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Overview of the New York State Long Island Expressway Dispersion Experiment

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The objective of this investigation was to collect particulate, gaseous, micrometeorological, and traffic data adjacent to a major highway in a nonurban setting. The experimental site was on a section of the Long Island Expressway that is heavily traveled and where development adjacent to the roadway is relatively minor. The data base is useful for (a) documentation of the distribution of sulfate, lead, total particulate, and carbon monoxide levels at an array of sampling points near the highway; (b) study of the micrometeorological structure adjacent to the highway with special attention to those parameters that are important in the determination of sigma and stability values as well as highway-generated turbulence; (c) reevaluation of highway air pollutant emission factors from the data gathered on tracer gas experiments; and (d) validation of several highway dispersion models. The location of the site and data acquisition techniques are presented. The experimental design of the roadway diffusion study is described and some of the preliminary results of the tracer gas release experiments and sulfate and lead measurements are presented. The data collected in this investigation are being analyzed and a more comprehensive analysis will be presented elsewhere.

Mathematical modeling techniques are being employed to estimate the pollutant concentrations adjacent to highways. A number of mathematical models have been developed for the prediction of pollutant levels, but only a few experimental programs have been undertaken for establishing a sufficiently detailed data base (consisting of traffic, pollutant concentrations, and meteorological data) to be used for model verification. In recent years, such studies were conducted by Stanford Research Institute, General Motors Corporation, and New York State Department of Environmental Conservation. The General Motors study was a controlled experiment on a test track, whereas the Stanford Research Institute and New York State studies were carried out along major highways.

EXPERIMENTAL PROCEDURES

The site chosen on the Long Island Expressway (I-495) is about 25 km east of the city limits of New York City. Figure 1 is a map of the sampling area, which shows nearby residential areas and highways. Recent estimates of vehicles per day as reported by the Suffolk County Highway Department are indicated next to the highways. The area does not contain any major industrial centers; the nearest large point sources are 6 km to the southwest in Bethpage. The highway at the site is fairly flat and straight. The land to the north and the south of the site is a sod farm and is undeveloped and open. Because of the relatively undeveloped nature of the location, the high vehicle density, the flatness of the terrain, and the distance from other highways and point sources, this site closely approximates the assumptions common to all at-grade dispersion models.

Data Collection and Equipment

A network of towers and sensors was designed and adapted for the project in order to collect data, both upwind and downwind, in a vertical plane perpendicular to the highway. Figure 2 shows the layout of these towers (looking west) and the specific location of air quality and meteorological measurements. A 12-m trailer that housed the instrumentation needed for this study was located about 100 m from the edge of the road and 20 m to the west of the sampling grid on the south side of the highway. This distance was necessary for minimal interference with the wind flow characteristics at the sampling plane. The trailer housed the data acquisition sys-

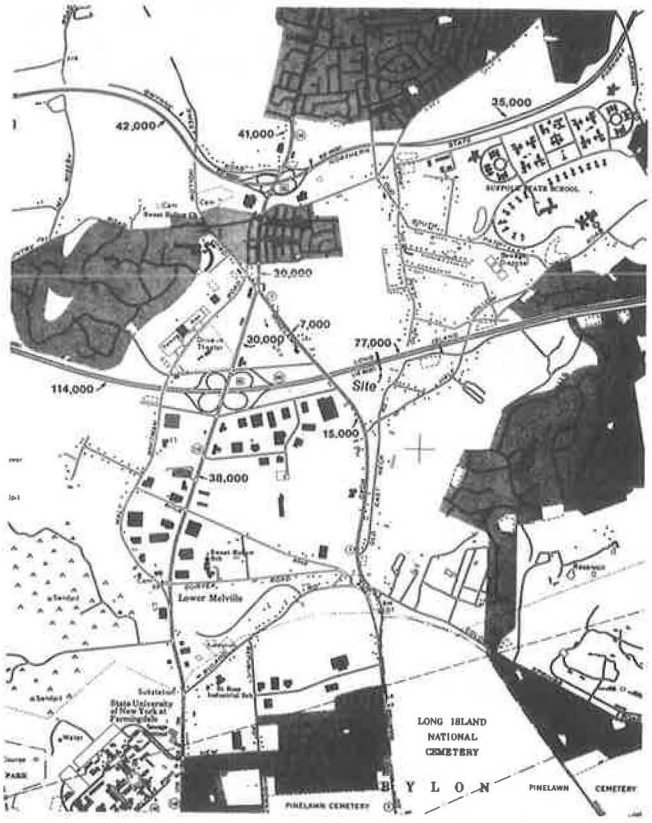
tem, the necessary electronic equipment, pumps, carbon monoxide (CO) and meteorological data monitors, as well as heating and air conditioning units.

Particulate Measurements

Eight dichotomous samplers, manufactured by the Environmental Research Corporation, were employed to sample ambient particulates in two size ranges—greater than 3.5 μm and less than 3.5 μm in diameter. Six samplers were located at heights of 2 m and 5 m on towers 5, 9, and 11. The remaining two were located at 2-m height on towers 3 and 12 (see Figure 2). Particulate measurements were taken 5 d/week for a duration of 2 h during the morning and evening peak traffic periods. Fluoropore filters (0.5 micron pore size and 47 mm in diameter) were used to sample particulates in both size ranges. Filters were collected manually, placed in petri dishes, and brought back to Albany at the end of each week for analysis. In addition, total suspended particulates were collected with high-volume air samplers at six locations (three on each side of the highway at various downwind distances) on a 24-h basis for a period of 3 months under a contract agreement with the Federal Highway Administration (FHWA).

Filters for the dichotomous samplers were weighed before and after the run with a Mettler M-5 microbalance under constant temperature and humidity conditions to determine the particulate mass. Further analyses of these filters for Pb and S were made using x-ray fluorescence (xrf) spectrometry. The xrf unit actually indicated the total S, but in the lower size range of particulate collected by the dichotomous sampler, it was expected that the total S-sulfate (SO_4) ratio would be close to unity. For additional information, soluble SO_4 was analyzed using a liquid ion chromatograph, developed by the Dionex Corporation.

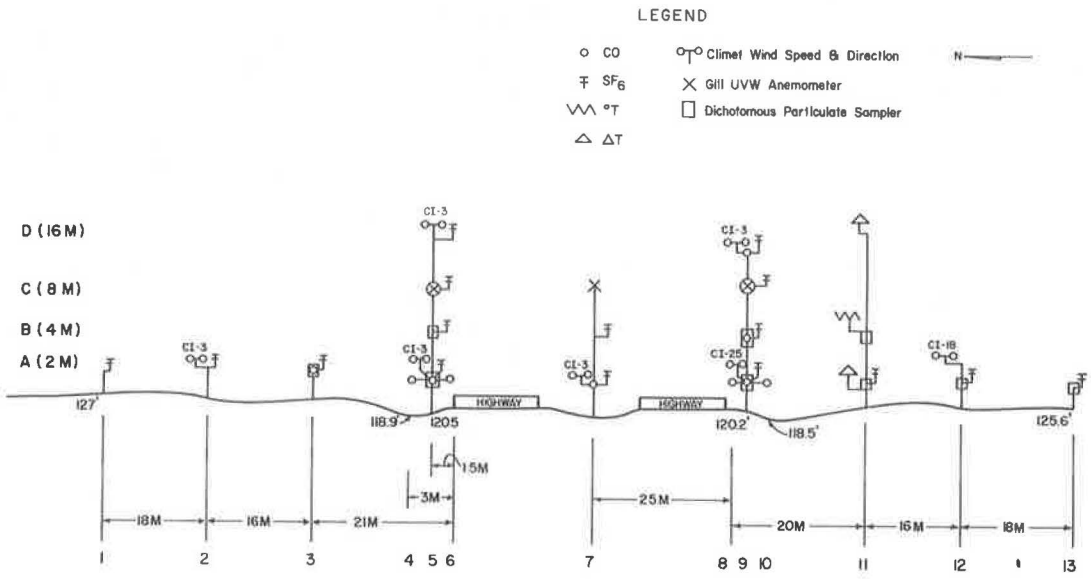
Figure 1. Map illustrating the location of the experimental site and nearby residential areas and highways in Long Island, New York.



CO Measurement

The locations of the CO measurements are indicated in Figure 2. Sampling was done using nondispersive infrared (NDIR) CO analyzers, manufactured by the Beckman Corporation. Samples were drawn from each specific location through Teflon tubing into a mixing chamber at a fixed sampling rate. The chamber's volume was designed to eliminate any rapid variations in the concentration within the sampling interval without masking any longer period changes. After passing through the averaging chamber, the sample was pumped into the monitor. The electronic output signal was then trans-

Figure 2. The location of the air quality and meteorological data measurements adjacent to the highway.



mitted to the data acquisition system. All NDIRs were automatically calibrated to 0 at least three times a day.

For tower 9, a profile system was designed to allow a single NDIR to measure the concentrations at four points in a vertical line during a 5-min sampling cycle. Flow through these four averaging chambers was produced by either of two pumps, separated by three-way solenoids controlled by the computer. Matched flowmeters were used through the system to assure the same constant flow for each chamber at all times. The main pump drew the samples through a collection tank and was used to maintain uniform flows through each chamber when that particular line was not being analyzed. During analysis, a solenoid was activated that closed that chamber's port to the collection tank and opened another port to the sampling pump and NDIR. Therefore, at any one time, three samples flowed to the collection tank while the fourth went to the NDIR.

Meteorological Measurements

Since dispersion parameters derived from meteorological data are critical in determining pollutant concentrations within 100 m of the highway, multiple measurements of meteorology were made. Four Gill 3-component anemometers were installed at a height of 8 m on towers 5, 7, 9, and 11. Seven Climet sensors were located at various positions, as shown in Figure 2. Temperature and temperature difference measuring systems (manufactured by Meteorology Research, Inc.) were located on tower 11. In addition, solar radiation, relative humidity, and precipitation were also measured.

Traffic Measurements

Each lane on the expressway had a pair of induction loops imbedded in the pavement. A separation distance of 3.5 m was used. These loops were connected to Streeter Amet Model-740 loop detectors. Via interface circuitry, each sensor was polled by the computer periodically for vehicle presence. The length and speed of each vehicle was computed from this information and classified into 5 length and 10 speed categories for each direction. A time-lapse photography system was used once a week to serve as a further check on the traffic measurements made by the computer.

Data Acquisition and Storage

All the electronic signals were transmitted to an 8-K memory NOVA 2 Data General mini-computer. In addition to providing a teletype output of all variables averaged over a sampling period of 10 min, the data were transferred to diskettes for storage and easy retrieval. The final output (10-min averages) of the data acquisition system was as follows:

1. CO concentrations at 11 locations in the sampling plane;
2. Westbound traffic counts in a two-dimensional matrix (50 elements—10 speed and 5 length categories);
3. Eastbound traffic counts similar to the westbound counts;
4. Average horizontal wind speed from seven Climet sensors;
5. Average horizontal wind direction from seven Climet sensors;
6. Average east-west component of wind from four Gill sensors;
7. Average north-south component of wind from four Gill sensors;
8. Average vertical component of wind from four Gill sensors;
9. Average temperature and vertical temperature gradient;
10. Radiation, humidity, and precipitation;
11. Resultant wind speed from the average east-west and north-south components; and
12. $\overline{UW}$, $\overline{UV}$, $\overline{WT}$, $\sigma_{i,j}$, where i = U, V, W and j = 1, 5, 10, and 25 s average time from four Gill sensors (the overbar indicates the mean over the sampling period).

Utilizing the above measured quantities, a data manipulation routine was written to compute Richardson number, flux Richardson number, Monin-Obukhov length, $\sigma\theta$ and $\sigma\phi$ from σ_1 for various averaging times, and ratios of eddy diffusitivities of heat and momentum.

TRACER GAS RELEASE, SAMPLING, AND ANALYSIS

Simulation of a line source was achieved in the vicinity of the sampling plane by releasing sulfur hexafluoride (SF_6) from six 1976 Plymouth Fury station wagons. The source was 99.99 percent pure instrument grade SF_6 gas contained in T-size cylinders with single stage regulators and gauges for tank and release pressure. This was modified by a third valve and pressure gauge with flowmeter so that close limits could be placed on the flow of SF_6 release. The third gauge and flowmeter were calibrated by Brooks Instruments for operation at 517 MPa. Copper tubing, 0.635 cm from the flowmeter, terminated near the vehicle's exhaust pipe. The SF_6 release set-up is shown schematically in Figure 3.

Sample collection was achieved via small battery-operated pumps mounted at each sampling point. The pumps were modified so that their on-off operation was centrally controlled. Acrylic rubber tubing ran from the pumps to Tedlar sampling bag at ground level. The procedure used in establishing and sampling a line source of tracer gas is described below.

All six automobiles were lined up at point A (see Figure 4), and each automobile left the ramp at intervals of 1.5 min. The SF_6 was released between the two overpasses on either side of the sampling plane. The duration of SF_6 release was recorded for each release. All automobiles travelled at 88 km/h during the release

Figure 3. Design of the SF_6 tracer gas release set up.

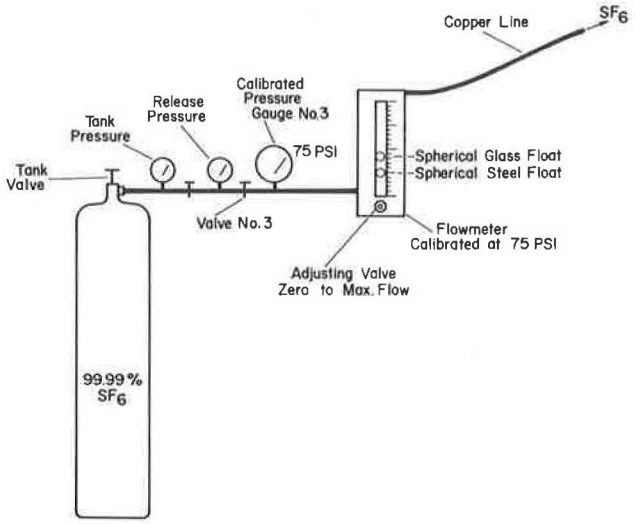
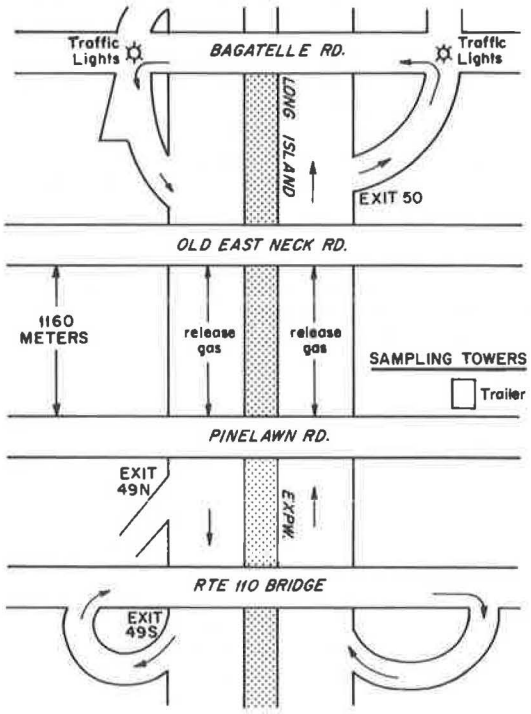


Figure 4. The course for the SF_6 releasing automobiles with respect to the sampling network.



periods and stayed in the center lane. The collection of SF_6 began when the second automobile passed the sampling plane on its eastbound return lap. This procedure was adapted to ensure creation of a line source before the collection of samples. The sampling was continued for 1 h, at the end of which all automobiles were signalled to stop the release of gas. The bags were then sealed and brought to the trailer for analysis. The location of SF_6 measurements is shown in Figure 2. The bags thus collected were analyzed immediately after the experiment using an Analytical Instrument Development, Inc., model 511-06 portable electron capture gas chromatograph and a Supergrator II integrator. The range of electron capture detection used was 0 to 59.6 $\mu g/m^3$. The analyses used three SF_6 standards, 0.596, 5.96, and 59.6 $\mu g/m^3$, which were prepared by Scott Environmental Technology. A total of 23 hour-long experiments were conducted over a period of 3 weeks.

MODEL PREDICTIONS

Two mathematical dispersion models—HIWAY, developed by the U.S. Environmental Protection Agency (EPA), and GM, developed by the General Motors Corporation—were tested to evaluate their capability to simulate dispersion from a line source. Both models are based on the assumption that the pollutant concentration at any given receptor is given by the Gaussian equation. Details on the model formulation and input requirements can be found in Zimmerman and Thompson (1) and Chock (2).

The above models were run for two stabilities using meteorological data from location 7C on the median tower. The wind speed and direction at this height (8 m) are thought to be representative of the advection process adjacent to the highway. Micrometeorological measurements also indicate that the mechanical turbulence generated by the traffic flow extends up to heights of 8 m.

A considerable variation of the atmospheric stability is observed for the same set of meteorological conditions at the site when different methods of estimating atmospheric stability are used. The more commonly used Pasquill-Turner (3) classification yielded neutral stability for almost all the hours during which tracer experiments were conducted. Slade's (4) method of atmospheric stability determination utilizing horizontal sigmas indicated that conditions during most of the tracer runs fall into unstable categories.

Preliminary analysis of the micrometeorological data collected at the site indicates that although neutral stability exists on the mesoscale, the stability in the vicinity of the roadway is dictated by the turbulence generated by the vehicular traffic and change of roughness. Hence HIWAY and GM models were run using both stability 4 (neutral) and stability 2 (unstable) conditions for the same set of SF_6 observations. Wind-road orientation angles in the range 0° to 30° are treated as parallel, 30° to 60° as oblique, and 60° to 90° as perpendicular cases.

Table 1 demonstrates that the HIWAY model yields better correlations using stability 2 criteria than neutral criteria for these experiments. For the GM model, on the other hand, there are no significant differences between the correlations for the two stabilities. This is to be expected because there is little variation in the sigma values for neutral and unstable classes in the GM model. The slope of the regression line, however, is closer to unity for unstable conditions in the GM model. Both HIWAY and GM predict concentrations with some confidence for perpendicular wind conditions. The predictive capability of the HIWAY model seems to decrease as winds deviate from the perpendicular to the roadway.

Table 1. Comparison of two highway dispersion models using the data collected during the tracer gas experiment.

	Atmospheric Stability						
	Neutral			Unstable			Number of Data Points
Wind-Road Angle	Correlation r^2	Intercept	Slope	Correlation r^2	Intercept	Slope	
Perpendicular							
HIWAY	0.70	0.97	0.48	0.88	0.60	0.71	41
GM	0.88	0.43	0.91	0.87	0.51	1.0	41
Oblique							
HIWAY	0.58	0.83	0.44	0.63	0.67	0.71	59
GM	0.59	0.56	0.86	0.58	0.64	0.97	59
Parallel							
HIWAY	0.52	1.78	0.15	0.67	1.35	0.40	40
GM	0.89	0.36	0.70	0.93	0.33	0.92	40
All combined							
HIWAY	0.43	1.74	0.20	0.66	1.07	0.52	140
GM	0.73	0.63	0.76	0.71	0.64	0.93	140

Figure 5. Concentrations of lead and sulfate adjacent to the roadway for parallel and perpendicular wind-road orientations.

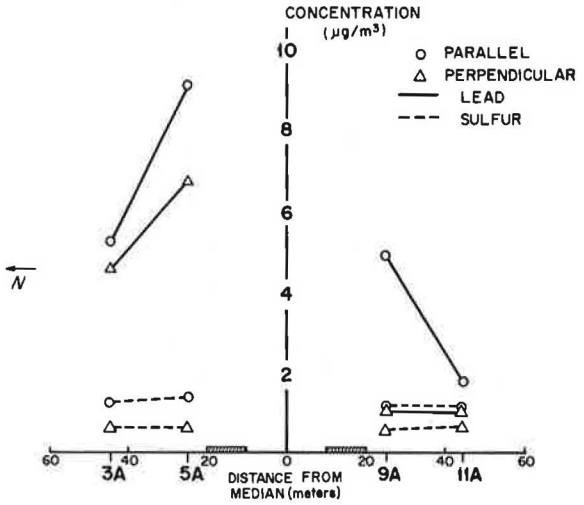


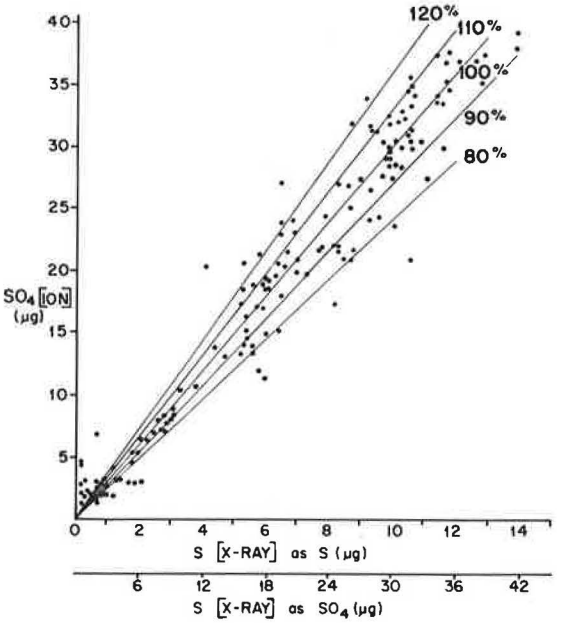
Table 2. Lead, sulfur, and sulfate concentrations for the small-particle fraction.

	Small-Particle Concentrations		
Position	Lead ($\mu g/m^3$)	Sulfur ($\mu g/m^3$)	Sulfate ($\mu g/m^3$)
5A	1.2	1.5	4.8
9A	8.1	1.5	4.9
9B	4.1	1.4	4.8
11A	4.8	1.4	4.6
11B	3.7	1.8	5.4
12A	3.7	1.6	4.9
13A	3.2	1.5	5.7

The GM model, on the other hand, has much higher correlations for both perpendicular and parallel wind-road orientations than for the oblique wind situations. This suggests that the empirical equation used in the GM model to derive the sigma values as a function of downwind distance and wind-road orientation angle needs closer examination. The equation would appear to be satisfactory for perpendicular and parallel wind-road orientations. From the above, one can infer the general observation that a model calibration and validation must be performed segmentally; that is, different wind regimes and stabilities should be examined separately rather than combining all cases together.

The observed SF_6 concentrations and source strength are being used to estimate the vertical diffusion parameter values, and these values are being compared to those used in the above mathematical dispersion models. Preliminary data from this type of analysis indicates that the sigma values applicable to near-roadway dispersion are closer to the vertical sigmas that are prescribed under stability 2 in the HIWAY model. This suggests that the importance of the atmospheric stability in dispersing pollutants near the roadway might be less significant than the effects of the turbulence generated by the vehicular traffic. Work is continuing in this direction to better define the diffusion parameter values applicable to near-roadway dispersion and to identify clearly the roles played by the natural turbulence and the local turbulence generated by the waste heat emissions from the automobile exhaust and the aerodynamic drag of moving vehicles. Also, comparisons of the SF_6 and CO data are under way to see if CO dispersion is similar to that of SF_6.

Figure 6. Comparison of sulfur and sulfate measurements using X-ray fluorescence spectrometry and ion chromatography techniques.



SO_4 AND Pb LEVELS ADJACENT TO THE HIGHWAY

Particulate samples collected with the dichotomous samplers were analyzed for total weight, Pb, S, and SO_4. At the start and end of the study, all the dichotomous samplers were placed at tower 11 and over 20 runs were made sampling the same air mass in order to estimate the range of sampling and analysis errors.

Figure 5 is a plot of the small particle (<3.5 μm) concentrations for Pb and S at the 2-m level. Two cases are presented. Run 1019R2 had a wind-road angle of 90° and a wind speed of 1.9 m/s, and run 1020R1 was a parallel case with an angle of 8° and a wind speed of 1.0 m/s. Table 2 contains the small particle concentrations of Pb, S, and SO_4 at 2-m and 5-m heights for run 1005R2, which had an oblique wind of 32° and a wind speed of 3.1 m/s.

The Pb concentrations for perpendicular and oblique winds reach a maximum immediately downwind of the roadway, with a subsequent decline both vertically and horizontally. As is to be expected, under parallel winds the Pb concentrations increased on both sides of the highway. The S and SO_4 concentrations do not display a similar trend. Their spatial variations show no perceptible pattern and are within the range of sampling error.

At the most, 30 percent of the automobiles on the expressway during sampling were equipped with catalytic converters and, therefore, used nonleaded gasoline. Assuming that each of these automobiles had a SO_4 emission rate of approximately 0.002 g/km, and the rest of the vehicles had a Pb emission rate of approximately 0.04 g/km each, the Pb emission rate on the roadway would be on the order of 50 times greater than the SO_4 emission rate. These estimates are supported by the observed concentrations.

The SO_4 contribution from the roadway is indiscernable at the site; therefore, the magnitudes of SO_4 levels found can be considered representative of ambient concentrations. Figure 6 is a scatter plot of S content of

the small particle fraction of particles collected in the dichotomous samplers by xrf versus soluble SO_4 by ion chromatography for the runs taken during the tracer periods. The two methods correspond fairly well, indicating that most, if not all, of the S is in the form of soluble SO_4.

ACKNOWLEDGMENTS

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Integrated Planning and Management of Transportation and Air Quality

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Efforts to implement the transportation control provisions of the Clean Air Act Amendments of 1970 have generated much discussion but little implementation of transportation measures to improve air quality. Reasons for this include conflicts over transportation priorities, inadequate institutional arrangements for combined transportation and air quality planning, and insufficient information concerning the relation between transportation and air quality. The Clean Air Act Amendments of 1977 provide a framework for handling these problems. However, important questions remain to be answered concerning organizational roles in transportation and air quality planning, the structure of the planning process, and the responsibilities of transportation and air quality decision makers.

The Clean Air Act Amendments of 1970 directed the U.S. Environmental Protection Agency (EPA) to establish national ambient air quality standards whose attainment would protect the public health and welfare from the adverse effects of major air pollutants. The pollutants for which health-based air quality standards now exist include carbon monoxide (CO) and photochemical oxidants, whose presence in urban air is primarily attributable to emissions by motor vehicles of CO, hydrocarbons (HC), and nitrogen oxides (NO_x). The areas in which one or more of these air quality standards are exceeded include most large cities in the United States and contain approximately two-thirds of the nation's population. The automobile is the source of roughly 70 percent of the CO, 50 percent of the HC, and 30 percent of the NO_x emitted in urban areas. Other transportation sources are responsible for approximately 20 percent of CO, HC, and NO_x emissions in these areas.

Because of the importance of motor vehicles relative to other sources of CO, HC, and NO_x, the reduction of motor vehicle emissions is a major objective of programs to improve air quality. The principal means of achieving this objective is the control of emissions from new vehicles. However, in many large cities, the current and projected future magnitudes of motor vehicle emissions are such that the CO or oxidant air quality standards cannot be attained and maintained through the control of emissions from new motor vehicles and nonvehicular sources alone. Furthermore, motor vehicles will remain among the two or three largest emissions sources, even after controls on new motor vehicles have become fully effective. In effect, the transportation systems of large cities are now and will continue to be major emissions sources that, like other major sources, must be controlled if the air quality standards are to be achieved.

Emissions from urban transportation systems can be reduced by improving traffic flow conditions and reducing traffic volumes. The measures through which these objectives might be achieved include virtually all of the ones currently encompassed by the term transportation system management. The Clean Air Act refers to transportation system management measures as transportation controls and requires their implementation in areas