AIR MONITORING PROGRAMME DESIGN FOR URBAN AND INDUSTRIAL AREAS

Prepared by the Secretariats of the

WORLD HEALTH ORGANIZATION and the WORLD METEOROLOGICAL ORGANIZATION

following a

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PREFACE

Both the World Health Organization (WHO) and the World Meteorological Organization (WMO) have for many years been engaged in technical cooperation with Member States in establishing or developing environmental control programmes, and several projects have been undertaken jointly by the two Organizations.[1,2] This collaboration was strengthened when the Global Environmental Monitoring System (GEMS) was established as part of the United Nations Environment Programme (UNEP).

The World Meteorological Organization has organized a global background air pollution monitoring network operated by Member States in rural and remote locations.[3] As air pollution is one of the factors that affect human health, the World Health Organization began to monitor air quality in selected urban and industrial areas in 1972.[4] Both WMO and WHO programmes are part of GEMS and are operated in cooperation with and with the support of UNEP.

A group of experts was convened in Geneva in June 1976, cosponsored by both Organizations, to consider the principles for the design of urban air monitoring networks, including meteorological aspects. The participants (see Annex 3) reviewed a document that had been drafted prior to the meeting on the basis of working papers prepared by Mr G. Akland, Dr D. Szepesi and Mr R. Waller. The document was subsequently edited for this publication by a small panel in collaboration with WMO and WHO staff. The members of the panel were Dr J. Mahoney and Mr R. Waller, who had both also participated in the consultation, and Dr D. Shearer, WHO Collaborating Centre on Environmental Pollution Control, United States Environmental Protection Agency, Washington, DC, USA.

INTRODUCTION

The main purpose of this publication is to provide guidance on the design of air quality monitoring programmes for urban and industrial areas. Such programmes are needed for almost all the actions taken to prevent or abate air pollution, from the initial assessment of existing conditions, to the enforcement of current control regulations, to the evaluation of the effectiveness of abatement programmes, and finally to the development of new control measures. It is also hoped that this publication will contribute to more effective harmonization of air monitoring procedures, permitting the comparison of data obtained throughout the world.

The information contained in this publication attempts to provide general guidance on when the institution of monitoring programmes should be considered, what should be monitored, where monitoring should be carried out and how it should be conducted.

Air pollution control procedures are not discussed, although they are definitely interrelated with those of air quality monitoring. Methods of analysis of air pollutants have been presented elsewhere.[5-10]

The information given should also serve to guide the further development of the Global Environmental Monitoring System (GEMS) activities[11] in urban areas. In addition, emphasis is placed on the need for a full and continuing cooperation between air pollution control agencies which are involved in air quality monitoring and the local and national meteorological services.

Air quality monitoring proposals should always be viewed in the broad context of environmental management. The decision-maker must often assign priorities amongst a multitude of environmental concerns and he must decide whether an air quality monitoring programme is justified, and if so, what level of technical support it should receive. It is important to beware of establishing too ambitious a programme unless there is a clear understanding of how the air quality data will be used.

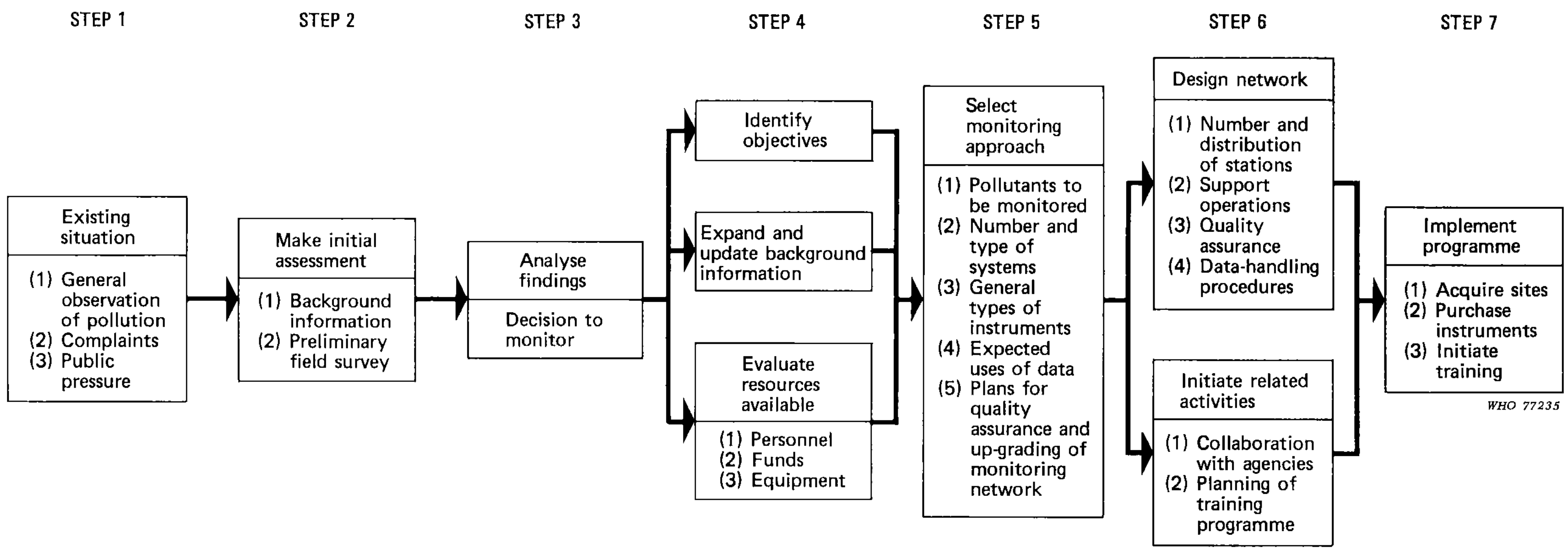
This publication is primarily directed at administrative and technical personnel in those countries that are becoming concerned about air pollution aspects of an increasingly developing industrial economy. The guidance provided should also be useful to those countries that have already established a monitoring programme and are making decisions for further development of their monitoring network. In this connexion it should also be noted that industry should be encouraged to monitor not only their plant emissions, but also the ambient air in and around their establishments. The guidelines presented will also aid them in this.

An overall picture of the major steps for the development of an air monitoring programme is presented in Fig. 1. The various developmental stages are shown in chronological sequence; some steps include a number of activities that can be carried out simultaneously.

The text is organized into four chapters as follows: (1) monitoring objectives and approaches, (2) monitoring network design, (3) station location criteria, and (4) other essential components of the monitoring programme. The principal information is contained in Chapters 2 and 3, where specific guidance is provided on the design of air quality monitoring networks. Chapter 1 serves primarily as an introduction to these chapters and Chapter 4 gives some additional helpful information.

In addition, three examples are given in Annex 2 to illustrate the development of different types of air quality monitoring programmes. The first example shows the development of a programme based primarily on the use of manually operated instruments; the second is based on the use of automatic monitoring instrumentation; and the third deals with the development of a monitoring programme in the vicinity of a large single source of air pollution. It should be stressed that these examples should only be taken as general guidance to illustrate some of the types of programmes that could be developed for a particular need. Specific suggestions about numbers of samples and costs are included; however, all such decisions and calculations must be made locally in any real situation, following the guidelines set out in the main part of the text.

FIG. 1 STEPS IN THE DEVELOPMENT OF AN AIR QUALITY MONITORING PROGRAMME



1.1 Objectives

Before considering the establishment or expansion of an air quality monitoring programme, it is essential to examine the objectives carefully if the appropriate data are to be collected with a minimum of effort and cost. Although it may be tempting to design a system that could serve a multitude of different objectives and associated data needs, in practice it appears that only certain combinations of objectives are realizable with a given network. For example, it is generally not possible to use a network designed to monitor long-term trends of air pollution levels to investigate a specific complaint. Of course, it is possible to modify a network designed primarily for one purpose so that it will serve another as well.

Monitoring objectives have been divided into two groups. The first group (a and b below and in Table 1) includes the objectives for a monitoring programme for an average industrialized city with an actual or potential air pollution problem. They cover the basic monitoring requirements and most of the remaining chapters deal with further information on these. The second group (c-i below and in Table 1) includes more specialized monitoring objectives, which are generally more optional in nature (and also technically somewhat more complex) and, according to the local situation, may or may not form part of the basic programme.

The basic monitoring programme will provide the essential data required to develop air quality standards and will in general permit the development of a viable air pollution control programme. Normally the major air pollutants (see Annex 1), such as suspended particulate matter, sulfur dioxide, carbon monoxide, nitrogen oxides and oxidants, would be considered for inclusion in this type of monitoring operation. Depending on the type of industries active in the general area, other pollutants, for example, hydrogen sulfide, may be added.[12] The meteorological parameters to be measured would be wind speed and direction. If possible, the frequency of inversions should also be recorded.

The objectives in the first group are as follows:

(a) To observe long-term trends

This is to detect any deterioration in air quality arising from residential or industrial development. For this purpose alone a network using manually operated equipment would be sufficient; 24-hour samples could be collected intermittently over relatively long periods and measurements might be made at only three or four sites within a given urban area (with the important proviso that these should remain in operation at the same places for many years). The siting must, however, be considered very carefully to avoid undue influence from nearby sources.

Much additional information can be gained, and the network can be made more versatile, if uninterrupted observations are made over 24-hour periods. Statistical analyses can then be done to provide not only the yearly averages, but the frequency distributions of the daily values. Trends can be studied separately for weekdays versus weekends, and interrelationships with meteorological factors can be examined.

Because of the large seasonal variations in the concentrations of some pollutants, it is always important when assessing trends to make sure that sampling has been carried out throughout each year, or at least for periods representative of it. Major changes in the weather pattern from one year to another can affect even the annual means and, to observe underlying trends, data for at least five consecutive years may be required.

(b) <u>To judge compliance with air quality standards and to evaluate control strategies</u>

In general, insufficient attention has been given to the monitoring procedures to be adopted when recommending air quality standards. It is important for them to be specified in detail, since results depend so much on the exact location of samplers and on the averaging periods adopted. For ambient air quality standards the aim should be to assess concentrations that are relevant to the exposure of the general population, without undue bias from local sources or unusual dispersion conditions. When new control measures are introduced, a long series of results, extending over at least five years, is required to establish their effectiveness, and the monitoring network should, if possible, be set up before the controls come into operation. Usually 24-hour averages are required. In some cases, such as for carbon monoxide, averages of less than 24 hours are needed.

The second group of objectives includes the following:

(c) <u>To activate emergency control procedures</u>

This is primarily a problem of forecasting the weather and, in turn, the likely concentrations of key pollutants for periods of about 24 hours ahead. A prerequisite is that mathematical models be developed relating concentrations of air pollutants to meteorological variables. Forecasts of pollution levels derived from such models need to be backed up by routine observations in the urban area, using sampling periods of the order of one hour. Systems designed specifically for emergency control can be highly sophisticated, with facilities for giving advance warnings, but these are only justified if such warnings can be used effectively to protect the population.

(d) <u>To evaluate risk to human health</u>

The effects of urban air pollutants can be considered under two headings: acute effects, usually observed in terms of day-to-day changes in some index of health; and chronic effects, which gradually become manifest after many years of exposure to pollution. For the first of these it is essential to have measurements of pollutants over short intervals; 24-hour sampling periods are in general adequate but to assess exposures to peak concentrations during the day observations averaged over shorter periods may be required. In relation to chronic effects, annual averages may suffice but, since a knowledge of seasonal variations and peak values may be relevant, series of observations over 24-hour periods, as required for acute effects, provide a suitable basis.

Where concentrations vary greatly over distances of a few metres, as they are liable to in the case of carbon monoxide or lead from traffic sources, then specially designed surveys are generally required for each study, possibly involving the use of personal samplers.

(*e*) To assess other environmental risks

Risks of damage to plants and trees within the urban area can usually be assessed on the basis of observations over 24-hour periods, as in objectives (*a*) or (*d*) above, but since a brief exposure to high concentrations (e.g., of sulfur dioxide or ozone) can damage sensitive flowers, continuous monitoring instruments may be required if such considerations are of any great importance.

Risks of damage to stonework and other building materials, particularly from sulfur dioxide, are best assessed with static monitors, for example, lead peroxide candles, which are exposed to the atmosphere for periods of one month at a time. Analysis of precipitation samples, especially for acidity, is also useful.

(*f*) To provide the data base for land-use planning

Land-use patterns and their accompanying activities determine to a large extent the types and amounts of pollutants generated in an urban area. With increasing concern for environmental quality, there is a need to relate existing pollution levels to the impact of new or expanded urban industrial complexes and of the establishment of new major public works.

For sulfur dioxide and suspended particulate matter the instrumentation and data requirements are similar to those in objectives (*a*) and (*d*) above, using instruments usually operating for 24-hour periods. The network should include sites representative of each kind of land use, such as high-density and low-density residential areas, industrial complexes and commercial districts. WMO regional stations may provide additional useful data.

(*g*) To validate dispersion models

Dispersion models may be related to the emissions from a single source or to the integrated effects of multiple sources in a large community and monitoring requirements will vary accordingly. In determining the frequency of sampling, the nature of the model must also be considered, whether it is to be used in relation to short-term variations in pollution over periods of 24 hours, and down to a few minutes, or in the assessment of long-term averages (1 month - 1 year). In most cases an extensive monitoring network using automatic instruments is required for a period of about one year, to "calibrate" the model.

(*h*) To investigate specific complaints

For the investigation of specific complaints the sampling may, in contrast with that in earlier sections, be deliberately aimed at picking up pollution from local sources. Since monitoring results are influenced by small changes in wind direction, a large number of samplers may be required and continuous monitoring equipment may have to be included so that transient peaks can be observed. There may be difficulties if the type of pollutant cannot be specified in advance, for it would probably not be practicable to set up special sampling stations for a variety of pollutants. Mobile sampling stations can be valuable in such cases.

(*i*) To carry out initial assessment surveys

Where no measurements have been made before or where a new type of pollution problem is emerging, an exploratory survey may be carried out

TABLE 1
AIR QUALITY INSTRUMENTATION IN RELATION TO OBJECTIVES

POLLUTANT	OBJECTIVES*	INSTRUMENT	SAMPLING PERIOD	COSTS CAPITAL	COSTS RUNNING	COMMENTS
Sulfur dioxide	All	Automatic instruments	Continuous	High	Moderate-high	Instruments include whole analytical process; skilled personnel must be available to ensure proper functioning.
	a,b,d,e,f,h,i	Mechanized bubblers	1-24 h	Moderate	Moderate	Sample analysis carried out in the laboratory; often used in conjunction with smoke samplers.
	a,b,d,e,h,i	Absorption tubes	30 min	Low	Moderate	Applicable to intensive surveys of urban areas; sampling at many sites visited according to statistically designed schedule.
	a,e,i	Lead peroxide candles	1 month	Low	Low	Useful to indicate relative distribution around major sources; do not give absolute concentrations.
Suspended particulate matter	a,b,d,e,f,h,i	Smoke samplers	24 h	Moderate	Low	Operated at a low flow rate, sampling only small particles; some chemical analysis of filter deposit possible.
	a,b,d,e,f,h,i	High-volume samplers	24 h	Moderate	Moderate	Sample particles up to 100 um; wide range of chemical analyses on filter deposit possible.
	All	Automatic instruments	Continuous (1-4 h/spot)	High	Moderate-high	Operated at low flow rates, with samples collected on filter tapes; some chemical analysis of filter deposit possible.

Deposited particulate matter	a,h,i	Dustfall gauges	1 month	Low	Low	Sample large particles only; results in general not relevant to effects on health; chemical analysis of deposits possible.
Carbon monoxide	All	Automatic instruments	Continuous	High	Moderate-high	In addition to on-site measurements, spot samples may be collected in the field and brought back to the laboratory for evaluation.
Oxides of nitrogen, oxidants	a,b,d,e,f,h,i	Mechanized bubblers	1-24 h	Moderate	Moderate	Sample analysis carried out in the laboratory.
	All	Automatic instruments	Continuous	High	Moderate-high	Instruments include whole analytical process; skilled personnel must be available to ensure proper functioning.
Oxidants (as ozone)	h,i	Mechanized bubblers	30 min	Moderate	Moderate	Sample analysis must be carried out in a laboratory 30-60 min after sampling.
	All	Automatic instruments	Continuous	High	Moderate-high	Instruments include whole analytical process; skilled personnel must be available to ensure proper functioning.

* Objectives:
a = trend analysis;
b = evaluate control strategies;
c = activate episode controls;
d = evaluate risk to human health;
e = evaluate risk of environmental damage;
f = data base for land-use planning;
g = validate dispersion models;
h = investigate complaints;
i = initial assessment.

for a limited period using manual samplers or, if available, a mobile sampling station. A knowledge of the kinds of fuel used and of industrial activities in the area is important as a guide to the types of pollutants to be sampled. Where there are requirements for heating during part of the year only, or where there are major changes in meteorological factors, the survey should include the period when air pollution levels are expected to be high.

1.2 Approaches to monitoring programme development

The design of a monitoring programme will always involve the consideration of a number of broad questions of what, where, why and how to monitor, which must be resolved before the detailed design of the specific network can proceed.[13] For example, every moderate or large-scale monitoring network adheres to one of two basic approaches: (1) many stations with measurements made for one or two pollutants only in each station; or (2) few stations with measurements made for several pollutants in each station. Even this basic division in approach has several other dimensions: general choices of instrument types, plans for the use of the data, etc. The list below summarizes the major factors to be considered in the development of the approach to a monitoring system design.

(1) Pollutants to be measured. Some networks will include instruments for measuring only the most common urban pollutants, sulfur dioxide and suspended particulate matter. Other networks will also include instruments for the other common urban pollutants, as mentioned in Annex 1.

(2) Number of stations. This is closely related to the objectives of the monitoring network and the resources available.

(3) Station deployment. The monitoring stations may be at fixed locations, or a mobile monitoring station may make measurements at a number of different locations. In some situations a combination of fixed and mobile stations is best.

(4) Instrument types. A brief review of the types of equipment available, as they relate to the monitoring objectives previously described, together with an estimate of relative costs is given in Table 1. This is also dealt with in greater detail in reference 14.

(5) Sampling periods. Three principal sampling periods should be considered: short term (e.g., 1 hour), moderate term (1 day) and long term (1 month). Instruments monitoring continuously can provide data for all time scales. The sampling period is particularly important if the monitoring results are to be compared with standards or criteria.

(6) Meteorological information. The availability of the meteorological information required to locate the monitoring station and to interpret the air monitoring data should be determined. The types of meteorological instruments typically required to meet the various monitoring objectives are given in Table 2.

TABLE 2. METEOROLOGICAL REQUIREMENTS IN RELATION TO OBJECTIVES

Monitoring objective	Instruments and measurements
Initial assessment	Recording wind instruments.
Trend analysis, evaluate risk to human health, evaluate risk of environmental damage	Recording wind instruments, thermo-hygrographs, precipitation gauges.
Evaluate control strategies	Recording wind instruments, thermo-hygrographs and precipitation gauges; vertical temperature profile observations useful, often based on radio-sond measurements from local meteorological services.
Validate dispersion models	Observations from a group of meteorological stations in the area; one site should be a tower station with temperature and wind observations at different heights; if not possible, atmospheric stability conditions can be estimated by using ground-based parameters: radiation intensity, cloudiness and wind observations; consultation with meteorological experts recommended.
Activate episode controls	As above; collaboration with local meteorological services essential; immediate access to current observations of wind and temperature (stability) parameters required.
Investigate complaints	Portable wind instruments, thermometers and precipitation gauges.
Data base for land-use planning	Portable wind stations useful if the topography of the area is complicated; vertical temperature observations useful.

2.1 Background information needed

2.1.1 Sources and emissions

One of the first steps in the design of a monitoring network is to gather information concerning the sources and emissions of air pollution in the area to assemble an emission inventory.

The main sources in a city usually include industries, motor vehicles, power plants, incinerators and heating equipment (see Annex 1). Information should be collected about their number, type, size and location, and this should be supplemented with data on types and quantities of fuels used and their composition (sulfur, ash and trace-element content). In some cases there may be publications that give local, regional and national totals. Fuels for stationary sources should be considered separately from fuels used in transportation.

There are guides available for making such emission inventories.[15,16] Once this information has been collected, a rough estimate of the ambient air pollution concentrations to be expected can be made using dispersion calculation models.[17,18,19] In this way, an initial assessment of the problems to be expected can be gained in a short period and at a relatively low cost.

When considering the distribution of sources it is important to make a distinction between large sources, which often emit through high stacks, and small sources, which emit at a relatively low height. Thus, smaller sources may have proportionately much greater impact on ground level concentrations in the surrounding area than the large industrial sources. In this connexion it is also important to make a distinction between pollutants emitted directly from the sources (primary pollutants) and pollutants resulting from photochemical reactions (secondary pollutants). The latter are particularly important with respect to emissions from transportation and the petrochemical industry. Since secondary pollutants are formed in the atmosphere the highest concentration may be found at some distance from the air pollution sources and this aspect should be considered when designing the air monitoring network.

2.1.2 Health and demographic information

The decision to start a monitoring programme is frequently based upon complaints. In many cases these are caused by nuisances, like malodours or dust. The origin and geographical distribution of the complaints, their type and number can help in the design of the monitoring network. It is often also useful to collect information on the pollutant damage to plants, animals and materials in the area, as an aid in selecting monitoring sites.

Information on the distribution of the population within an area is required, particularly where the objective is to evaluate human exposure. Air quality monitoring for epidemiological studies is usually done in a number of residential areas having significantly different air pollution levels. Information on age and socioeconomic conditions of the population, normally obtained from the results of national population censuses, would also be required for these areas.

2.1.3 Meteorological information

Contact should be made at an early stage with the meteorological service to learn about the types of information available. Meteorological data are generally assembled for purposes other than air pollution monitoring, e.g., weather forecasting, air traffic assistance, and agriculture and hydrological services. Moreover, meteorological measurements are not usually made within large cities. The collaboration of the meteorological service is therefore essential to complement the existing information by stationing some additional instruments in places that are part of the air pollution monitoring programme.

The local meteorological services usually have general information about climatic conditions in the area. Wind direction, wind speed and temperature variations with the time of day and year are some of the more common parameters measured. Other measurements that are often available are precipitation data, hours of sunshine, relative and absolute humidity and the potential for fog formation. Temperature gradient observations and data on the height of inversion base are very useful but are not always readily available.

2.1.4 Topographical information

Topography plays an important role in the selection of monitoring sites because of its effect on local wind and stability conditions. Many industrial areas have developed in river valleys, where there is an increased tendency for temperature inversions to develop and to trap the air pollution. In cities built on hilly ground there are substantial variations in concentrations within the urban area. In general, the more complex the terrain, the more samplers will be needed to determine the distribution of pollution. Other topographic features that affect the dispersion of pollutants include mountains, lakes and oceans.

2.1.5 Previous air quality information

Even if a continuous monitoring programme has not yet been established, there is often some information on air quality that has been collected in a sporadic manner, for example, special studies done by health and meteorological services, university and scientific researchers or even students preparing their graduation theses. All this information should be collected and if possible, tabulated. Sometimes a first estimate of the magnitude of the problem can be obtained in this way. Caution should be exercised in the use of these data since a variety of sampling and analytical procedures may have been used.

2.1.6 Land-use zoning considerations

If air pollution data are to be used in estimating concentrations to be expected elsewhere in similar circumstances, it is important to classify each site in terms of sources and activities in the area. This can be done conveniently in terms of the description of existing land use. Generally it is sufficient to assess this by on-site observation, but in some areas planning authorities may have drawn up maps showing land use. In the United Kingdom National Survey, for example, the immediate vicinity of each measuring site was classified as residential, commercial, industrial or mixed, qualified by other features such as the density of the housing, and whether there were parks or other open spaces near by.

2.2 Organization and resource requirements

2.2.1 Organizational arrangements

The type of organization responsible for the monitoring of air quality varies from country to country and within countries as well. In some, responsibility has been assigned to specialized agencies for environmental pollution control, in others, to the health ministries, to other governmental agencies or to industrial, scientific or educational institutions. Whatever the case, there is a real need for the responsible agency to involve other organizations, as appropriate, in the planning, design and operation of the network.

Other organizations that can assist in the development of the monitoring programme include industrial associations, census bureaux and urban planning agencies. Much of the data on emissions, population density and distributions, source locations, traffic distribution, zoning and the like can be obtained from these organizations. It is important to ensure meteorological support, particularly in the planning stages.

The capabilities and experience of other environmental monitoring programmes should also be taken into account. Thus, those responsible for water quality and environmental radiation monitoring programmes as well as occupational exposure surveillance programmes should be consulted and their facilities used as much as possible, especially for training, laboratory services and data evaluation.

Depending on the air pollution dispersion characteristics (related to topography and meteorology) of the area to be surveyed, the development of the monitoring network may require the establishment of cooperative programmes among communities having their own jurisdictional responsibilities for environmental pollution control. In such cases it might be useful to establish some kind of formal cooperative arrangement, such as a consultative or advisory committee.

In many cases there are also advantages to be gained by participating in international monitoring programmes, such as those carried out by WHO and WMO in collaboration with the UNEP Global Environmental Monitoring System. These programmes include, for example, quality assurance components that could assist local air monitoring agencies in the development of their efforts in this area.

2.2.2 Personnel, equipment and finance

Although development of an air quality monitoring programme can be difficult, it is possible to get good preliminary results with simple equipment and a restricted budget. The first step should be the selection of a small group to undertake the initial work. One professional, acting part-time or full-time as head of the group, could, with the help of one or two technicians, start assembling the available information for the preparation of a report on the conditions within the city.

Information on the levels of suspended particulate matter and sulfur dioxide can be collected with inexpensive equipment, easily serviced by semi-skilled personnel. The cost of a complete first station of this type is approximately US$ 2500, including equipment for analysis. Additional stations within the same city will cost only US$ 1000 since there will be no need to duplicate the analytical equipment. Approximately

US$ 1000 will be required each year for reagents, materials and spare parts. Labour costs, transportation and the support of a good laboratory will be the main additional costs.

The initial monitoring results obtained and the information collected should form the basis for expansion of the monitoring network to include the measurement of other pollutants. If possible, an approximate diffusion model should be made at this time to guide the further development of the network. Examples of the development of air quality monitoring programmes are given in Annex 2. In addition to illustrating the personnel and financial requirements for different situations, these examples emphasize the development of a programme in stages.

2.3 Design considerations

The types of preliminary information that are useful in the design of the monitoring programme were outlined above in section 2.1. Once this information is obtained and evaluated the basic framework of the monitoring programme can be developed. This will include:

(i) selection of the pollutants to be measured, initially and in the future;

(ii) definition of the area in which the measurements are to be made;

(iii) determination of the number and distribution of the monitoring stations; and

(iv) determination of the sampling duration and frequency.

These decisions will depend upon the objectives that are to be fulfilled (see Chapter 1) and the information to be provided. They will also depend upon the phasing of the development of the programme. In almost all instances the development of a programme must be gradual, with new pollutants being selected and the number of stations being reduced or increased over the years as the programme gains experience and is refined to respond more accurately to the need for which it was established.

2.3.1 Selection of pollutants

The selection of pollutants is commonly done in one of two ways. The first method recognizes that the most common air pollutants (see Annex 1) are present in varying amounts in almost all urban areas. A monitoring programme therefore usually begins with the measurement of suspended particulate matter and sulfur dioxide; in many cases carbon monoxide is also measured if warranted by the traffic situation. The programme is then gradually developed to include other pollutants whose presence might be suspected as a result of comparisons with other cities where they have already been confirmed by air quality measurements. This approach to pollutant selection is the most common. It also indicates the need for standards where pollutant concentrations are shown to be exceeding or approaching levels considered to be harmful,[20-23] or where levels still meet the criteria but a considerable increase in population or industrialization in the area is anticipated.

The second method for selection is less empirical. It relies on emission inventories to identify not only the pollutants that could be potentially dangerous for human health and the environment in general but also the priorities if the programme is to be developed in stages. Ideally this approach is used in conjunction with modelling to calculate the expected ambient levels of various pollutants. Usually the first emission inventories are done for the major pollutants and the programme is then initiated. Subsequently inventories may be done for specific types of industries, which may be emitting particular pollutants that are not common to all urban areas, for example, hydrogen sulfide, arsenic, fluorine, asbestos, etc.

Although, for purposes of clarification, two separate approaches have been identified for selecting air pollutants to be measured, in most cases the choice will be made using a combination of the two.

2.3.2 Selection of the area to be studied

In most instances air monitoring networks should encompass an entire urban complex. The reasons for this are obvious; air pollutants can travel long distances and their effects can occur many kilometres from the point of emission, particularly in cases where the emissions are discharged from high stacks.

In order that the problem may be studied comprehensively, it is extremely desirable that the entire air basin be included in the monitoring network. The area to be covered will, in many cases, include more than one administrative region and this may require the development of co-operative programmes with neighbouring communities.

Certain characteristics of an urban region are important in the definition of the study area. Thus, for example, high mountain ranges or large bodies of water can effectively serve as boundaries of the area. In cases where a monitoring system should provide information about ambient concentrations around a single source, the selection of the study area depends mainly on the stack height and the topographical and meteorological conditions. Some of the sampling sites should be located where the maximum ambient concentrations will be expected. In general, maximum ground level concentrations may be expected downwind from the source at a distance of 10-20 times the stack height.

2.3.3 Number and distribution of sampling sites

The number of sampling sites depends on (1) the size of area to be covered by the network, (2) the variability of pollutant concentrations and (3) the data requirements, which are related to the monitoring objectives.

Table 3 presents a general guide to the number of stations needed for monitoring trends of the common pollutants in urban areas. The population figures are assumed to be indicators of region size and pollution variability. The number of stations recommended is based largely on experience gained in some cities and should only be considered as a guide. It includes a number of modifying factors that summarize particular situations where the recommended number should be increased or decreased. For other monitoring objectives, particularly in relation to epidemiological requirements, the numbers will usually have to be increased.

TABLE 3. SUGGESTED AVERAGE NUMBERS OF STATIONS FOR AIR QUALITY TREND MONITORING IN URBAN AREAS OF GIVEN POPULATIONS*

Urban population (million)	Average number of stations per pollutant					
	Total suspended particulate matter	Sulfur dioxide	Nitrogen oxides	Oxidants	Carbon monoxide	Wind speed and direction
< 1.0	2	2	1	1	1	1
1.0-4.0	5	5	2	2	2	2
4.0-8.0	8	8	4	3	4	2
> 8.0	10	10	5	4	5	3

* Modifying factors are as follows:

(1) In highly industrialized cities the number of stations for suspended particulate matter and sulfur dioxide should be increased.

(2) In areas where large amounts of heavy fuel are used the number of stations for sulfur dioxide should be increased.

(3) In areas where not much heavy fuel is used the number of stations for sulfur dioxide may be reduced.

(4) In regions with irregular terrain it may be necessary to increase the number of stations.

(5) In cities with extremely heavy traffic the number of stations for nitrogen oxides, oxidants and carbon monoxide may need to be doubled.

(6) In cities with a population of 4 million or more, with relatively low traffic, the number of stations for nitrogen oxides, oxidants and carbon monoxide may be reduced.

The distribution of a given number of monitoring stations over a certain area can basically be of one of two types, (1) a geometrical network in which the sampling points are sited at the intersections of a grid or within each rectangle, or (2) a more selective network that refers to the choice of sites within the area to be surveyed, taking into consideration distribution of sources, population, etc.[24]

Geometrical networks have been used in a number of countries for a variety of purposes.[25,26] In many cases such networks were part of studies aiming to determine the number of stations required to characterize adequately the air pollution level in an area; others are being used to make routine air pollution measurements.

There are a number of possible variations regarding the operation of a regular grid pattern network. All the cross points in the grid may have monitoring stations or only some (sometimes because the others have been eliminated after data analysis has shown that a reduction was possible without loss in precision of data). There is also the possibility of using mobile sampling facilities to visit the grid points following a (random) schedule using statistical procedures to calculate air pollution levels for the area.

Although regular grid pattern networks are being used today, they are not generally favoured because of some inherent shortcomings. They are, for example, very limited with regard to the sampling and analytical techniques that can be used economically. They also tend to require a lot of staff time to operate.

A more selective network involves the choice of more representative sampling points and generally affords a more detailed picture of air pollution levels in the most polluted and populated areas by increasing the monitoring sampling network density there, with a concurrent reduction in the outskirts where the air quality is generally better. The number of air quality monitoring stations that can be installed will not generally permit full resolution of ambient air pollution patterns for the region concerned. The use of dispersion models, however, can provide additional information, through interpolation, for example, about maximum pollution levels expected or the spatial distribution of ambient concentrations between distant monitoring stations.[27]

Table 4 gives an example of the distribution of the sample sites between the city centre or industrial areas and residential areas. While single stations are often used to monitor several pollutants, this will not generally provide the greatest amount of information concerning the various types of pollutants. For example, monitoring sites for sulfur dioxide and suspended particulate matter can frequently be distributed as shown in Table 4; however, a different grouping should be adopted for carbon monoxide monitors. Nearly all the latter should be placed in areas of high traffic density, because carbon monoxide concentrations will be found to decrease rapidly away from such areas. On the other hand, the maximum concentrations of oxidants are likely to be found at the downwind edge of a city, or beyond, because of the time delay involved in the formation of these substances in the atmosphere. Therefore a monitoring programme for oxidants should always include some sites on the periphery or even outside the urban region.

TABLE 4. AN EXAMPLE OF THE DISTRIBUTION OF SAMPLING STATIONS

Total number of stations	Number of stations	
	in city centre or industrial areas	in residential areas
1	1	0
2	1	1
3	2	1
4	2	2
5	3	2
10	6	4

Mobile stations can often be used to augment substantially the information available from fixed-site networks. However, particular care must be exercised to see that the equipment performance is not changed during the changes in location. More frequent calibration will be required to guard against this. Also, the pollution distribution information from such mobile sites is based on samples usually collected over a small fraction of the year. Therefore, precautions will have to be taken to ensure that the measurements represent actual pollution conditions during the periods of sampling, and that they are not applied to other periods of the year.

2.3.4 Sampling duration and frequency

The duration of a monitoring programme can be viewed on three time scales: (1) short-term: (2) intermittent; and (3) permanent.

Short-term monitoring is normally carried out for special purposes such as a preliminary assessment of pollution levels prior to beginning a more extensive monitoring effort. A limitation of this type of monitoring programme is that the data obtained may not be fully representative because of the particular meteorological or emission conditions that may have prevailed during the sampling period. Intermittent monitoring (for example, 1 month per season or 1 day out of every 6) can save costs, especially when manual samplers are employed. If the sampling record is long enough (for example, several years) the data can be very useful for trend analysis and control strategy evaluation. However, care must be exercised in not over-interpreting data that may be biased due to an incomplete record. Permanent monitoring is usually carried out whenever an air pollution agency has determined, on the basis of either short-term or intermittent measurements, that such sampling is needed. In most cases, a small monitoring network will be established initially with a view to increasing the number of stations in the future as further urbanization and industrialization take place.

It should be noted that with permanent monitoring long-term trend analysis of the data is very important to allow the agency to institute the necessary air pollution control programme planning and legislation and/or regulations. Thus it is essential that the monitoring sites remain the same for long periods of time.

With respect to sampling frequency, two factors play a dominant role, (1) the inherent variability of the pollutant (e.g., diurnal, day of the week, seasonal), and (2) the required precision of the air quality data, which is related to the monitoring objective.

Experience has shown, for example, that concentrations of sulfur dioxide and suspended particulate matter exhibit diurnal fluctuations that are related to source emission and typical daily meteorological variations. Carbon monoxide concentrations, on the other hand, exhibit diurnal variations based primarily on traffic flow and density patterns. Seasonal differences in air pollution levels are related to source emission and meteorological variations.

Weekday/weekend sampling has been shown to be very useful in assessing industrial emissions as most industrial sources either curtail or cease operations during the weekend. Air pollution sampling during the weekend, if carried out long enough, can also give very useful information on the effects of automobile traffic on air pollution levels.

To determine characteristic pollutant concentration fluctuations, sampling should be more frequent than the expected frequency of variation. For example, to measure diurnal variation hourly samples should be taken. If the measurements are not continuous, the individual observations should be uniformly distributed throughout the day to get a representative pattern. Similarly, to study a weekly pattern of daily means one should sample both on weekdays and at weekends.

If an annual average is to be computed from the data, then it is essential that all portions of the year be represented equally. Recognition of the seasonal variation of measurements made for certain pollutants shows why this is essential. As a convenient rule, it may be assumed that the monitoring programme is adequately balanced if each calendar quarter contains not less than 20% of the total number of observations made within the year.

The accuracy of the average associated with various sampling frequencies has been calculated theoretically and determined empirically at a number of locations throughout the world.[28] Obviously the accuracy decreases with sampling frequency. For example, if samples are collected every other day, deviation from the annual average obtained by daily sampling is less than $\pm$ 2%. Sampling only every twelfth day yields a value within $\pm$ 10% of the average obtained with daily sampling.

If the air quality data are to be used for comparison with air quality standards or criteria the sampling period must be related to the averaging time of the applicable standard.[29] It must be stressed that different averaging times produce results that are not directly comparable. The reason for this is the strong influence of the averaging time on the variance of a sample and through this on maximum and percentile values.[30] Wherever possible it is best to employ comparable sampling and averaging times.

CHAPTER 3. STATION LOCATION CRITERIA

The exact location of each monitoring station is a very important aspect of the network development since a faulty choice may cause the data produced to be of very limited value, possibly for years to come.

The location for an air quality monitoring station should satisfy the following:

(1) The site should be representative of the area selected in the general design;

(2) The station should be set up and operated so as to yield data that can be compared with those from other stations within the network;

(3) Certain physical requirements should be satisfied at the site.

The ultimate choice for each site will be a compromise optimizing these various considerations.

3.1 Representativeness

A station is representative if the data obtained reflect concentration levels and fluctuations of air pollutants within the given area.

In practice, the guidelines for this are difficult to specify. Whether the position of a station is satisfactory might, however, be checked by making simultaneous measurements at one or more temporary stations within the area concerned. The station should be located in a place where interferences in the immediate vicinity are most unlikely, i.e., away from:

(1) nearby air pollution sources. The recommended distance will depend on the height and emission strength of the sources; the station should be at least 25 m away from domestic chimneys, especially if the chimneys are lower than the sampling point; with larger sources the distance should be greater;

(2) absorbing surfaces (foliage and absorbing building materials). The clearance to be allowed will depend on the absorbing properties of the material for the pollutant in question, but it will normally be at least 1 m;

(3) areas where substantial rebuilding or land-use changes are foreseen in the near future, especially if long-term trends are to be observed.

The guidelines above are valid for stations measuring general pollution levels and for most of the objectives listed in Chapter 1.

For objectives such as the study of health effects and the evaluation of damage to vegetation or building materials, or the investigation of specific complaints, the location of sampling stations is representative if the data obtained reflect the actual exposure of the receptor. For human exposure this means that the movements of a population group under study should be covered by a number of monitoring stations, in order to assess the average exposure. There is a fundamental problem here, however, for air quality monitoring activities are generally conducted in outdoor air, whereas people normally spend much time indoors. The concentrations of some pollutants, notably sulfur dioxide, are often reduced through absorption on walls and other surfaces. On the other hand, there are circumstances in which air pollution concentrations may be higher indoors than outdoors.[31] The diversity of conditions affecting indoor concentrations is so great that it is impracticable to recommend the inclusion of indoor sampling as part of a general monitoring programme. This feature must, however, be considered in epidemiological studies.

The measurement of air pollution from motor traffic needs special attention because of the sharp gradients in concentration likely to be encountered. It may not need to be done at all of the network stations. As far as primary pollutants from traffic are concerned (carbon monoxide, nitrogen oxides, hydrocarbons, lead, and smoke from diesel vehicles), the highest concentrations are likely to be found in busy streets in the centre of a city, particularly where there are tall buildings along both sides, limiting the natural ventilation. If the street is much frequented by pedestrians, then it may be appropriate to set up a sampling station near by, if a suitable site can be found.[32]

A heterogeneous group of pollutants called photochemical oxidants, with ozone as the main component, occur in ambient air as a result of complex reactions between pollutants from traffic, in certain atmospheric conditions. As these require time to develop, concentrations of oxidants may be higher at or beyond the periphery of the urban area than within it. This should be taken into consideration when siting instrumentation for the measurement of oxidant pollutants.

3.2 Requirements for comparability

To facilitate the comparison of air quality data obtained at different sites, the details of each location should be standardized as far as possible.

If pollutants originating from stationary sources are being measured, the sampling intake should preferably be 3-4 m above the ground and 1-1.5 m from the nearest vertical or horizontal surface. On all other sides it should be open, which means that the intake should not be within a confined space (closed courtyard or patio), in a corner, under or above a balcony, etc.

For traffic pollution measurements the sampling intake should be 3 m above the street level and at a horizontal distance of 1 m from the kerb. Deviations from these requirements are critical and if they have to be made, they should be the same for all stations within a network. The height of 3 m is recommended to avoid re-entrainment of particulates from the street, to permit free passage of pedestrians and to protect the sampling intake from vandalism.

Certain monitoring instruments (e.g., high-volume samplers) have to be outdoors, and for practical reasons these are often located on the roofs of low buildings, caravans, etc.

Instruments for monitoring gaseous pollutants, as well as some of those for sampling suspended particulate matter (e.g., smoke measurement devices), are normally located indoors or in special shelters. They are connected with the outdoor air by a sampling tube ending with an inverted funnel, which serves to prevent the intake of precipitation and of large particles with the sample air. If suspended particulates are being sampled the intake flow characteristics (flow rate and funnel diameter) must be standardized and the sampling line should not have sharp bends. It should also be as short as possible, preferably no more than 3 m, and made of a material that does not react with the pollutant being sampled or release interfering vapours. The diameter of the tube will depend on the flow rate and should be standardized for the whole network.

Since it is often difficult to meet all the requirements listed in sections 4.1 and 4.2, possible differences should be acknowledged and their influence recognized, especially when making comparisons between the results from the various stations.

It is well known that air pollution levels in an urban area vary according to the general type of neighbourhood in which the measurement is made. For this reason it is useful to provide a description of the physical surrounding of each site that may be used when analysing the data. Most commonly, the description is made on a form especially designed for this purpose, which, in addition to giving the address of the site, identifies whether it is located in the city centre or the suburbs and whether it is in an industrial, residential or commercial area.[5] Additional information regarding the time zone, elevation above ground and so on can also be given.

3.3 Physical requirements

The site where the station is located should fulfil one or more of these requirements, depending on the type of instruments used:

(1) It should be available for a long period;

(2) It should preferably be accessible 24 hours a day throughout the year;

(3) Electrical power of sufficient rating should be available;

(4) It should be vandalproof;

(5) It may need to be protected from extreme temperatures.

Public buildings are often convenient and are frequently used for the siting of monitoring stations.

CHAPTER 4. OTHER ESSENTIAL COMPONENTS OF THE MONITORING PROGRAMME

4.1 Laboratory requirements

The operation of air quality monitoring networks will require the support of laboratory facilities. The pollutants of interest, types of monitoring instruments used, size of network and frequency of sampling will dictate the kind and extent of these.

Generally, the minimum equipment required for an air quality laboratory comprises: analytical balance, colorimeter, water distillation or ion exchange apparatus, air volume and air flow-rate measurement devices, laboratory glassware, drying oven, calibration equipment with appropriate standards, and, if possible, sufficient reagents and supplies for a year to ensure uniform quality. A reflectometer or transmissometer may be required for the assessment of smoke stains on filter-papers. Spare sets of sampling equipment should be available to allow observations to be maintained in the event of breakdowns.

In the initial stages of operation of a network, it is advisable to seek the advice and assistance of staff from a laboratory or international organization having experience in the relevant field. Even the analysis of the more common pollutants may present difficulties for those not experienced in this work, and the analysis of trace amounts of other pollutants requires elaborate and expensive facilities and highly skilled personnel.

In all cases preference should be given to the use of internationally recommended standardized procedures, with a view to achieving better comparability within the network and between networks on a national and international scale.[5]

4.2 Quality assurance

A quality assurance component is essential to any monitoring programme in that it provides information indicating whether the data produced are acceptable according to procedures set out for this purpose. Since air pollution measurements are made by numerous agencies at a large number of monitoring stations and laboratories, quality assurance is also concerned with establishing and assessing comparability of data quality among agencies.

Quality assurance may be divided into internal and external quality assurance.[33] Internal quality assurance may be understood to include normal internal procedures such as periodic calibrations, duplicate checks, split samples, spiked samples and the keeping of adequate and neat records. External quality assurance may be taken to include those activities that are peformed on a more occasional basis, usually outside the normal routine operations, e.g., on-site system surveys, independent performance audits, interlaboratory comparisons, and periodic evaluation of internal quality assurance data.

4.3 Data acquisition and handling procedures

For results from manually operated equipment it may be sufficient to collate the results on standard forms, but where continuous equipment is included in the network, costs versus benefits of an automatic data acquisition system should be considered. In many instances, however, pen recorders are satisfactory for data acquisition.

The flow of data should be handled in the following stages:

(1) Assembly of raw data (strip charts, digital print-outs, lists of manually written observations) and supporting data such as flow rates, volume meter read-outs, observations of weather conditions, calibration data, remarks on operational particulars of instruments, change of reagents, observations of exceptional events like agricultural burning, recalibration with or without adjustment of the appropriate instrument or replacement of parts of the equipment.

(2) Validation: rejection of erroneous data, correction of data according to results of calibration and flow rates and proper coordination with time of observation.

(3) Storage: filling in of standardized forms, card punching and generation of computer print-outs and tapes.

(4) Retrieval: development of systems to facilitate access to sets of data.

(5) Analysis: application of statistical routines aimed at producing a few characteristic quantities, such as frequency distributions, seasonal variations, averages and standard deviations.

Advanced data-handling systems are available that not only convert analogue signals to digital data and store them, but also permit automatic adjustment of zero and concentration range to be done and provide read-out of critical instrument variables. Data may also be transmitted by use of a telephone link from remote sites to a central computer for further processing and storage. Generally, it is advisable to make use of the experience of agencies already operating similar equipment prior to acquiring a system, and to start with a single station to gain experience.

4.4 Data presentation

Data presentation should permit interpretation of data in accordance with the initial objective of the monitoring network. Commonly they are presented as averages (arithmetic or geometric) and maximum values, as well as frequency distributions, over a given period of time.

Yearly averages will reveal long-term trends, and monthly means will reveal seasonal variations. Daily means will give greater resolution and will show day-of-week variations and the effect of changes in weather patterns. Hourly data are useful to show variations related to human activity and to the meteorological diurnal cycle.

Cumulative frequency distributions of the data are useful, to show the percentage of time a given value has been exceeded, and graphical presentations are very helpful in presenting large volumes of data.

If sufficient data points are available they can be presented as isopleths. Concentration wind-roses are also useful: in combination with topographical data they can provide information about the location of pollution sources in the area.

To ensure uniformity of output across the world, a data reporting system used by WHO is available for the handling of air quality data.[5] Examples of retrieval formats, such as a plot of monthly averages for a single pollutant and a cumulative frequency distribution of all values for a year, are also available.[4]

REFERENCES

1. World Meteorological Organization. Urban climates, Geneva, 1970 (document No. 254.T.P.141)

2. World Meteorological Organization. Observation and measurement of atmospheric pollution, Geneva, 1974 (document No. 368)

3. Wallén, C. C. Global atmospheric monitoring. Environm. Sci. Technol., 9: 30-34 (1975)

4. Air quality in selected urban areas, 1973-1974. Geneva, World Health Organization, 1976 (WHO Offset Publication No. 30)

5. Selected methods of measuring air pollutants. Geneva, World Health Organization, 1976 (WHO Offset Publication No. 24)

6. World Meteorological Organization. Operations manual for sampling and analysis techniques for chemical constituents in air and precipitation, Geneva, 1974 (document No. 299)

7. Pan American Health Organization. Annex 1: Manual of operations. In: Pan American Air Pollution Monitoring Network. Report of results, June 1967-December 1970, Lima, CEPIS, 1972, pp. 103-126 (CEPIS Technical Series No. 10)

8. Gallay, W. et al. Environmental pollutants - selected analytical methods, London, Butterworths, 1975 (Scientific Committee on Problems of the Environment (SCOPE) Report No. 6)

9. Schneider, T., ed. Automatic air quality monitoring systems, Amsterdam, Elsevier, 1974

10. International Conference on Environmental Sensing and Assessment. . . Las Vegas, 1975, New York, Institute of Electrical and Electronic Engineers, 1976, vol. 1 and 2

11. Munn, R. E. Global Environment Monitoring System (GEMS): Action plan for phase 1, Toronto, International Council of Scientific Unions, 1973 (Scientific Committee on Problems of the Environment (SCOPE) Report No. 3)

12. Suess, M. J. & Craxford, S. R., ed. Manual on urban air quality management, Copenhagen, WHO Regional Office for Europe, 1976

13. International Atomic Energy Agency. Objectives and design of environmental monitoring programmes for radioactive contaminants, Vienna, 1975 (Safety Series No. 41)

14. Environmental Instrumentation Group, Lawrence Berkeley Laboratory. Instrumentation for environmental monitoring, Berkeley, CA, University of California, 1975, vol. 1, 1A and 2

15. Düwel, L. & Zündorf, O. J. Erhebung und Katastermässige Dokumentation der Emissionen luftfremder Stoffe in die Atmosphäre, Köln, Technizcher Überwachungs-Verein Rheinland, 1974

16. United States Environmental Protection Agency. Guide for compiling a comprehensive emission inventory (revised), Research Triangle Park, NC, 1973 (Publication No. APTD-1135)

17. Turner, D. B. Workbook of atmospheric dispersion estimates, Cincinatti, OH, Public Health Service, 1970 (Public Health Service Publication No. 999-AP-26)

18. World Meteorological Organization. Dispersion and forecasting of air pollution, Geneva, 1972 (WMO Technical Note No. 319)

19. Delance, O. M. An urban diffusion model for estimating long-term values of air quality, J. Air Pollut. Control Ass., 21: 16-19 (1971)

20. WHO Technical Report Series, No. 506, 1972 (Report of a WHO Expert Committee on Air Quality Criteria and Guides for Urban Air Pollutants)

21. World Health Organization. Health hazards of the human environment, Geneva, 1972

22. United States Environmental Protection Agency. The world's air quality management standards, Washington, DC, 1974, vol. 1 and 2 (EPA Publications No. EPA-650/9-75-001a and b)

23. Larsen, R. I. A mathematical model for relating air quality measurements to air quality standards, Research Triangle Park, NC, 1971 (Office of Air Programs Publication No. AP-89)

24. Gorshko, B. B. /The optimum number of sampling stations and the sampling frequency for surveying urban air pollution/, Trudy Glavnoj Geofiziceskoj Observatorii, 254: 140-150 (1971)

25. Williams, J. D. & Edmisten, N. G. An air resource management plan for the Nashville metropolitan area, Cincinnati, OH, Public Health Service, 1965 (Public Health Service Publication No. 999-AP-18)

26. Stratmann, H. Basic principles of the management of gaseous air pollutants, Staub-Reinh. Luft, 25(9): 10-16 (1965)

27. Air pollution. Proceedings of the Sixth International Technical Meeting on Air Pollution Modeling and its Application, Batelle Institute, Frankfurt a/M, 1975 (NATO Committee on the Challenges to Modern Society publication N. 42)

28. Nehls, G. J. & Akland, G. G. Procedures for handling aerometric data, J. Air Pollut. Control Ass., 23: 180-184 (1973)

29. Prinz, B. Ambient air quality standards and their application. In: Manual on urban air quality management, Copenhagen, WHO Regional Office for Europe, 1976, pp. 51-66

30. McGuire, J. & Holl, V. E. Relationship between concentrations of atmospheric pollutants and averaging time, Atmospheric Environment, 5: 291-298 (1971)

31. Biersteker, K., de Graaf, H. & Nass, A. G. Indoor pollution in Rotterdam homes, Int. J. Air Water Pollut., 9: 343-350 (1965)

32. Ludwig, F. L., Berg, N. J. & Hofman, A. J. The selection of sites for air pollutant monitoring: paper No. 76-11.5 presented at the 69th Annual Meeting of the Air Pollution Control Association, Portland, OR, 1976

33. United States Environmental Protection Agency. Quality assurance handbook for air pollution measurement systems. Volume 1 - principles, Research Triangle Park, NC, 1976 (EPA Publication No. EPA-600/9-76-005)

ANNEX 1

PRINCIPAL SOURCES AND POLLUTANTS OF POSSIBLE CONCERN IN URBAN AREAS

Type of source	Fuel	Main pollutants
Domestic heating or cooking	Wood, peat, dung, etc.	Suspended particulate matter Carbon monoxide Oxides of nitrogen
	Coal	Suspended particulate matter Sulfur dioxide Carbon monoxide Oxides of nitrogen
	Light oil, gas	Oxides of nitrogen Sulfur dioxide
Industrial boilers, power plants	Coal, heavy oil	Sulfur dioxide Oxides of nitrogen Suspended particulate matter
Manufacturing industrial processes	-	Specific pollutants related to nature of process, e.g., sulfur dioxide and mercaptans from pulp mills, heavy metals from smelters, fluorides from aluminium smelters, iron oxide from steel works, dust from cement works, etc.
Transportation	Gasoline	Carbon monoxide Oxides of nitrogen Lead Hydrocarbons Oxidants*
	Diesel fuel	Suspended particulate matter Oxides of nitrogen Odours Sulfur dioxide

* Secondary pollutant formed in photochemical reactions in the atmosphere involving other pollutants.

ANNEX 2

EXAMPLES TO ILLUSTRATE THE GUIDELINES FOR THE DEVELOPMENT OF AN AIR POLLUTION MONITORING PROGRAMME

This annex presents three examples to illustrate the guidelines for the development of an air pollution monitoring programme given in the main part of the text. Two of these describe alternative approaches to the implementation of a monitoring programme for an urban area, one based primarily on a manual operation, with relatively low capital costs, and the other incorporating a fully automatic telemetered system. It must be stressed that these examples are put forward as extremes of a wide range of possibilities. Automatic samplers could, for example, be used without the telemetry, which would decrease the capital cost but with a concomitant increase in personnel time to collect and evaluate the data. Alternatively, there could be one central site with a complete range of manual and automated equipment, and more limited observations at other sites. It is intended that these descriptions of urban monitoring programmes should illustrate the need to develop a programme in stages, over several years, and to train local professional and support personnel to implement the programme.

The third example provides an illustration of the steps for implementation of an air pollution monitoring programme in the vicinity of a planned or existing industrial source. It shows the importance of designing a programme that is responsive to the details of topography and meteorology in the vicinity of each site.

Specific suggestions for numbers of stations, budgets and personnel requirements are presented in the examples. However, these have been put forward for illustrative purposes only. In practice, the details for any air monitoring programme must be developed from the actual conditions found in the area to be monitored.

Example 1. Starting an air pollution monitoring programme based primarily on manually operated instruments

The programme is for a city with slightly over two million inhabitants. It has 12 000 industrial establishments, of which 2500 are potentially important emitters of air pollution. There is a power plant burning oil and a municipal incinerator. Some garbage goes to a primitive sanitary landfill, where part of it burns spontaneously. There are about 15 000 multi-family buildings, with garbage incinerators. Mild climatic conditions mean that heating is required only for brief periods. Traffic congestion is severe in the central part of the city and many of the vehicles are poorly maintained. Meteorological data are available from two stations, one on the outskirts of the city and another at the nearby airport.

Objectives of the programme

(1) To evaluate the general air quality conditions in the city and to provide the basis for a study of long-term trends of pollutant concentrations.

(2) To provide data for the subsequent development of an air pollution prevention and control programme for the city.

Implementation of the monitoring programme

First year

(1) Collect and collate background information relevant to the pollution problem, including data on the types, locations and emission characteristics of stationary sources, the numbers and types of mobile sources, the meteorological data from existing stations and the distribution of complaints about air pollution.

(2) Establish contacts with other organizations, including the meteorological service and the university, that will be invited to participate in a joint effort with the health authority.

(3) Install two stations for the measurement of suspended particulate matter and sulfur dioxide, one at the city centre and the other in an industrial zone, the precise sites being selected with the help of the meteorological service.

(4) Set up meteorological instruments at the two fixed sampling sites.

(5) Obtain a portable instrument for the measurement of carbon monoxide to be operated on a specified schedule, in relation to pollution from traffic.

(6) Acquire a motor vehicle for servicing the fixed stations and carrying out the carbon monoxide survey (initially this might be on a shared basis with some other service).

(7) Obtain laboratory equipment for assessing the concentrations of suspended particulate matter and sulfur dioxide in air samples.

(8) Conduct a short basic course (two weeks) for personnel of the air pollution department and other professionals from the meteorological service, university and industry involved in the monitoring programme; a specialist lecturer would be required for this.

Second year

(1) Continue measurements started in the first year.

(2) Prepare a simple diffusion model.

(3) Provide travel funds to allow the director of the programme to visit monitoring networks in other cities.

(4) Prepare a report on the first year of operation of the programme.

Third year

(1) Using the results of the diffusion model, select three additional sites to be equipped with monitors for suspended particulate matter and sulfur dioxide.

(2) Consider the relocation of one or both meteorological instruments, in view of network expansion.

(3) Assign one staff member to a well-established air pollution agency for training for a period of three months.

(4) Prepare a report on the second year of operation and on the need for a control programme.

Fourth year

(1) Prepare a complete report at the end of three years of measurements analysing all the information collected and making recommendations concerning: (a) future course of action for the programme; (b) further considerations on the need for a prevention and control programme, and requisite legislation.

Additional activities

As the monitoring programme is developed, some control activities will be implemented, especially to take care of complaints and to reduce heavy smoke emissions.

Personnel

The following personnel will be assigned to the programme. An inspector is included in the staffing in the third and fourth years to permit a control programme to be started concurrently with the monitoring programme.

Type of personnel	Number of man-years 1st year	2nd year	3rd year	4th year
Engineer	1	1	2	2
Chemist	1/2	1/2	1	1
Inspector	-	-	1	1
Assistant	1	1	2	2
Technician	1	1	1	1
Driver	1/2	1/2	1	1
Total	4	4	8	8

Summary of costs (1976 figures)

These costs do not include freight, duty and installation charges that may be involved with equipment imported from other countries and a safety factor of 2 may be required on the overall budget.

Cost of personnel is not included due to large variations between different countries. This cost can be calculated from the preceding table.

Item	US $				
	1st year	2nd year	3rd year	4th year	Total
Suspended particulate matter and SO_2 sampling equipment	2 500	-	3 000	-	5 500
Portable CO monitor	2 000	-	-	-	2 000
Meteorological equipment	4 000	-	-	-	4 000
Laboratory equipment	2 000	-	1 000	500	3 500
Reagents	500	500	500	500	2 000
Motor vehicle	4 000	-	-	-	4 000
Fuel and maintenance	2 000	3 000	3 000	3 000	11 000
Training	4 000	3 000	4 000	-	11 000
Office furniture and expenses	2 000	1 000	1 000	1 000	5 000
Miscellaneous	1 500	1 300	1 000	1 000	4 800
Total	24 500	8 800	13 500	6 000	52 800

Example 2. Development of an urban air pollution monitoring programme based primarily on automated equipment

The programme is for a city with the same general characteristics as that in Example 1, but with emissions and meteorological conditions such that there is a real risk of episodes of high pollution occurring. It is assumed that a fully automated monitoring system capable of yielding real-time observations may be warranted, and that sufficient resources are available for this.

Objectives of the programme

(1) To assess the range of concentrations of pollutants resulting both from stationary sources and from motor vehicles, in terms of average and peak values, at selected points in the urban area.

(2) To provide a basis for following long-term trends in pollution.

(3) To guide the development of control strategies.

(4) To develop and validate atmospheric dispersion models for application to all emissions of pollution in the urban area.

(5) To activate emergency control procedures during episodes of high concentrations of pollutants.

Implementation of the monitoring programme

First year

(1) Review available equipment for the network and prepare detailed specifications for measurement and computing equipment, together with plans for network operation.

(2) Establish contact with all pertinent agencies for the development of a plan for the monitoring network.

(3) Obtain sampling equipment for suspended particulate matter (high-volume sampler, plus low-volume smoke sampler) and sulfur dioxide for two manually operated stations; install and begin to operate before the end of the year.

(4) Obtain two portable carbon monoxide monitoring instruments for an exploratory survey of pollution from motor vehicles.

(5) Develop data-reporting formats for all parameters.

(6) Prepare a first approximation of an emission inventory for stationary sources and motor vehicles.

(7) Determine detailed staffing requirements and develop plans for the training of necessary personnel.

(8) Obtain two sets of meteorological equipment, installing one on a standard 10 m tower close to one of the initial sampling sites and the other on a tall tower, e.g., 100 m, if a suitable one exists.

Second year

(1) Purchase two sets of automatic continuous instruments for measuring sulfur dioxide, oxides of nitrogen, oxidants and carbon monoxide, installing these in the two stations already operating with manual instruments; no computing equipment will be purchased at this time, the records on initial installation being maintained on pen recorders or data loggers.

(2) Use the two initial stations to train technical and maintenance staff.

(3) Initiate a quality assurance and calibration programme for the automatic instruments.

(4) Expand the analysis laboratory to support the calibration activities.

(5) Provide special training (three months) for the programme director and the principal engineer.

(6) Carry out model calculations to assist in choosing locations for the monitoring stations to be installed during the following year.

Third year

(1) Purchase six additional sets of automatic monitoring equipment (for sulfur dioxide, nitrogen oxides, oxidants and carbon monoxide), together with computing equipment for the central analysis facility. Install at sites as indicated by the above calculations, but if integrated stations are to be set up, where all pollutants are measured, then one should be at a site close to traffic, selected on the basis of the exploratory carbon monoxide survey, and another should be on the leeward edge of the urban area, where relatively high concentrations of oxidants may be found. There may be no need to monitor carbon monoxide at sites away from traffic, and it is assumed that this instrument could be omitted from at least two of the sampling sites.

(2) Purchase six additional sets of equipment for measuring suspended particulate matter, and install at the new sites; these will require regular site visits by the technical staff.

(3) Prepare communication links between the sampling sites and the central analysis facility.

(4) Conduct a training programme for engineering and technical staff assigned to operate the network.

Fourth year

(1) Implement the operation of the communication links and the computer in the central analysis facility; note that the operation of the two sets of manual instruments and on-site recording of outputs from automatic instruments are planned to continue at least through the end of the fourth year.

(2) Begin full operation of the network.

(3) Institute regular reporting procedures.

(4) Implement an episode control programme, using the real-time communication capability of the network.

Additional activities

Regular summaries of the observations will be prepared and the type of legislation required and appropriate control techniques considered during the third and fourth years, in the light of results obtained from the manual and automatic instruments.

Personnel

Personnel recommended for the system include staff for data analysis and interpretation, as well as staff for operation of the network. In the fourth year, when the network will be in operation, a total of 20 staff is recommended including two inspectors for control activities.

Type of personnel	Number of man-years 1st year	2nd year	3rd year	4th year
Director	1	1	1	1
Instrument engineer	½	2	2	2
Data analyst	½	½	1	1 ½
Computer operator	-	½	1	1
Computer programmer	-	½	½	1
Analytical chemist	1	1	1½	2
Meteorologist	½	½	1	1
Inspector	-	-	-	2
Technician	2	3	3	5
Secretary	1	2	2	3
Driver	1	1	1	1
Total	7 ½	12	14	20½

Summary of costs (1976 figures)

The following external costs are estimated for the monitoring network, based on experience in the United States of America:

First year	US $
Manual sampling equipment for SO_2 and particulates, 2 sets	2 500
Portable CO monitors, 2	4 500
Meteorological instruments, 2 sets, with recorders and tower	30 000
Consultant assistance on system design	10 000
Miscellaneous	3 000
Total	50 000

Second year	
Automatic monitoring instruments with recorders for SO_2, CO, NO/NO_2 and oxidants, 2 sets; shelters for each set included	100 000
Laboratory instruments and supplies	40 000
Training for director and principal engineer	10 000
Motor vehicles with expenses	14 000
Office supplies	3 000
Miscellaneous	3 000
Total	170 000

Third year	US $
Automatic monitoring instruments with shelters, 6 sets	280 000
Small computer	20 000
Communication interface equipment for 8 stations	24 000
Short course for staff	15 000
Vehicle maintenance	6 000
Total	345 000

Fourth year	
Vehicle maintenance	6 000
Office supplies	2 000
Communication line cost to connect 8 stations to central facility	16 000
Total	24 000

Total external costs, four years	589 000
Contingency (10%) for other equipment and supplies	59 000
Total	648 000

Because of uncertainties in the costs of importing and installing equipment in various countries, a safety factor of 2 is recommended for this cost estimate. Therefore, the external costs for the system are estimated to be in the range of US$ 650 000-1 300 000. In addition, costs for personnel and facilities must be included in the total budget. Provision may also need to be made for the purchase of at least one spare set of equipment to maintain observations in the event of failures.

Example 3. Developing an air quality monitoring programme in the vicinity of a large single source

The large single source is a 500-MW coal-fired power station situated along a river on the outskirts of a medium-sized city. Most of the other industrial activity in the urban area consists of secondary production plants with relatively low air pollution emission rates. Consideration is currently being given to doubling the capacity of the power station.

Objectives of the programme

(1) To determine the distribution of air pollution emanating from the power station in time and space.

(2) To provide a data base for calculating the impact of the expansion of the station on current ambient air quality levels.

Implementation of the monitoring programme

First stage

(1) Estimate the emission rates of the various air pollutants emitted from the power station stacks, notably sulfur dioxide and particulates.

(2) Study the topographical map of the region, noting ridges and valleys that may affect the dispersion of the air pollutants.

(3) Undertake a site inspection, noting land use and vegetation patterns and possible signs of vegetation damage, and classify complaints by area.

(4) Prepare a wind-rose for the area, based on local meteorological observations; an experienced meteorologist should review the representativeness of this wind-rose in locations having uneven terrain. If sufficient meteorological observations are available, compute the pollution potential for the area, taking special note of the frequency of limited mixing conditions (i.e., inversions based just above the expected plume height).

(5) Undertake diffusion model calculations for various meteorological conditions to obtain estimates of ground level concentrations, preferably in the form of frequency distributions of hourly values at fixed grid points surrounding the power plant.

Second stage

(1) On the basis of the diffusion calculations and any evidence of vegetation damage, select a network of stations and pollutants to be monitored. For major single-source monitoring a network of three to six stations is frequently (but not always) chosen. Fewer than three stations would be inadequate for the task, and data from more than six stations can have limited use, except in large-scale programmes. Concentrations of ambient sulfur dioxide and suspended particulate matter are normally monitored in assessment programmes for coal-fired power plants. Nitrogen oxides and trace metals in the airborne particulates are also measured in some programmes.

(2) Install one or more continuously-recording anemometers at the appropriate sites. One anemometer should be at standard exposure height (10 m) in flat, open surroundings, to permit comparisons with other wind observation records. A second anemometer is often installed on a tower at an elevation similar to the stack top; this permits evaluation of representative wind dispersion conditions for the elevated plume.

(3) Arrange for the estimation of emission data from the power station stack. This can be provided by direct measurement in the stack or estimated from data on fuel use and/or boiler operation.

(4) Use the monitoring data and the emission estimates to calibrate the dispersion model. Cases of high concentrations should be specially evaluated to describe the conditions that produce maximum impact.

(5) Forecast the impact of the power station expansion on ambient air quality levels in the region.

Personnel

The conduct of the programme described above will require the services of an engineer, a meteorologist, a computer programmer, one or two technicians and a secretary. The total time required for both stages will frequently be four to six months. However, it may be desirable to spread the actual monitoring activity over an entire year (e.g., 1 month of field operation in each of the four seasons) in order to evaluate the changes in impact throughout an annual cycle.

Costs

Assuming that one or two anemometer sites and from three to six monitoring sites for sulfur dioxide and suspended particulate matter will be established, the equipment costs will be about US$ 35 000-70 000. Computer services and expendable supplies for the instruments will add US$ 5000-15 000 to the basic cost. Personnel costs are not included in these estimates.

ANNEX 3

LIST OF PARTICIPANTS IN THE WHO/WMO CONSULTATION ON AIR QUALITY MONITORING IN URBAN AND INDUSTRIAL AREAS, GENEVA, 21-25 JUNE 1976

Mr G. Akland, United States Environmental Protection Agency, Research Triangle Park, NC, USA

Dr K. Biersteker, Municipal Health Department, Rotterdam, Netherlands (Vice-Chairman)

Mr F. Burmann, United States Environmental Protection Agency, Research Triangle Park, NC, USA

Ms M. Fugas, Institute for Medical Research and Occupational Health, Zagreb, Yugoslavia

Dr O.-H. Killingmo, Air Protection Laboratory, Nyköping, Sweden

Dr A. Kulmala, Finnish Meteorological Institute, Helsinki, Finland

Dr J. Mahoney, ERT International, Concord, MA, USA

Dr R. Munn, Department of the Environment, Downsview, Ontario, Canada (Chairman)

Dr M. Pinigin, Institute of General and Community Hygiene of the Academy of Medical Sciences of the USSR, Moscow, USSR

Dr B. Prinz, State Office for Air Pollution Control and Soil Protection, Essen, Federal Republic of Germany

Dr D. Szepesi, Central Institute of Atmospheric Physics, Budapest, Hungary

Dr K. Takeuchi, Japan Meteorological Agency, Tokyo, Japan

Dr R. Waller, St Bartholomew's Hospital Medical College, London, England (Rapporteur)

Mr E. Weber, Federal Ministry of the Interior, Bonn, Federal Republic of Germany

Representatives of other organizations

United Nations Environment Programme
Dr F. Sella, Global Environmental Monitoring System, Nairobi, Kenya

International Atomic Energy Agency
Mr G. Dillon, Division of Nuclear Safety and Environmental Protection, Vienna, Austria

Commission of the European Communities
Dr A. Berlin, Directorate of Health Protection, General Directorate of Social Affairs, Luxembourg

International Council of Scientific Unions
Professor T. Hutchinson, Monitoring and Assessment Research Centre, Chelsea College, London, England

Organization for Economic Cooperation and Development
Mr A. Bromley, Environment Directorate, Paris, France

Secretariat

Dr H. de Koning, Control of Environmental Pollution and Hazards, WHO, Geneva, Switzerland (Secretary)

Mr E. Giroult, WHO Regional Office for Europe, Copenhagen, Denmark

Mr R. Haddad, PAHO Pan American Centre for Sanitary Engineering and Environmental Sciences, Lima, Peru

Ms S. Jovičic, Industrial Application and Climatology Branch, WMO, Geneva, Switzerland

Mr A. Köhler, Consultant, WMO, Geneva, Switzerland

Mr G. Ozolins, Control of Environmental Pollution and Hazards, WHO, Geneva, Switzerland

Dr C. Wallén, Environmental and Special Applications Division, WMO, Geneva, Switzerland

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