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# *Air Pollution Monitoring and Surveillance*

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## I. STATIONARY MONITORING NETWORKS

The US Environmental Protection Agency (EPA) has established National Ambient Air Quality Standards (NAAQS) for protection of human health and welfare. These standards are defined in terms of concentration and time span for a specific pollutant; for example, the NAAQS for carbon monoxide is 9 ppmV for 8h, not to be exceeded more than once per year. For a state or local government to establish compliance with the NAAQS, measurements of the actual air quality must be made. To obtain these measurements, state and local governments have established stationary monitoring networks with instrumentation complying with federal specifications, as discussed in Chapter 17. The results of these measurements determine whether a given location is violating the air quality standard.

Stationary monitoring networks are also operated to determine the impact of new sources of emissions. As part of the environmental impact statement and prevention of significant deterioration processes, the projected impact of a new source on existing air quality must be assessed. Air quality monitoring is one means of making this type of assessment. A monitoring network is established at least 12 months before construction to determine prior air quality. Once the facility is completed and in operation, the network data determine the actual impact of the new source.

Long-term trends are measured by stationary air quality monitoring networks. Figure 8.7 shows the long-term decrease of SO<sub>2</sub> in the atmosphere resulting from the implementation of air pollution control technology. The trends in other atmospheric trace gases such as CH<sub>4</sub>, NO, NO<sub>2</sub>, and CO are similarly measured in rural as well as urban locations. Atmospheric budgets of various gases are developed to allow estimation of whether sources are anthropogenic or natural.

A stationary monitoring network should yield the following information: (1) background concentration levels, (2) highest concentration levels, (3) representative concentration levels in high-density areas, (4) the impact of local sources, (5) the impact of remote sources, and (6) the relative impact of natural and anthropogenic sources.

The spatial scale of an air monitoring network is determined by monitoring objectives. Spatial scales include personal (<1 m, on person), microscale (1–100 m), middle scale (100 m–0.5 km), neighborhood scale (0.5–4.0 km), urban scale (4–50 km), and regional scale (tens to hundreds of km). Table 18.1 shows the relationship between spatial scale and monitoring objectives [1].

Sampler siting within a network must meet the limitations of any individual sampling site and the relationship of sampling sites with each other [2]. The overall approach for selection of sampling sites is to (1) define the purpose of the collected data, (2) assemble site selection aids, (3) define the general areas for samplers based on chemical and meteorological constraints, and (4) determine the final sites based on sampling requirements and surrounding objects [3]. Several purposes of air quality monitoring were mentioned earlier, such as air quality standard compliance, long-term trends, and new facility siting.

The tools available for site selection include climatological data, topography, population data, emission inventory data, and diffusion modeling. Climatological data are useful in relating meteorology to emission patterns. For example, elevated levels of photochemical oxidant are generally related to stagnant meteorological conditions and warm temperatures. Seasonal climatological patterns of prevailing winds and frequency of inversions will influence the location of sampling stations. Various types of maps are useful for establishing topography, population density, and location of sources of

TABLE 18.1

Relationship of the Scale of Representativeness and Monitoring Objectives

Siting scales	Monitoring objectives
Personal	Personal cloud
Personal, micro, middle, neighborhood (sometimes urban)	Highest concentration affecting people
Neighborhood, urban	High-density population exposure
Micro, middle, neighborhood	Source impact
Neighborhood, region	General/background concentration

various pollutants. Wind roses overlaid with emission sources and population densities help to locate the general areas for location of samplers.

Various types of dispersion models are available which can use as input emission patterns, climatological data, and population data to rank sampling locations by concentration threshold, resolution of peak concentrations, and frequency of exposure [4] or to rank sampling locations for maximum sensitivity to source emission changes, to provide coverage of as many sources or to cover as large a geographic area as possible [5].

The last step in selecting specific sites is based on the following: availability of land and electrical power, security from vandalism, absence of nearby structures such as large buildings, probe height (inlet >3 m), and cost.

An example of matching scale and objective is the determination of CO exposure of pedestrians on sidewalks in urban street canyons. The location of a station to meet this objective would be an elevation of ~3 m on a street with heavy vehicular traffic and large numbers of pedestrians.

Figure 18.1 shows the Los Angeles, California, basin stationary air monitoring network, one of the most extensive in the United States [6]. At most of

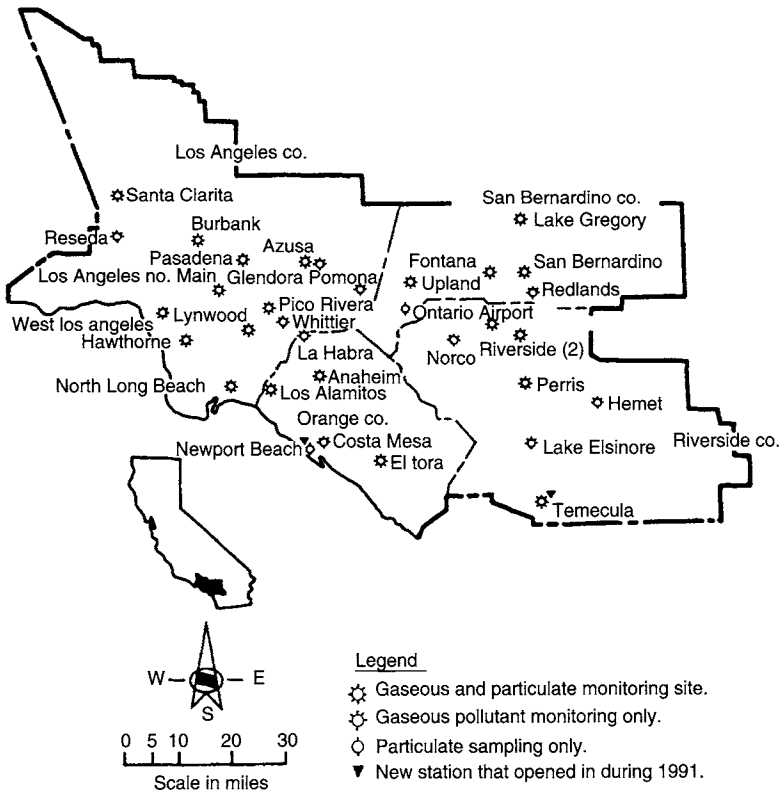


Fig. 18.1. California South Coast Air Basin stationary monitoring locations operating during 1991 (LA: Los Angeles). Source: California Air Resources Board, *Summary of 1991 Air Quality Data, Gaseous and Particulate Pollutants*, Vol. 23, 1991.

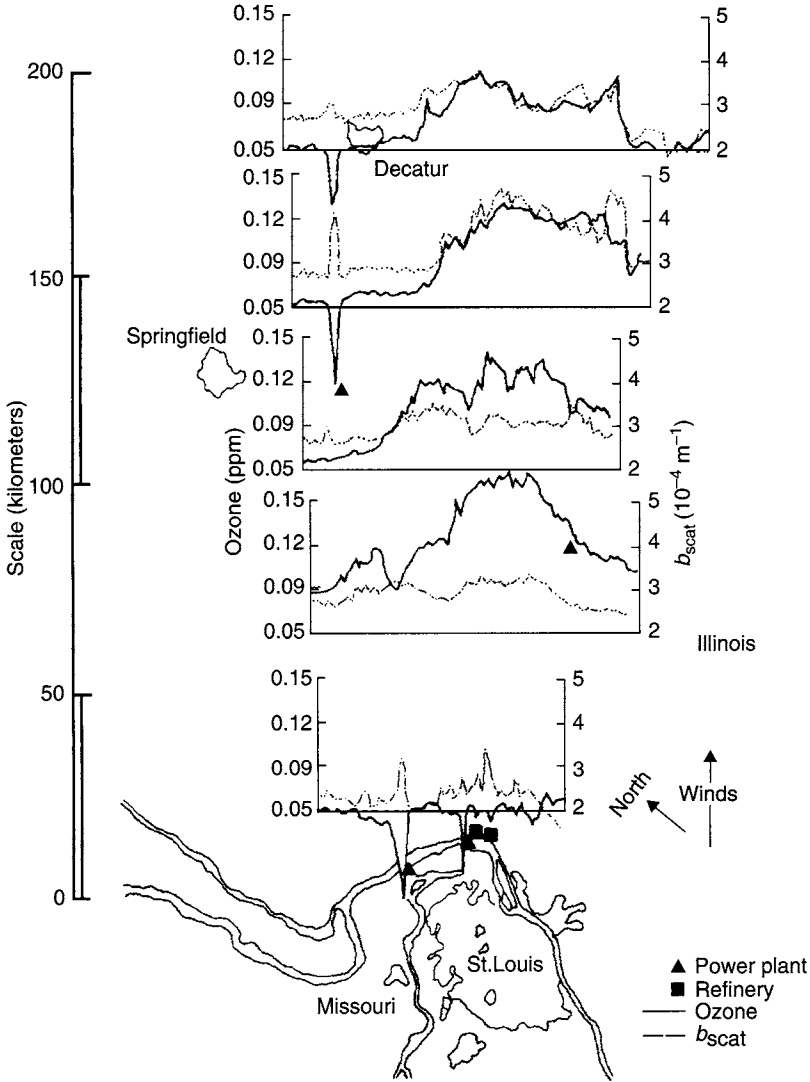
these locations, automated instruments collect air quality data continuously. Five pollutant gases are monitored, and particulate matter filter samples are collected periodically.

## II. MOBILE MONITORING AND SURVEILLANCE

Mobile monitoring is accomplished from a movable platform, i.e., an aircraft or vehicle. Emissions are measured by source monitoring techniques (see Chapter 35). Atmospheric transport and chemical transformation processes occur in the region between the source and the receptor. By using mobile platforms containing air pollution instrumentation, one can obtain data to help understand the formation and transport of photochemical smog, acidic deposition, and the dispersion of air pollutants from sources. Mobile monitoring platforms may also be moved to *hot spots*, areas suspected of having high concentrations of specific air pollutants. These areas may be nearby locations downwind of a large source or a particular location that is an unfavorable receptor due to meteorological conditions. Vehicular and aircraft monitoring systems can also be moved to locations where hazardous chemical spills, nuclear and chemical plant accidents, or volcanoes or earthquakes have occurred.

The major advantage of a mobile monitoring system is its ability to obtain air quality information in the intermediate region between source monitors and stationary fixed monitors. The major disadvantage is the sparsity of suitable instrumentation that operates properly in the mobile platform environment. Limitations of existing instrumentation for the use on movable platforms are inadequate temperature and pressure compensation; incompatible power, size, and weight requirements; and excessive response time. Most movable platforms are helicopters, airplanes, trucks, or vans. These platforms do not provide the relatively constant-temperature environment required by most air quality instrumentation. Equipment mounted in aircraft is subject to large pressure variations with changing altitude. Most instrumentation is designed to operate with alternating current (AC) electrical power, whereas relatively low amounts of direct current (DC) power are available in aircraft or vans. Space is at a premium, and response times are often too slow to permit observation of rapid changes in concentration as aircraft move in and out of a plume.

Despite these limitations, mobile monitoring systems have been used to obtain useful information, such as the verification and tracking of the St. Louis, Missouri, urban plume. The measurement of a well-defined urban plume spreading northeastward from St. Louis is shown in Fig. 18.2 [7]. These data were collected by a combination of instrumented aircraft and mobile vans. Cross-sectional paths were flown by the aircraft at increasing distances downwind. Meteorological conditions of low wind speed in the same direction helped to maintain this urban plume in a well-defined condition for several hundred kilometers downwind. The presence of large point sources of NO and SO<sub>2</sub> was observed by the changes in the O<sub>3</sub> and  $b_{\text{scat}}$  profiles.



**Fig. 18.2.** The St. Louis, Missouri, urban plume. Ozone and  $b_{scat}$  profiles at four distances downwind of St. Louis track a detectable urban plume for 150 km. Source: Wilson Jr., W. E., *Atmos. Environ.* 12, 537–547 (1978).

Sharp decreases in ozone concentration occurred when large amounts of NO were present, and rapid increases in  $b_{scat}$  were caused by the primary and secondary particulate matter from power plant plumes embedded in the larger urban plume. The overall increasing level of ozone and  $b_{scat}$  at greater downwind distances was caused by the photochemical reactions as the urban plume was transported farther away from St. Louis. This type of plume mapping can be accomplished only by mobile monitoring systems.

III. REMOTE SENSING

Remote sensing involves monitoring in which the analyzer is physically removed from the volume of air being analyzed. Satellites have been used to monitor light-scattering aerosol over large areas [8]. Large point sources such as volcanic activity and forest fires can be tracked by satellite. The development and movement of hazy air masses have been observed by satellite imagery (see Fig. 14.9). Remote sensing methods are available for determining the physical structure of the atmosphere with respect to turbulence and temperature profiles (see Chapter 5).

Differential absorption lidar (DIAL) is used for remote sensing of gases and particles in the atmosphere. *Lidar* is an acronym for *light detection and ranging*, and the technique is used for measuring physical characteristics of the atmosphere. DIAL measurements consist of probing the atmosphere with pulsed laser radiation at two wavelengths. One wavelength is efficiently absorbed by the trace gas, and the other wavelength is less efficiently absorbed. The radiation source projects packets of energy through the atmosphere, which interact with the trace gas. The optical receiver collects radiation backscattered from the target. By controlling the timing of source pulses and processing of the optical receiver signal, one can determine the concentration of the trace gas over various distances from the analyzer. This capability permits three-dimensional mapping of pollutant concentrations. Applications are plume dispersion patterns and three-dimensional gaseous pollutant profiles in urban areas.

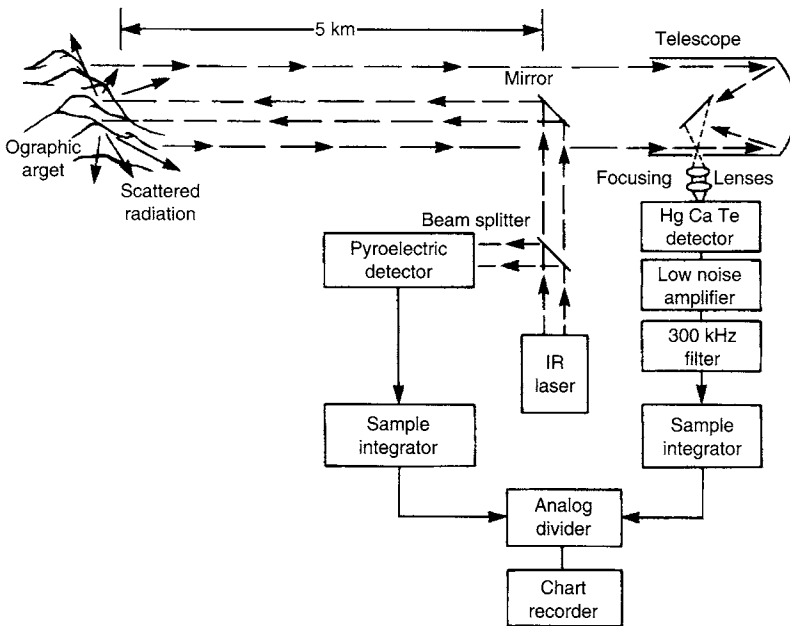
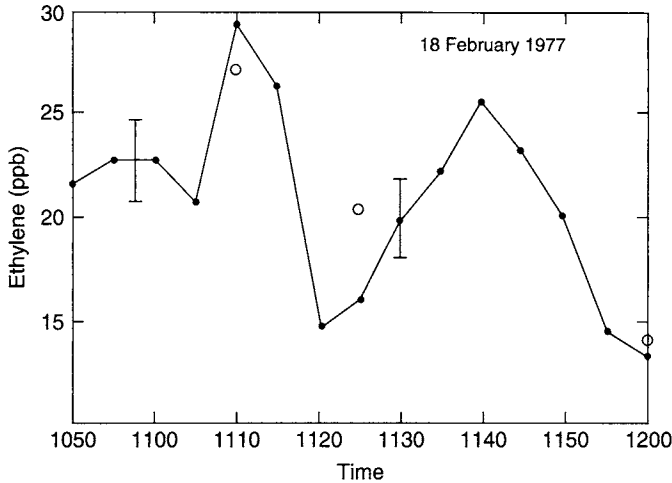


Fig. 18.3. An infrared DIAL system. Source: Murray, E. A., and Van der Laan, J. E., *Appl. Opt.* 17, 814-817 (1978).



**Fig. 18.4.** Ethylene concentrations measured by the DIAL system along a 5-km path length near Menlo Park, California. The open circles are ethylene concentrations of samples taken at three ground-level locations near the line of sight and analyzed by gas chromatography. *Source:* Murray, E. A., and Van der Laan, J. E., *Appl. Opt.* 17, 814-817 (1978).

$\text{SO}_2$  and  $\text{O}_3$  are detected by an ultraviolet DIAL system operating at wavelengths near 300 nm [9]. Tunable infrared  $\text{CO}_2$  lasers are used in applications of IR-DIAL systems which are capable of measuring  $\text{SO}_2$ ,  $\text{CO}$ ,  $\text{HCl}$ ,  $\text{CH}_4$ ,  $\text{CO}_2$ ,  $\text{H}_2\text{O}$ ,  $\text{N}_2\text{O}$ ,  $\text{NH}_3$ , and  $\text{H}_2\text{S}$  [10]. The components of this type of system are shown in Fig. 18.3 [11]. The laser source is switched between the low-absorption and high-absorption frequencies for the trace gas to be detected. The system is pointed toward a target, and focusing lenses are used to collect the returning signal. The beam splitter diverts a portion of the transmitted beam to a detector. The backscattered and transmitted pulses are integrated to yield DC signals. Figure 18.4 shows ethylene concentrations measured on a 5-km path in Menlo Park, California, with this system.

Satellites are being used to detect global distributions of large areas of  $\text{CO}$  and  $\text{O}_3$  [12].

#### IV. PERSONAL MONITORING

Ambient and even indoor measurements of air pollutants are not often a good indication of the levels of exposure to air pollutants that people actually receive. Their activities and locations often vary considerably from person to person. In fact, the phenomenon known as "personal cloud" has recently been characterized to help predict a person's exposures and risks to air pollutants. The cloud indicates an increased personal exposure to air pollutants compared

TABLE 18.2

## Comparison of Ambient Concentrations of Air Pollutants to Personal Exposures

Pollutant <sup>d</sup>	Summer					Fall				
	<i>n</i>	ND	LOD	Mean ± SD	Maximum	<i>n</i>	ND	LOD	Mean ± SD	Maximum
<b>Ambient concentrations</b>										
<i>Particles</i>										
PM <sub>2.5</sub>	65	0	0	20.1 ± 9.3	46.6	72	0	0	19.3 ± 12.2	50.7
SO <sub>4</sub> <sup>2-</sup>	61	0	0	7.7 ± 4.8	25.0	72	0	0	6.2 ± 4.7	22.4
EC	56	0	1	1.1 ± 0.5	2.9	71	0	0	1.1 ± 0.7	3.6
<i>Gases</i>										
O <sub>3</sub>	62	0	4	29.3 ± 13.4	74.8	72	0	21	16.0 ± 8.1	42.4
NO <sub>2</sub>	62	1	44	9.5 ± 7.4	37.9	71	0	16	11.3 ± 6.0	27.9
SO <sub>2</sub>	63	23	53	2.7 ± 3.9	21.9	71	24	43	5.4 ± 9.6	63.6
<b>Personal exposures</b>										
<i>Particles</i>										
PM <sub>2.5</sub>	169	0	0	19.9 ± 9.4	59.0	204	0	0	20.1 ± 11.6	66.0
SO <sub>4</sub> <sup>2-</sup>	165	0	2	5.9 ± 4.2	25.6	188	0	0	4.4 ± 3.3	16.3
EC	166	7	12	1.1 ± 0.6	4.6	197	1	1	1.2 ± 0.7	6.2
<i>Gases</i>										
O <sub>3</sub>	183	2	168	5.3 ± 5.2	35.7	226	84	207	3.9 ± 4.4	21.3
NO <sub>2</sub>	183	1	117	9.9 ± 6.0	38.9	228	1	32	12.1 ± 6.1	38.8
NO <sub>2</sub> <sup>b</sup>	130	1	93	9.0 ± 5.2	38.9	139	1	28	9.9 ± 4.6	28.7
NO <sub>2</sub> <sup>c</sup>	53	0	24	12.3 ± 7.1	33.5	89	0	4	15.7 ± 6.4	38.8
SO <sub>2</sub>	185	99	173	1.5 ± 3.3	30.4	228	72	217	0.7 ± 1.9	14.2

<sup>a</sup> PM<sub>2.5</sub>, SO<sub>4</sub><sup>2-</sup>, and EC in units of micrograms per cubic meter; O<sub>3</sub>, NO<sub>2</sub>, and SO<sub>2</sub> in units of parts per billion.

<sup>b</sup> Samples from subjects without gas stoves in their homes.

<sup>c</sup> Samples from subjects with gas stoves in their homes.

ND: number of samples with values below the analytical LOD (i.e. not detected).

Source: Sarnat, S. E., Coull, B. A., Schwartz, J., Gold, D. R., and Suh, H. H., Factors affecting the association between ambient concentrations and personal exposures to particles and gases. *Environ. Health Persp.* 114 (5), 649–654, 2006.

to indoor concentrations, or compared to the time-weighted indoor and outdoor concentrations. Results from several recent studies suggest that a number of factors, such as relative humidity and ventilation may lead to very different exposures based on personal measurements versus ambient concentrations of air pollutants. For example, one recent study found that while ambient fine particle concentrations may somewhat represent exposures to fine particles, the ability of either ambient gases or ambient fine particles to represent exposure to gases is quite small (see Table 18.2).

With personal monitoring, the monitoring device is worn by individuals as they proceed through their normal activities. This approach is most common in workplaces. The radioactivity sensors worn by nuclear power plant workers are one example. Personal monitoring is increasingly being used, however, to estimate total human exposures, including exposures from the air people breathe, the water they drink, and the food they eat.<sup>1</sup> One advantage of personal monitoring is that the data provide valuable insights into the sources of the pollutants to which people are actually exposed. A challenge with personal monitoring is ensuring that sufficient sampling is done to be representative of the population being studied.

## V. QUALITY ASSURANCE

Air quality monitoring for standards compliance, new facility siting, and long-term trend measurement has been going on for many years. Historically, a large number of federal, state, and local organizations, both governmental and nongovernmental, have been using a variety of technologies and approaches to obtain air quality data. This has resulted in multiple data sets of variable accuracy and precision. Questionable or conflicting air quality data are of little value in ascertaining compliance with air quality standards, determining whether air quality is improving or worsening in a given region over an extended period, or understanding the chemistry and physics of the atmosphere.

In order to minimize the collection of questionable air quality data, the US EPA has established and implemented stringent regulations requiring well-documented quality assurance programs for air quality monitoring activities [13].

Quality assurance programs are designed to serve two functions: (1) assessment of collected air quality data and (2) improvement of the data collection process. These two functions form a loop; as air quality data are collected,

<sup>1</sup> Examples of personal monitoring include EPA's Total Exposure Assessment Monitoring (TEAM) studies and its National Human Exposure Assessment Survey (NHEXAS), and the Relationship of Indoor, Outdoor, and Personal Air (RIOPA) study conducted by the Mickey Leland Center.

procedures are implemented to determine whether the data are of acceptable precision and accuracy. If they are not, increased quality control procedures are implemented to improve the data collection process.

The components of a quality assurance program are designed to serve the two functions just mentioned—control and assessment. Quality control operations are defined by operational procedures, specifications, calibration procedures, and standards and contain the following components:

1. Description of the methods used for sampling and analysis
2. Sampling manifold and instrument configuration
3. Appropriate multipoint calibration procedures
4. Zero/span checks and record of adjustments
5. Control specification checks and their frequency
6. Control limits for zero, span, and other control limits
7. The corrective actions to be taken when control limits are exceeded
8. Preventative maintenance
9. Recording and validation of data
10. Documentation of quality assurance activities

Table 18.3 contains a specific example of these components for ambient monitoring for ozone.

TABLE 18.3

**Quality Control Components for Ambient Ozone Monitoring**

Component	Description
Method	Chemiluminescent O <sub>3</sub> monitor Calibration method by certified ozone UV transfer method
Manifold/instrument configuration	Instrument connected to sampling manifold which draws ambient air at 3 m into instrument shelter
Calibration	Multipoint calibration on 0.5-ppm scale at 0.0, 0.1, 0.2, and 0.4 ppm weekly
Zero/span check	Zero check $\pm 0.005$ ppm Span check 0.08–0.10 on a 1.0-ppm full-scale daily
Control specification checks	Ethylene flow Sample flow, daily
Corrective limits	$\pm 0.005$ ppm zero and span
Corrective action	Do multipoint calibration; invalidate data collection since last zero/span check within control limits
Preventive maintenance	Manufacturer's procedures to be followed
Recording and validating data	Data reported weekly to quality assurance coordinator, with invalid data flagged
Documentation	Data volume includes all quality control forms, e.g., zero/span control charts and multipoint calibration results

In addition to fulfilling the in-house requirements for quality control, state and local air monitoring networks which are collecting data for compliance purposes are required to have an external performance audit on an annual basis. Under this program, an independent organization supplies externally calibrated sources of air pollutant gases to be measured by the instrumentation undergoing audit. An audit report summarizes the performance of the instruments. If necessary, further action must be taken to eliminate any major discrepancies between the internal and external calibration results.

Data quality assessment requirements are related to precision and accuracy. Precision control limits are established, i.e., +10% of span value, as calculated from Eq. (18.1). The actual results of the may be used to calculate an average deviation (Eq. 18.3):

$$d_i = (y_i - x_i)/x_i \times 100 \quad (18.1)$$

where  $d_i$  is the percentage difference,  $y_i$  the analyzer's indicated concentration of the test gas for the  $i$ th precision check, and  $x_i$  the known concentration of the test gas for the  $i$ th precision check:

$$d_{av} = \frac{1}{n} \sum_{i=1}^n d_i \quad (18.2)$$

$$S_j = \sqrt{\frac{1}{n-1} \left[ \sum_{i=1}^n d_i^2 - \frac{1}{n} \left( \sum_{i=1}^n d_i \right)^2 \right]} \quad (18.3)$$

The external audit results are used to determine the accuracy of the measurements. Accuracy is calculated from percentage differences,  $d_i$ , for the audit concentrations and the instrument response.

## VI. DATA ANALYSIS AND DISPLAY

In general, air quality data are classified as a function of time, location, and magnitude. Several statistical parameters may be used to characterize a group of air pollution concentrations, including the arithmetic mean, the median, and the geometric mean. These parameters may be determined over averaging times of up to 1 year. In addition to these three parameters, a measure of the variability of a data set, such as the standard deviation or the geometric standard deviation, indicates the range of data around the value selected to represent the data set.

Raw data must be analyzed and transformed into a format useful for specific purposes. Summary tables, graphs, and geographic distributions are

some of the formats used for data display. Air quality information often consists of a large body of data collected at a variety of locations and over different seasons. Table 18.4 shows the tabular format used by a local air pollution authority to report the status of compliance with air quality standards [6].

TABLE 18.4

Summary of Air Quality Statistics in the California's South Coast Air Basin and the Desert Area of Coachella Valley in the Salton Sea Air Basin for December 2002.

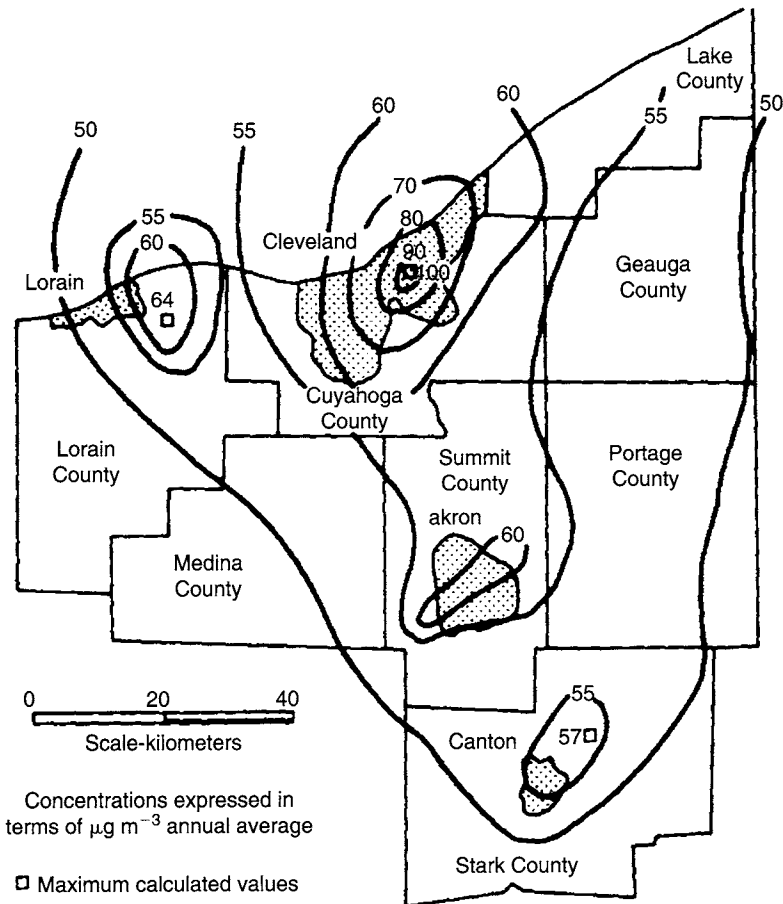
Pollutant averaging time	State standard	Federal standard	Maximum concentrations			
			ppm $\mu\text{g}^{-1}\text{m}^{-3}$	% State standard	% Federal standard	Location
Ozone 1 h	>0.09 ppm	>0.12 ppm	0.06	60	48	Several Locations
8 h		>0.08 ppm	0.055		65	Banning Airport
Carbon monoxide 8 h	>9.0 ppm	>9 ppm	8.40	92	88	South Central Los Angeles County
Nitrogen dioxide 1 h	>0.25 ppm		0.10	38		Southwest Coastal Los Angeles County
24 h			0.069			South San Gabriel Valley
Sulfur dioxide 1 h	>0.25 ppm		0.02	8		South Coastal Los Angeles County
24 h		>0.04 ppm	>0.14 ppm	0.010	24	7
Particulate (PM <sub>10</sub> ) 24 h	>50 $\mu\text{g m}^{-3}$	>150 $\mu\text{g m}^{-3}$	95	186	63	Metropolitan Riverside County
Particulate (PM <sub>2.5</sub> ) 24 h		>65 $\mu\text{g m}^{-3}$	55.4		85	South Coastal Los Angeles County
Sulfates 24 h	$\geq 25 \mu\text{g m}^{-3}$		4.7	19		South Central Los Angeles County
Lead <sup>a</sup> 30 Days	$\geq 1.5 \mu\text{g m}^{-3}$		0.03	2		Central Los Angeles
30 Days <sup>a</sup>			0.19	13		Several Locations

<sup>a</sup> Maximum monthly average concentration recorded at special monitoring sites in the immediate vicinity of major lead sources.

Source: *South Coast Air Quality Management District Air Quality Standards Compliance Report*, December 2002, and *Summary Statistics for 2002*, Vol. 15, No. 12.

The format has location, maximum values, annual means, and number of occurrences of hourly values above a given concentration as a function of the month of the year. One can quickly determine which areas are violating a standard, at what time of the year elevated concentrations are occurring, and the number of good data points collected.

Pollutant concentration maps may be constructed as shown in Fig. 18.5 [14]. In this example, elevated levels of ambient particulate matter are associated with population centers. For a given geographic area, isopleths, lines showing equal concentrations of a pollutant, are drawn on a map. Regions of high concentration are quickly identified. Further action may be taken to determine the cause, such as review of emission inventories of additional sampling.



**Fig. 18.5.** Concentration isopleth diagram of ambient particulate matter calculated by a computer model. *Source:* Zimmer, C. E., *Air Pollution*, 3rd ed., Vol. 3 (Stern, A. C., ed.). Academic Press, New York, 1976.

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## QUESTIONS

1. List the two major functions of a quality assurance program and describe how they are inter-related.
2. List the advantages and disadvantages of remote sensing techniques by optical methods.

3. Determine which month and location have the greatest number of hours with ozone concentrations  $\geq 0.01$  ppm, using Table 18.4.
4. Determine how many monitoring stations per million people are located in the four counties in southern California shown in Fig. 18.1.
5. What are the physical constraints in placing instrumentation in aircraft or motor vehicles?
6. What are appropriate uses of mobile platforms for monitoring?
7. Describe the chemical behavior of the  $b_{\text{scat}}$  and ozone concentration profiles of the St. Louis urban plume in Fig. 18.2. What is the reason for the sharp increase of  $b_{\text{scat}}$  and the sharp decrease of ozone in the vicinity of power plants?
8. List the reasons for establishing a stationary air monitoring network.
9. What factors can account for differences between ambient concentrations of a pollutant and actual, personal exposures to the same pollutant?