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Air Quality Monitoring Programme Design

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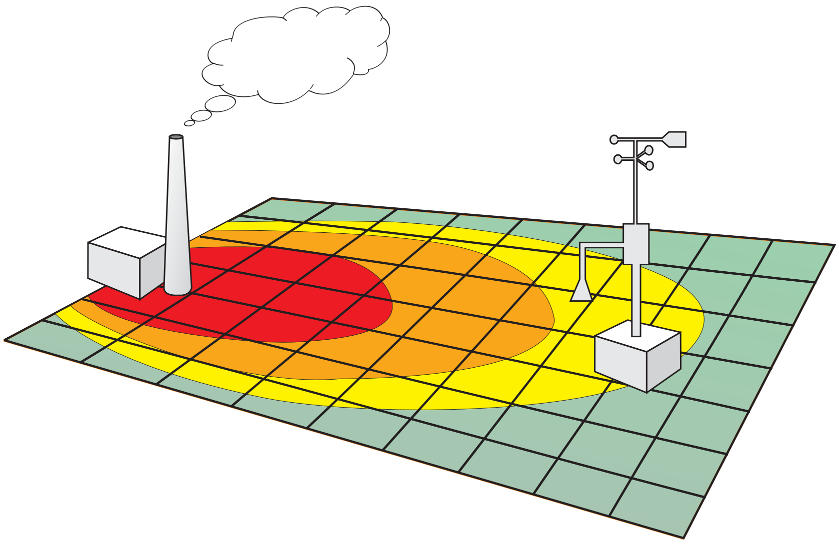

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1 Introduction

The ultimate purpose of monitoring is not merely to collect data, but to provide the information necessary for scientists, policy makers and planners to make informed decisions on managing and improving the environment. Monitoring fulfils a central role in this process, providing the necessary sound scientific basis for policy and strategy development, objective setting, compliance measurement against targets and enforcement action (Figure 1).

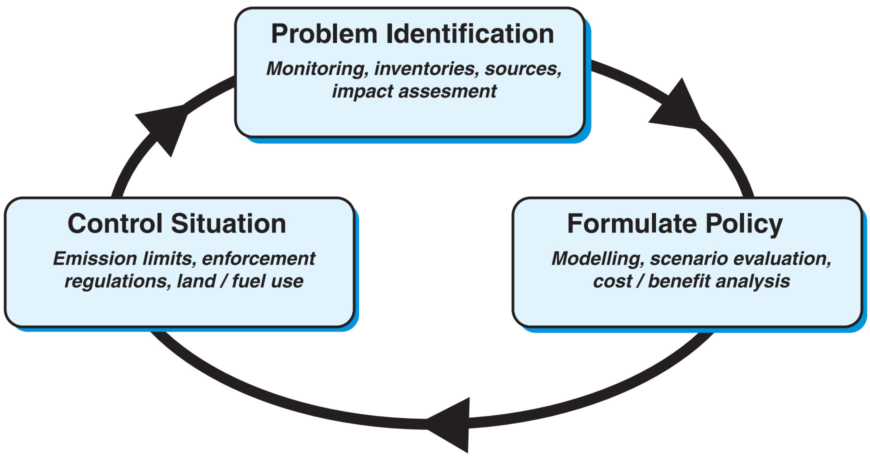


Figure 1: The Role of Monitoring in Air Quality Management.

However, the limitations of monitoring should be recognized. In many circumstances, measurements alone may be insufficient -or impractical- for the purpose of fully defining population exposure in a city or country. No monitoring programme, however well funded and designed, can hope to comprehensively quantify patterns of air pollution in both space and time. At best, monitoring provides an incomplete - but useful - picture of current environmental quality. Monitoring therefore often needs to be used in conjunction with other objective assessment techniques, including modelling, emission measurement and inventories, interpolation and mapping.

2 Objectives

An important objective for the modern environmental surveillance platform is to enable on-line data and information transfer with direct quality control of the collected data. Several monitors and sensors that make on-line data transfer and control possible are available on the market. For some compounds and indicators, however, this is not the case.

A general objective for the air quality measurement programme (monitoring, sampling and analysis) is often to adequately characterise air pollution for the area of interest, with a minimum expenditure of time and money. The measurement and sampling techniques to be used in each case will be dependent upon a complete analysis of the problem. The main objectives stated for the development of an air quality measurement and surveillance programme might be:

1. Background concentrations measurements,
2. Air quality determination to check,
   - Air quality standards to monitor current levels,
   - To detect individual sources,
   - To collect data for land use planning purposes,
3. Observe trends (related to emissions),
4. Develop abatement strategies,
5. Assess effects of air pollution on health, vegetation or building materials,
6. Develop warning systems for prevention of undesired air pollution episodes,
7. Research investigations,
8. Develop and test diffusion models,
9. Develop and test analytical instruments.

3 Design the programme

In the design of a complete sampling and monitoring programme for air quality there are several phases and steps that have to be considered:

1. Define the objectives and strategies for the measurement programme,
2. Define the contents,
3. Perform a screening,
   - Problems and relevant air pollution sources,
   - Collect available data (meteorology and air quality),
4. Evaluate existing data,
   - Representativeness of equipment,
   - QA/QC procedures,
5. Plan the programme in detail,
   - Siting studies,
   - Consider field investigations,
   - Emission source locations, simple modelling,
   - Select relevant sites,
6. Optimise measurements, (cost/effective design),
7. Procure instruments,
   - Specify technical requirements,
   - Purchase and test instruments
8. Establish and initiate operation,
   - Laboratory control systems,
   - Develop standard operational procedures (SOP),
   - Define and describe QA/QC procedures,
9. Training.

4 Operational sequence

Once the objective of air sampling is well defined, a certain operational sequence has to be followed. A best possible definition of the air pollution problem together with and analysis of available personnel, budget and equipment represent the basis for decision on the following questions:

1. What spatial density of sampling stations is required?
2. How many sampling stations are needed?
3. Where should the stations be located?
4. What kind of equipment should be used?
5. How many samples are needed, during what period?
6. What should be the sampling (averaging) time and frequency?
7. What other than air pollution data are needed:
   - Meteorology,
   - Topography,
   - Population density,
   - Emissions,
   - Effects and impacts, etc.?
8. What is the best way to obtain the data (configuration of sensors and stations)?
9. How shall the data be communicated, processed and used?

The answers to these questions will vary according to the particular need in each case. Most of the questions will have to be addressed in the site studies discussed in the next chapter.

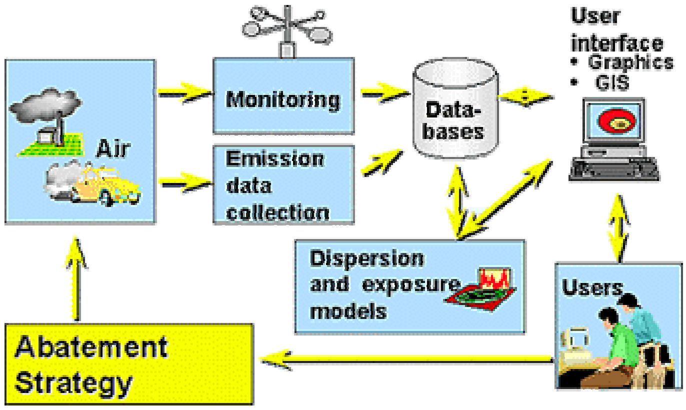
5 The modern air quality monitoring system

A modern air quality monitoring system should include:

- Data collectors; sensors and monitors,
- Data transfer systems and data quality assurance/control procedures,
- Data bases,
- Statistical and numerical models (included air pollution dispersion models and meteorological forecast procedures),
- User friendly graphical presentation systems including Geographical Information Systems (GIS),
- A decision support system,
- Data distribution systems and communication networks for dissemination of results to “outside” users.

The key features of the system described above is the integrated approach that combines monitoring, surveillance, information and planning and enables the user in a user friendly way to not only access data quickly, but also to use the data directly in the assessment and in the planning of actions.

The demand of the integrated system to enable monitoring, forecasting and warning of pollution situations has been and will be increasing in the future. The data may also be used for generating new indicators that relate directly to health impacts. This will require that numerical models are available with on-line data input as a part of the system.



The GIS based AirQUIS air quality information and surveillance system developed by Norwegian research institutions, includes several modules for air pollution monitoring and air quality planning.

The system will in a modular way include a data acquisition system, measurement data base, emission inventories, input data pre-processors, numerical dispersion models and data presentation tools all operated in a Geographical Information System. When planning and designing on-line advanced air quality monitoring system the AirQUIS platform included a GIS-based mapping system and databases may serve as a perfect support system.

In the operational mode of a monitoring system the AirQUIS data retrieval and databases with the statistics and presentation tools are perfectly suited for using the air quality information to raise awareness and to improve the air quality of the region or area.

6 Site selection

The urban air quality monitoring programme shall normally provide information to support and to facilitate the assessments of air quality in a selected area. The information shall be available in such a form that it is suitable to:

- Facilitate a general description of air quality, and its development over time (trend);
- Enable comparison of air quality from different areas and countries;
- Produce estimates of exposure of the population, and of materials and ecosystems;
- Estimate health impacts;
- Quantify damage to materials and vegetation;
- Produce emissions/exposure relations and exposure/effect relations;
- Support development of cost-effective abatement strategies;
- Support legislation (in relation to air quality directives);
- Influence/inform/assess effectiveness of future/previous policy.

The assessments should be based upon concentration fields (space-time fields) produced by the monitoring and information network or by a combination of monitoring and modelling, and should cover local as well as regional scale. The modelling efforts are essential in forming the link between emissions on the one hand and exposure and effects on the other hand.

7 Representativity

It is important to bear in mind, when measuring air quality or analysing results from measurements that the data you are looking at is a sum of impacts or contributions originating from different sources on different scales.

The total concentration is a sum of
- a natural background concentration,
- a regional background,
- a city average background concentration (kilometre scale impact),
- local impact from traffic along streets and roads,
- impact from large point sources; industrial emissions and power plants.

To obtain information about the importance of these different contributions it is therefore necessary to locate monitoring stations so that they are representative for the different impacts. This normally means that more than one monitoring site is needed for characterising the air quality in the urban area. It is also important to carefully characterise the monitoring representativeness, and to specify what kind of stations we are reporting data from. An often-used terminology is

- urban traffic,
- urban commercial,
- urban residential and
- rural sites.

The position of all measurement sites should be exactly identified and evaluated. The exact locations should be specified and the co-ordinates should be specified located on maps. As part of the data specifications in Europe sites should be characterised according to classifications specified by the European Air Quality Monitoring and Information Network (EUROAIRNET).

The objectives of EUROAIRNET is to establish a network with sufficient spatial coverage, representativeness and quality to provide the basic data as soon as possible, which is necessary to fulfil the information requirements to the EEA.

The station classes are relevant to differing degrees for exposure of populations, materials and ecosystems (EUROAIRNET Technical report no. 16, Nov 1998):

Station classes	***Relevant for exposure of***		
	Population	Materials	Ecosystems
Traffic stations	x	(x)	
Industrial stations	x	x	X
Background stations			
- Urban background stations	x	x	(x)
- Background stations			
- Suburban background stations	x	x	X
- Regional background stations	x	(x)	X
- Remote stations			X

Information concerning networks, stations and measurement techniques are presented in the European Commission Decision 97/101/EC of 17 October 2001, Annex II.

The classification of measurement stations is divided into 3 types of areas; urban, suburban and rural. In each of the areas there may be 3 types of stations; traffic, industrial and background. The background stations are divided into; near-city background, regional and remote background stations.

Descriptions of the areas are given in the Table below:

Type of area	**Description**	**Type of station**
Urban	Continuously built-up area	Traffic Industrial Background : - Near city - Regional - Remote
Suburban	Largely built-up area: continuous settlement of detached buildings mixed with non-urbanized areas	
Rural	Areas that not fulfil the criteria for urban/suburban areas	

When considering the location of individual samplers, it is essential that the data collected are representative for the location and type of area without undue influence from the immediate surroundings.

7.1 Some design guidelines

In the design of an urban air quality monitoring programme the following general guidelines should be considered:

- All stations (air intake) should be located at the same height above the surface, a typical elevation in residential areas is 2 to 6 m above ground level.

- Constraints to the ambient airflow should be avoided by placing the air intake at least 1,5 meters from buildings or other obstructions.
- The intake should be placed away from microscale or local time varying sources.

7.1.1 Sampling Station Density

The number of stations needed to answer the objectives of the air pollution sampling, depends on many factors such as

- types of data needed,
- mean values and averaging times,
- frequency distributions,
- geographical distributions,
- population density and distribution,
- meteorology and climatology of the area,
- topography and size of area,
- location and distribution of industrial areas.

A rough indication of the minimum number of sampling stations needed have been presented as a function of population density for a typical community air quality network. For a city of 1 million people one need at least 5 to 8 continuous monitors (measuring 1 hr averages), or equivalent to about 20-25 sequential samplers (measuring 24 hr averages). Automatic continuous sampling equipment in general involve fewer stations than an integrating sampling device (24 hr average or more).

The selection of sampling time is a function of the air pollutant characteristics (emission rate, life time) and time specifications of the air quality criteria.
The ability of combining the air quality data with meteorological data through dispersion modelling, also is a very important tool in the design of sampling networks.

If the location of the maximum air pollution area is known from limited information about the region's meteorology, and the only objective is to check that air quality standards are met, in some cases even one sampling station may be sufficient.

In a topographical complex area with hills, valleys, lakes, mountains etc., there are considerable local spatial and temporal variations of the meteorological parameters, and thus the dispersion conditions. To answer the same questions, more sampling stations are needed in such areas than in flat homogeneous terrain.

Typical for a flat area is also that spaced stations (as proposed by the German Federal regulations or by the New York City's aerometric network) average out spatial variations and thus can give net results representative for the area as a whole.

To be able to use the data for comparing air pollution levels between cities or countries or different environments, we may need some specific additional information about station location for some of the stations. Such additional information includes for instance:

For TRAFFIC stations:	♦ Traffic volume (accuracy: ± 2,000 vehicles/day) ♦ Traffic speed (accuracy: ± 5 km/h, average daytime traffic) ♦ Distance from kerb (accuracy: ± 1 meter
For BACKGROUND/RURAL stations:	♦ Distance to nearest built-up areas and other major sources.

8 Selection of indicators

It is normally not possible to measure all the air pollutants present in the urban atmosphere. We therefore have to choose some indicators that should represent a set of parameters selected to reflect the status of the environment. They should enable the estimation of trends and development, and should represent the basis for evaluating human and environmental impact. Further, they should be relevant for decision making and they should be sensitive for environmental warning systems.

8.1 Background for selection of indicators

Many national and international authorities are at present working with processes to select environmental indicators. The selected parameters for air quality are strongly related to air pollutants for which air quality guideline values are available. The interrelationships between the indicators and other related compounds, may, however, vary slightly from region to region due to differences in emission source profiles.

The selected set of environmental indicators are being be used by local and regional authorities as a basis for the design of monitoring and surveillance programmes and for reporting the state of the environment.

Air quality indicators should:

- Provide a general picture,
- Be easy to interpret,
- Respond to changes,
- Provide international comparisons,
- Be able to show trends over time.

Measurement techniques should be reasonably accurate and within an acceptable cost. The effect of indicators on health impact, building deterioration, vegetation damage, etc., should be adequately documented and linked to public awareness. Selected indicators should respond to mitigation actions to prevent manmade negative impacts on the environment.

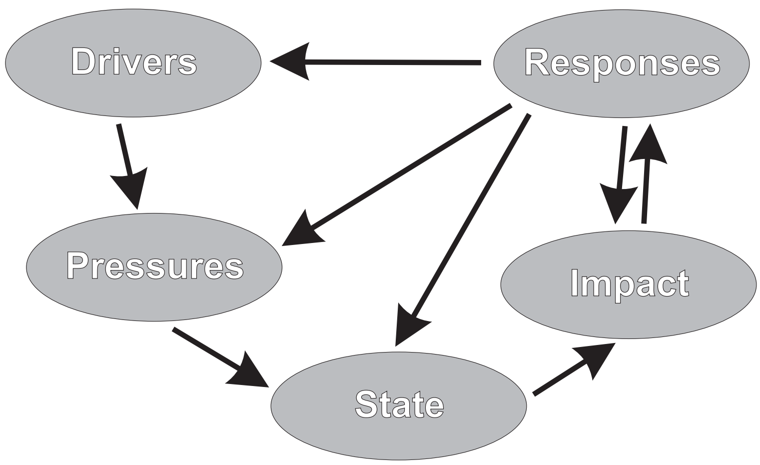
The selection of parameters included in the monitoring and model estimate programme should enable an automatic access to data relevant for assessing the environment included air pollution and atmospheric conditions, pollution of rivers and seas, ground water, waste, noise and radiation. For all these environmental compartments there should be a set of environmental indicators.

These indicators should represent a set of parameters selected to reflect the status of the environment. An indicator may be a single variable of sufficient sensitivity to reflect changes in the status of the environment. In some cases, however, indicators may be derived from a set of independent variables in the system. The selection of indicators should also allow evaluation of trends and developments. The aim is that the indicators can form a basis for evaluating the impact on humans and the environment as a whole and thereby be relevant for information, warning and decision making purposes.

8.2 Indicators in a DPSIR framework

In the development of indicators it has been important during the last years to establish these indicators within the framework of Drivers - Pressure - State – Impact - Response (DPSIR). The DPSIR framework is based on a concept of causality:

- Human activities exert Pressures on the environment and change its State ; i.e. quality and the quantity of natural resources.
- The Pressure-State implies Impact to the Environment which the
- Society Response to through environmental, general economic and sector policies.



Local and regional authorities will use the selected set of environmental indicators as a basis for the design of measurement programmes and for reporting the state of the environment.

The establishment of environmental indicators will help to:

- Identify the quality of the environment,
- Quantify the impact,
- Harmonize data collection,
- Assess the status and the rate of improvement/deterioration,
- Identify needs for and support the design of control strategies,
- Support input to management and policy changes.

The indicator should represent the "pressure" on the environment and include both background indicators and stress indicators. So-called response indicators are selected to reflect the society awareness or response to its surroundings.

The indicator should:

- be relevant in connection with environmental quality,
- be easy to interpret,
- respond to changes,
- provide international comparisons,
- have a target or threshold value that provides a basis for assessment,
- be able to show trends over time.

It should also be possible to measure with reasonable accuracy. It should be adequately documented and linked to public awareness; health impact, building deterioration, vegetation damage etc. Selected indicators should respond to mitigation actions taken to prevent human made negative impacts on the environment.

Indicators might also be aggregated data and not necessarily observed single parameters. The modern environmental surveillance and information systems (e.g. AirQUIS) include good quality on-line meteorological data, numerical dispersion models with emission inventories. These models are capable of estimating concentration distributions on an hourly basis. These distributions can be linked to population distribution maps, building material inventories, and vegetation maps etc. to give exposure estimates.

These aggregated, estimated data will express directly the impact and stress to the environment (health, materials, vegetation) and will in the future represent a better indicator for international comparisons and trend analyses. It will also represent an improved measure for the actual air pollution problem in a given (well-defined) area or region.

8.3 Selected Air Quality Indicators (AQI)

Air quality indicators have been selected for different environmental issues and challenges. Not all indicators are specific enough to address only one issue. The nature of air pollution involves that some indicators address several issues. Some of the issues that have to be addressed are

- Climate change,
- Ozone layer depletion,
- Acidification,
- Toxic contamination,
- Urban air quality,
- Traffic air pollution.

As can be seen from the list the indicators have to cover all scales of the air pollution problems (in space and time) to address different type of impacts and effects.

In Europe different indicators have been established for characterising different air pollution types. (Sluyter, 1995)

Table 1: Indicators selected for different types of air pollution in Europe. The number of cities in Europe where given Air Quality Guideline (AQG) values are exceeded are given. (Sluyter, 1995).

Pollution type	Indicator	AQG ($\mu g/m^3$)	Cities with observed exceedances (%)	Effects
Short term effects				
Summer smog	O_3	150-200 (hour)	84	Lung function decrements, respiratory symptoms
Winter smog	SO_2+PM	125+125 (day)	74	Decreased lung function; increased medicine use for susceptible children
Urban traffic	NO_2	150 (day)	26	
Long term effects				
Traffic/industry	Lead	0.5-1.0 (year)	33	Effects on blood formation, kidney damage; neurologic cognitive effects
Combustion	SO_2	50 (year)	13	Respiratory symptoms,
	PM	50 (year)	0	Chronic respiratory illness

The most commonly selected air quality indicators for urban air pollution are:

- Nitrogen dioxide (NO_2),
- Sulphur dioxide (SO_2),
- Carbon monoxide (CO),
- Particles with aerodynamic diameter less than 10 µm (or 2,5 µm), PM_{10} ($PM_{2,5}$),
- Ozone.

Some selected air quality guideline (AQG) values for these indicators are presented based on impact on public health (WHO, 1987 and 2000).

In the European EUROAIRNET programme priority indicators have been selected for different types of impact to the environment as shown in the Table below.

Table 2: Indicators to be included in EUROAIRNET, Stage 1.

	Population exposure		Materials exposure		Ecosystems exposure	
	Aver. time	Medium/ compound	Aver. time	Medium/ compound	Aver. time	Medium/ compound
Priority 1	1h (24h)[1)]	Air. SO_2, NO_2, NO_x, O_3	24h or longer	Air: SO_2, O_3, NO_2, temp., relative humidity	1h 24h	Air: O_3 SO_2, SO_4^{2-}, NO_2
	1h or 24h	PM_{10}, $PM_{2.5}$	“	Precipitation: mm, pH	aa	NO_X
	24h or[2)] longer	Pb	aa	Materials[3)]: Weight loss, steel panels	24h	Precipitation: SO_4^{2-}, NO_3^-, NH_4^+, Ca^{2+}, pH, (H+)
Priority 2	1h	CO	24h or longer	Air: HNO_3 (gas)	1h	Air: VOC, NO_x
	1h or 24h	SPM (or TSP), BS	“	Precipitation: Cl, SO_4^{2-}, NO_3^-		
	24h or[2)] longer	Benzene, PAH, Cd, As, Ni, Hg	“	Soiling: PM_{10}, SO_4^{2-}		
			aa	Materials[3)]: Weight loss, zinc panels		
Priority 3	Other compounds		aa	Materials[3)]: Weight loss, copper panels. Damage to calcareous stone		

aa: Annual average/exposure.

1) To be able to fully evaluate the measured levels relative to guidelines, these compounds should be reported as 1-hour averages.
24-hour average data from integrating samplers will also be accepted.

For these compounds, mainly long term average concentrations are of interest for the assessment of effects. However, measurement methods often take much shorter samples (e.g. 24-hour or weekly samples), and shorter samples are also needed in order to explain variations in terms of source contributions etc.

9 Instrumentation for air pollution measurements

Instruments for measurements of air pollutants may vary strongly in complexity and price from the simplest passive sampler to the most advanced and most often expensive automatic remote sampling system based upon light absorption spectroscopy of various kinds. The following Table indicates four typical types of instruments, their abilities and prices.

Table 3: Different types of instruments, their abilities and price.

Instrument type	Type of data collected	Data availability	Typical averaging time	Typical price (US $)
Passive sampler	Manual, in situ	After lab analyses	1-30 days	10
Sequential sampler	Manual /semi-automatic , in situ	After lab analyses	24 h	1 000
Monitors	Automatic Continuous, in situ	Directly, on-line	1h	>10 000
Remote monitoring	Automatic/Continuous, path integrated (space)	Directly, on-line	<1 min	>100 000

Relatively simple equipment is usually adequate to determine background levels (for some indicators), to check Air Quality Guideline values or to observe trends. Also for undertaking simple screening studies, passive samplers may be adequate. However, for complete determination of regional air pollution distributions, relative source impacts, hot spot identification and operation of warning systems more complex and advanced monitoring systems are needed. Also when data are needed for model verification and performance expensive monitoring systems are usually needed.

9.1 Samplers

9.1.1 Passive samplers

Simple passive samplers have been developed for surveillance of time integrated gas concentrations. These type of samplers are usually inexpensive in use, simple to handle and have an adequate overall precision and accuracy dependent upon the air pollution concentration level in question. This method has been used in industrial areas, in urban areas and for studies of indoor/outdoor exposures

A sensitive diffusion sampler for sulphur dioxide (SO_2) and nitrogen dioxide (NO_2) developed by the Swedish Environmental Research Institute (IVL) and has been used in several investigations by NILU to undertake a screening of the spatial concentration distribution in ambient air.

9.1.2 Filter pack sampling

The filter pack for air sampling consists of a filter holder with Teflon pre-filter for particles and two impregnated paper filters for gases. The filter holder is connected to a pump with flow controller, which pull a steady airflow through the filters. The detection limit is better than for the other methods but the method is more labour intensive and is dependent of extra sampling equipment such as a high precision electric pump.

9.1.3 Glass filter sampling

The Glass filter sampler consists of a glass bulb with a impregnated glass filter inside. The glass bulb is connected to a calibrated pump that draws a steady airflow through the filters. After exposure the glass bulb is sent to the laboratory for analysis, then the filter is washed and used again. The detection limit is better than for the other methods but the method is more labour intensive and depends of extra sampling equipment such as a high precision electric pump.

9.1.4 Canister sampling

Canister sampling can be used for volatile hydrocarbons up to C9. Air samples are collected in stainless steel canisters by the aid of a pump or just by opening the valve of an evacuated canister. The canisters are sent to the laboratory for analysis and then cleaned by evacuating it (vacuum).

9.1.5 Adsorbent tubes

Adsorbent tubes can be used for sampling of a wide number of volatile organic compounds. The tubes can be filled with different kinds of adsorbents, depending of which components of interest. When used as a passive sampler, there is no need for any extra equipment. To decrease the minimum sampling period or to improve the detection limit, the tube can be connected to a pump. Adsorbent tubes are not suitable for some of the most volatile hydrocarbons.

9.1.6 High volume PUF-sampler

The high volume PUF-sampler can be used for sampling of a wide spectre of organic pollutants like poly-aromatic hydrocarbons (PAH), dioxins, pesticides (like DDT) etc.

The sampler consists of a glass cylinder and a filter holder. The glass cylinder holds two polyurethane foam (PUF) plugs for trapping the gas phase of the pollutants. The filter holder in front holds a glass fibre filter to collect pollutants condensed on particles. The air is drawn through the sampler by a pump. 500 m^3 of air would be a typical sample volume for a 24-hour sample.

9.1.7 Precipitation dust fall collection

Precipitation samples are collected in plastic cans. To avoid evaporation during the hot season, the liquid is normally collected through a narrow inlet into a jar. Dust fall is collected in open buckets. The collection periods vary from 1 day/week (for precipitation) to 30 days for dust fall.

When analysing heavy metals, the cans are sent to the laboratory where the samples are analysed and the cans are cleaned with acid. If no heavy metals are analysed, only a portion of the samples are taken out of the can and sent to the laboratory. The can is then flushed with cleaned water and used again. All precipitation samples are stored in a cool place.

9.1.8 Semi-automatic sequential samplers

The determination of pollutant concentrations undertaken by samplers requires that a sample be brought to the chemical laboratory for analysis.

Traditionally, sampling and analysis have been described as separate events. Intermittent sampling systems collect gases in a solution or particles on a filter, typically over a period of 24 hours. For most programmes of this type such a sample is collected only once every 6 day.

A few semi-automatic sequential samplers have been developed and are still available on the marked. These have been widely used, especially in Europe, for daily average SO_2, NO_2, and PM/Black Smoke (BS) sampling. After collection, the sample is removed from the collection device and transported to the laboratory where it is analysed manually by chemical or physical methods.

Automatic sequential samplers have been developed and used for collection of time integrated samples with averaging times from a few hours and usually up to 24 hours. The most commonly used device has been the bubble, often together with a filtration system. A chemical solution is used to stabilise the pollutant for subsequent analysis with minimum interference by other pollutants. Impregnated filters for absorption of SO_2 and NO_2 are also being used in sequential samplers.

The NILU SS 2000 Sequential Air Sampler is a user-friendly automatic filter sampler. The sampler may be used for gases which can be absorbed on impregnated filters or other kinds of substrates e.g. the iodide absorption method for NO_2) and the KOH-impregnated filter method for SO_2. A programmable logic controller (PLC) controls the NILU SS 2000. The flow is set with a restrictor and measured with a mass flow meter. The sample volumes are recorded in standard litres accumulated over the sampling period. The user can set the desired start time for 8 samples in a sequence. The sampling will normally start at the same time every day at 24 hours interval.

To determine the pollutant concentration, it is necessary to measure the air volume sampled. The gas flow rate or the total gas volume sampled.

9.1.9 Hi-vol sampling

The high volume sampler has been most common in air quality monitoring programmes worldwide. A collecting glass fibre filter is located upstream of a heavy-duty vacuum pump which operates on a high flow rate of 1 to 2 m^3 /min. The sampler is mounted in a shelter with the filter parallel to the ground. The covered housing protects the glass fibre filter from wind and debris, and from the direct impact of precipitation. The hi-vol collects particles efficiently in the size range of 0.3-100 micrometers. The mass concentration of total suspended particles (TSP) is expressed as $\mu g/m^3$ for sampling times of usually 24 hours.

9.1.10 Paper tape samplers

In contrast to the high-volume sampler, paper tape samplers are semi continuous with averaging times of about one to two hours as normal.

Paper tape samplers draw ambient air through a cellulose tape filter. After a two hour sampling period, the instrument automatically advances to a clean piece of tape and begins a new sampling cycle

9.1.11 Size Selective Samplers.

A variety of sampling devices are available that segregate collected suspended particulate matter into discrete size ranges based on their aerodynamic diameters. These particle samplers may employ one or more fractionating stages. The physical principle by which particle segregation or fractionation takes place is inertial impaction. Therefore, most such devices are called impactors.

Other impactors have been developed to fractionate suspended particles into two size fractions, i.e., coarse (from 2.5-10 μm) and fine (less than 2.5 μm). Although these virtual or dichotomous impactors operate like a typical inertial unit, large particles are impacted into a void rather than an impervious surface.

9.2 Continuous automatic monitors

Methods and instruments for measuring continuous air pollutants must be carefully selected, evaluated and standardised. Several factors must be considered:

* *Specific*, i.e. respond to the pollutant of interest in the presence of other substances,
* *Sensitive* and range from the lowest to the highest concentration expected,
* *Stable*, i.e. remain unaltered during the sampling interval between sampling and analysis,
* *Precise, accurate* and representative for the true pollutant concentration in the atmosphere where the sample is obtained,
* Adequate for the *sampling time* required,
* *Reliable and feasible* relative to man power resources, maintenance cost and needs,
* Zero drift and calibration (at least for a few days to ensure reliable data),

* Response time short enough to record accurately rapid changes in pollution concentration,
* Ambient temperature and humidity shall not influence the concentration measurements,
* Maintenance time and cost should allow instruments to operate continuously over long periods with minimum downtime,
* Data output should be considered in relation to computer capacity or reading and processing.

If one consider the typical air concentrations of some pollutants of interest in air pollution studies, it is seen that as we go from background to urban atmosphere, the concentration for the most common pollutants increase roughly by a factor 1000. In the next step from urban to emission we see another factor of about 1000.

Table 4: Typical concentrations of pollutants in samples of interest in air pollution.

Pollutant	Background	Urban ambient	Stack effluents
CO	0.1 ppm	5-10 ppm	2,000-10,000 ppm
SO_2	0.2 ppb	0.02-2 ppm	500- 3,500 ppm
NO_x	0.2-5 ppb	0.2-1.0 ppm	1,500- 2,500 ppm
O_3	10 ppb	0.1-0.5 ppm	-
Suspended particulates	10 $\mu g/m^3$	60 $\mu g/m^3$	$35x10^6$ $\mu g/m^3$
Methane	1.5 ppm	1-10 ppm	
Other hydrocarbons	<ppm	1-100 ppb	

Few techniques or instruments are capable of measuring the total range of 10^6 ppm. Also the ambient conditions (temperature, humidity, interfering substances etc.) may differ greatly from ambient to emission measurements. The expected concentration level and the surrounding conditions thus influence the selection of sampling system. We usually find that instruments, techniques and analytical approaches are designed for application of specific concentration ranges as represented by background levels, ambient urban air concentration levels and typical stack emission concentrations.

The most commonly used methods for automatic monitoring of some of the major air quality indicators are discussed in the following:

Sulphur dioxide (SO_2)

SO_2 should be measured from the fluorescent signal generated by exciting SO_2 with UV light.

Nitrogen oxides (NO and NO_2)

The principle of chemilumiscent reactions between NO and O_3 will be used for measuring NO_x. NO and total NO_x is being measured.

Ozone (O_3)

An ultraviolet absorption analyser is being used for measuring the ambient concentrations of ozone. The concentration of ozone is determined by the attenuation of 254 nm UV light along a single fixed path cell.

Suspended particles; TSP, PM_{10} and $PM_{2.5}$

Gravimetric methods including a true micro weighing technology have been used to measure ambient concentrations of suspended particulate matter. For automatic monitoring an instrument named "Tapered Element Oscillating Microbalance (TEOM)" has been most frequently used. Using a choice of sampling inlets, the hardware can be configured to measure TSP, PM_{10} or $PM_{2,5}$.

Measurement on filter tape using the principles of beta attenuation for estimating 30 minute or one hour average concentrations of PM_{10} or PM2,5 have been operated with an air flow of about 18 l/min.

Carbon monoxide (CO)

The CO analyser often used in urban air pollution studies is a non-dispersive infrared photometer that uses gas filter correlation technology to measure low concentrations of CO accurately and reliable by use of state-of-the-art optical and electronic technology.

Hydrocarbons and VOC

Hydrocarbons (NMHC, Methane and THC) should be measured using a flame ionisation detector (FID). However, problems in +power supplies may interrupt these continuous measurements.

10 Reference methods in Europe

The measurement reference methods are presented in Annex IX of the EU Council Directive 1999/30/EC. A brief summary of these reference methods is presented in the following.

I. Reference method for the analysis of sulphur dioxide:

Ambient air - determination of sulphur dioxide - ultraviolet fluorescence method. ISO/FDIS 10498. A Member State may use any other method, which it can demonstrate, gives results equivalent to the above method.

II. Reference method for the analysis of nitrogen dioxide and oxides of nitrogen:

Ambient air - determination of the mass concentrations of nitrogen oxides - chemiluminescence method. ISO 7996: 1985: A Member State may use any other method, which it can demonstrate, gives results equivalent to the above method.

III. Reference method for the sampling and measurement of PM10

Member States will preferably use the reference method of the directive (sampling method according to CEN 12341 followed by gravimetric mass determination) or whatever method the Member State can demonstrate to produce equivalent results or to show a consistent relationship to the reference method. If a method other than the reference method is used, the report should also contain a demonstration of the equivalence or of the consistent relationship between the method and the reference method

The reference method for the sampling and measurement of PM10 will be that described in EN 12341 "Air Quality - Field Test Procedure to Demonstrate Reference Equivalence of Sampling Methods for the PM10 fraction of particulate matter".

The measurement principle is based on the collection on a filter of the PM_{10} fraction of ambient particulate matter and the gravimetric mass determination. One accepted method for PM_{10} sampling is using the German “Kleinfilter gerat”, another is the Anderson high volume sampler with hood.

Every PM_{10} sampler obtained for air quality monitoring should be equivalent to those approved according to CEN standard EN12341. This standard formulates criteria of the equivalence. Other certifications, including USEPA approvals, do not necessarily constitute compliance with CEN standard EN12341.

If monitors are to be used for PERSONAL measurements the new Eberline beta gauge monitor could be applied, even if this is still not a completely accepted method.

IV. Reference method for the sampling and analyses of lead:

For sampling of lead use the reference method specified for sampling of PM_{10} .A Member State may use any other method, which it can demonstrate, gives results equivalent to the above method.

For the analysis of lead, use ISO 9855: 1993 “Ambient air - Determination of the particulate lead content of aerosols collected in filters”. Analyses to be performed with atomic absorption spectroscopy method.

V. Provisional reference method for the sampling and measurement of $PM_{2,5}$

The Commission will produce guidelines, in consultation with the committee referred to in Article 12 of Directive 96/62/EEC, for an appropriate provisional reference method for the sampling and assessment of $PM_{2.5}$ by 19 July 2001.

The dual head sampler $PM_{10}/PM_{2.5}$ has not been accepted a reference method.

11 Meteorological data

Meteorological data are important input data to a system that is to be used for information, forecasting and planning purposes. Meteorological data are also important for explanatory reasons together with climatological data.

Meteorological data are needed from the surface, normally collected along 10 m towers, and up to the top of the atmospheric boundary layer. Automatic weather stations are currently being used in most large field studies, in remote areas and in complex terrain. Meteorological “surface data” such as winds, temperatures, stability, radiation, turbulence and precipitation are normally located together with the air quality monitoring station and data are being transferred to a central computer via radio communication, telephone or satellite.

Continuous measurement of meteorology using Automatic Weather Stations (AWS) requires sensors for at least the most important parameters such as:

1. Wind speeds,
2. wind directions,
3. relative humidity,
4. temperatures or vertical temperature gradients,
5. net radiation,
6. wind fluctuations or turbulence,
7. atmospheric pressure.

12 Data retrieval and QA/QC

When the air quality monitoring programme have been designed and indicators selected, it is important to prepare the Quality Assessment and Quality Control programme.

Procedures for Quality Assessment (QA) and Quality Control (QC) are developed to ensure that the data emerging from the monitoring will at least satisfy the data quality objectives (DQOs) defined by the responsible authorities. Complete QA/QC procedures are rather complex, and they should be documented. A very important element in the quality control procedures is the calibration procedures and the traceability of the calibration standards used in the network/station back to absolute standards of known quality. Institutions responsible for the QA/QC procedures and their follow-up may be national, regional or local

12.1 Data Quality Objectives

The accuracy of the air quality data and their spatial and temporal representativeness is obviously very important for the quality of the assessments produced from the data.

Data Quality Objectives (DQOs) are set, so that when they are fulfilled, one can use the data confidently for the purposes for which DQOs have been set.

In Europe the objectives that guide the quantification of DQOs, are defined as:

- the data shall enable comparison of air quality across Europe;
- the data shall enable detection of the trend in air quality in Europe, as well as in each area where stations are located, over a reasonable time period (3-5 years, dependent upon the magnitude of the trend).
- the data shall enable the assessments of exposure.

DQOs have been set for the following Data Quality Indicators:

- Accuracy
- Precision
- Area of representativeness
- Data termoral coverage

A summary of the European data quality objectives set so far is presented in the following table:

Monitoring objective	Data Quality Objectives				
	Accuracy	Precision	Data completeness		Representative-ness (spatial)
			Temporal	Spatial	
Mapping/comparability	≤ 10%	≤2 ppb	≥90%	1)	1), 2)
Trend detection	3)		≥90%	1)	1), 2)

1) The DQOs are set for station-by-station comparison (for same station class) and for trend detection at any one station.
In the case of comparisons of e.g. cities or larger entities, or trend assessment for larger areas, the requirements to spatial coverage and representativity would be strict, and to quantify those requires more analysis.
2) To be eligible for comparison with a station of the same class in another location (city, country), representativeness criteria should be complied with, as described on page 37-39.

To detect a trend with a certain accuracy, the combined accuracy and precision of the measurement must be considerably better than the expected trend (expressed as relative change.

12.2 Data retrieval and storage

For every site there is a need for a data acquisition system (DAS) to receive the measurement values collected by one or several gas or dust analysers, meteorological sensors or other parameters. These parameters must be stored, every minute, every 5 min. or every hour locally and then transmitted to a central computer via modem and telephone lines. The local storage time must be several days or up to some months in case of problems with modem, transmission lines or the central computer.

12.2.1 Data retrieval via telephone lines

The data retrieval from monitoring stations, which are equipped with modems and telephone lines, may be performed by the Computer centre using the following procedures:

- The Computer centre data base system asks for data automatically once a day (normally during night hours, at 02:00 hrs).
- The Computer centre operator initiates download (manually) which requires that the modem is functioning.

12.2.2 Monitoring stations without telephone lines

If telephone lines are not available at a monitoring station, data have to be collected manually via diskettes. Calibration values should always follow the diskettes, as there is no procedure for retrieving this information automatically on the diskette.

The data from diskettes should be imported to the Central data base system directly and checked. Reports should be printed daily or as a minimum on a weekly basis.

12.3 QA/QC procedure

Data QA/QC is performed at several levels:

- Calibration of monitors before installed in field
- Calibrations in field,
- Quality checks at data retrieval into the Station/ and System Manager,
- Data adjustment before entering data into the data base,
- Data quality controls through statistical analyses and evaluation.

12.3.1 Calibrations

Quality controls performed through various types of calibrations have been described in different documents, such as:

- Standard Operations Procedures Manuals
- History log book manuals
- Station manuals
- Data validation manuals
- Calibration and maintenance schedules
- Various reference materials.

12.3.2 Why calibrate

All instruments have to be calibrated on a routine basis for various reasons:

- Instrument response changes over time
- Secure correct response
- Example: NO output value
- Instrument parameters changes over time
- Secure correct parameter settings

For Gas monitors such as SO_2, NOx, CO there are different levels of calibrations undertaken before the data at all enters into the local and central data base:

- Multi-point calibration,
- Travelling standard gases with known concentration and
- Zero span check (two point calibrations weekly).

Ozone monitors are calibrated with O_3 generator with photometer. Sequential sampler, High volume samplers, and PM_{10} monitors are calibrated through flow calibrations.

For every operation there is a Standard Operation Procedure (SOP):

- SOP for calibrating a monitor in the lab
- SOP for calibrating a monitor at the station
- SOP for correcting data at the Monitoring Centre

Secures that a specific operation is performed the same way by all operators

12.3.3 The Quality Assurance (QA) procedure

Data quality assurance (QA) is an important part of data acquisition and data storage procedures. The data quality objectives for the monitoring network should be:

- a high data rate, sufficient to ensure acceptable temporal and seasonal representativeness
- the data capture should be evenly distributed throughout the year, dependent upon site characteristics and pollutants
- the data prepared for storage should be accurate, precise and consistent over time
- the data must be traceable to accepted measurement standards.

Monthly data capture rates (given in percent) should be reported in the data presentation reports. The average goal should be ~95% accepted data.

12.3.3.1 QA at the site

The need of QA undertaken at the measurement site varies with the type of equipment used. Passive samplers need only a written protocol, while a complex monitoring station needs protocols, calibration gas cylinders and zero air generators. Different kinds of calibrators may also be needed to make ozone and dilution of other gases.

The gas blenders should be able to dilute gases from verified high concentration table gases to working gas level to make a multi point calibration of monitors. The gas blenders are also used to control the concentration of the working gas cylinder. This is normally undertaken at a central laboratory. Rotameter to control the air flows are needed at the site.

The air quality network sites should be routinely visited once a week by the local site operators (LSO) and serviced every six months by equipment support units (ESU). In case of instrument breakdown or other site problems, the LSOs have to undertake non-routine site visits. The frequency of such non-routine visits provides a useful indication of the overall smooth running of the network.

12.3.3.2 Network calibration

A network QA is performed as a total calibration or inter calibration, dependent upon how the network is operated. This part of the QA system must be performed by the central monitor laboratory or by a reference laboratory. These controls should be undertaken regularly in 5-months or 6-months intervals. The purpose of such (inter)-calibration is to

- ensure consistency of the measurements in the network
- determine the accuracy and precision of the data
- identify deviations from standard operation procedures (SOP)
- investigate systematic measurement
- check the integrity of the site infrastructure

The tests that are undertaken include a number of performances such as

- accuracy
- response times
- noise levels
- linearity
- efficiency (of NO_2 converters, HC “kickers”, etc.)
- integrity of the sampling system

12.3.3.3 Routine controls at the reference laboratory

Well defined control routines should be developed and defined in standard operational procedures including

- questionnaires,
- forms and schemes,
- control routine check points,

To measure air volumes the reference laboratory must also have available wet gas meters including flow rates of 3 and 20 litres/min. A good calibrated pressure and temperature device is also needed.

There is a need for a zero air generator, which has the capability of delivering air to gas blenders and ozone calibrators. The air must be cleaned for all components and must be free from water vapour.

13 References

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