Design for Air Monitoring Surveys Near Highways

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Because it is required by the National Environmental Policy Act of 1970, monitoring of air pollution near highways has been recently undertaken by many state transportation departments, private highway builders, and transportation planning organizations. This paper discusses the design of surveys for air monitoring near highways and includes an overview of the systems approach to survey design and equipment requirements in addition to definitive methods for the selection of sampling sites and the numbers of samples required. The methods presented for site selection employ results from modeling the atmospheric diffusion of highways. In addition to modeling, survey design requires expertise in analytical instrumentation, data acquisition, meteorological data interpretation, statistics, and systems engineering. This paper shows how to integrate these various disciplines so that cost-effective surveys for air monitoring can be designed.

In recent years, the monitoring of ambient air has become an important part of many environmental impact statements because it is a requirement of the National Environmental Policy Act (1). The provisions of this act have also made air quality surveys more complex: They require comprehensive planning to ensure that prescribed objectives can be attained in the shortest possible time and at the least cost, as well as adequate planning and good survey design since the actual monitoring is an expensive and time-consuming undertaking that requires skilled personnel and sophisticated analytical equipment.

A well-designed air quality survey (2, 3) will

1. Set the objectives of the air monitoring investigation;
2. Determine the physical parameters to be measured;
3. Set the network specifications, including the location of air monitoring stations, the duration of the study and sampling schedules, and the air-sampling method to be used;
4. Set the specifications for the individual stations in the network, including the equipment needed to conduct the study, the method and frequency for equipment calibration, and the methods for recording data; and, finally,
5. Determine the type of data analysis to be performed and the method for reporting data.

It should be recognized that these steps are interdependent and that a properly designed survey would consider each step, in order, in terms of its effect on the other parts of the survey design.

One of the most critical elements of a survey design for air monitoring is the location of sampling sites. Criteria for site selection have not been well defined in the literature; they consist mostly of recommendations that are subjective and general. Experience and technical judgment have been essential for determining the number and location of sampling sites.

It is the objective of this paper to present methods for applying available mathematical dispersion models to assist in site-selection decisions. This paper provides a discussion of the role of air monitoring in assessment of environmental quality and of the planning and management process. A detailed methodology for the selection of air monitoring sites near highways is then provided.

Most of the available information concerning the location of an individual sample or a continuous monitoring station is directed toward ensuring that a representative sample, free of undue influence from the immediate surroundings, is obtained (4, 5, 6, 7). The guidelines consider (a) the uniformity of site locations in terms of height above ground level; (b) avoiding constraints to airflow from any direction; (c) the selection of surrounding areas that are free of stacks, chimneys, or other local emission points; and (d) the most suitable elevation for a representative sample, especially in residential areas—3 to 6 m (9.8 to 19.7 ft) is suggested.

The need for nationally standardized criteria for selecting locations for monitoring stations has been suggested (8) since there have been indications that air monitoring stations located near city streets give drastically different results when moved only a short distance. Because of the complex nature of the spatial variations in urban carbon monoxide (CO) concentrations, a dual monitoring system has been proposed that consists of a background exposure station location outside the range of influence of nearby traffic and a pedestrian exposure station that has a sampling probe above the sidewalk. The

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pedestrian exposure station provides a means for measuring the individual's exposure to CO levels on downtown streets. The background exposure station measures the CO concentrations that occur over a large physical area of the city.

The design of an air monitoring network involves a trade-off between what is considered desirable from a strictly technical point of view and what is feasible with the available resources. The following guidelines suggested by the Environmental Protection Agency (EPA) (4) are important criteria for selecting network sites.

1. The priority area is the zone of highest pollutant concentration within the region. One or more stations should be located in this priority area.
2. Close attention should be given to densely populated areas within the region, especially in the vicinity of heavy pollution.
3. The quality of air entering the region must be assessed; therefore, stations must also be situated on the periphery of the region. Meteorological factors such as frequencies of wind direction are of primary importance for determining the locations of these stations.
4. The effects that future development will have on the environment should be considered; therefore, sampling should be undertaken in areas of projected growth.
5. A major objective of surveillance is to evaluate the progress made in attaining the desired air quality; therefore, sampling stations should be strategically situated to facilitate the evaluation of the implemented control tactics.
6. Air quality information that represents all portions of the region should be available.

MONITORING AND MODELING IN AIR QUALITY ASSESSMENT

To determine the environmental impact of a new or existing highway and to provide for routine source surveillance or the operation of a control program for intermittent air pollution, it is necessary to estimate air pollution concentrations by monitoring, by modeling, or by a combination of these methods. The interrelation between monitoring and modeling that can lead to an optimum design for an air quality survey is shown in Figure 1. As it indicates, the purpose of mathematical models is to quantitatively combine the effects of source strength and meteorology to describe the resulting ambient air pollution concentration. Source strength is affected by a number of variables that include the size of the source, variable emission rates, and the efficiency of equipment employed for air pollution control. The meteorological factors that affect air pollution control are wind speed and direction, atmospheric stability, inversion height, and terrain features. To be useful, mathematical models must be able to account for all these parameters.

Air pollution models vary in complexity from simple models that measure atmospheric dispersion on a microscale to sophisticated models that measure multisource factors on a mesoscale by describing transport, dispersion, and photochemical reactions of pollutants. Microscale models are used to estimate the ambient pollution levels near a single source or project ($C_{project}$). Mesoscale models are used to estimate the areawide impact of a proposed source or project or the background concentrations ($C_{background}$) due to other sources.

Ambient air pollution concentrations occurring downwind of a source consist of two components: pollution contributed directly by the source and the background. In most analyses, these components should be determined separately. The total air quality impact, represented in Figure 1 by the concentration C_x, is equal to the sum of the background plus the concentration contributed by the highway under study. Whenever other major highways are nearby, their contribution of pollution must also be added to the highway contribution. The objective of most air quality surveys is to determine the maximum value of C_x as accurately as possible and to compare that concentration with the National Ambient Air Quality Standards (9).

The role of monitoring is to measure ambient pollution concentrations, meteorological parameters, and source strength parameters. Air monitoring at carefully selected sites provides for direct measurement of background concentrations. Measurements of meteorological or source strength parameters can be used to verify model input data or to validate models that measure the atmospheric dispersion of air pollution. Measurements of source strength, meteorology, and both microscale and mesoscale (background) air pollution concentration are required to validate the microscale models. The measurements of source strength, meteorology, and air pollution must all be representative of areawide conditions to validate the mesoscale models.

A basic premise of the design approach presented here is that air quality measurements can best be used to supplement and verify air quality predictions from mathematical models since the spatial and temporal variations of air pollution concentration that occur in the environment are too complex to resolve by monitoring alone (the numbers of stations required approaches infinity). For this reason, the site-selection methods presented are designed to provide data for model validation. Validated models can then be used to determine spatial variations in pollution levels since they can be used to estimate concentrations even at sites where monitoring was not performed. Thus, a greater amount of air quality information can be derived from models than by monitoring alone.

OBJECTIVES AND PLANNING FOR AN AIR MONITORING SURVEY

Figure 2 shows an overview of the important decision points required in the initial phases of planning a survey. In general, the broad objectives of any study for monitoring air quality are to determine the extent of the existing air pollution problem and to validate any mathematical models or assumptions used to estimate the future impact on air quality of a new highway or change in emissions from an existing highway. More specific objectives may include

1. Checking for compliance with ambient air quality standards at critical locations,
2. Determining when and where the worst case background pollutant concentrations occur within the impact area,
3. Validating or calibrating a mesoscale model to accurately predict future background concentrations, and
4. Validating or calibrating a microscale model to accurately estimate the air quality impact of a proposed facility or change in emissions from an existing facility.

Consideration should also be given to the potential exposure of people to air pollutants. If sensitive receptors such as children, the elderly, or the sick are to be exposed to additional pollutant concentrations after the completion of a proposed project, it may be important to document the current levels of exposure of sensitive populations so that the future levels of exposure can be more accurately estimated.

Once the objectives of the air quality study are de-

Figure 1. Interaction of modeling and monitoring to assess the air quality impact of a project.

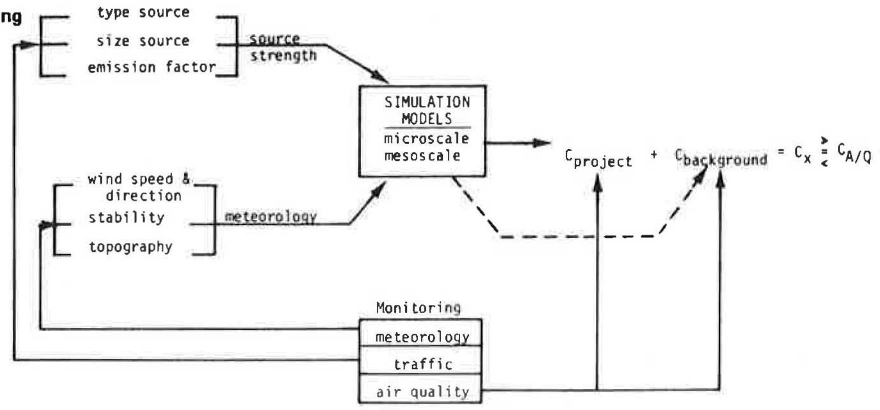
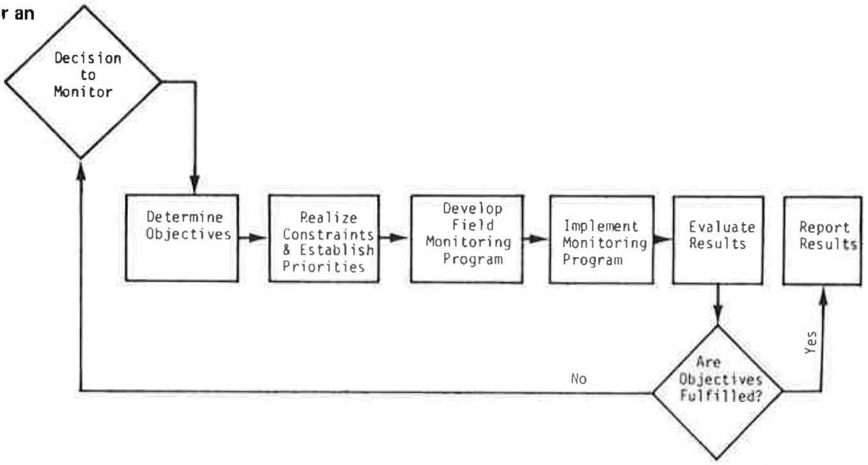


Figure 2. Planning and management process for an air quality survey.



termined, it is possible to develop and implement a field monitoring program that will fulfill the objectives. By working within the constraints of money, manpower, and time, priorities can be set in terms of the objectives that can be realistically met within the cost constraints imposed on the air quality study. If available resources are severely limited, a study for monitoring air quality may not be advisable at all because a poorly planned, poorly financed, and hurriedly conducted air-sampling survey will not provide data that can be easily evaluated in terms of the survey objectives and may thus detract from, rather than improve, the technical quality of the final report.

AIR MONITORING NETWORK SPECIFICATIONS

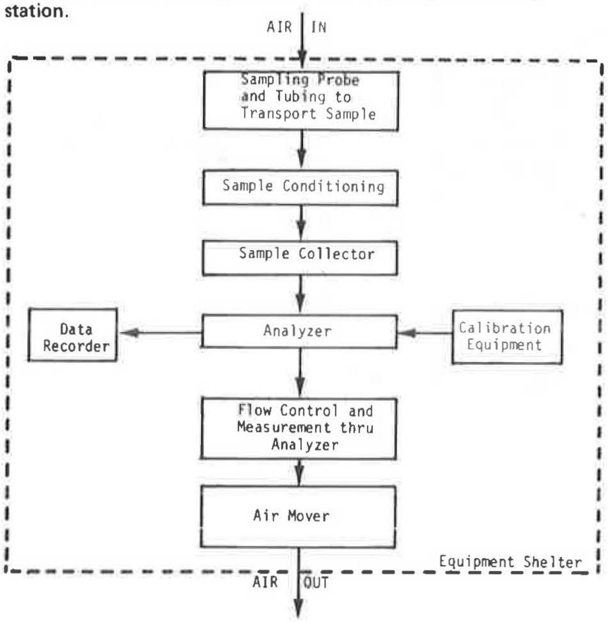
The sum total of all air monitoring stations, meteorological stations, calibration equipment, and data-acquisition equipment required to meet the total objective of an air quality survey represents the air monitoring network. To understand the interrelation between the component parts of the network and to allow decisions to be made about the number and type of each piece of equipment and their interdependence in meeting the survey objectives, a set of specifications for the network must be developed early in the planning process.

Network specifications for air monitoring should include (a) the number of sites to be monitored, (b) the air pollution and meteorological measurements required at each site, (c) the duration of the study, and (d) the manpower requirements. Network specifications should be determined in light of the known limitations of the physical, engineering, economic, and human factors, as well as the limitations due to completion deadlines or time delays in equipment procurement. Time, manpower, and budget constraints may significantly affect the feasibility of using specific techniques or equipment to conduct the study.

By considering all of the stated sampling requirements and available resources, the types of air quality and meteorological monitoring equipment to be employed, including the total number of samplers and analyzers for each type of measurement to be performed, can be identified. A consideration of possible equipment trade-offs should also be evaluated, e.g., the number of continuous analyzers versus semiautomatic samplers versus manual sampling methods. Obviously, the mobility of air-sampling equipment should be considered and factors such as the high capital costs of continuous analyzers versus the high operating costs of semiautomatic or manual methods should be optimized for cost-effectiveness.

The calibration system to be used for ensuring that accurate data will be obtained from all the analyzers should be considered next. Each station can be equipped with calibration hardware, or calibration procedures can be employed either when portable instruments are calibrated at a central laboratory or when permanent instruments are calibrated with a portable calibration device. The choice of calibration equipment will depend on the number of stations, the distance separating the stations, and the frequency with which calibrations are performed. A typical integrated calibration system might consist of sophisticated apparatus used for dynamic calibration in a central laboratory and several portable calibrators or span gas bottles that are used for frequent on-site single-point calibration checks.

Figure 3. Hardware components of an air quality monitoring station.



Once the air monitoring and calibration specifications have been fixed, the requirements of the data-acquisition system can be evaluated. The data rates and data quantities generated by the monitoring network should be determined as a whole to calculate the data-handling capacity needed for the overall sampling network. Data-recording equipment that is ideal for a single monitoring station may be too expensive for use at numerous monitoring stations. Frequently, it is less expensive to replace a variety of special devices with a central general-purpose control element, even though the speed and flexibility requirements of the system do not require it. Data telemetry and central data-processing systems may represent the most efficient approach for monitoring networks that have many remote sampling stations that employ continuous air pollution analyzers. Conversely, for single-station applications, strip-chart recorders with manual data reduction may represent the most cost-effective method for data collection.

The network design will determine the number of air monitoring stations to be employed and set the functional sampling objectives for each station. At this point, station specifications for air monitoring can be developed for each monitoring site in the network. Station specifications include the setting of sampling objectives for each station and the selecting of compatible hardware components for the station, thus producing an integrated design for a station that monitors air quality samples.

Figure 3 shows the nine discrete component elements used in a station designed for air monitoring. The sequence of selection of station equipment should be arranged so that the primary components are chosen before the supportive or supplementary hardware. For example, equipment shelters should be designed after the total amount of equipment to be housed in the shelter has been determined; thus, the shelter will be of the proper size and will have adequate electrical wiring, plumbing, instrument mounting, and storage space for the hardware components.

SELECTING AIR MONITORING SITES

Choosing the right location for the right monitoring objective requires insight into the nature of air pollution emission, transport, and dispersion from different types of sources. Because many variables must be considered, site selection is one of the most complex and critical elements in the design of a survey for monitoring air quality. If the wrong sites are chosen or if a critical site is missed, no amount of accurate data will allow the objective of the study to be fully realized. Variables to be considered regarding the transport and dispersion of pollutants include the relative locations of pollution sources (inside and outside the study area), sensitive receptors, and the effects of topography, source size and configuration, and meteorology.

Before air monitoring sites can be effectively selected, an understanding of the spatial distribution of pollution concentration is necessary. It is useful to define three separate air pollution regimes, shown in Figure 4.

1. Microscale—The microscale air pollution regime represents a relatively small air mass that exhibits large variations in air pollution concentrations at ground level. This phenomenon usually occurs close to sources of air pollution when the rate of increasing atmospheric dispersion with downwind distance is great.
2. Mesoscale—The mesoscale regime represents a community-sized air mass that exhibits fairly homogeneous ground-level concentrations of air pollution, such as the ambient concentrations within urban areas that are caused by the emission of relatively small quantities of air pollutants from a large number of ground-level sources (i.e., automobiles, residential and commercial space-heating furnaces, and even numerous small industrial sources). These local background concentrations can vary considerably at different locations within an urban area.
3. Macroscale—A macroscale regime represents a regional background with air pollution concentrations that can be fairly homogeneous over linear distances of from tens to hundreds of kilometers. Large variations in pollutant concentration indicate the presence of mesoscale and microscale air pollution regimes that are superimposed on the regional regime.

Pollution levels near major sources consist of three component parts: the microscale concentration (the concentration directly due to nearby pollution sources), the mesoscale concentration (the local background concentration due to areawide sources of pollutant emissions), and the macroscale concentration (the regional background concentration due to distant pollution sources). The macroscale pollution concentration is frequently so low that this term can be ignored, leaving only two components to any ground-level observation—the local background air pollution concentration and the microscale concentration due to a nearby source. Air monitoring sites located outside the microscale regime measure only mesoscale and macroscale concentrations (background). Sampling sites located within the microscale regime measure the concentration due to the combined microscale, mesoscale, and macroscale regimes.

Monitoring Sites Near Highways

Whenever air quality near a specific highway is to be monitored, mathematical dispersion models should be employed to assist in the determination of sites for optimum air sampling. Line-source models are available (10, 11) that can be used to calculate where the maximum ground-level concentrations are expected to occur. Models can also be used to determine the profiles of ground-level concentration at various distances from the source so that the extent of the impact area can be determined.

According to the California line-source dispersion models (10), pollution emitted from automobiles is thoroughly mixed above the highway in the mechanical mixing cell, a region in which concentrations are uniform and relatively high. As the pollutants are transported and dispersed by the wind, the concentrations decrease as the distance away from the highway increases. When the concentration approaches the local background concentration, the boundary of the microscale regime has been reached (2).

This microscale regime can be illustrated graphically by plotting isopleth lines of concentration levels as a function of the concentration in the mixing cell. Figure 5 shows lines of similar concentration downwind from the edge of a highway source in both the horizontal direction, plotted on the abscissa, and the vertical direction, plotted on the ordinate. The family of curves illustrates the vertical and horizontal locations at which the pollution concentration is reduced to 80, 60, 40, 20, and 10 percent of the original levels. (All the curves plotted were determined for crosswind conditions and C stability.)

These curves may be used to locate optimum sampling sites for validating the microscale model. Sites should be spaced so that the pollution gradient can be sampled at equal intervals of decreasing concentration. This technique helps minimize the effects of errors in experimental measurements (ensuring measurable differences among sites) and avoids redundant sites. As described in Figure 4, the optimum locations for the five sites would be 0, 2, 7, 23, and 200 m (0, 6.5, 22.9, 75.4, and 656 ft) from the edge of the road.

Figure 5 provides optimum site spacing for C stability and crosswind conditions but less than optimum site spacing for other conditions. To design the best possible site-spacing pattern, an evaluation should be performed that uses historical meteorological data and diffusion models to determine the full spectrum of events likely to occur downwind of the source. Figure 6 shows the results of such an evaluation and the normalized concentration gradient versus normal distance from the road for all possible conditions described by the California line-source model (10).

Since the precise conditions of meteorology that will be encountered in the field cannot be predicted, the sampling sites should be selected according to optimum spacing for the most probable stability and wind direction condition determined from historical records. Choosing sites that use the most probable stability and wind direction should provide the greatest amount of data collected from sites that are optimally located. If optimum spacing of sites is desired for measurements under a different condition of meteorology, particularly the worst case condition for dispersion (e.g., F stability and parallel wind for at-grade highways) that occurs less often, additional sampling sites may be added to supplement the coverage provided by sites already chosen. In this way, the sampling array is designed to provide the best data under specific meteorological conditions (most probable and worst case), while providing less than optimum coverage for other conditions likely to be encountered during the study.

The site-selection procedure can be described by an example. The sites shown in Figure 6 that are located at distances 1, 2.3, 7.2, 33, and 260 m (3.3, 7.5, 23.6, 108.2, and 852.8 ft) from the road were chosen to allow sampling at regular intervals of 100, 80, 60, 40, and 20 percent of the roadside mixing cell concentration (C_{mc}) and within a measurement error of 10 percent of C_{mc} for crosswind conditions that, in this example, occur 85 percent of the time. The site locations shown in Figure 6 should meet their intended objectives 100, 85, 81.6, 78.2, and 51 percent of the time for sites 1 through 5 respectively. These sites, which measure roughly 100, 97, 89, 53, and <1 percent of the mixing-cell concentrations for sites 1 through 5 respectively, do not provide good coverage for parallel wind conditions. If model validation under parallel winds is desired, then additional sites may be needed to measure ~70 and ~25 percent of C_{mc}.

The optimum location of each site is the distance from the road at which the target concentration (e.g., 40 percent of the mixing cell) can be measured most frequently (i.e., where the tolerance limits cross the concentration profile lines that have the greatest frequency of occurrence). In the example given, the poorest coverage is at site 5, which meets its stated objective only 51 percent of the time. An alternative design, which should provide measurements of 20 percent C_{mc} ~78 percent of the time, would move site 5 to 150 m (492 ft) (site 5A) and add a sixth site at 600 m (1968 ft) (site 6). Site 5A could be used to measure 20 ± 10 percent C_{mc} during stabilities B, C, and D, and site 6 could measure 20 ± 10 percent C_{mc} during D, E, and F stabilities. This sixth site should allow an additional 27 percent of the data collected to be within the stated objectives at all sites. The use of a sixth monitoring site may be the most cost-effective design, especially if it allows the duration of the study to be shortened because of the improved coverage of the sites.

Mesoscale Sites

Data from downwind sampling sites describe the concentration of pollution from the project plus the background. For this reason, data from an additional station located outside the microscale regime but within the same mesoscale regime are required. These data separate the pollution concentrations into two components by subtracting the local background from the microscale concentrations measured. The contribution from the project can then be compared with model predictions. If the regional background levels are relatively low, a single properly chosen monitoring station can be used to establish background levels within the mesoscale regime. Usually, a microscale model-validation experiment will use an array of air samplers located on both sides of the highway. As long as winds do not blow parallel to the roadway, samplers on one side of the highway will provide background data, while samplers on the other side of the highway will measure the additional highway contribution.

Figures 5 and 6 can also be used to determine a good location for a mesoscale site. The isopleth lines can be used to estimate the theoretical boundary that separates the microscale regime of a nearby highway from the mesoscale regime. Once the boundary has been determined, stations designed to sample background concentrations can be located outside the boundary, while stations designed to sample pollutants from the highway plus background can be located within the boundary.

The isopleth that represents the boundary separating the microscale and mesoscale regimes depends on both the concentration within the mixing cell and the background concentration. Figure 7 provides a graphic method for determining which isopleth to use. The equations are

$$\%\, C_{mc} = (0.5 - BKG)/C_{mc} \qquad (1)$$

where $C_{mc} \leq 2.5$ or

$$\%\, C_{mc} = (0.2\, C_{mc} - BKG)/C_{mc} \qquad (2)$$

where $C_{mc} \geq 2.5$. This calculation can be used to determine what percentage of the mixing-cell concentration

Figure 4. Definition of background air quality.

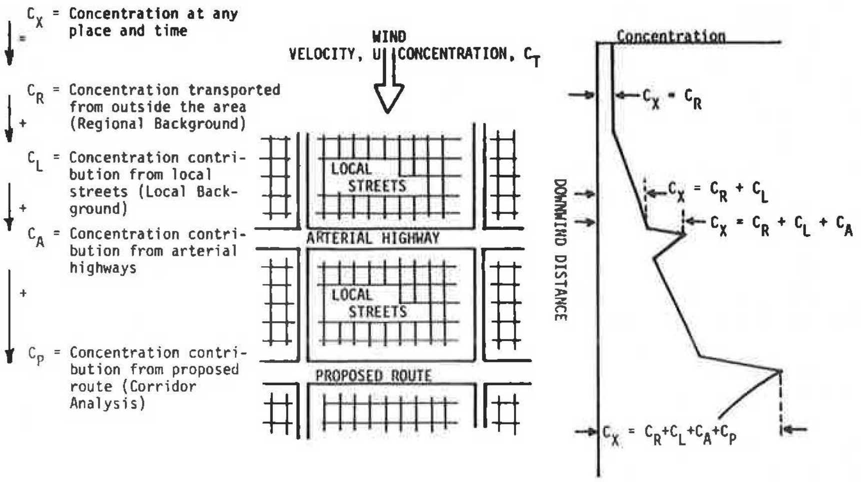


Figure 5. Isopleth concentration lines downwind of a highway line source.

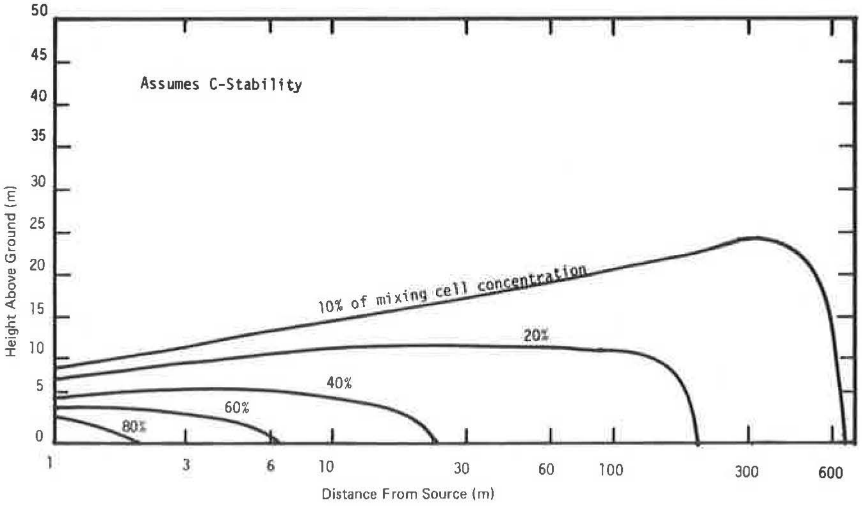
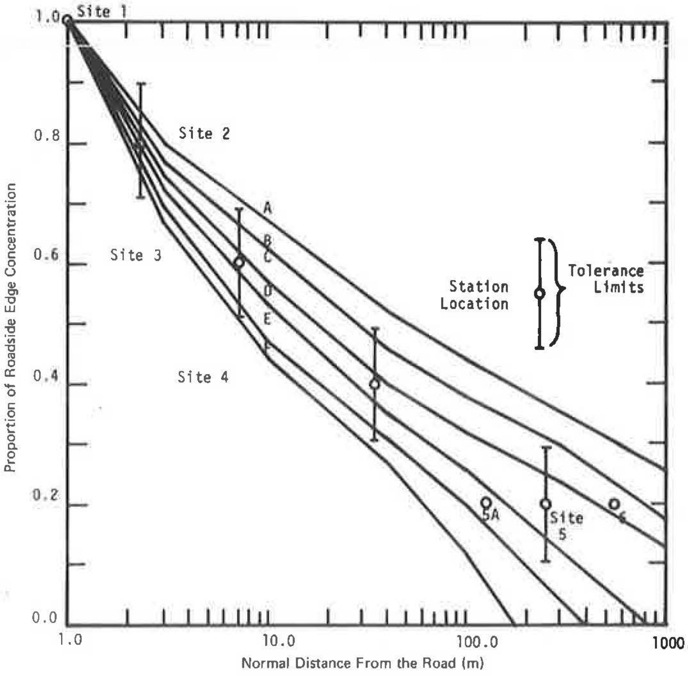


Figure 6. Optimum locations for air-sampling sites determined by crosswind conditions.



($\%C_{mc}$), when added to the background concentration (BKG), will increase the background concentration by 0.5 ppm of CO or 20 percent (whichever is larger). This means that an air monitoring site located outside the designated isopleth (measured as a percentage of the mixing-cell concentration) will measure the local background concentration with an error of up to 20 percent or 0.5 ppm CO (whichever is larger).

By using Figures 6 and 7, one can determine the minimum distance from a highway at which a monitoring site should be located for measuring background levels. There is also a maximum distance within which the sampling site should be located if there is another major source of pollutants nearby. Figure 8 shows the maximum distance that a background site should be located from the highway corridor. The limiting value is based on a maximum error of 20 percent between the value measured at the distant air-sampling site and the expected local background concentration at the highway corridor.

In addition to measuring the ground-level sampling-site locations discussed above, background air pollution concentrations can be measured at air-sampling stations located on the tops of buildings. However, the buildings must not be too tall or the measurements will not represent the background concentration at ground level. Pollution from nearby sources may contribute significantly to the ground-level concentrations of the background but not to those measured on top of a tall building. For this reason, the height of the sampling site must be limited.

As in the case of the maximum horizontal distance away from a project corridor, the maximum height for a mesoscale monitoring site depends on the distance from the closest major source. Figure 9 shows the relation between the distance from a contributing source and the percentage of ground-level air pollution concentrations that occur at different heights. This figure can be used to measure and to determine (within an accuracy of 20 percent of ground-level background) the maximum height at which the local background concentrations occur. This error estimate is conservative, since it assumes that the closest major source contributes 100 percent of the ground-level concentration and 80 percent at the indicated height. In practice, no single source would be responsible for all of the local background pollution concentration because sources located at greater distances from the sampling site contribute more uniformly to the concentration both at ground level and on top of a building.

Figures 5, 7, 8, and 9 were developed by using the California highway line-source model for at-grade highway sections, crosswind conditions, and atmospheric stability class C. Stability class C was selected as the stability class most frequently encountered under daytime conditions with urban terrain. Clarke and McElroy (12) have reported measurements of a relatively unstable boundary layer over urban terrain that tend to reinforce the use of C stability as the most probable condition encountered within urban environs.

Locations for Validating Microscale Models

The data obtained for validating microscale models may be taken at monitoring sites at which

1. The highest concentrations from the project occur (due to large traffic volumes or narrow right-of-way),
2. The highway configuration and upwind topography are most representative of the whole project, or
3. The basic assumptions of the model are violated (due to highway configuration or topography).

The model may be validated at a location at which the highest concentrations occur because this is where the greatest confidence in the model is needed. Model validation at the most representative location allows the model to be applied generally to the whole project. It may be required to validate the model for irregular terrain (hills, valleys, or nearby tall buildings) or complex highway configurations (intersections, elevated or depressed sections, and unusual land configurations), since models are the least reliable when basic assumptions are violated, i.e., smooth, level terrain, uniform wind flow field, and wind speeds greater than 1 m/s (3.3 ft/s).

Once the sites have been selected, the highway route can be monitored by a cross-section sampling at various horizontal or vertical distances from the highway. Special attention should be given to measuring the air pollution concentration at the right-of-way edge and other upwind and downwind sites near the highway. Background concentration measurements are subtracted from downwind measurements to determine the contribution due to the highway.

NUMBER OF SAMPLES NEEDED

Statistical methods for determining the number of samples needed to accurately define the mean and maximum pollution concentrations expected to occur during a year have been presented in the literature by several authors (13, 14, 15). In general, these methods assume that the samples collected are representative of the total population, which is either normally or lognormally distributed, and that each sample is chosen randomly. Under these conditions, the simplified methods presented by Hale (13) can be conveniently used to determine the total number of samples needed.

The methods presented by Hale assume that samples are collected from a finite population. For a lognormal distribution, the number of samples (n) required to determine the tolerance and confidence interval is given by

$$n = (NZ^2 \ln^2 S_g)/[N \ln^2(P + 1) + Z^2 \ln^2 S_g] \qquad (3)$$

where

N = population size,
Z = normal deviate corresponding to the upper percentage point for a specified level of confidence (Z = 1.96 for a 95 percent level of confidence),
S_g = standard geometric deviation of samples, and
P = fraction of the geometric mean by which it can differ from the true geometric mean with specified probability.

Figures 10 and 11 are based on equation 3 and can be used to determine the number of samples needed as a function of the standard geometric deviation and the size of the population being sampled. Figure 10 should be used to determine the geometric mean within ±10 percent (at 95 percent confidence), and Figure 11 should be used for a ±20 percent tolerance (at 95 percent confidence).

DURATION OF THE STUDY

The duration of study required can be estimated by using the historical meteorological data and the statistical methods given above. The average and range of concentrations expected to be measured at each station can be determined by using the model calculations. The range divided by about six can be used to estimate the standard deviation. The number of samples needed can be estimated from Figures 10 or 11. The duration required

Figure 7. Percentage of mixing-cell concentration for effective measurement of background concentrations.

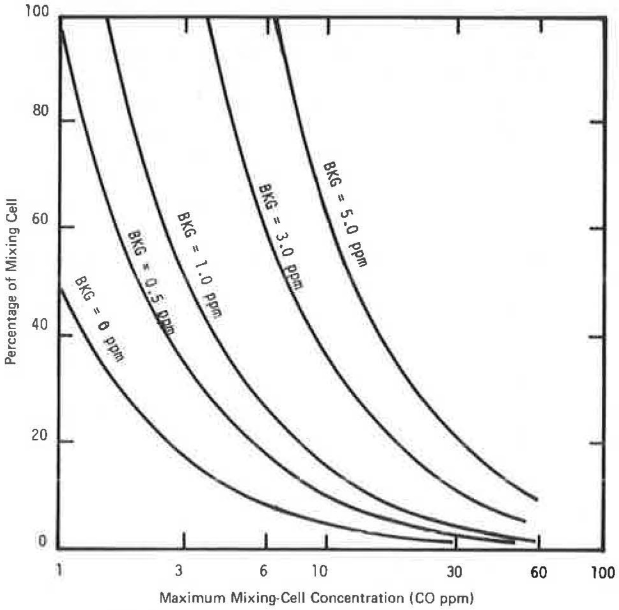


Figure 8. Maximum distance from project corridor for location of a mesoscale station.

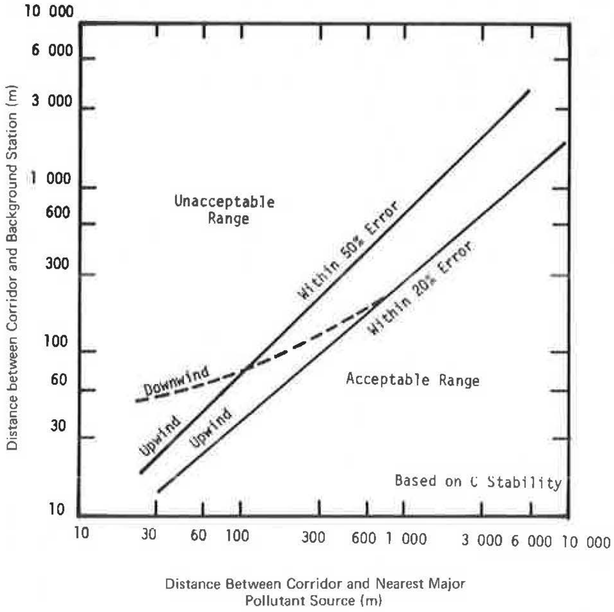


Figure 9. Height of a mesoscale monitoring station for measuring ground-level concentrations.

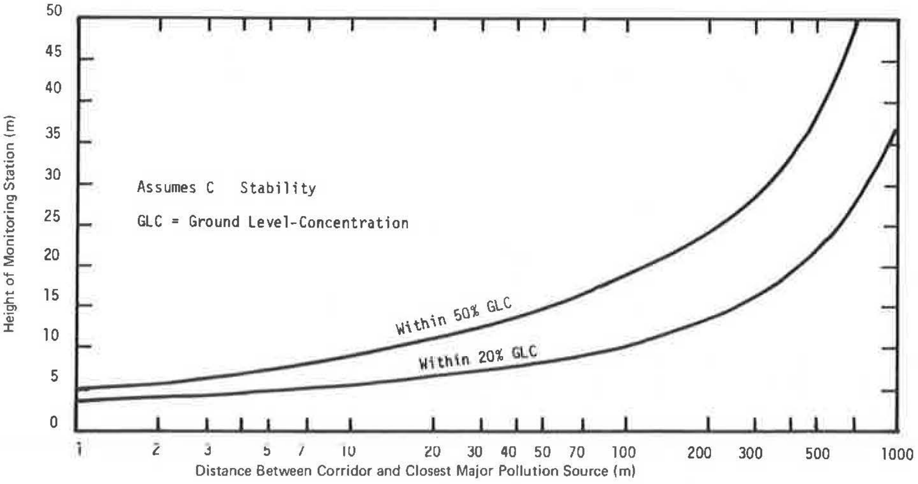
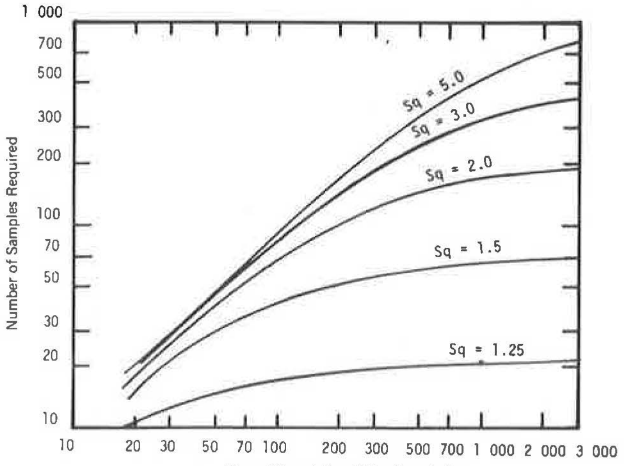
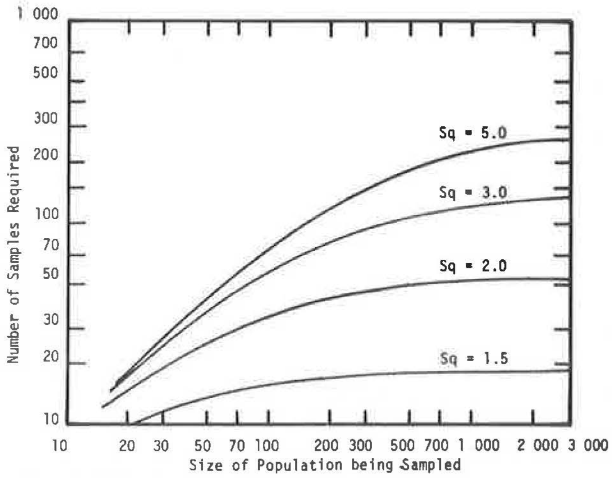


Figure 10. Number of samples required to determine the geometric mean within ±10 percent with 95 percent confidence.



Note: Z = 1.96 and P = 0.10.

Figure 11. Number of samples required to determine the geometric mean within ±20 percent with 95 percent confidence.



Note: Z = 1.96 and P = 0.20.

can then be determined by dividing the number of samples required (n) by the frequency of occurrence of a particular condition of meteorology (f) multiplied by the number of samples (S) collected at each site per day or hour (n/fS). Typically, values of n range from 30 to 100 samples and S might be from 1 to 4 per hour. For unusual events occurring less than 5 percent of the time and if 40 samples were needed with S = 4 per hour, then the duration of study required would be 200 h. At 12 hours a day of sampling, this would require a study lasting more than 2 weeks. For frequently occurring conditions, sufficient data might be obtained in a few days.

The sampling survey should be conducted for a sufficiently long duration that observations are made under a wide range of source-related and meteorology-related conditions. In most cases, air samples should be collected using 15 to 60-min averaging times, but sampling for shorter averaging times can be used if traffic and wind data are gathered for comparable intervals. Averaging samples for time periods longer than 1 h produces additional errors because changing wind direction has a nonlinear effect on the downwind concentration. Whenever the wind direction is not persistent, the short averaging time samples (i.e., 15-min averages) may be the best.

Air sampling may be conducted either during peak-hour traffic or 24 h/day. For model validation, it is desirable to sample during each hour of the day and night that there is enough traffic to produce measurable pollutant concentrations. In this way, a large amount of data can be collected over a short period of time to allow validation of the model under different meteorological conditions.

CONCLUSION

Air-monitoring survey design requires expertise in analytical instrumentation, diffusion meteorology, statistics, and systems engineering. The systems design overview and the definitive methods for site selection presented in this paper can be used to improve current survey design methodologies. If cost-effective surveys are to be designed, then available air sampling and analytical methods, atmospheric diffusion models, and historical meteorological data must be evaluated by using systems engineering principles. This procedure can result in objective decision making and design tradeoffs that consider the magnitude of the survey required and the resources available to conduct the study. Without this approach, survey designs will be based on guesswork and subjective reasoning that may not be cost-effective or even adequate to meet the intended objective of the survey.

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