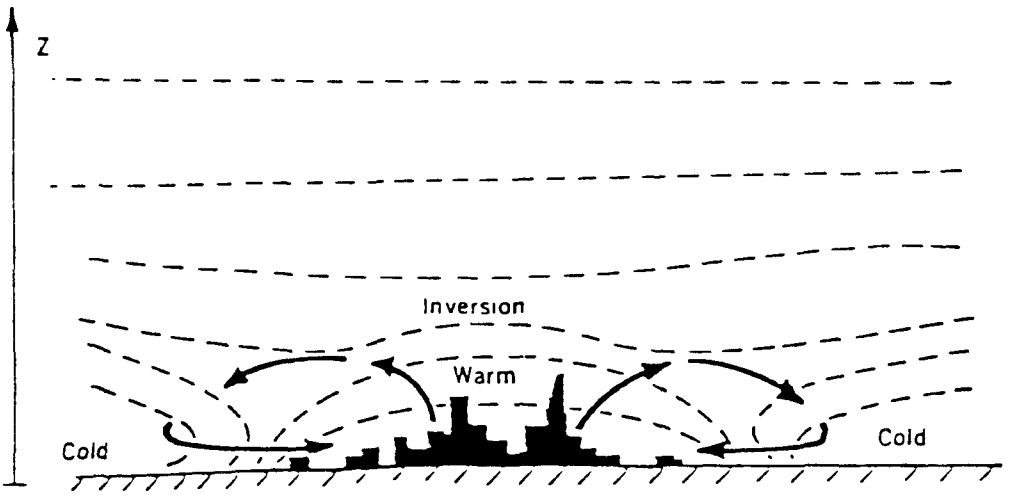


Figure 7. Idealized urban heat island air flow (after Landsberg 1975).

Under sufficiently strong winds, the heat island circulation is overwhelmed. Oke and Hannel (1970) have developed a simple relationship between the threshold wind speed to prohibit the circulation and relative city size. Oke and Hannel's empirical formulation is as follows:

$$U_{lim} = 3.4 \text{ Log}P - 11.6$$

where P is the population number. Thus, a large urban area whose population is counted in the millions can exhibit a heat island circulation even if regional winds are quite strong. Although this relationship showed a high correlation (94 percent variance explained) for the cities studied, it should not be treated as an absolute measure. Each urban setting will have its own idiosyncracies due to local terrain, presence of water bodies, or other factors.

OBSERVED PATTERNS

The highest concentrations of lead air pollution have been observed in the vicinity of major point sources, such as those listed in Table 5, and near major highways and traffic interchanges. A map of the locations of point sources listed in Table 5 will identify areas of concern for monitoring. Development of a lead emissions inventory following the procedure described in detail by Smith et al. (1979, pp. 5-19) is recommended if this has not been done. Emissions of lead are also recorded in the Hazardous and Trace Emissions System (HATREMS) data bank, and this source may also be of some help.

Lead emissions from automobiles are obviously significant. Guidance for estimating automotive emissions is provided in EPA document number

TABLE 5. SOURCES OF ATMOSPHERIC LEAD

Mining and milling--lead ore
Primary lead production
Primary copper production
Primary zinc production
Secondary lead production
Storage battery production
Gasoline additives
Solder
Cable covering
Type metal
Brass and bronze manufacturing
Waste oil combustion
Municipal incineration
Sewage and sludge incineration
Coal combustion
Distillate and residual oil combustion
Steel production
Gray iron foundaries
Cement production
Pigments
Silicomanganese electric furnaces
Ferromanganese electric furnaces--blast furnaces

EPA-450/2-78-038a. Preparation of an emissions density map provides some of the necessary information for determining the number and location of lead monitors.

Many studies have been conducted to determine the pattern of lead air pollution resulting from the dispersion and deposition of lead particles from automotive exhaust. A recent study that provides the most complete data on the distribution of automotive-generated lead particles near a highway is referred to as the Philadelphia Roadway Study (Burton and Suggs 1982). The study included horizontal and vertical arrays of samplers to collect particulate matter in fine (0 to 2.5 μm) and coarse (>2.5 to 15 μm) size fractions. The average traffic density during the observation periods varied from 2119 to 3783 vehicles per hour. The average background concentration of lead observed over a 2-month period was coarse particles 0.02 μg m^{-3} (25 percent) and fine 0.05 μg m^{-3} (75 percent), indicating lead was carried primarily on the smaller particles. The horizontal array of samplers (2 m above ground level) shows the distribution of lead in the downwind direction from the roadway to be as follows:

- The highest concentration of lead occurs at the edge of the roadway (0.15 μg m^{-3} (coarse), 0.53 μg m^{-3} (fine), 0.67 μg m^{-3} (total) above background).
- Concentrations decreased with distance from the roadway at a rapid rate out to 75 m, then decreased at a much slower rate out to 175 m.
- The downwind lead concentration stayed significantly above background levels all the way to 175 m from the roadway.
- At 175 m downwind the total lead concentration was 0.1 μg m^{-3} above background; the lead content of fine particles accounted for 0.09 μg m^{-3} of the total.

Sampling at 2, 7, and 15 m above ground level at downwind distances of 5 and 25 m showed that lead concentrations for fine and total particles were significantly above background at all six sampling locations. Lead concentrations were significantly above background concentrations for all size fractions to 175 m (the farthest distance at which sampling was done) downwind of the roadway. The Philadelphia Roadway Study included sampling only when the wind was ±45 degrees from a direction perpendicular to the roadway; therefore, the rapid dropoff of higher lead concentrations close to the roadway is more pronounced than if the samples had been collected over the full range of wind directions that actually occurred.

Daines, Motto, and Chilko (1970) reported on the distribution of lead in the vicinity of roadways with traffic density ranging from 19,800 to 58,000 vehicles per day. Samplers were placed 1.2 m above ground level and

spaced from 3.0 to 152.4 m downwind of the roadway. The relationship between lead concentration and distance from the highway was reported as a function of traffic density (see Figure 8). Concentration of lead (above background) was reduced by 50 percent between the 3- and 9-m sampling sites with a traffic density of 58,000 vehicles per day. Beyond 45.7 m distance from the roadway, the lead concentrations dropped off at a much slower rate. The gradient of lead concentration close to the roadway was much less with lower traffic density. Daines, Motto, and Chilko measured lead content in various particle sizes and observed that the percentage of lead in larger particles is above the background percentage only near the highway. The percentage of lead present in smaller particles was above background when sampled 533 m from the highway.

Daines, Motto, and Chilko concluded that a curvilinear decrease in lead concentrations (as shown in Figure 8) can describe average concentrations over long sampling periods but that the relationship may not describe short-term conditions. For short-term periods, the distance to background levels was found to be constantly changing due to meteorological parameters.

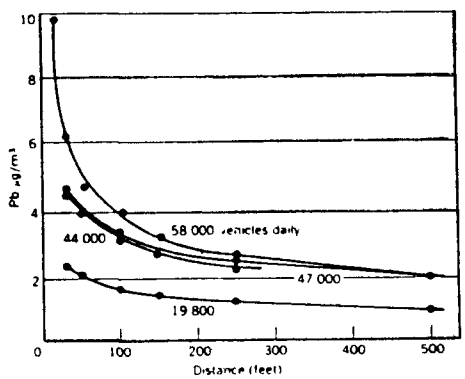


Figure 8. Observed daily mean concentrations of lead downwind of a busy highway (Daines, Motto, and Chilko 1970).

These investigators also note significant correlations of lead concentrations with wind direction. When the sampler at 9.1 m setback was downwind of the highway, the concentrations were 5.3 times higher than when the sampler was upwind; when the sampler at 22.7 setback distance was downwind, the concentrations were 3.9 times higher than when the wind direction placed the sampler upwind of the highway. A sampler at 37.9 m from the highway had concentrations 5.0 times higher when it was downwind than when it was upwind of the source. Their data indicate seasonal variations of lead concentrations over the 2-year sampling period.

The lowest seasonal average at the two setback distances (9.1 and 151.5 m) occurred during March, April, and May, while the highest seasonal concentrations appear to occur in September, October, and November. The seasonal influence may well be due to more stable conditions occurring more frequently in the fall months. The Daines study also noted that the zone of influence of the highway source is somewhat wider during the fall months when atmospheric turbulence is at a minimum.

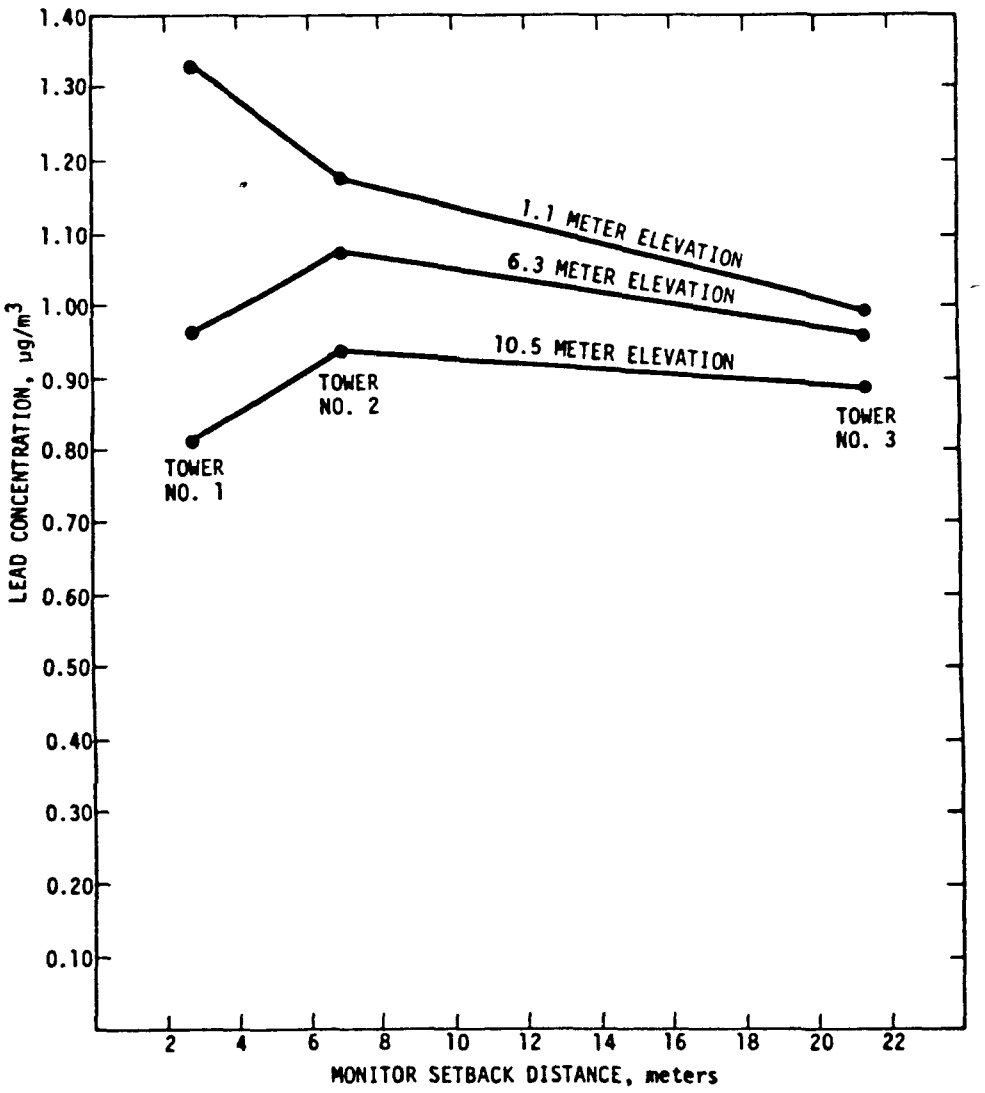
A recent field study, performed by PEDCo (1981b) to determine the spatial variability of lead from roadways, indicates that higher average concentrations were measured with a sampler inlet at 1.1 m above ground level than at 6.3-m or 10.5-m elevations at all setback distances from the highway. The experiment included setback distances of 2.8, 7.1, and 21.4 m from the highway, with sampling at three elevations at each setback distance. PEDCo also reports the lead concentrations at the upper elevation (10.5 m) were lower at the tower nearest the highway (2.8 m) than at the same elevation on the tower set 7.1 m back from the highway (see Figure 9).

Hunt (1983) reviewed the PEDCo data and noted that the confidence interval about the mean for the sampler at 6.3 m elevation and 7.1 m setback overlaps the confidence interval about the means of all other samplers in the array, except for the sampers at a setback distance of 2.8 m and elevations of 1.1 m and 10.5 m. This finding was of special interest because the sampler at 6.3 m elevation and 7.1 m setback distance was the only sampler set up within the EPA criteria for the microscale roadway-type site. Hunt noted that this indicates the EPA siting criteria are valid to obtain representative samples in the vicinity of a roadway.

The setback distance from the roadway does not appear to be as critical when comparing the means of all the 24-hour averages for the sampler placed at 6.3 m elevation, e.g., the range and means of lead concentrations observed are as follows:

Setback Distance (m)	Range ($\mu g/m^3$)	Mean ($\mu g/m^3$)
2.8	0.18-2.13	0.96
7.1	0.40-2.35	1.07
21.4	0.29-2.22	0.97

Ondov, Zuller, and Gordon (1982) report results similar to those of Daines, Motto, and Chilko, e.g., airborne lead concentrations drop off rapidly with distance from the highway, especially within the 45 m bordering the downwind side of the highway. Ondov, Zuller, and Gordon found that most of the trace elements found in motor vehicle exhaust returned nearly to the upwind concentration before reaching a site 45 m downwind. However, lead, bromine, and chlorine that are emitted on fine particles in the exhaust remained above background out to 90 m from the roadway.



Source: PEDCo 1981b.

Figure 9. Average 24-hour concentration of lead at various elevations and setback distances.

The particle sizes of aerosols containing lead are primarily small and remain airborne. Little and Wiffen (1978) observed that not more than 10 percent of the airborne lead samples collected near highways are associated with particles exceeding about 2 μm diameter. In fact, within 1.5 m of the roadway, Little and Wiffen found less than 10 percent of the airborne lead is associated with particles larger than 5 μm. Little and Wiffen's studies were conducted along two busy highways in England where the mix of automobiles and exhaust characteristics may differ slightly from those in the United States. They calculated the emission of lead from automobiles, measured the deposition of lead within 100 m of the highway, and concluded that only 9 percent of the lead emitted from automobiles at cruise speed on a level roadway is deposited within 100 m of the roadway. Their results demonstrate that although the concentrations fall off rapidly with distance, most of the lead emissions from automobiles remain airborne for long-range dispersal.

Evidence that significant deposition of lead to soil and vegetation does occur due to fallout of lead aerosols has been investigated by Motto et al. (1970). The lead content in soil increases with traffic volume and decreases with distance from the roadway. Motto's observations indicate the major effect of traffic occurs within 100 ft of the highway. Although these observations made in northeastern New Jersey do not contradict those of Little and Wiffen, they suggest that fallout must not be overlooked when accounting for lead exposure due to pickup from the soil. This is especially of concern in considering the exposure of young children.

Data collected along roadways in Texas by Bullin and Moe (1982) provide further information on the horizontal and vertical distribution of lead particles near roadways. Sample sites were selected so the prevailing wind could move perpendicular to the road section being studied; actual wind data were not provided by the author. The data reported by Bullin and Moe show the rapid decrease of atmospheric lead concentration with distance from the highway that was reported by Daines, Motto, and Chilko. In general, Bullin and Moe's results show the following:

- Lead concentrations decrease rapidly with distance from the highway to approximately 45 m from the road edge.
- Lead content is primarily in the fine particles.
- Vertical profiles of lead approximately 23 m from the road edge show a decrease in concentration with height (on fine particles) but quite low concentrations of lead on coarse particles throughout the vertical profile.

Feeney et al. (1975) determined the contribution of traffic-derived aerosols to samplers adjacent to roadbeds. The study included sampling activity near at-grade, raised, and depressed roadbed configurations. Feeney's data show lead concentrations drop off rapidly with distance from the roadbed for samplers spaced 27 m, 40 m, 100 m, and 160 m from the roadway, at the at-grade and cut-section roadbed configurations. Near the fill raised roadbed section, the concentrations remained remarkably constant out to 160 m from the road for a set of observations made in August. This is consistent with concentrations close to the source being caused by fallout of larger particles and concentrations further downwind being caused by vertical dispersion of an elevated source. Feeney reported that dispersion calculations using an elevated source for this type of configuration showed reasonable qualitative agreement with the observations.

Hutzicker, Friedlander, and Davidson (1975) have estimated that one-third of the lead exhausted to the air in the Los Angeles basin is advected out of the basin. That lead, carried out of the basin, is the principal source of atmospheric lead for regions immediately downwind of the basin. Dramatic evidence of the long-range transport of airborne lead is shown by the analysis of lead in snow from the Greenland ice pack (National Academy of Sciences 1972). Lead in the ice pack increased gradually from the beginning of the industrial revolution until 1950 when consumption of leaded gasoline in the United States increased by doubling from 1940 to 1950, then more than doubling again by 1968.

Various researchers (Bullin and Moe; Burton and Suggs; Daines, Motto, and Chilko; Little and Wiffen; Ondov, Zoller, and Gordon; PEDCo Environmental, Inc.) have reported that lead concentration falls off rapidly with increasing distance from the edge of the roadway over short-term (e.g., 1 hour) periods. In general, the zone where the rapid decline occurs has been reported at between 7 and 50 m downwind of the roadway. At distances farther than about 50 m from the roadway, the concentration levels off and declines at a much lower rate. Within the 50 m nearest the roadway, the measured concentrations can vary considerably, due in large part to the prevailing wind direction during the sample collection period.

Samples collected over a 3-month period may include wind directions ranging from perpendicular to parallel for a roadway where a monitor is located. The wind may blow from the road to the sampler or from the sampler to the road. Therefore, the reported concentration for the quarter will reflect a variety of sampling conditions.

As the wind direction becomes more aligned with the roadway, the zone of influence due to traffic emissions becomes smaller, but the peak concentrations is higher and the concentration gradient is steeper (see Figure 17

and later sections on selection of micro and middle scale monitoring sites). Figure 17 shows how the concentrations may be expected to vary along a roadway when the wind direction is at 90, 45, or 10 degrees in relation to the roadway. The peak concentration from a wind blowing at a 10-degree angle with the road would occur about 6 m from the median, but would be more than twice as high as the concentration from a wind blowing at a 90-degree angle with the road. As meteorological conditions vary over a long sampling period, the observed concentrations will reflect the average of the conditions that exist during the sampling period.

The high concentrations of lead near roadways are most prominent when the sampling period is short and the wind speed remains constant and nearly parallel to the roadway. However, the lead standard is based on a 3-month average which, due to the normal variation of meteorological conditions during the averaging period, will reduce the influence of the maximum concentration conditions. The result of using a composite of samples collected over a long period that includes a variety of sampling conditions is to reduce the variation of high and low concentrations that is seen in short-term samples taken at the same location. Another result is that the gradient of long-term concentrations with distance from a highway is much lower than the gradient of short-term concentrations. This is particularly evident in the PEDCo observations (Figure 9). Therefore, the distance that measurements are made from a nearby highway is not as critical for measurements of the maximum quarterly mean as it is for measurements of the maximum 24-hour concentration.

In summarizing, the following observations of airborne lead concentrations are relevant to monitor siting:

- Emissions from motor vehicles using leaded gasoline are the primary source of airborne lead.
- Airborne lead is principally associated with fine particles.
- Highest concentrations occur close to roadways with high traffic density; the concentration gradient falls rapidly with distance from the roadway during short-term periods and much less rapidly over long-term periods.
- Fine particles are carried well beyond the immediate area of roadways.

Studies of patterns of airborne lead concentrations show that a significant portion of the lead from automobile exhaust is deposited near roadways, but most is transported long distances in small particles. As a consequence, the selection of lead monitoring sites must be influenced by proximity to emission sources and meteorological parameters.

SPATIAL SCALES OF REPRESENTATIVENESS

Monitoring sites required by SIPs describe a spatial scale of representativeness typically referred to as follows:

- Microscale--ambient air volumes ranging in horizontal extent from a few meters to as much as 100 m. The microscale encompasses the immediate vicinity of the monitor. In the immediate presence of lead sources, exposure may in reality be only representative of the microscale. For this reason, the microscale is the final judgmental factor in site selection and requires a site visit to make this appraisal, because maps rarely portray confounding influences in sufficient detail.

- Middle scale--ambient air volumes covering areas larger than microscale but generally no more than 0.5 km in extent. In settled areas, this may amount to several city blocks. This is essentially the lower limit of resolution for most models.

- Neighborhood scale--ambient air volumes whose horizontal extent is generally between 0.5 and 4 km. The neighborhood scale is aptly named. It is useful in defining extended areas of homogeneous land use.

- Urban scale--ambient air volumes whose horizontal extent may range between 4 and 50 km. This is frequently the most desirable representative spatial scale, because it captures an entire urban area. However, the diversity of sources that prevail within such areas argue against homogeneity at this scale.

- Regional scale--ambient air volumes whose horizontal extent ranges from tens of kilometers to hundreds of kilometers. Monitors that are unaffected by specific sources or by localized groups of sources can be representative at this scale.

- National and global scales--seek to characterize air quality from a national perspective (thousands of kilometers) or from a global perspective (tens of thousands of kilometers).

The concept of representative spatial scale is used to define a characteristic distance over which pollutant concentrations are uniform or nearly so. As a corollary, we can define homogeneous areas in which measurements performed in the relatively small air volume near a sampler (nominal horizontal extent of 1 m) can represent conditions prevailing over some much larger area.

Representative spatial scales illustrated in Figure 10 have been previously identified (U.S. EPA 1977) and are compatible with spatial scales of source areas. The scales of representativeness that will be of most concern for lead monitoring are microscale for maximum concentrations and middle or neighborhood scales for more general application.

To assess the scale of representativeness, the area must be analyzed with respect to emissions, physical setting, and meteorological and climatological characteristics.

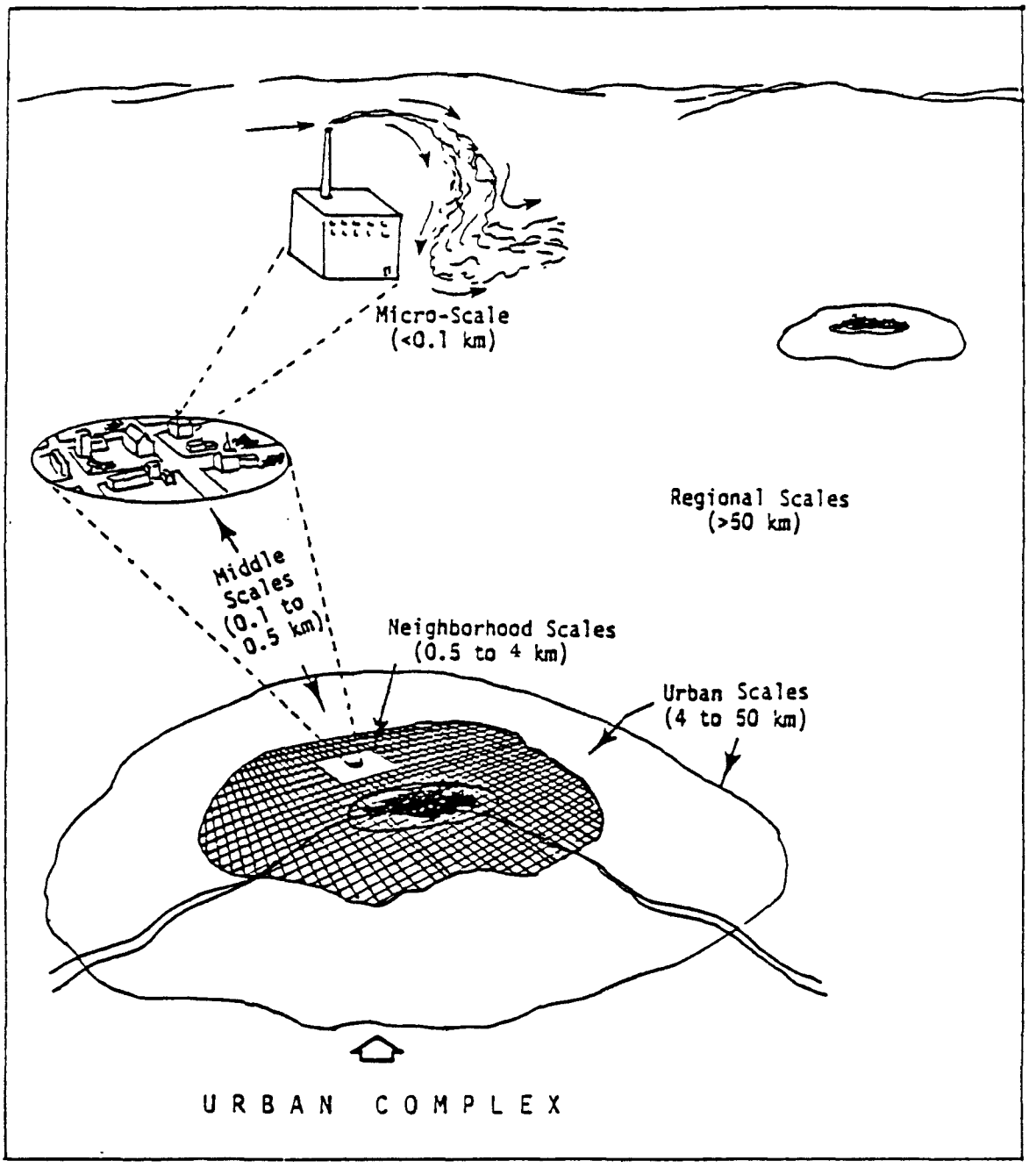


Figure 10. Illustration of various spatial scales of representativeness (Ball and Anderson 1977).

SECTION 4

SITE SELECTION METHODOLOGY

The general procedure recommended for selecting sites to monitor airborne lead concentrations is shown in Figure 11. Variations in the details performed within each step are recommended for different topographical situations and different configurations of sources of emissions.

OVERVIEW OF METHODOLOGY

The siting of monitors is part of a continuing planning cycle for monitoring. The three basic elements of the cycle are defining the objectives of monitoring, reviewing monitoring data, and making judgments about the adequacy of the air quality data. The iterative process provides flexibility in the use of monitoring resources. The need is clearly recognized in EPA's monitoring regulations and has resulted in the development of three types of monitoring activities by state and local agencies, including National Air Monitoring Stations (NAMS), State and Local Air Monitoring Stations (SLAMS), and Special Purpose Monitoring (SPM). The locations of NAMS and SLAMS must be coordinated with EPA regional offices because these must be designed to meet EPA needs in addition to state and local needs. The siting methodology is applicable to all three types of monitoring stations and will be useful to industrial operating facilities as well as air pollution control agencies.

The NAMS monitoring sites for lead will include a roadside site and a neighborhood site. The roadside site must be adjacent to and downwind of a traffic volume that exceeds 30,000 vehicles per day. Additional SLAMS sites may be established to determine that an area of special interest does not exceed the ambient air quality standard, to establish that lead control measures are effective in reducing exposure levels, or to measure background levels. The following six-step procedure for selecting monitoring sites is recommended:

1. Analyze existing monitoring data.

2. Determine adequacy of mapping analysis and/or select a modeling procedure.

3. Perform air quality modeling if necessary.

4. Determine the number of monitoring sites required to describe the area of interest.

5. Propose locations for those sites.

6. Document and update site exposure experience.

Specific suggestions for each of these steps is given in the following paragraphs.

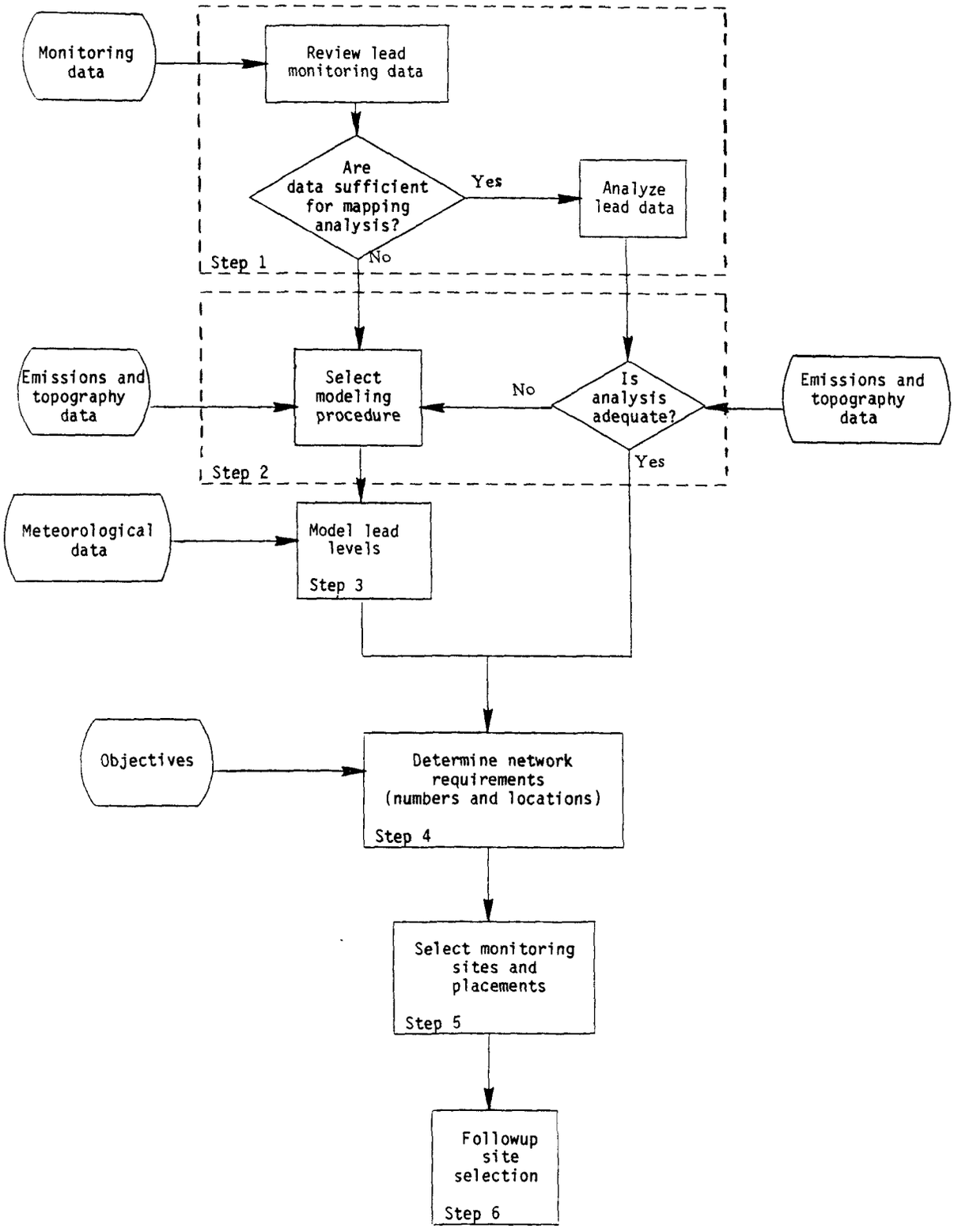


Figure 11. Procedure for selecting lead monitoring sites.

Site planning may vary in scope of responsibility and may include any of the following:

- Design multipurpose network
- Supplement existing network for specific purpose
- Design single-source impact or compliance monitoring network
- Monitor a designated area or location.

The procedure for site selection can proceed once the objectives of the monitoring effort have been established. The need for emissions maps and the meteorological and topographical influences have been discussed in the preceding section. In this section a process is presented for using the information available for site selection to develop a monitoring network that meets the operator's desired goals.

ANALYZE EXISTING MONITORING DATA

To select monitoring sites, the monitoring planner must form a conception of the spatial distribution of lead concentrations over the area of concern. If an adequate data base of ambient lead measurement is not available to meet this need, the distribution must be estimated by mathematical simulation modeling or by a reasonable, physically based qualitative analysis. The best method of estimating the distribution of air quality levels will depend on the amount, type, and quality of available information. The information of interest includes the following categories:

- Ambient lead measurements
- Locations and amounts of lead emissions
- Air pollution climatology and meteorology data
- Maps of topographical features.

The amount of lead monitoring data available to help design a monitoring network is likely to be incomplete. However, whatever data are available will be valuable. The SAROAD data base, available from EPA regional offices, is a convenient source of much of the available data. State and local air pollution control offices are also important sources of additional data and information about other data that may have been collected by nongovernment parties or in special studies. The available ambient lead observations should be critically reviewed to eliminate any data that are suspect because of poor quality control.

Mapping Analysis

Mapping the data will identify areas of special concern, e.g., locate areas of high concentrations. The analyst must decide if there are sufficient valid data within the area of concern to warrant mapping the data. If data are available from fewer than six sites, single station analysis is likely to be more practical than mapping. Mapping analysis will simply involve drawing isopleths of lead concentration. The lead concentration data must represent data from a time period common to all points and data collected by reasonably similar sampling and analytical techniques. The number and value of contours to be drawn will depend on the range of values observed and the nature of their spatial distribution. Computer graphics packages are available to perform the contouring analysis if manual analysis is not practical. Generally, about six contours will provide a useful display. However, as few as 1 or as many as 10 may be appropriate, depending on the magnitude of the range relative to the mean of the values observed. The maps will be used to identify representative spatial scales and preliminary siting selections.

Single-Station Analysis

Single station analysis of quarterly means will include analysis for trends over time, peak concentrations, number of exceedances of the standard, mean, and standard deviation. Single-station analyses may be performed to identify the significant influencing factors that affect the lead air quality levels observed. This identification process will help determine how wide an area the station represents. Conclusions drawn from one station should be compared with results from other stations in the area of interest. Trends and frequency distributions help in analyzing single-station data. Case study analyses of peak quarterly values will also be helpful.

Another useful single-station analysis is the pollution rose. The pollution rose is constructed by computing the average measured concentration for all values when the prevailing wind is in a given direction. The values may be limited to days when the wind persistence index (ratio of vector to scalar wind speed) exceeds a certain value.

DETERMINE ADEQUACY OF MAPPING ANALYSIS AND/OR SELECT A MODELING PROCEDURE

An important step in the process of selecting monitoring sites is to identify the unique local influences that are affecting air quality. The types of topographical features and the magnitudes and locations of lead emissions have a major impact on where the worst air quality levels will occur. In assessing the value of available monitoring data and in selecting an air quality simulation model, it is necessary to take these local influences into account.

While the mapping and station analysis data may be helpful in identifying the spatial distribution of lead, they may be inadequate. Having analyzed

the available data, the monitoring planner must consider whether modeling is needed to supplement the available monitoring data. Consideration should be given to gradients evident in the observations, locations of major sources, terrain, and meteorology. In most cases, the available lead observations will not be adequate for planning a new monitoring network.

The adequacy of the data analysis may be judged by whether the air quality pattern can reasonably explain the inventory of sources and the influences of terrain and meteorology. Two tests of the air quality pattern are suggested. One test involves the time history of the pattern; the other test examines the shape of the pattern of emission densities and topographical features.

If the patterns of annual means or maximum 24-hour concentrations for several years show the same shape and same locations of peaks when superimposed on each other, the pattern is consistent with time. This consistency is evidence of a stable pattern, which is a reasonable guide for planning monitoring sites. If the pattern is changing with time, the analysis may be adequate, but the reasons for the changing pattern should make sense in terms of changes in sources or in meteorological conditions. If there are no apparent reasons for the changes, modeling results should be obtained and reviewed.

Emission densities that are chronologically consistent with the air quality data should be plotted and used to generate contour patterns. Topographical features may also be located on these patterns. When the emission density contours are superimposed on the air quality patterns, there should be a reasonable relationship. A reasonably consistent pattern would be one in which the air quality pattern is offset from the emission pattern in the direction of prevailing wind flow. If the influence of major peaks in emission density are not evident in the air quality pattern, a modeling analysis may be helpful in identifying the magnitude of the pattern deformation that can be expected.

AIR QUALITY MODELING

Computer models that mathematically simulate air quality levels can provide help in selecting monitoring sites, especially where overlapping contributions from multiple sources need to be considered. The following factors influence how useful computer models will be:

- The air quality estimates are limited by the accuracy of the assumed time, location, and rate of emissions.

- The air quality estimates are also limited by how representative the meteorological data are of the area between each pair of source and receptor locations.

- The cost of assembling and preparing data and of running computer models for multiple sources can be expensive and must be carefully and knowledgeably planned.

Selecting a model to analyze lead must be done with due consideration of uncertainties that will influence the results such as limitation of the models to treat the processes that cause changes in the particle size after it is emitted from the source, limitations of the models to treat wet or dry deposition of the emitted particles, limitations of the quality of emission factors, limitations due to a constantly changing mix of vehicles using leaded and unleaded gasoline, and limitations of simulation models to treat special terrain-induced changes to the dispersion pattern.

With appreciation of the limitations mentioned, modeling analysis will be useful because lead monitoring sites are usually selected close to the emission source. The dispersion models recommended in EPA's guidelines on modeling and on lead SIPs (U.S. EPA 1978a, 1978b, and 1978c) provide the capability required for the analysis. EPA regional offices can be of considerable help in determining the value of modeling and in selecting an appropriate model.

SELECTING REPRESENTATIVE SITES WITHOUT MONITORING OR MODELING DATA

There may be situations in which it is not possible to use monitoring data or the results of a modeling analysis to define the pattern of air quality levels in an area that is to be monitored. In this case, the monitoring network can be planned by identifying representative sites on the basis of available information on sources of emissions, climatological data, and topographical considerations. Observations from other locations and previous modeling analyses of general classes of source influences may be used to select monitoring sites for these situations. Requirements for monitoring lead concentrations will cover various scales of representativeness, including micro-middle scale, neighborhood scale, regional scale and monitoring near major sources isolated from other significant sources. Steps for locating monitors for each of these four types of representative sites are suggested in Figures 12, 13, 14, and 15. The most frequently encountered situation is the roadside monitor representing the micro and middle scales.

Selecting Micro and Middle Scale Monitoring Sites

The most common lead monitoring sites will be those near heavily traveled roadways in urban areas where there are no major point sources. Monitoring will be representative of areas classified as middle scale. Figure 12 indicates appropriate steps for selecting monitoring sites for this situation.

The first step is to obtain and analyze traffic and urban development data that can be used to identify potential variations in otherwise homogeneous neighborhood-scale patterns of concentrations. Areas of high traffic density, such as major highways, shopping centers, sports arenas, amusement parks, airports, and parking facilities, need to be identified. Other known sources of lead emissions such as waste incinerators or sources that are not considered major sources should be identified. Estimates of the impact of

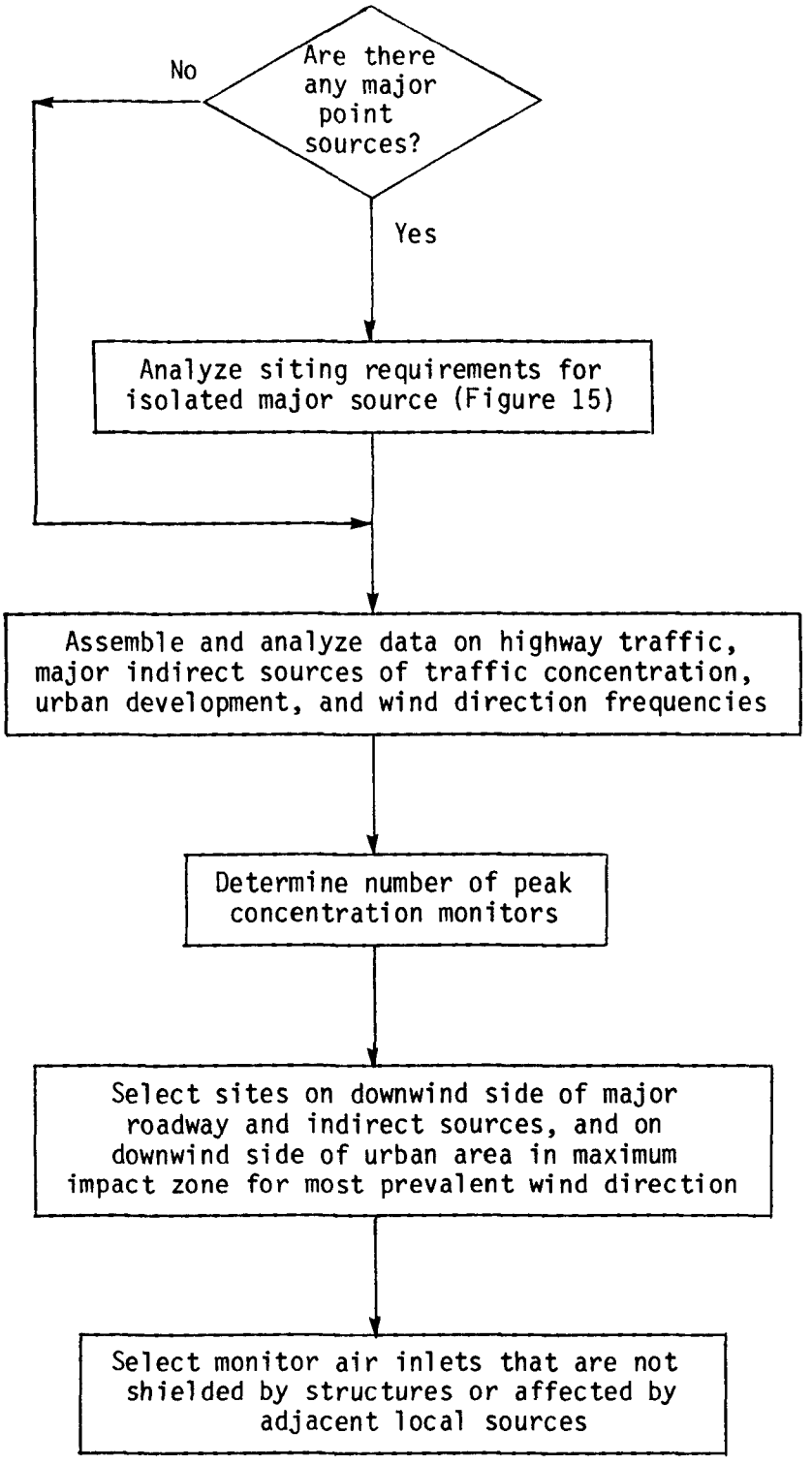


Figure 12. Steps for locating micro and middle scale monitoring sites in urban areas.

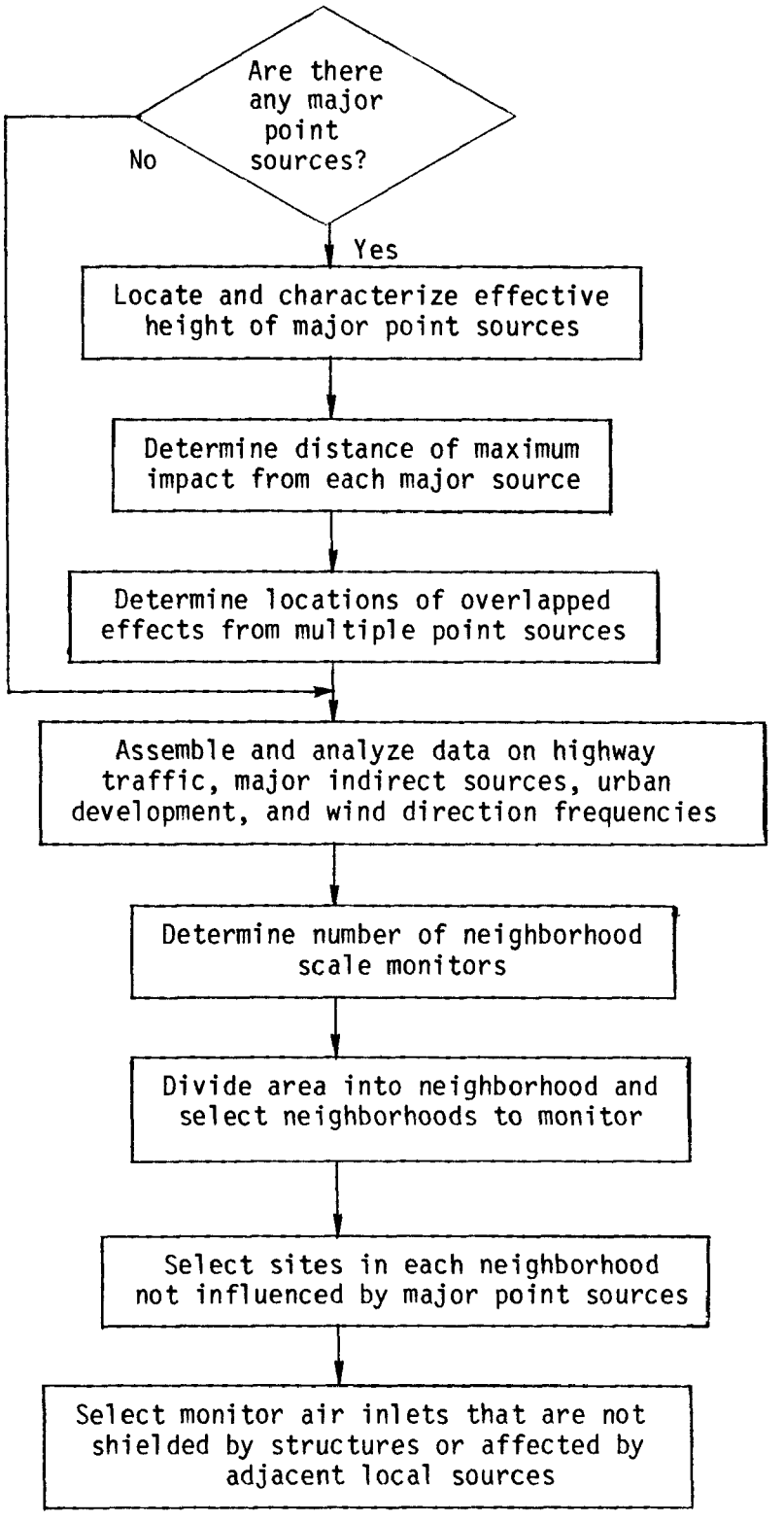


Figure 13. Steps for locating a neighborhood scale monitoring site in an urban area.

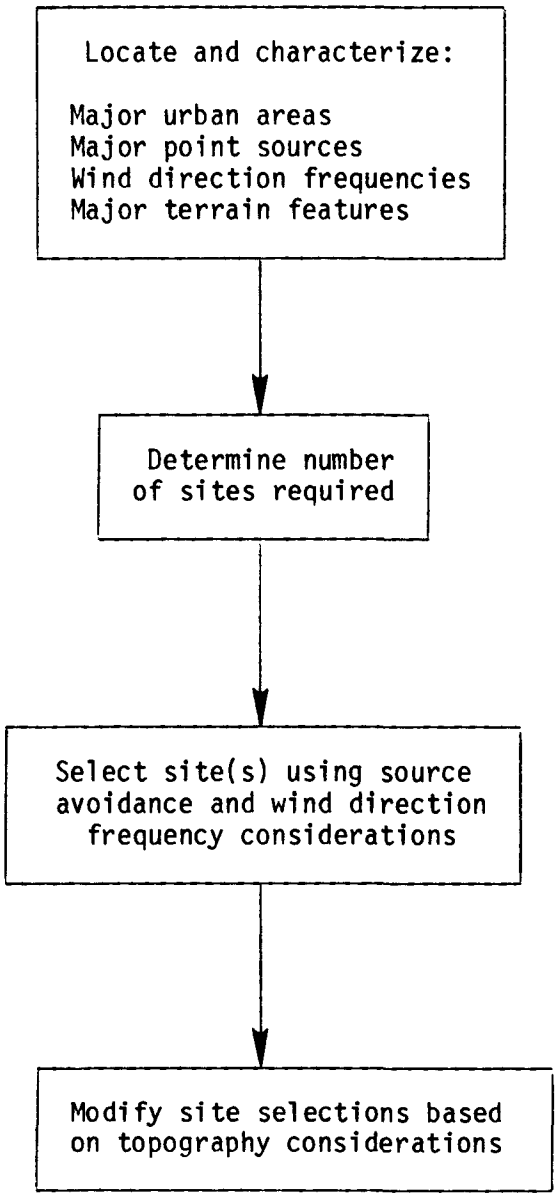


Figure 14. Steps for locating a regional scale monitoring site.

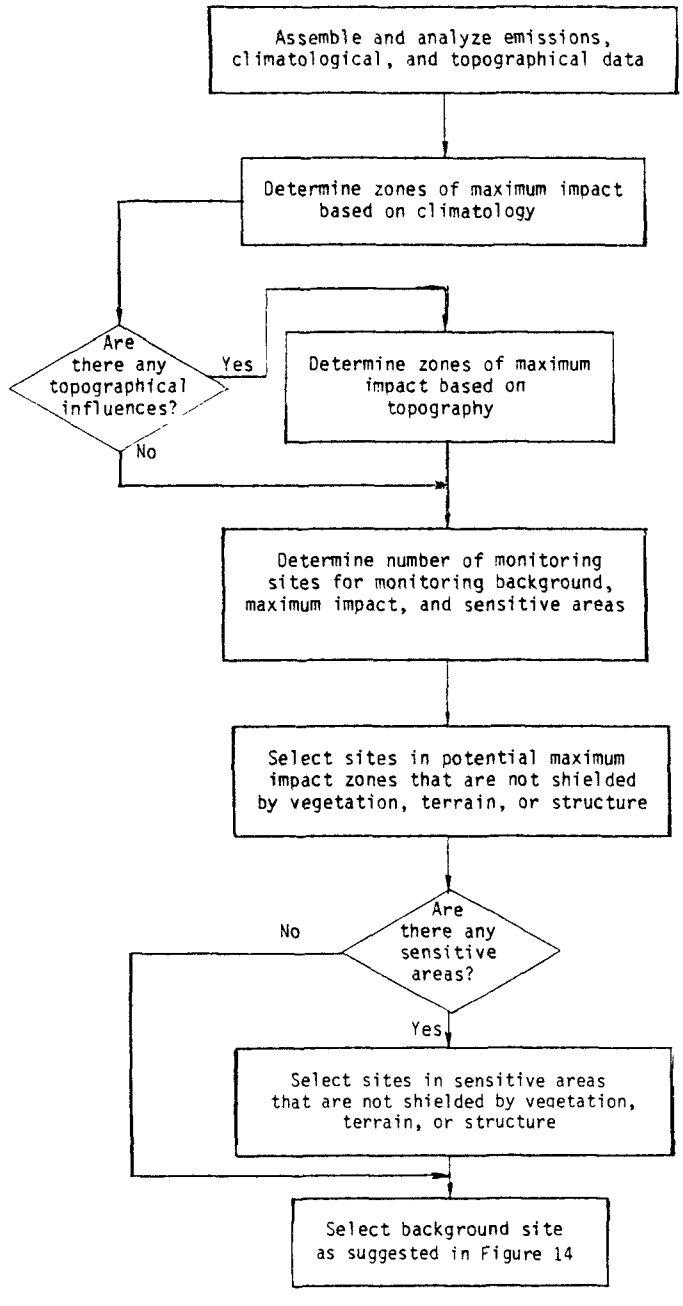


Figure 15. Steps for locating monitoring sites near isolated major sources.

lead emissions from automobile exhaust on quarterly mean lead concentrations can be prepared using the 1-hour concentration profiles for a variety of conditions shown in Figures 16, 17, and 18 as a guide. These figures indicate the areas of major impact along a highway as a function of meteorological variables. Graphs similar to these will be helpful in determining which sections of a roadway offer the greatest potential for high concentration of lead merely by inspecting the data. For instance, if a major roadway is oriented from northeast to southwest and the predominant wind speed and direction is 4 m/s from the northwest, the zone of maximum concentration would occur approximately 10 to 14 m from the median as shown in Figure 16. The concentrations shown are for a traffic density of 3000 vehicles per hour and an emission rate of 0.056 g per km per vehicle. The location of the maximum is not affected by changes in the emissions or the traffic density. The value of the maximum can be adjusted for different emission rates or traffic densities by multiplying the values read from the graph by the ratio of actual traffic or emission rate to the one shown in Figure 16. Figure 17 shows how the orientation of the highway to the prevailing wind direction affects the magnitude and location of the peak. These curves, prepared for guidance only, use calculations for 1-hour averages; longer-term averages will flatten the slope from the peak somewhat.

On the basis of the concentrations predicted for all the traffic-concentrated areas and the locations of the source areas relative to the downwind edge of the city for the most prevalent wind direction, a decision must be made on how many monitors will be used to measure the maximum lead concentration. Unless a single source or source area is clearly more significant than any other, a number of sites should be selected as potential peak concentration monitoring sites. These sites will be representative of micro or possibly middle scale areas. The monitoring site should be located as close to the source as possible without infringement or interference from the source. The most suitable sites are within 5 to 15 m of the sources on the downwind side of the prevailing wind direction. It is usually not practical (nor acceptable, on the basis of Appendix D of 40 CFR 58) to locate a site less than 5 m from a source. Generally, one site is sufficient for each source area.

Neighborhood Scale Monitoring Sites

Steps for locating a neighborhood scale monitoring site are indicated in Figure 13.

Neighborhood sites are needed to represent the areas that encompass or surround the peak concentration sites. Due to variations in the type and intensity of land uses throughout an urban area, a large metropolitan area may be characterized by well over 1000 different neighborhoods. It is possible to characterize neighborhoods in a qualitative fashion by preparing a detailed emission inventory that identifies the spatial distribution of lead emissions on a gridded basis using traffic and other relevant data. By examining the locations and magnitudes of lead emissions by gridded area in

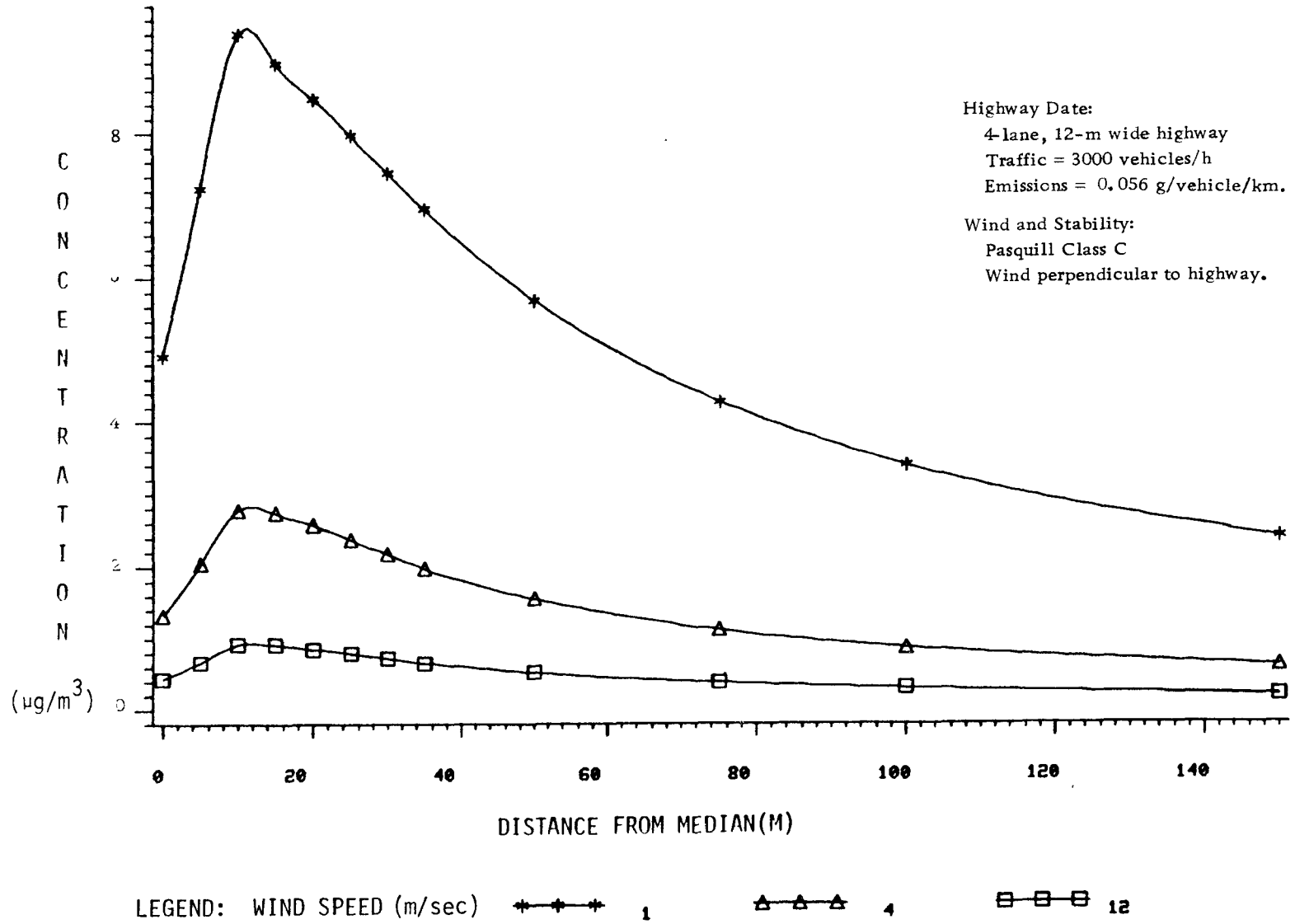


Figure 16. Concentration as a function of wind speed, computed using HIWAY2 model.

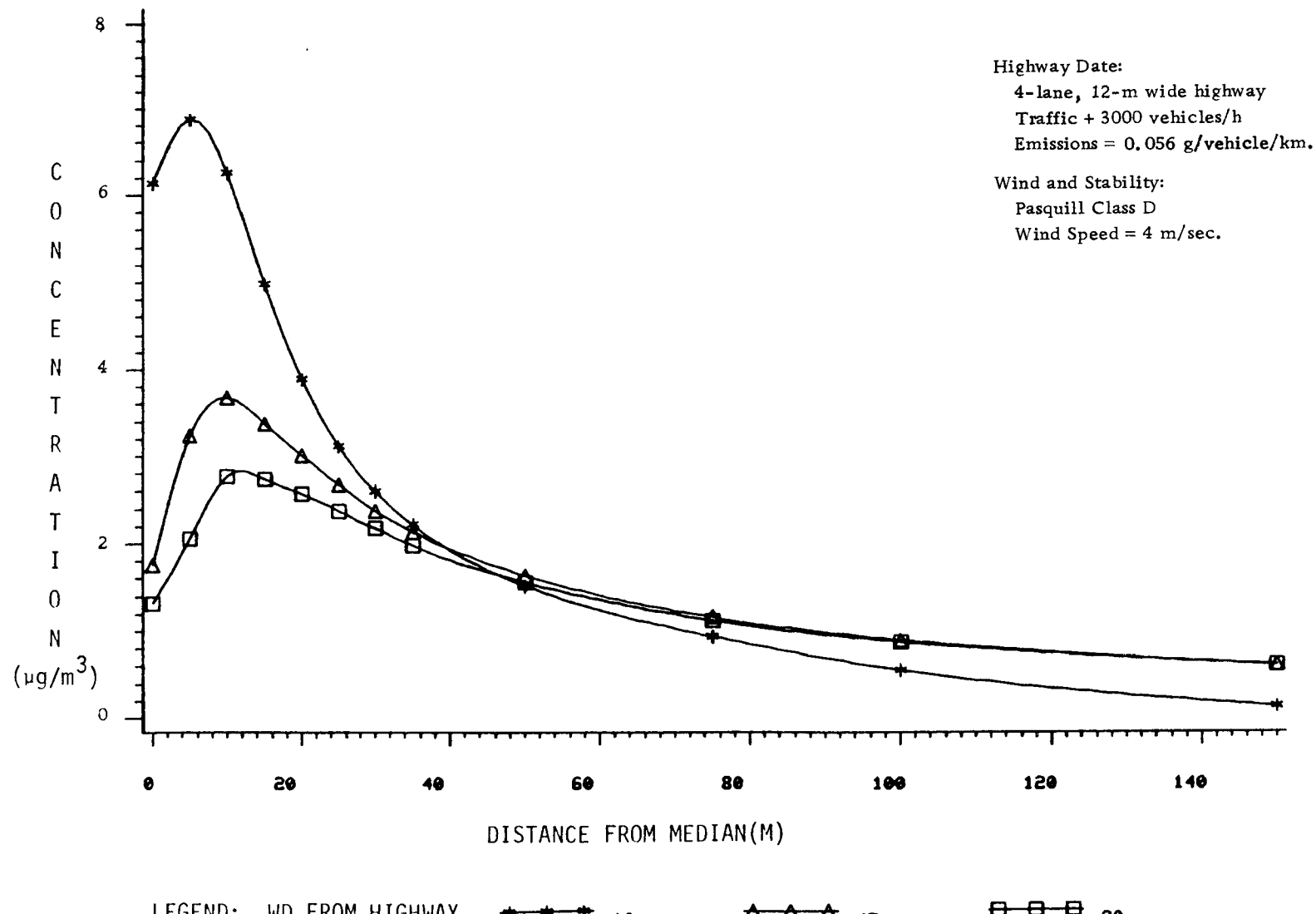


Figure 17. Concentration as a function of wind direction, computed using HIWAY2 model.

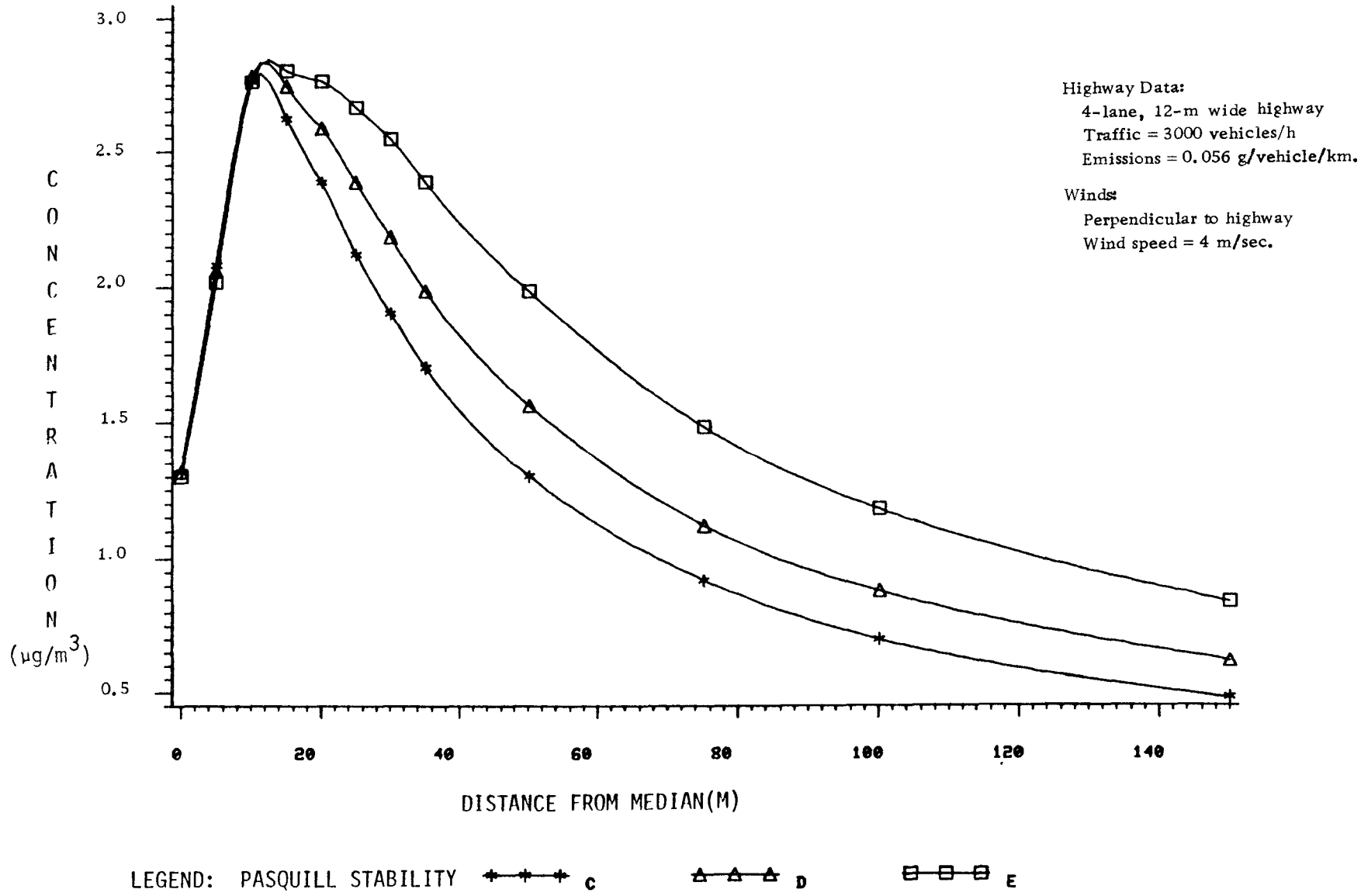


Figure 18. Concentration as a function of stability class, computed using HIWAY2 model.

relation to the climatology of wind direction frequencies, one can rank neighborhoods in terms of their expected levels of high concentrations.

Neighborhoods that encompass the middle or micro scale areas that are expected to contain high concentrations are clearly high priority neighborhoods for monitoring sites. One or two neighborhoods adjacent to the maximum concentration neighborhoods are desirable secondary sites. A third category of monitoring sites includes neighborhoods that are of special interest because of large population density, because of rapid growth expectations, or because of a highly sensitive population such as elementary school children.

Sites in the third category of interest may also meet the second category of interest. There are no firm rules to determine how many sites to monitor. Each monitoring jurisdiction must determine what its priorities are and how far down the priority list of potential sites it is able and willing to go.

Regional Scale Monitoring Sites

Regional scale monitoring sites may be needed to measure background levels of lead that are transported into the area being monitored. It is important that regional scale monitoring sites not be affected by nearby sources, which would significantly alter their scales of representativeness, for large periods of time. It may be necessary to use two or more sites to measure background concentrations when a single site cannot be found that is never influenced by nearby sources. Figure 14 suggests four steps to follow in selecting the site(s).

Monitoring Isolated Major Sources in Flat Terrain

Figure 15 suggests steps to be followed in selecting monitoring sites near an isolated major source. A distinction must be made between sources with the principal emissions from a tall stack and sources with the principal emissions from ground level. For ground-level sources, the maximum concentrations will occur immediately adjacent to the source in the most prevalent downwind directions from the source. Wind observations will easily identify the most suitable siting areas. Additional monitors may be used to help define the extent of the area near the source that has high concentrations and the neighborhood scale level of lead in the vicinity of the source. Two types of information can be helpful in determining the extent of the high impact area: (1) the relative concentration isopleths from the EPA (Turner 1970) Workbook of Atmospheric Dispersion Estimates and (2) annual wind direction frequency statistics published by the National Climatic Center.

NETWORK DESIGN

The information that will be gained from lead monitoring may include determination of the maximum concentration, the background concentration, and a determination of the area impacted by significant concentrations of lead. The primary matter of concern is to determine if the air quality standard is

exceeded, especially in areas where human exposure will occur. The discussion on selection of monitoring sites has, for the most part, addressed the issue of determining the pattern of atmospheric lead concentrations. Only in very few situations will the emissions and dispersion patterns be simple enough to require only one monitoring site to accurately reflect the maximum exposure area. Such a situation would arise if the peak concentration occurred in the same location most of the time. Complex patterns have two or more peaks that may or may not lie within a single closed contour of impacted areas of interest. Unless one peak is much higher than the others, two or more peak areas will need to be monitored.

The number of monitors needed to define impacted areas will include a minimum of two and may include six or more, depending on how large, how complex, and how definitive the impacted area is. A single, well-sited monitor, located well away from any nearby sources or source areas, may be adequate for determining background concentrations. If it is impractical to locate a monitor far away from nearby sources, it may be desirable to select two nearby monitors, one or more of which is measuring background concentrations on any given day, depending on wind direction. Because lead concentrations are measured over 24-hour periods and because the wind direction is frequently variable over a 24-hour period, this is a less desirable option than a single, well-sited monitor.

In planning and revising air monitoring plans, it is important to bear in mind that the need for monitoring data is dynamic and will change from year to year. Once the nature of the air quality pattern for lead concentrations has been established or verified, fewer stations are needed to evaluate general ambient conditions and trends. This is especially true for areas where the ambient levels are well within acceptable limits and there is no significant impact area. Reducing the amount of resources allocated to fixed monitoring stations will allow resources to be reallocated to meet other special-purpose monitoring needs.

Previous monitoring and modeling provide a first estimate of the lead air quality patterns, but a large amount of uncertainty may still exist regarding both the shape and the magnitude of the pattern. Therefore, some monitoring resources should be allocated to verifying the assumptions made regarding the pattern. Installation of temporary monitors can be a useful approach to confirming the results or patterns observed from the previous study. A monitoring site should be established in any area where there is a good probability the lead concentration may exceed the standard and human exposure will occur.

SPECIFIC SITE SELECTION

Once a general area for a monitoring site has been selected, it is necessary to select a specific location for the sampling operation. The intake for the monitor must be representative of the siting area, as close to the breathing zone as possible, and not biased abnormally high or low by influences that are representative only of the probe intake.

Some requirements for monitoring sites are established by existing rules and guidelines. The guidance for siting high-volume samplers that are used for collecting airborne lead is given in Appendix E of 40 CFR 58. The following guidelines for siting were promulgated in Section 2 of Appendix E (40 CFR 58):

- 2-15 m above ground, as near to breathing height as possible, but high enough not to be an obstruction and to avoid vandalism
- At least 2 m away horizontally from supporting structures or walls
- Should be 20 m from trees
- Should not be near furnace or incinerator flues
- No nearby obstructions to air flow due to buildings, structures, or terrain, at least in directions of frequent wind.

DOCUMENTATION

With any worthwhile activity, documentation of the work is necessary to substantiate the data that have been or will be produced. When a monitoring site is established, a description of the site should be prepared. The site description should include the following information:

- Exposure diagram
  - Horizontal depiction showing location relative to nearby streets, buildings, and other significant structures, terrain features, or vegetation
  - Vertical depiction showing location relative to supporting structures, including buildings, walls, etc.
- Height of sampling intake above ground level
- Microinventory map showing locations of roads (with traffic counts), open fields, storage piles, and any visible emissions within 500 m of sampler
- List of all inventoried point and area sources within 1.5 km of sampler and all major point sources within 8 km of sampler
- Types of meteorological and other air monitoring equipment operated at the site
- Make, model, and serial number of the sampler.

SECTION 5

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APPENDIX A

A SUMMARY OF RECENT FINDINGS ON THE CHARACTERISTICS OF LEAD EMISSIONS

Automotive exhaust contributes up to 90 percent of the measured atmospheric lead. As a result of the dominating effect of automotive emissions on atmospheric lead, a considerable amount of research has been directed toward characterizing the exhaust particles and their environmental fate. Provenzano (1978) has discussed a number of factors that influence automotive lead emissions. Among the variables listed by Provenzano are the following:

1. The rate of lead emissions is dependent upon the mode of vehicle operation, "...at higher speeds larger percentages of lead burned are emitted. Emission rates averaged 33 percent at 60 miles per hour but ranged from 27 to 71 percent at 45 mph to from 49 to 91 percent at 70 mph."

2. Average lead emission rates varied from 28 to 45 percent for cars tested under city-suburban driving conditions.

3. Some of the retained lead is re-entrained into the exhaust stream at high speeds. Full throttle acceleration to high speed can produce emissions of 900 to 2000 percent of the lead burned.

4. There is an increase in the lead emission rate as vehicles accumulate mileage. Exhaust lead is deposited and accumulated in the exhaust system.

5. Less lead is added to gasoline refined for winter use than is added to gasoline for summer use. Less lead is added to gasoline sold in the northern states.

Finally, Provenzano states, using 1975 data, for the entire United States over 60 percent of motor vehicle lead emissions occur in urban areas.

Habibi (1973) has reported on the character of vehicular exhaust particulates, noting the following:

1. Reports from early literature (prior to 1958) indicate lead particle sizes range from 0.01 micron to several millimeters in diameter. Under city driving conditions, 50 to 75 percent of lead exhausted is associated with particles 5 microns and smaller in diameter. The size of lead particles from the 1957 data has been questioned, however.

2. The effects of mileage accumulation on the automobile was characterized in two ways: (a) Lead salt emission increased with increasing mileage on the vehicle. (b) Particle size distribution shifted; a higher percentage of lead was emitted on larger particles as mileage accumulated on the vehicle.

3. The results of data including tests on 26 cars indicated 55 percent of the exhausted lead is associated with particles >5 μm equivalent diameter.

4. Particle size and exhaust particle composition are related. Large particles have a composition similar to exhaust system deposits and are 60 to 65 percent lead salts; the major lead salt is PbBrCl. The submicron particles contain more soot and carbonaceous material with the primary lead salt being $2PbBrCl \cdot NH_4Cl$.

Boyer and Laitinen (1975) state the mass emission rate of filter particulates is about a factor of 20 higher when lead gasoline is burned in an automobile without a catalytic converter than when nonleaded gasoline is burned under the same conditions, but the mass of ether extractable organics stayed about the same, indicating the increase in mass is due to inorganic substances. In the same paper, they reported that although the gasoline consumption rate doubled for a vehicle operating at 60 mph, as compared with 30 mph, the filter particulate emission rate was approximately 6 times greater. Boyer and Laitinen reported that the filter particulates loading was much higher for tests with leaded gasoline than for nonleaded gasoline. The experimental design included sampling the engine exhaust with a cyclone sampler to obtain a gross size separation of particles. Sampling was also done with a filter sampler. The emission rate for particles collected by cyclone was much more variable than for particles collected by filter. They suggested this may mean the formation of small particles is dependent on nonvariable factors such as engine condition, but the formation of large particles is more dependent on variable factors such as condition of the exhaust system.

Lead, as organic compounds, was reported by Rohbock, Georgii, and Muller (1980) to be less than 1 to 9 percent of the total atmospheric lead based on a study in Frankfurt/Main area in Germany. They note that gaseous lead/particulate lead ratios are low at a site near a highway where automobile engines are hot, whereas higher gaseous lead/particulate lead ratios occurred in areas where automobile engines were cold and evaporative emissions would be more likely. Higher ratios of gaseous to particulate lead were measured in urban and residential settings (e.g., 2 to 7 percent of total lead was gaseous lead). Inner-city air samples were 4 to 15 percent gaseous lead; air in a garage contained about 30 percent gaseous lead of the total lead. DeJonghe and Adams (1980) measured organic lead as 2 to 24 percent of total lead, depending to a large extent upon the siting of the sampler. Samples from rural locations had less than 1 percent organic lead, whereas samples

collected near a gasoline station were 24 percent organic lead. It may be deduced that gaseous lead may in some situations be an important source of exposure to some portions of the population. The reference method for measuring lead concentrations does not account for the gaseous lead because this portion of the atmospheric lead passes through the filters.

Gerstle and Albrinck (1982) have reported the content of metal found in typical municipal sewage sludges. Lead content of sludge was reported to range from 80 to 26,000 mg lead per kg dry sludge. Gerstle and Albrinck report that a large incinerator (~200 t/d) could emit from 20 to 30 pounds of lead per day depending on the amount of lead in the sludge and the efficiency of the emission control system. The form of the lead may be lead oxide, lead chloride, or elemental lead. Lead chloride is classified as intermediate in volatility. At the temperatures that are reached in an incinerator (980° C, 1800° F), lead is potentially volatile. Greenberg, Zoller, and Gordon (1981) reported lead emissions of 2.0 ± 0.84 g/d from a sewage-sludge incinerator with a capacity of 540 to 610 kg of dry sludge per hour (~14-16 t/d). The emission control devices at that incinerator were 99 percent efficient; the lead content of the dry sludge was reported as 430 ± 20 μg lead per gram of dry sludge. Gerstle and Albrinck reported the lead content of dry sludge from 16 cities to average 1940 mg/kg; the median lead content from those 16 cities was 600 mg/kg.

APPENDIX B

PLANT LOCATIONS AND PRODUCTION TRENDS FOR LEAD PRODUCTION AND REFINING

An air monitoring strategy can be developed more rationally if there is some appreciation for the production, use, and consumption of lead. Therefore, some basic data regarding the amount of lead produced and consumed in the United States are provided. The data presented in Table B-1 indicate a decline of approximately 15 percent in the amount of lead produced and consumed over the past 5 years. The Bunker Hill smelter-refinery at Kellogg, Idaho, terminated operations in 1981. Locations of primary and secondary lead smelters are listed in Tables B-2 and B-3. Figure B-1 shows the locations of lead mines, and primary and secondary smelters in the United States. Mines and smelters listed in Tables B-2 and B-3 are keyed to the locations shown in Figure B-1.

TABLE B-1. U.S. LEAD PRODUCTION AND CONSUMPTION IN METRIC TONS

	1977	1978	1979	1980	1981
Production					
Domestic ores	537,499	529,661	525,569	550,366	445,535
Primary lead refined	486,659	501,643	529,970	508,163	440,238
Foreign ores	62,041	63,530	45,641	39,427	55,085
Consumption					
Primary and secondary	1,435,473	1,432,744	1,358,335	1,070,303	1,167,101

Source: Minerals Yearbook 1981--Lead, Bureau of Mines, U.S. Department of Interior.

TABLE B-2. PRIMARY LEAD PRODUCTION AREAS IN THE UNITED STATES

State	No.		District	County
			Mines	
Missouri	1		Buick	Iron
	2		Magmont	Iron
	3		Viburnum	Iron
	4		Fletcher	Reynolds
	5		Milliken	Reynolds
	6		Brushy Creek	Reynolds
	7		Viburnum	Washington
	8		Indian Creek	Washington
	9		Viburnum	Crawford
	10		West Fork	Reynolds
Idaho	11		Lucky Friday	Shoshone
	12		Bunker Hill	Shoshone
	13		Star Unit	Shoshone
Colorado	14		Leadville Unit	Lake
	15		Bulldog Mountain	Mineral
			Smelters (S) and refineries (R)	
Idaho	1	S&R	Kellogg	Shoshone
Montana	2	S	East Helena	Lewis & Clark
Texas	3	S	El Paso	El Paso
Nebraska	4	R	Omaha	Douglas
Missouri	5	S&R	Glover	Iron
	6	S&R	Boss	Iron
	7	S&R	Herculaneum	Jefferson

Source: Lead Industries Association, Inc., New York, New York.

TABLE B-3. SECONDARY SMELTERS AND REFINERIES IN THE UNITED STATES

State	No.	City
Alabama	1	Leeds
	2	Troy
California	3	Carson
	4	City of Industry
	5	City of Industry
	6	Los Angeles
	7	San Francisco
Florida	8	Jacksonville
	9	Tampa
	10	Tampa
Georgia	11	Atlanta
	12	Atlanta
	13	Cedartown
	14	Columbus
Illinois	15	Chicago
	16	Granite City
	17	McCook
	18	Savanna
Indiana	19	Beech Grove
	20	East Chicago
	21	East Chicago
	22	Indianapolis
	23	Muncie
	24	Whiting
Kansas	25	Olathe
Louisiana	26	Baton Rouge
	27	Heflin
Minnesota	28	Eagan
	29	St. Louis Park
	30	St. Paul

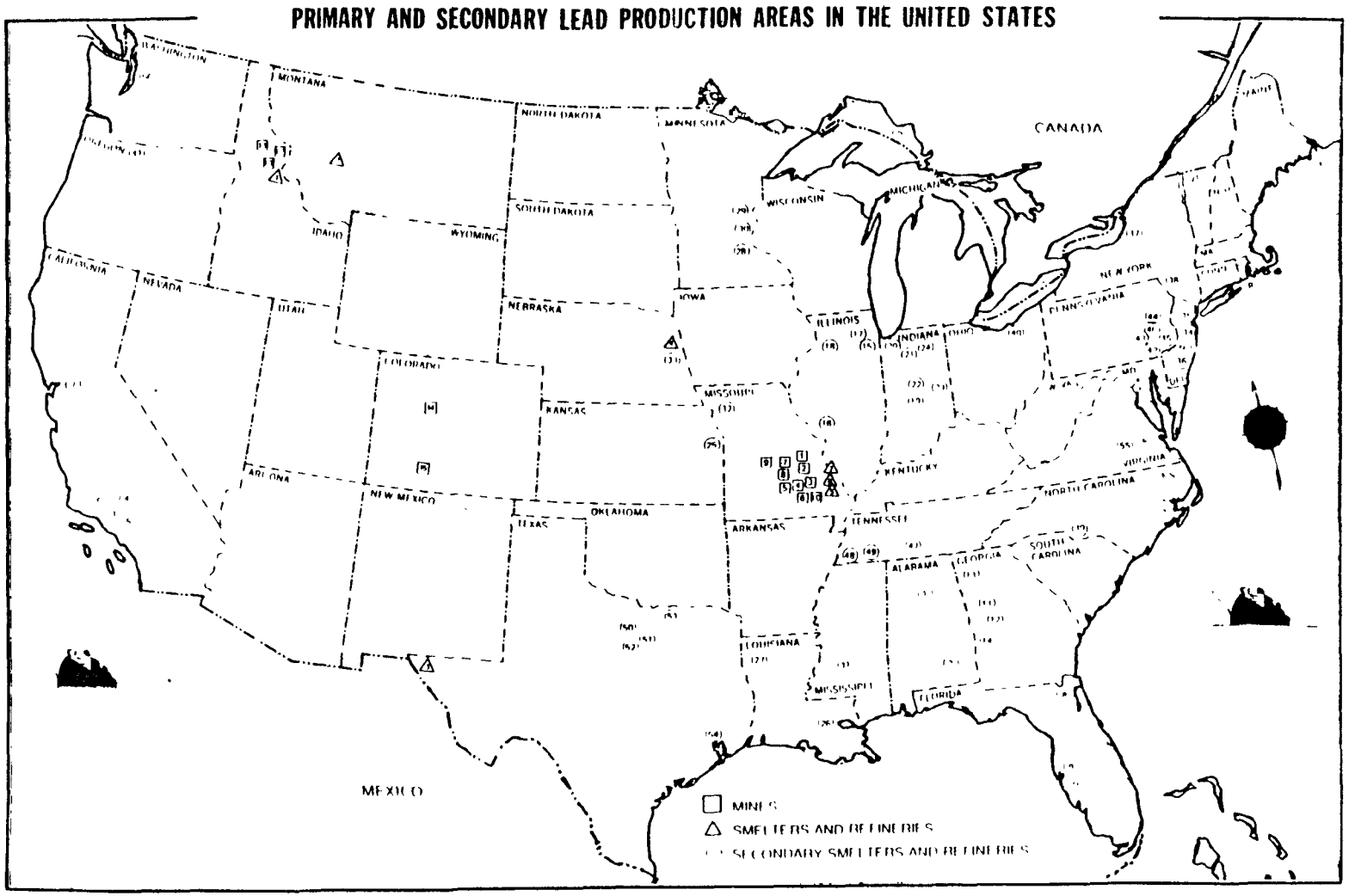
(continued)

Source: Lead Industries Association, Inc., New York, New York.

TABLE B-3. (continued)

State	No.	City
Mississippi	31	Florence
Missouri	32	Forest City
Nebraska	33	Omaha
New Jersey	34	New Brunswick
	35	Newark
	36	Pedricktown
New York	37	DeWitt
	38	Walkill
North Carolina	39	Charlotte
Ohio	40	Cleveland
Oregon	41	St. Helenes
Pennsylvania	42	Lancaster
	43	Lyons Station
	44	Nesquehoning
	45	Philadelphia
	46	Reading
Tennessee	47	College Grove
	48	Memphis
	49	Rossville
Texas	50	Dallas
	51	Dallas
	52	Dallas
	53	Frisco
	54	Houston
Virginia	55	Richmond
Washington	56	Seattle

Source: Lead Industries Association, Inc., New York, New York.



Source: Lead Industries Association, Inc., New York, New York.

Figure B-1. Lead production areas in the United States.