

AUTOMATIC AIR QUALITY MONITORING SYSTEMS

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INTRODUCTION

Monitoring^b of air quality has become an increasingly important function of all air pollution control agencies. In the past, initial monitoring schemes used a single monitoring station or a small number of stations, often operated by different laboratories. To cope with the rapidly growing demand for comparable data from many locations some automated monitoring systems are now in operation and many more are in the planning or implementation stages. An effective atmospheric monitoring programme requires reliable ambient air pollution measurements over prolonged periods that indicate changes and trends in the air quality, and properly trained personnel are needed to carry out the programme.

Before establishing a sampling scheme or conducting a sampling programme the objectives must be clearly stated in sufficient detail to permit the selection of a system based on the specific requirements. Only if precise instructions are given concerning the information to be obtained is it possible to obtain comparable results on a national and international basis. Monitoring site selection, sampling frequency and duration, and data processing procedures are closely linked to the objectives of the programme. The amount of preliminary information needed before sampling can start will depend on the complexity of the system to be used.

PURPOSE AND USE OF MONITORING SYSTEMS

Once the problem to be studied has been clarified it is possible to select a monitoring system that can be used to provide all the relevant information. The more common types of system can be broadly divided into three areas—namely, research, surveillance, and special purpose monitoring. For the purposes of this discussion, however, it is simpler to divide them into categories according to their suitability for dealing with the following specific questions.

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^b The term "monitoring" is used here to signify the process of making repetitive quantitative observations for defined purposes of the concentrations of one or more pollutants in the air, or of other indicators of the state of the environment, according to prearranged schedules in space and time. If, as is usual, this involves making measurements at a number of sites, the measurement and data-handling methods must be similar, or at least comparable, at all the sites. This definition follows closely that given by the United Nations Inter-Agency Working Group on Monitoring (1).

(1) *Geographical distribution of pollution.* Data are required for estimating the amount and composition of pollution in the area concerned. For planning purposes both urban and rural areas may have to be surveyed and studies made of "background pollution levels".

(2) *Determination of air pollution trends.* Data for establishing trends in the degree of pollution with time (e.g., from year to year) and the influence on these trends of changes in emissions due to planning, growth of industry, density of traffic, and population movements.

(3) *Origin of the pollution at any given locality.* Determination of the source and dispersion of pollution on the local, regional, national, and international scale. The study of pollution transport from source to receptor is an integral part of all adequate control strategies. In this type of system use is often made of dispersion models to estimate the local (up to approximately 20 km), regional (20–200 km), or long-range (several hundred to several thousand kilometres) transport of air pollutants.

(4) *Determination of the effect of pollution.* Here, the influence of pollution on human health, animals, vegetation, and materials is studied. When information on acute effects is wanted, the period over which the monitoring system should provide average pollution concentrations is short. In connexion with epidemiological studies, however, short-term peak concentrations are of little value. Here, a suitable longer period of sampling (24 hours, for example) can be selected. Site selection plays an important role in this type of monitoring system. The stations should be located, for instance, in places where people are living or working, both inside and outside buildings, or where the damaged plants or materials are found. The measuring stations should be selected in such a way that the area containing the population under study is well covered.

(5) *Compliance with air quality standards.* Pollution levels are related to accepted or proposed air quality standards. In most cases the monitoring systems themselves have been used to gather data for establishing the standards. Once these goals for air pollution control programmes are set, regular progress in compliance with the standards must be made and confirmed.

(6) *Assessment of control.* Directly related to the previous question is the availability of a monitoring system for assessing the effectiveness of measures to

reduce pollution levels. It is extremely important to determine the effect of countermeasures on the trend of pollution. A continual effort must be made to obtain data that permit the evaluation of progress towards meeting air quality standards and goals.

(7) *Air pollution warning systems.* These systems are developed to give short-term warning of pollution risks; that is, to allow an undesirably high level of pollution under unfavourable meteorological circumstances, and the possibility of the pollution spreading over wide areas, to be predicted so that countermeasures can be taken before danger levels are reached. It is sometimes possible to use a single pollutant as a tracer for all pollutants coming from the same type of source when high pollution concentrations occur only under certain meteorological conditions that influence uniformly all pollutants coming from the same type of source. For the purpose of issuing warnings, the control centre must receive the data from monitoring or sampling stations immediately. Tele-transmission is therefore necessary in this type of system. Air pollution hazards arising from accidents can generally not be dealt with by a measuring network unless the monitoring or sampling stations are arranged in extremely high density; in fact, better results can be expected from well equipped mobile units kept in a state of alert.

STRUCTURE OF AUTOMATED SYSTEMS

Level of automation

Once the problem to be studied is defined, and the type of system indicated, a decision must be made on the level of automation to be applied. This decision often depends on the available resources. Whenever possible, the level of automation necessary for optimal functioning of the system should be chosen, but there may be exceptions to this rule. In countries where labour costs are high and instrumentation relatively cheap it is possible that automated systems, providing more information than is required, will be cheaper than manually operated or semi-automatic systems that produce the minimum amount of information needed. The following systems can be distinguished.

(1) *Manually operated measurements.* Manual start and stop procedures with sampling through an

instrument; laboratory analysis of the sample may be more or less automated.

(2) *Automatic sampling.* Automatic start and stop procedure (time-switch); sample removed manually (if this takes place after each sample is taken it should be called semi-automatic sampling; automatic sampling should only refer to sampling by means of a time-switch combined with a sequential sampler). Here also, laboratory analysis of the samples can be more or less automated.

(3) *Automatic monitoring.* The sampling and analysis is performed by automatic monitoring instruments that produce printed data sheets, charts, or paper or magnetic tape recordings of air pollution concentrations and other relevant information (meteorological factors, etc.) without human intervention except for regular maintenance visits to change reagents and renew tapes, graph paper, etc.

(4) *Fully automatic monitoring with data transmission.* The electrical output of the instrument is not only recorded at the measuring station but also transmitted, possibly via a telephone line, to the central control office where the data are recorded and stored in a computer for subsequent evaluation.

The principal characteristics of a monitoring system should be:

- (1) a modular structure, the system being built up of separate, easily interchanged parts or elements;
- (2) the possibility of extending the measurement capacity;
- (3) operational flexibility, so that changes in the system can easily be made when necessary;
- (4) low maintenance costs.

The system can be made up of several units, as follows.

Monitoring station

A monitoring station contains equipment for:

- (1) sampling,
- (2) measuring,
- (3) data collection,
- (4) data transmission and control.

The sampling part of the measuring station together with the sensors are the most important units in the whole system. The validity of the final data depends on the correct location of the sampling probes and choice of sensor.

Local peculiarities that could invalidate the sampling results must be avoided: for example, localized windfields and the absorption or adsorption of pollutants on nearby surfaces such as walls or the ground. Acts of vandalism must also be guarded against. These criteria indicate that the air intake should, if possible, be located at a distance of several metres from buildings and vegetation (trees), and elevated 3–4 metres above ground level. Apart from the correct siting of the air intake it is important that the whole sampling system should be constructed in such a way that data from stations measuring the same parameters are comparable.

A high capacity sampling manifold should be used. The aim should be to achieve uniformity in the sampling volume and velocity, the number of possible connexions for different monitors, the material used for the construction of the manifold, and protection against the effects of external temperature and pressure changes, with particular regard to condensation within the sampling system. On account of the different requirements, separate sampling probes should be used for gaseous pollutants and suspended particles (aerosols). If possible, automatic controls signalling and correcting deviations from the desired performances of the monitors should be built into the sampling system. Regular maintenance of the whole sampling system at intervals of 3–6 months, with careful cleaning of the manifold, is necessary for avoiding inaccuracies due to the contamination of the walls.

Sensors

Although a large number of measuring instruments have recently become available, only a small number are suitable for use in automated monitoring systems, one reason being the uncertainty about whether the required specifications can be met. In choosing a sensor the following questions have to be answered.

- (1) What range of sensors will cover the pollutant concentrations under investigation?
- (2) What are the required averaging times (minutes, hours, days)?
- (3) What types of personnel are available to operate and maintain the system?
- (4) What other pollutants are, or may be, present that could interfere with the functioning of the monitor?
- (5) Are laboratory or technical workshop facilities available?

Without answers to these questions the selection of instrumentation is extremely difficult.

Apart from the selection of a sensor it is necessary to judge the merits of a given type of instrument. For this purpose two sets of data must be available. The first set should consist of data, including performance details obtained through laboratory evaluation of the instrument carried out under carefully controlled testing conditions. The second set of data should be obtained from field observations over a long period, and should include maintenance, calibration, and repair requirements.

The following points must all be considered:

- (1) functional characteristics—measuring ranges, measuring interval, accuracy, repeatability, selectivity;
- (2) operational characteristics—behaviour with respect to external conditions such as temperature and humidity, and energy and maintenance requirements;
- (3) dimensions of instruments and associated equipment;
- (4) control of the correct functioning of the instruments ("status" signals);
- (5) reference measurements and determination of zero drift (zero check);
- (6) signals indicating need for maintenance and repair.

Data collection

Traditionally, continuous monitoring instruments have been used together with a strip-chart recorder. This type of recorder has certain advantages over even the most elaborate data acquisition system. Briefly, these advantages are as follows. The recorder provides a visual record of the instrument's past performance. Daily zero drift corrections, which are generally more serious than the span drift, can easily be made. A permanent record is provided, permitting supervision of the operator and daily validation using original data. The main disadvantage of the strip-chart recorder is the manpower requirement. Some of the manpower needed for reading out and averaging records or charts can be replaced by the use of magnetic tapes or punched paper tapes for data collection. However, a visual control mechanism has always been built into even the most complex automated monitoring systems so that a final validation can be made of the computer output against an original record. The collected data com-

prise two sets; one set is related to actual measurements, the other to reference measurements and zero checks. Both sets of data can be transmitted to a central control where subsequent data validation is performed, or corrections can be applied to measured values at the station itself by taking into account zero and reference measurements made at the station. Representative values for measured levels of pollutants and meteorological quantities have to be related to a chosen integration interval. To benefit from a high repeatability characteristic (necessary for warning purposes), each monitor must be interrogated at a sampling interval of 1 minute. As a standard, hourly averages for air pollutants can be used. When hourly averages are built up from 1-minute values corrections for the time-constant of the monitor itself and the rate of change of the concentration of the pollutant under study have to be taken into account. Usually, special provision is made for the visual presentation or other on-line use of the 1-minute values when required.

Data transmission and control

In fully automated systems the measured data (and status signals) are transmitted by telephone or telex lines reserved for this purpose directly to the central control office, or through a regional centre when a large number of stations (30 or more) are in operation. Signals are sent over the same line from the control centre to the monitoring stations to control the collection and transmission of data as well as to supply reference measurements.

Regional centres

The regional centre collects, by means of telephone links, all raw data gathered by the automated monitoring stations. After pre-processing (data reduction to hourly averages, for example) and presentation, the data are transmitted to the national centre. If the regional centre is equipped with a process computer it may control all the monitoring stations. At the regional centre a display of data is used by the regional authorities for forecasting purposes. However, warning and forecasting are often left to the national centre since air quality control regions are in most cases larger than the regional networks. Regional data processing comes under control of the national centre when a coordinated approach over a larger (national) area is required. Some of the automatic functions that the regional processor could be expected to perform are as follows:

- (1) data collection from the monitoring stations;

(2) validation of messages transmitted between the centre and the station; tests for both the acceptance of electric signals and individual measurements;

(3) data reduction to hourly averages;

(4) intermediate data storage (before collection by the national centre);

(5) data presentation (on teletype, visual display, and other media);

(6) operational performance of the monitoring instruments through signalization control for all monitors;

(7) automatic restarting after a power failure.

(j) data presentation and visual display—logging typewriter, analogue recorder, or punched paper tape.

(2) Non-automatic functions:

(a) dialogue with monitoring stations and regional centre,

(b) change of parameters (calibration constants, time, etc.)

(c) starting and restarting in a region or the whole network,

(d) display of selected data,

(e) off-line data processing.

The national control centre

Depending on the existence and layout of regional centres, the national centre has the following principal functions:

(1) timing and control of the whole network;

(2) organization and verification of communications with the regional centres (if any exist);

(3) processing and storage of information received from the network;

(4) control of data presentation.

To perform all these functions a computer room and a network control room, from which all operations can be supervised, may be necessary.

To obtain the optimal benefit from a large automated system the control centre should deal with the following activities.

(1) Automatic functions:

(a) timing of the network,

(b) control of the network,

(c) data transmission and processing,

(d) continuous information on actual air quality in the different regions of the network,

(e) survey of error messages,

(f) survey of number of times threshold values are exceeded,

(g) survey of occurrence of high pollution levels or alert situations,

(h) survey of technical failures,

(i) data storage and peripheral devices (magnetic tape, discs, etc.),

DATA ANALYSIS AND PRESENTATION

With the new automatic monitoring systems, as compared with manual systems, it is possible to obtain a very large amount of information in a short time. The use of such a system is only worthwhile, however, when the data output is also analysed automatically; that is, within the system itself. At the end of the data flow within the system the analysis and presentation of data can be performed on-line or off-line. In the first instance this processing is concerned with the actual measured data, the presentation of which has to show the degree of pollution over the study areas. For this purpose a wall map with indicator lights is useful for displaying the monitoring stations where measured pollution concentrations exceed a certain level. If air quality standards exist they can be used as automatic warning levels to indicate that action must be taken.

Even more important than the actual measured values are the changes of the pollutant concentrations with time. For this, it is necessary to calculate on-line the short-term changes during hours or days. In this way it is possible to study the development of critical situations ("smog", for example) due to certain meteorological conditions (low dispersion) or high emissions of reactive pollutants. Most warning systems incorporate on-line data analysis to forecast the development of these critical situations in various regions. The existing Rijnmond system in Rotterdam, Netherlands, is an example of this approach. The data analysis provides possibilities for rapid evaluation of changes in short-term trends and the study of correlations between neighbouring monitor-

ing stations for different environmental conditions. This study of area and time correlations will also yield much information on the system structure required for the monitoring networks. Displays of measured data from a large number of monitoring stations over short periods (1–10 minutes) also offer the possibility of studying the transport of pollutants over greater distances (up to several hundred kilometres). Using the meteorological information collected at the monitoring stations, the operator of the system at the national centre can track the drift of pollutant clouds from high emission regions in the direction of the wind, and the spread of the "plumes" of pollution over larger regions when the wind speed is high. The possibility of establishing monitoring stations at different heights on high towers should be investigated when monitoring systems are designed. Such elevated stations improve and facilitate the interpretation of measured data.

Apart from the on-line analysis of data it is necessary to have facilities for data reduction and presentation for statistical studies, planning purposes, trend studies, etc. For data reporting a suitable format must be chosen. Frequently used indexes are average concentration values with time (day, month, season, year) and area (averages for a number of monitoring stations). A classification of average pollutant concentrations according to wind direction and speed is used to study the location of the most important sources of the pollution. Examples of this application are given in Table 1 and Fig. 1, based on measured values from a monitoring station of a pilot network in the city of Enschede, Netherlands.

A useful method of data reduction employs the frequency distribution of air pollution concentrations. The total number of measured concentrations during a certain period is divided into classes of absolute concentration values. A logarithmic scale is often used for sulfur dioxide concentrations expressed in a cumulative frequency distribution (see Table 2). From this is obtained the concentration below which the chosen percentage of the total number of measured values (percentiles) is found (Fig. 2). In most cases, the logarithmic fit is not very close at the higher concentration end of the curve. Frequency distribution is also used in relation to certain air quality standards. In practice, it is not possible to establish as a standard a maximum concentration that should never be exceeded. Every concentration lower than emission concentrations will be exceeded sooner or later. The standard for

Table 1. Monthly average sulfur dioxide in the air in relation to wind direction in January 1973 measured at the town centre monitoring site in Enschede, Netherlands

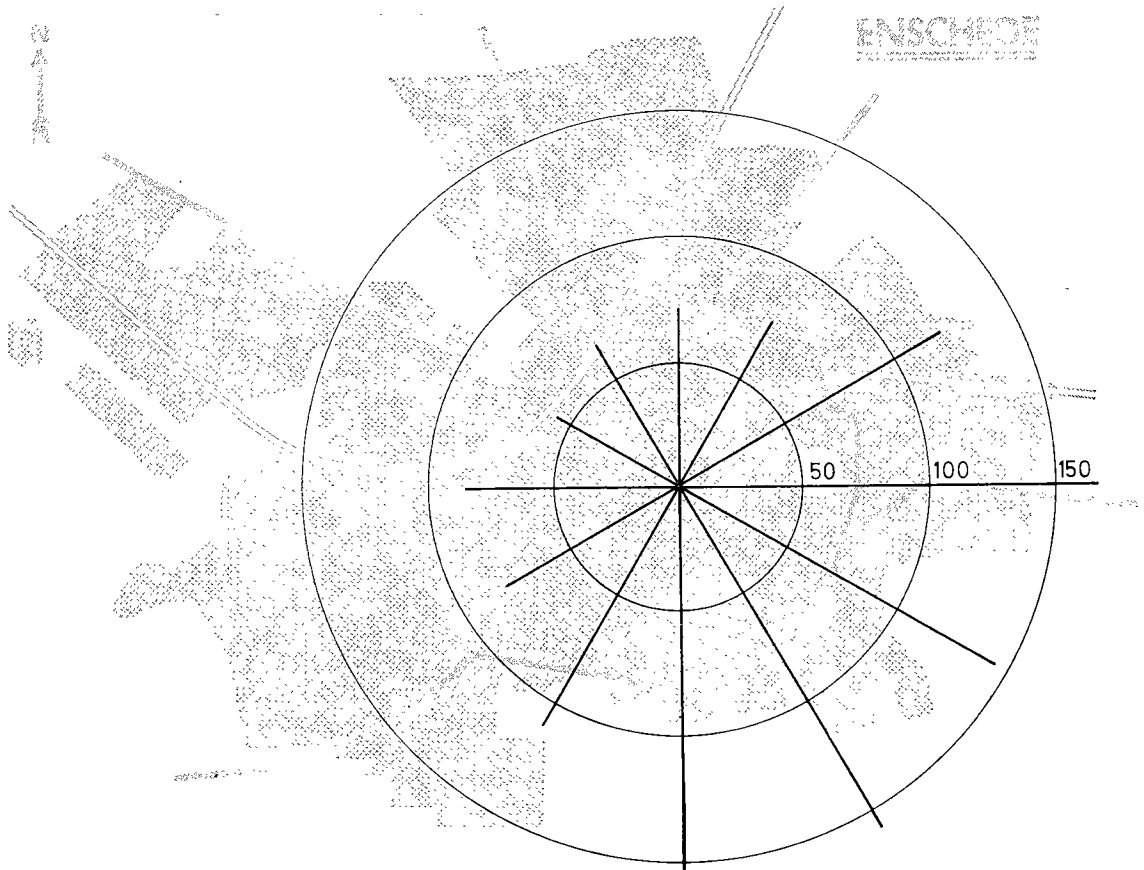
Average wind direction	Monthly average SO ₂ (μg/m ³)
E	139
ESE	131
SSE	135
S	108
SSW	70
WSW	55
W	57
WNW	46
NNW	48
N	52
NNE	68
ENE	100

Table 2. Cumulative frequency distribution of 24-hour averages of sulfur dioxide concentrations measured at the town centre monitoring site in Enschede, Netherlands, during the period 1 October 1972 to 1 April 1973

Class interval (μg/m ³)	Percentage
< 30	3.79
< 60	40.15
< 90	61.36
<120	73.48
<150	83.33
<180	93.94
<210	97.73
<240	98.48
<280	99.24

ambient air quality should be a maximum concentration combined with the percentage of time during which this concentration may be exceeded. This maximum is therefore often expressed as the 95- or 98-percentile of the cumulative frequency distribution. Frequency distributions expressed in graphic or tabular form are, however, not suitable for general

Fig. 1. Monthly averages for sulfur dioxide in relation to wind direction in the town centre of Enschede, Netherlands, January 1973 ^a



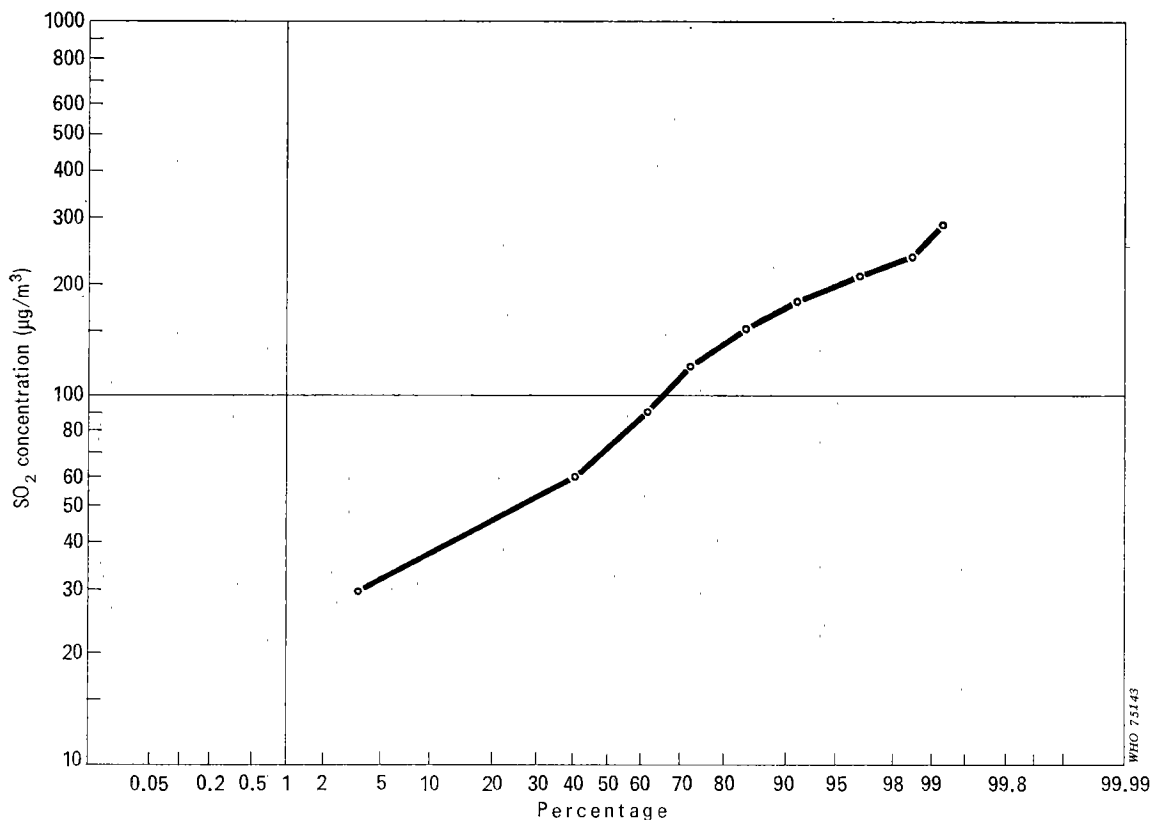
^a Values shown are $\mu\text{g SO}_2$ per m^3 .

presentation. A map with superimposed lines of equal pollution concentrations calculated from the measured concentrations by interpolation of the concentration gradients between the monitoring stations is often used (Fig. 3). When only time averages are used in preparing such maps there is a serious loss of information about the duration of periods of high or low concentrations. A comparable method based on frequency distributions was therefore developed by Brassier (2). For measurements over a period of 1 year the frequency distributions are determined for all stations in the area. In each distribution the percentage of measurements that exceed a certain concentration is calculated and mapped, thereby producing lines of equal interval in excess of the chosen concentration. Another pos-

sibility is to map the concentrations found at a chosen percentile of the frequency distributions, as in Fig. 4.

When the standard is used as the chosen concentration, the part of the study area where the standard is exceeded can be seen directly on the map. Another method for comparing measured concentrations with the standard, also based on frequency distribution, has been developed recently by Brassier (3). From the cumulative frequency distribution a curve is constructed on log-normal paper. For example, the proposed standard for sulfur dioxide in the Netherlands is presented as two points (the 50-percentile and the 98-percentile). A test index can be calculated as the quotient of the 50- and 98-percentile concentrations of the frequency distribution,

Fig. 2: Cumulative frequency distribution of 24-hour average concentrations of sulfur dioxide in the town centre of Enschede, Netherlands, for the period 1 October 1972 to 1 April 1973.



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each divided by the standard concentrations at the same percentiles. When the test index is 1.0 the situation exactly meets the standard. This test index gives a clear picture of the overall pollution situation in the area under study. An example is given by Brasser (3).

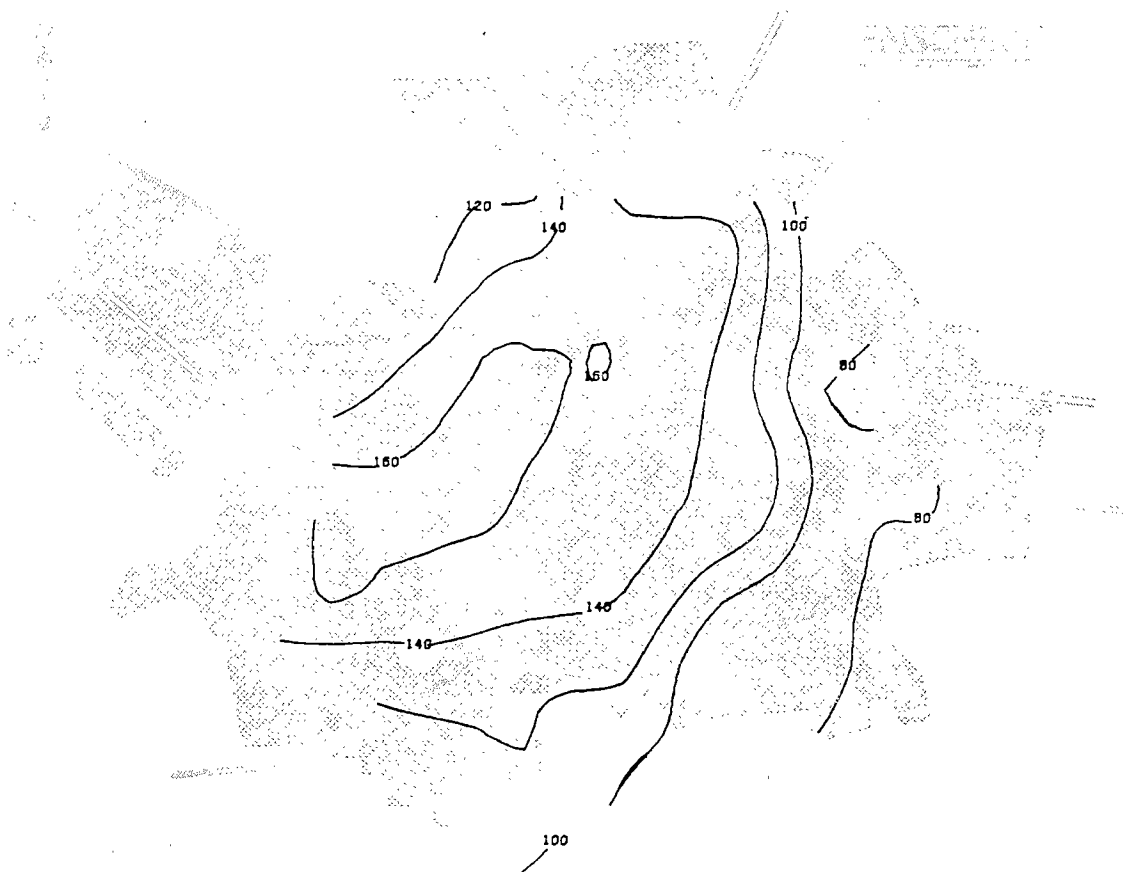
Although the various ways of presenting data described here do not exhaust all the possibilities, these procedures are found in practice to provide the information needed by planners, air quality control officers, air management officers determining control strategies, and officials concerned with initiating legal action against offenders. In this section dealing with data analysis and presentation no mention has been made of the difficulties encountered in using data stored in data banks. The correct storage and retrieval of relevant data for different evaluation purposes require extensive review and are therefore not covered in this chapter. However, for a properly

functioning and useful data bank a prerequisite is the systematic and harmonized collection of data from the various monitoring systems. A systems approach similar to that used in well designed and carefully operated monitoring systems is of extreme importance, especially for international data banks of environmental information.

EXISTING MONITORING SYSTEMS AND FUTURE DEVELOPMENTS

In the past, monitoring systems consisted only of a number of monitoring stations where one pollutant, or sometimes two, was measured by means of manual or semi-automatic methods. The layout of the total network of stations was largely *ad hoc* and depended on the availability of trained personnel in

Fig. 3. Lines of equal monthly average concentrations of sulfur dioxide in the town centre of Enschede, Netherlands, January 1973 ^a

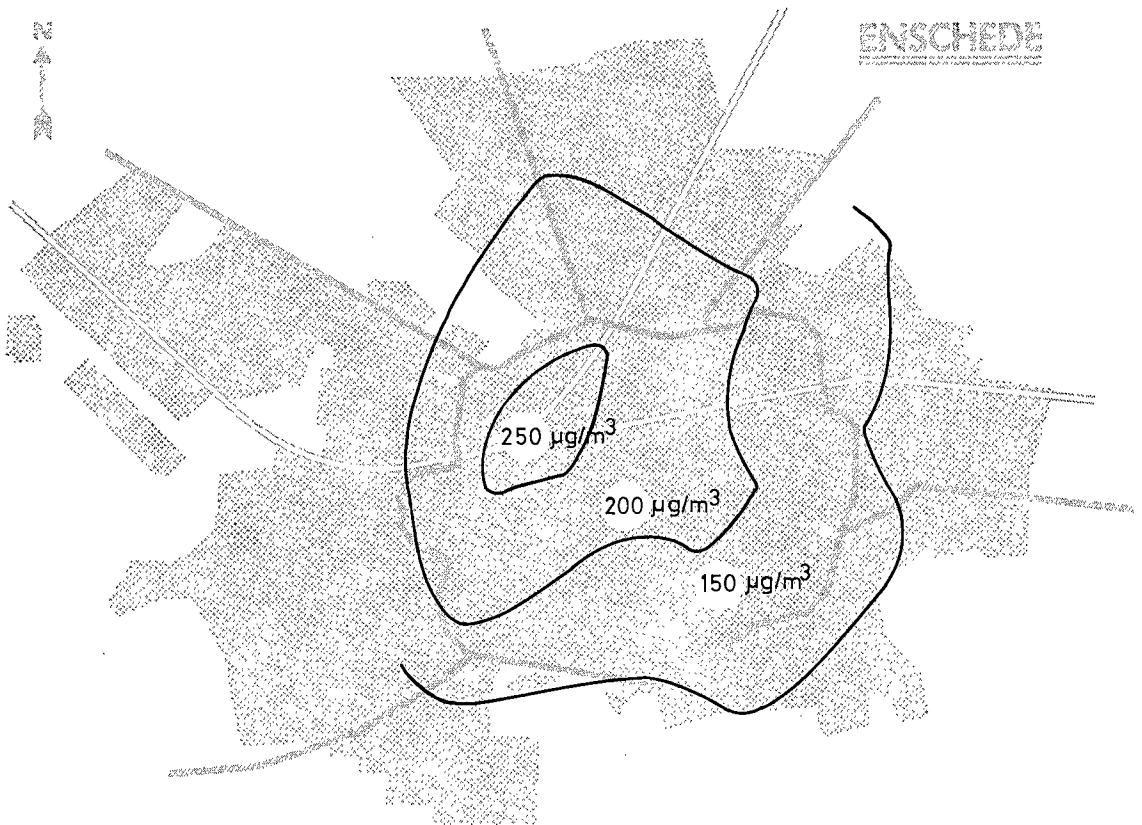


^a Values shown are μg of SO_2 per m^3 .

the study area. As a rule, almost all the stations were located in urban areas and the immediate surroundings of an industrial zone. Comparison of results from different stations was often difficult because of differences in sampling location and equipment, and in the analytical techniques employed. In recent years larger networks developed along the lines described earlier in this chapter have been constructed and are now in use. The United States Environmental Protection Agency (EPA) networks may be described briefly; first, the Continuous Air Monitoring Programme (CAMP) that has been in existence since 1962 in six major cities throughout the USA. Several pollutants have been measured continuously and the data have been used for determining pollution

trends. In the Community Health and Environmental Surveillance System (CHESS) a Continuous Health Air Monitoring Programme (CHAMP) will come into operation in the near future. This network will consist of approximately 50 continuous measurement stations with some telemetering facilities to permit data processing at a central control station. An even more fully automated system is planned for the Regional Air Pollution Study (RAPS) in St Louis, MO. Here, 25–40 stations are planned to study air pollution processes and effects in a single urban region in order to verify existing air pollution simulation models and develop better models. Most of the monitoring stations mentioned in the existing or planned systems in the USA are located in urban

Fig. 4. Distribution of 24-hour average sulfur dioxide concentrations in the town centre of Enschede, Netherlands, for the period 1 October 1972 to 1 April 1973 ^a



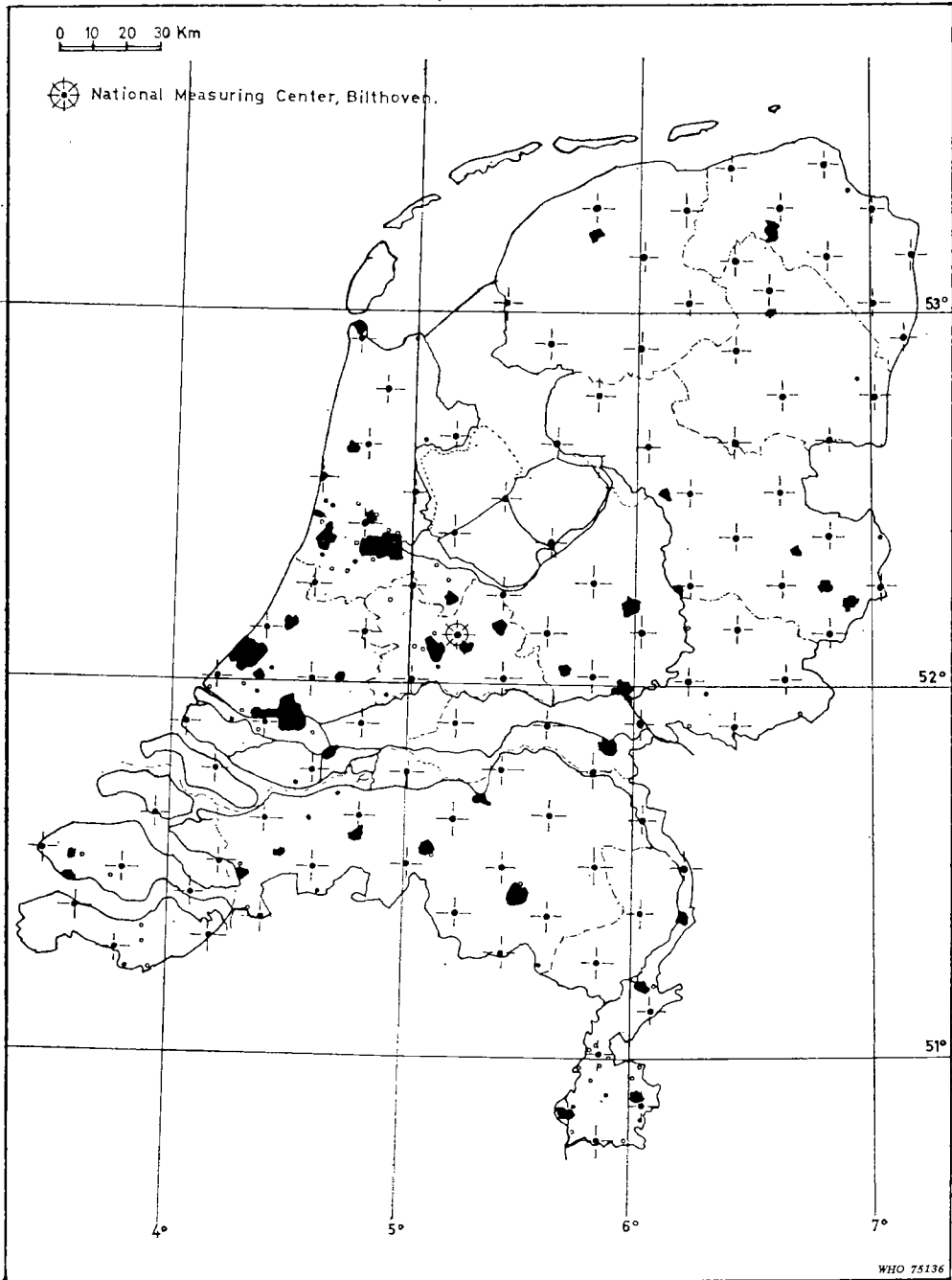
^a The contours enclose areas in which 98 % of the average values fall below the value indicated (i.e., 98-percentiles).

areas. This is also the case in Japan, where adequate monitoring systems exist in Osaka and Tokyo. To study the transport of air pollutants and their fate over a period of time (i.e., sources and sinks for the separate pollutants) it is imperative to have also rural monitoring stations outside the areas with the high concentrations, that is, urban and industrial zones. The first network to incorporate rural monitoring stations on a large scale is installed in the Netherlands. Here, approximately 100 monitoring stations are located in a regular grid pattern with an additional set of approximately 100 stations in the cities and industrial areas, as shown in Fig. 5. Most of the grid stations are located outside the cities and are sited in such a way that direct effects from local sources are avoided. With this system it is possible to study the

fate of pollutants at distances of 20–100 km from the sources when sink mechanisms are significant. For warning purposes also, it has been shown that it is important to have a continuous survey of the pollutant levels over a larger area than the one for which the warning is delivered. Systems comparable with that in the Netherlands are being planned for several areas in Belgium, the Federal Republic of Germany, Mexico, and some other countries. Smaller, but fully automatic, monitoring systems are already in operation in Italy and Sweden.

Although a fully automatic system has many advantages and is sometimes essential when warnings have to be issued or when a large number of stations are in operation, semi-automatic or even manual systems can also serve several purposes. In the

Fig. 5. The Netherlands national network for air pollution monitoring



field of international cooperation, especially where large areas are involved and comparability of results and practical restraints are important, less elaborate monitoring stations often have to be used. In the project on long range transport of air pollutants of the Organization for Economic Cooperation and Development (OECD) a large number of ground stations are in use all over Western Europe. Semi-automatic sampling is used to collect the samples for subsequent laboratory analysis according to agreed measuring methods. This project has been set up for restricted research purposes and is to operate for a limited period. It therefore does not come within the strict definition of monitoring given at the beginning of the chapter (p. 179). The WHO collaborative programme in air monitoring is another example of a system in which elaborate methods are not necessary. Here, the aim is to improve the international comparability of data and to study trends of air pollution in urban and industrial areas.

It is to be expected that the future international cooperative developments in monitoring systems will be based on existing national and international systems. An example of this is the proposed Global Environmental Monitoring System (GEMS) within the Earth Watch of the Environmental Programme of the United Nations. The principles governing intergovernmental cooperation in monitoring include the following:

(1) with regard to monitoring on an international basis, priority should be given to global and multinational problems;

(2) the exchange of information about local problems that are of widespread occurrence, and the methods used to monitor them, is of high importance;

(3) monitoring systems should be designed to meet adequately defined objectives, and arrangements for the evaluation of the data must be an integral part of the system design.

It is clear, therefore, that there must be international agreement on sampling locations, measuring

methods, the use of instruments, etc., and that arrangements must be made to collect suitably processed and condensed data according to an agreed standard format so that they will have international significance. Apart from the construction of new monitoring systems, it is therefore to be expected that international collaboration will be intensified in these two fields. This will probably apply not only to fixed ground stations, but also to mobile measuring units in motor vehicles and eventually to those in aircraft and earth satellites.

Traditional approaches to the study of pollutants in separate single media (air, water, food, etc.) will also be extended to the study of transfers of pollutants between these media and to chemical transformations of the pollutants. Better mathematical and ecological models will be developed to describe both the transport and the environmental pathways of pollutants. To design and establish a monitoring system that can fulfil all the above-mentioned tasks will require considerable resources and a continuous exchange of knowledge and experience gained with existing systems. The main and overall deciding factor should, however, always be clear and adequate descriptions of the intended objectives in planning the system and of the actual results obtained once the systems are in operation.

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