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Understanding Air Pollution

Air Quality Surveillance and Planning

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1 Introduction

Development of technical monitors and telemetric systems has made environmental data more readily available to planners, authorities and to the public. In line with awareness and the strong focus on our environment the modern environmental monitoring and surveillance systems have also become information systems that can provide relevant information at different levels about the state of the environment, quickly and precisely.

The integrated approach towards environmental management is based on the view that the environment should be monitored and followed as an entity. This is also in line with the concept “sustainable development” introduced by the Brundtland Commission, and which has been widely adopted by both national governments and international organizations.

Today’s environmental information systems combine the latest sensor and monitor technologies with data transfer; data base developments, quality assurance, statistical and numerical models and advanced computer platforms for processing, distribution and presenting data and model results. Geographical Information Systems (GIS) are an important tool, particular for the presentation of data.

These technologies can be used in environmental management to support integrated pollution prevention and control. They can also be part of an emergency management system to support actions and crisis management during emergencies and accidents of various kinds. The content and operability of the system might be quite different in the two cases. In the following we will describe the content of a surveillance system for local and regional environmental management, for urban areas or regions dealing with industrial problems, traffic, energy sources and solid and liquid waste.

Most of the examples below are related to the development of a system for air pollution monitoring and information. The examples given mostly apply to air quality studies in urban areas. However, the descriptions can also very well be applied to other types of environmental issues. Biological monitors or direct impact monitoring (on man and the environment) is not covered by the described system.

Part 1: The Monitoring Programme

2 The Air Quality Management System (AQMS)

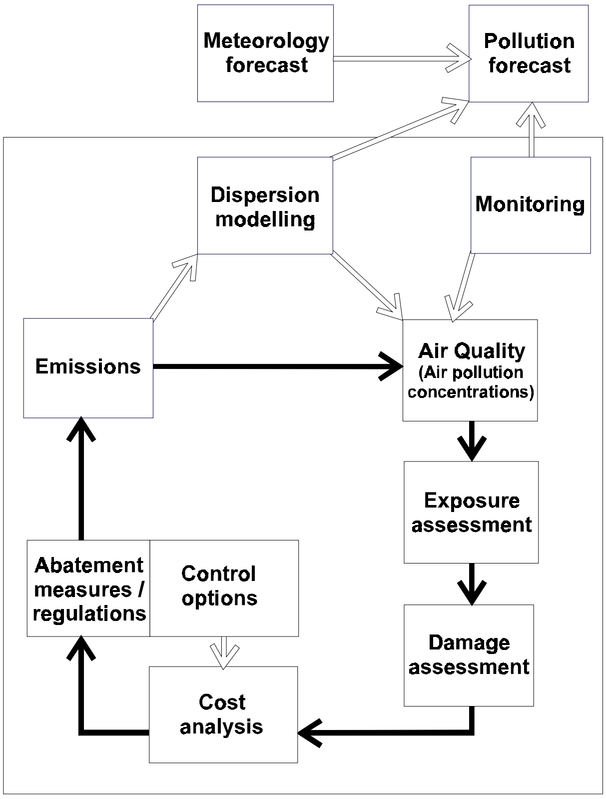
The basic concept for an Air Quality Management Strategy contains the following main components:

- Air Quality Assessment
- Environmental Damage Assessment
- Abatement Options Assessment•
- Cost Benefit Analysis or Cost Effective-ness Analysis
- Abatement Measures
- Optimum Control Strategy

The Air Quality Assessment, Environmental Damage Assessment and Abatement Options Assessment provide input to the **Cost Benefit or Cost Effectiveness Analysis**, which is also based on established Air Quality Objectives (i.e. guidelines, standards) and Economic Objectives (i.e. reduction of damage costs). The final result of this analysis is **Optimum Control Strategy**.

A system for air quality management requires continuing activities on the urban scale in the following fields:

- Inventorying of air pollution activities and emissions
- Monitoring of air pollution and dispersion parameters
- Calculation of air pollution concentrations, by dispersion models
- Inventorying of population, materials and urban development
- Calculation of the effect of abatement/control measures
- Establishing/improving of air pollution regulations.



The modelling concept of an Air Quality Management Strategy System

To perform an optimal project, the Air Quality Management Strategy (AQMS) system normally will consist of two main components, which are **assessment and control**. In parallel with the AQMS development, and to facilitate checking the effectiveness of the air pollution control actions, a third component is necessary, which is **surveillance**.

The urban area develops, and population, sources and technology change. Throughout this process, it is very important to have an operating Information System of Air Quality (AQIS), in order to:

- Keep the authorities and the public well informed about the short-term and long-term air quality development
- Control the results of abatement measures, and thereby
- Provide feedback information to the abatement strategy process.

The Air Quality Assessment, Environmental Damage Assessment and Abatement Options Assessment provide input to the Cost-Benefit Analysis (CBA), or a Cost-Effectiveness Analysis (CEA), which is also based on established air quality objectives (i.e. guidelines, standards) and economic objectives (i.e. reduction of damage costs).

The final result of this analysis is Optimum Control Strategy. A basis for both the Assessment, the Impact evaluation and the Surveillance is the modern environmental monitoring and information system described in the following chapter.

3 A modern environmental monitoring and information system

3.1 The technical features of the system

The key features of the modern environmental information system is the integrated approach that enables the user in a user friendly way to not only access data quickly, but also 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 dispersion models for air pollutants are available with on-line data input as a part of the system in urban areas.

Several systems are currently being developed and have been demonstrated in selected areas in Europe. One such system, ”ENSIS ‘94”, an Environmental Surveillance and Information System, was developed as part of the Eureka project for the Winter Olympic Games in Lillehammer. (Sivertsen and Haagenrud, 1994). The following description is based on this prototype.

The ENSIS concept has later been developed further into an AirQUIS module for air pollution surveillance, a WaterQUIS module for water pollution, and similar modules for noise, deterioration of materials and buildings etc. The different modules are all operated under the same main framework and can be combined in a flexible total system.

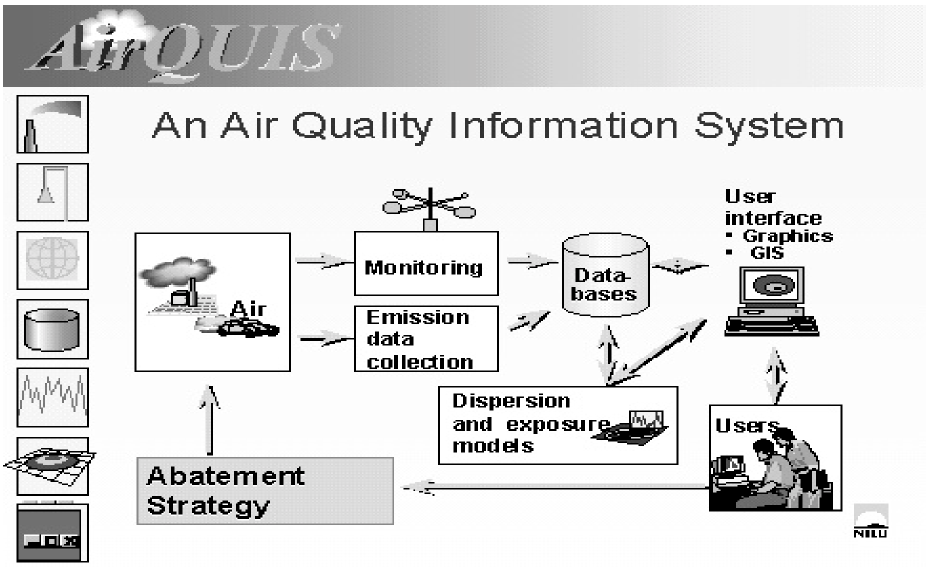


Figure 3.1: The principal structure of a modern environmental monitoring and information system.

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. This may require new sensor technology or modification of present monitoring methods. Several monitors and sensors that make on-line data transfer and control possible are already available on the market. For several other compounds and indicators this is not the case.

The system should include:

- Data collectors; sensors and monitors,
- data transfer systems and data quality assurance/control procedures,
- data bases included emission and discharge modules,
- 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 different parts will in the following be described in more detail.

3.2 Sensors and monitors

3.2.1 New instruments needed

Modifications and development of new sensors and monitors are necessary to establish a complete environmental information system that meets the requirements of today’s users. Several sensors and monitors for meteorology, noise, air- and water quality are already available on the market. However, not all of these can be linked on-line to a data transmission and data quality control system.

A description of measurement techniques for environmental parameters is presented in later chapters. For air pollutants it is important to decide whether one wants to measure *in situ* to obtain a point measurement or take an integrated sample over a distance or a volume. In the latter case different optical methods using light absorption have been developed and used during the last few years. Specific methods including single line spectroscopy with advanced optical filters or tuneable diode lasers emitting light at one particular wavelength have also been, or are being developed for selected individual air pollutants. However, it is difficult to obtain *in situ* measurements i.e. in streets with these instruments. The cost of these instruments is also high, depending on the number of parameters needed to get a good indication of the status of the air quality. (See indicators.)

3.2.2 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 ground, 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 being transferred to a central computer via radio communication, telephone or satellite.

One of the more difficult parameter to obtain on a routine basis is the height of the boundary layer as a function of time. This height is often related to and referred to as the mixing height. When air quality models are being applied for exposure modelling, information and forecasting and decision-making purposes, meteorological input data from the boundary layer are crucial.

To improve the meteorological input data for numerical air quality models in urban areas, more advanced three-dimensional wind and turbulence measurement equipment should be included. These instruments can measure the atmospheric turbulence directly. These turbulence data can be used directly to estimate the dispersion more accurately. Many areas have already installed Doppler sodar systems that can measure the vertical structure of wind and turbulence. These data are also subject to certain ambiguities, but represent a valuable additional input to the models for on-line information and warning.

A combination of measurement data (at several locations) and model estimated wind fields will represent the necessary input to numerical air pollution dispersion models in a complex urban area. These models are usually set to estimate concentration distributions on an hourly basis, and the most important parameters are therefore the flow pattern and a correct picture of the transport of pollutants. In some cases, especially when applying mesoscale and regional scale models, remote sensing of weather systems from satellites may prove a useful tool for estimating input data.

3.3 Environmental indicators

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.

Many national and international authorities are presently working with processes to select environmental indicators. The result of this work will not be available in another few years. In the meantime, for air quality, the selected parameters are mostly related to air pollutants for which air quality guideline values are available.

The development of environmental indicators in Europe will contribute to the harmonization of several initiatives. This activity will be important input to the design and content of monitoring programmes. Harmonization is an important concept both in monitoring and in modelling. It allows different methods to be used to measure the same variable to predetermined levels of accuracy and precision. Even if different methods are applied the data from each location can be comparable and compatible.

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 societies 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 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 (ENSIS) 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.

3.4 Data transfer and quality assurance

Specially designed data loggers for environmental data are available. Data loggers designed and built by NILU were included in the ENSIS ’94 application. The logger should be robust and serve as a local backup storage unit in case of link brake down (lightening, storms etc.). The logger is directly linked to a modem.

Data transfer can be via local radio communication for limited distances. This has been the case for a distributed local net of several meteorological stations where data are transmitted via radio link to the main station in the area. Data will further be transmitted on public telephone lines or via satellite to the main computer facility. The central unit might be a major field station or a central laboratory. For an emergency system developed for the Eureka project MEMbrain, a field laboratory has been established with a workstation computer including all modelling tools. (Sivertsen, 1994b)

Data quality assurance programmes including direct quality control is performed at different levels in the data collection process;

- in field during automatic and manual calibrations and controls,
- at the central data collection base following quality assurance routines as described i.e. in ISO 45001 from the International Standardization Organization,
- in approvals to the final data base,
- through simple statistical and graphical evaluations to check validity and representativeness of data.

The quality control procedures give the data credibility. The data become reliable, which is essential when using the data for reporting, controls and planning. To be used with confidence for scientific and environmental management purposes the data must also be comparable and compatible.

Integrated data from local sites and from various environmental compartments require comparable data quality. The various local networks have to operate to high standard including proper implementation of good practice by network managers and site responsible personnel.

3.5 The data bases

The development of an associated database or metadata is important to all modern environmental monitoring and information systems. The data base system may consist of several data bases which serve as main storage platforms for:

- on-line collected environmental data,
- emission and discharge data included emission modelling procedures,
- historical data and background information like area use, population distributions and trends,

- regulations, guideline values and information on the support and decision making process.

The data bases contain information that enables an evaluation of the actual state of the environment and it includes data for establishing trend analyses, warnings and the undertaking of countermeasures in case of episodic high pollution.

3.5.1 The on-line data base

All data collected on-line will after quality assurance and controls be part of the information data base. From this base it will be possible to obtain quick graphical presentations, or to subtract data for public information purposes etc.

3.5.2 The emission data base

The emission database is an interactive platform for collecting input data for emission estimates. It contains information about the sources, emission factors, consumption data, information on locations (gridded co-ordinates), stack heights, stack parameters, fuels etc. The emission database can be operated directly by the user, who can use the emission models directly to present emission data directly. Any changes and additions to the emission database will result in updated emission estimates with links to the dispersion models and resulting database for graphical presentation.

3.5.3 Historical and background data base

The historical and background data base module includes relevant objects and information such as monitoring stations and sensors, sensor developers, responsible institutions, locations and measurement schedules, methods, data owners, maintenance routines etc. It also contains information about earlier and additional environmental data collected in the area. Background information such as area use, population distributions and inventories of vegetation and materials/buildings in the area may be an important part of this data base. Such information can be used for impact assessment estimates and for some of the emission estimates.

3.5.4 Supporting data base

The supporting database, which may be part of the background data base contains information on regulations, requirements, air quality guideline values or water quality standards for various applications.

Information about regulations and plans given by local authorities or by governmental bodies should be included in this database, as well as support actions and emergency procedures. The total associated database system will also serve as a link to a meta information system which includes information on external environmental data. These functions might also include:

- navigation facilities to access the needed information,
- support for standardization activities,
- world wide web/internet functions and bridges.

The data base model is designed to support local and regional levels and meets most of the requirements specified by the users.

Modifications and additions must be easily made in the database. Routines for safety copying and reconstruction must be available. Different data deliveries might be operating in different systems. This requires the establishment of different communication systems with open communication solutions.

3.6 The models

In the modern multi compartment environmental information system (like ENSIS) steps have been taken to establish models for air pollution dispersion, for water quality and noise and for other environmental impact assessment estimates. Models for these media will be essential when the programmes are to be used for planning purposes.

The air pollution dispersion models are a well-established and fully implemented part of the system. These models have been tested and demonstrated as part of the integrated surveillance systems and are presently being operated in several cities on a routine basis. Different types of dispersion models have been developed and applied to estimate the ambient impact of air pollution emissions from point-, line- and area sources.

The selection of models to be used in a specific case is dependent upon the spatial and temporal scales, complexity of source configurations and chemistry, topographical features, climate and instationarity/inhomogeneity in the meteorological conditions of the area. It is advisable to consult experts in this process.

A variety of different models are available on the market today. However, one should note that it might be a significant step from obtaining a model to actually having an operable modelling tool for a specific area and application.

Different types of models available are taken from the air pollution surveillance programmes. They range from single quasi-stationary Gaussian type single source models based upon analytical solutions of the mass balance equations, to advanced numerical models, which require large computers.

The simplest models can be used on personal computers for impact assessment. These models can estimate 1 h average concentration distributions downwind from ground level, diffusive and elevated single sources. (Sivertsen 1980, Bøhler 1987)

One step up represents the short-term model for estimating 1 h average concentration distributions for emissions from multiple source industrial complexes (Bøhler 1987). This includes the multiple source Gaussian type models for estimating short term or long term integrated concentrations in a gridded co-ordinate system. Two different type of such models have been developed at NILU; CONDEP for monthly, seasonal and annual average concentration distribution estimates (Bøhler 1987) and KILDER which is a flexible emission inventory linked to multiple source Gaussian type dispersion models for line, area and point sources. (Gram 1996).

The grid system used by the models is specified by the user to match the specific problem and the area considered. The resolution, grid spacing and total area can easily be modified and changed depending upon the specific needs.

These models need as input data some background information on;

- source characteristics and emission data,
- area characteristics (surface roughness, topography etc.),
- measurement data (measurement type, heights etc.),
- meteorological data (wind, stability, mixing height, temperatures etc.),
- dispersion coefficients (type to be used and parameters),
- dry and wet removal coefficients,
- location of receptor points (distances or grid specifications).

All the NILU models have been well documented and are being used for planning purposes and for impact assessments both nationally and internationally.

Small scale models are also available for estimating the air pollution load from traffic in street canyons and along roads. A commercially available model, ROADAIR (Larssen and Torp, 1993), estimates emissions, concentrations and exposure along the road system based upon traffic data. These input data may originate from traffic models or from traffic density data and on-line traffic counting.

On a spatial scale from about 1 to 100 km there are several types of numerical models available; both Lagrangian type and Eulerian type models. The Lagrangian type models follow puffs of air pollutants estimating in each puff the turbulent diffusion, chemical reactions and deposition processes. The turbulence description and the diffusion processes may be treated in different ways.

One example is the INPUFF model (Knudsen and Hellevik, 1992) which is based upon Gaussian concentration distributions in the puff. This model also includes chemical and physical reactions and processes. Another model of this type is the Danish operational puff diffusion model RIMPUFF (Mikkelsen et al., 1987). This model was developed by Risø National Laboratory to provide risk and safety assessment in connection with e.g. nuclear installations.

One example of a Eulerian type numerical dispersion model is the EPISODE model developed by Grønskei et al. (1993). This is a time-dependent finite difference model normally operating in three vertical levels, combined with a puff trajectory model to account for subgrid effects close to individual sources. When the size of the puffs reaches the horizontal and vertical grid size the transport and dispersion is treated as a numerical box model. The mass of pollutants is then added to the average value for that grid element. The model can thus treat point sources, area/volume sources and line sources. The wind field used as input to the model may be homogeneous or inhomogeneous for each time step dependent upon the meteorological input data available.

For the selection of models to be used in a specific case there have been different methods indicated. Sivertsen (1979) indicated a flow chart for selecting models dependent upon type and complexity of the sources, spatial and temporal scales, chemical composition (secondary or primary pollutants), topographical features, climate and meteorological features of the selected area.

For further information on the use of models, Hanna et al. (1982) give a good overview of the topic. One important issue when using dispersion models is to obtain adequate meteorological input data. Meteorological pre-processors have been developed during the last few years to handle this problem. (Paumier et al., 1985 and Bøhler et al., 1996). These pre-processors can estimate meteorological dispersion and the basic meteorological variables of interest for diffusion modelling based upon the current concepts regarding the structure of an idealized boundary layer. (Gryning et al., 1987). Methods are also provided for estimating the vertical profiles of wind velocity, temperature and the variances of the vertical and lateral wind velocity fluctuations.

3.7 Data presentation; graphics and GIS

Environmental data collected through the automatic monitoring and telemetric network will be quality controlled and transferred for storage in the integrated relational databases. Statistical programmes for control of quality and representativeness will be used, and the first results can within one hour after field collection be presented using user-friendly graphical tools.

The information may be multimedia: texts, tables, graphs, images, sound or video dependent on the end user. The presentations have to be designed to meet the user needs. These users may be:

- authorities at different levels (municipal, regional, national, international),
- industrial users,
- schools, universities and the scientific community,
- various organisations,
- the public and media.

The environmental data are usually linked to geographical sites. In particular when monitoring data are supported and supplied by model estimates of spatial concentration distributions and impacts, it is suggested that the presentation of the results would involve the use of maps or digitalized Geographical Information Systems (GIS).

Geographical information systems based on advanced raster/vector technology has been developed to handle maps, networks, symbols and various objects. They can handle both geographical information and technical documentation and present this in graphical form. The basic raw map information has normally been workstation based, but user friendly PC based applications for displaying e.g. environmental data have been developed during the last few years.

The GIS user can easily organise selected data from various databases. Thematic maps can be produced combined with time series graphical presentations and results from model calculations. The system will display the results of planned actions based upon simulation models and thus act as a more user-friendly decision support system.

3.8 Environmental information to the public

A wider distribution of environmental data to the public has become a part of the development of modern environmental surveillance and information systems. New approaches have been developed for dissemination of environmental information, which can be adapted to different information distribution systems. These systems could be teletext, public telephone network, special designed health advice information lines, telefax distributions, INTERNET networks etc.

The design of the web solutions has been based upon specifications developed by the users. Air quality data may be available on maps, and as spreadsheets. The Internet pages are dynamic, using an Oracle database for storage of information and Cold Fusion as the technical software. A specially designed WEB Desk is used for administrating all the websites/pages.

NILU has participated in the European Web application development; IRENIE, which demonstrated and evaluated the telematics options for increasing the efficiency of flows of data and information at the local, national and international levels. The project also aimed at providing European-wide information services for the European Environment Agency and its customers such as the European Commission Information of air quality in urban areas. Information has been issued to the public on a daily basis described in terms of “very good”, “good”, “poor” etc. Many European cities already provide this type of information.

A further development of the system for providing faster access to data and easier information to the public is ongoing in Europe.

The key issues in this development are:

- Real time information, early warning and forecasting of air pollution,
- Cross border information exchange between cities and professionals,
- Fix and mobile communication channels and technology,
- Interfaces to electronic street panels, voice and mail servers.

The technical approaches include to:

- Build an easy-to-use novel interface on air pollution data for citizens by
- combining several data sources with online population
- providing different technology access methods (Web - GIS, WML-WAP, street panels.

4 The Monitoring Programme

4.1 Programme design

As part of the establishment of an air quality monitoring and surveillance system, a programme has to be established to design and plan the details and content of such a system. This programme should be undertaken including the following topics:

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 equipment,
    - QA procedures,
5. plan the programme in detail,
    - siting studies,
    - consider field investigations,
    - emission inventorying, simple modelling,
    - select relevant sites,
6. optimise measurements, (cost/effective design),
7. procure instruments,
    - specify technical requirements,
8. establish and initiate operation,
    - laboratory control systems,
    - develop standard operational procedures (SOP),
    - define and describe QA/QC procedures,
9. training.

An air quality monitoring programme may consist of all type of equipment; from simple passive samplers, via active samplers of different makes and sequential samplers to the most advanced on-line monitoring systems.

Traditional sampling system needs collection of samplers in the field following some chemical or physical analyses in the laboratory. Data have to be quality assured, and are normally not available until at least one week after they were collected.

4.2 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.

4.3 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, 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 siting studies discussed in the next chapter.

4.4 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);
- to enable comparison of air quality from different areas and countries;

- to produce estimates of exposure of the population, and of materials and ecosystems;
- to estimate health effects;
- to quantify damage to materials and vegetation;
- to produce emissions/exposure relations and exposure/effect relations;
- to support development of cost-effective abatement strategies;
- to support legislation (in relation to air quality directives);
- to 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.

4.4.1 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.

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.

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 micro scale or local time varying sources.

4.4.2 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.

Criteria for the selection of sites have been presented in Europe for the assessment of population exposure.

Table 4.1: Assessment of population exposure: Criteria for selection of areas/ stations to be fulfilled by each state as far as possible.

Type of area	Criteria	
	Area selection	Station selection
Cities and Agglomerations		
>0.5 mill	All cities	All stations, for up to 20 stations in the agglomeration. When subset is selected (when >20 stations), the selection must contain all station categories represented in the city, and must be spatially distributed in the agglomeration to cover the whole population.
0.25-0.5 mill	At least 25% of the cities	The selected areas (cities) must represent high, medium and low levels of industrialization, as occurring in the country.
0.05-0.25 mill	At least 10% of the cities	The selected areas (cities) must represent high, medium and low levels of industrialization, as occurring in the country.
Rural areas	1)	
Industrial areas outside cities	All areas with air pollution above the WHO AQ Guidelines	All existing monitoring stations in these areas.

1) Monitoring needs and network/station selection to be done by each country. At least 50% of the rural population should be covered in terms of being reasonably well represented by monitoring stations for the relevant compounds, e.g. O_3, PM_{10}, $PM_{2.5}$.

Different types of measurement sites have been classified in: Traffic (street canyons and roadside), industrial, urban, residential and background sites. The different types/classes of measurement sites are relevant to differing degrees for exposure of populations, materials and ecosystems:

Table 4.2: Relevance of station class for types of exposure.

Station classes	***Relevant for exposure of***		
	Population	Materials	Ecosystems
Traffic stations	x	(x)	
Industrial stations	x	x	x
Background stations			
- Urban/suburban background stations	x	x	(x)
- Background stations			
- Near city background stations	x	x	x
- Regional background stations	x	(x)	x
- Remote stations			x

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.

5 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.

5.1 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, might, 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. (Sivertsen 1994).

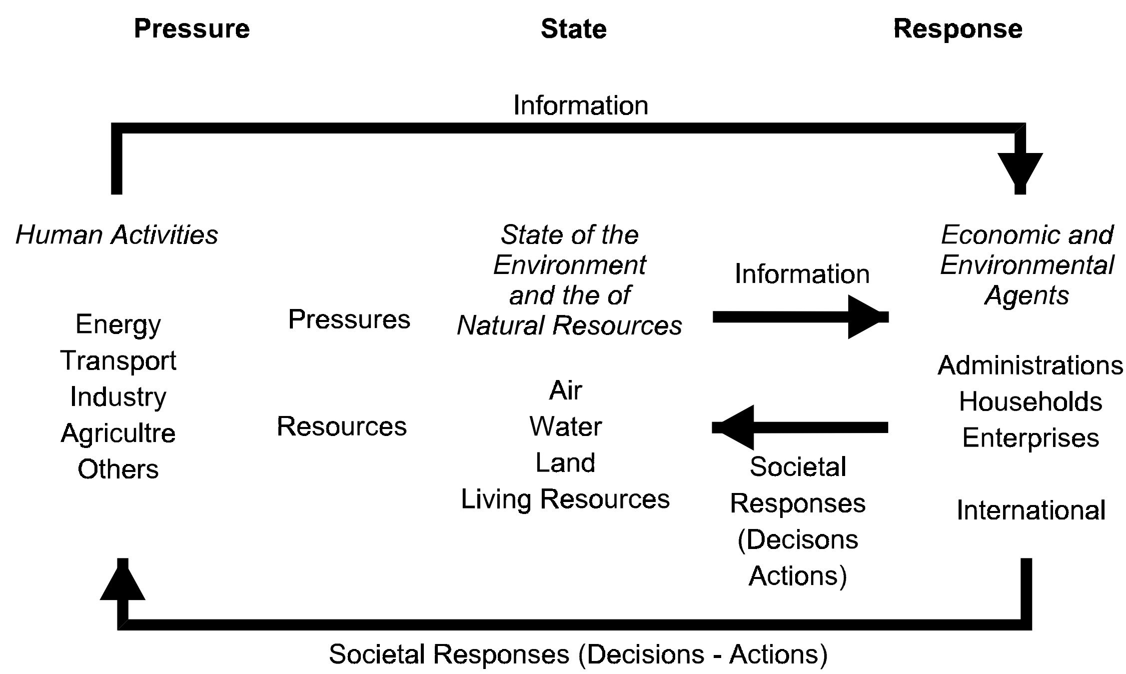
The selection of parameters included in the monitoring and model estimate programme should enable an automatic access to data relevant for assessing the environment included air pollution and atmospheric conditions, pollution of rivers and seas, ground water, waste, noise and radiation. For all these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

5.2 Indicators in a PSIR framework

In the development of indicators it has been important during the last years to establish these indicators within the framework of Pressure - State – Impact - Response (PSIR). The PSIR 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.



The selected set of environmental indicators will be used by local and regional authorities 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. (Sivertsen 1994)

Indicators might also be aggregated data and not necessarily observed single parameters. The modern environmental surveillance and information systems (e.g. ENSIS) 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, 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.

5.3 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 5.1: 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 exceedences (%)	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; neurological 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 1995)

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 5.2: 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)] 1h or 24h 24h or[2)] longer	Air. SO_2, NO_2, NO_x, O_3 PM_{10}, $PM_{2.5}$ Pb	 24h or longer “ aa	Air: SO_2, O_3, NO_2, temp., relative humidity Precipitation: mm, pH Materials[3)]: Weight loss, steel panels	 1h 24h aa 24h	Air: O_3 SO_2, SO_4^{2-}, NO_2 NO_X Precipitation: SO_4^{2-}, NO_3^-, NH_4^+, Ca^{2+}, pH, (H+)
Priority 2	1h 1h or 24h 24h or[2)] longer	CO SPM (or TSP), BS Benzene, PAH, Cd, As, Ni, Hg	 24h or longer “ “ aa	Air: HNO_3 (gas) Precipitation: Cl, SO_4^{2-}, NO_3^- Soiling: PM_{10}, SO_4^{2-} Materials[3)]: Weight loss, zinc panels	 1h	Air: VOC, NO_x
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.

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.

6 Instrumentation

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.

Figure 6.1: Different types of instruments, their abilities and price.

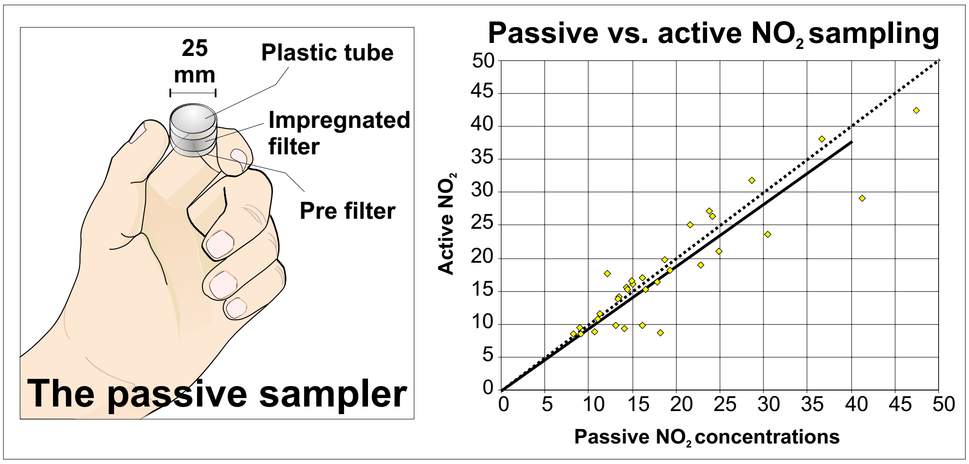
Instrument type	Type of data collected	Data availability	Typical averaging time	Typical price (US $)
Passive sampler	Manual, in situ	After lab analyses	1-30 days	10
Sequential sampler	Manual /semi-automatic , in situ	After lab analyses	24 h	1 000
Monitors	Automatic Continuous, in situ	Directly, on-line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

6.1 Samplers

6.1.1 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.

6.1.2 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.

6.1.3 Glass filter sampling

The Glass filter sampler consists of a glass bulb with an 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.

6.1.4 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).

6.1.5 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.

6.1.6 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.

6.1.7 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.

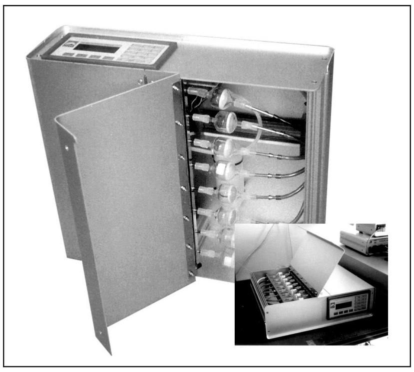
When analysing heavy metals, the cans are sent to the laboratory where the samples are analysed and the cans are cleaned with acid. If no heavy metals are analysed, only a portion of the samples are taken out of the can and sent to the laboratory. The can is then flushed with cleaned water and used again.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

6.1.8 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.



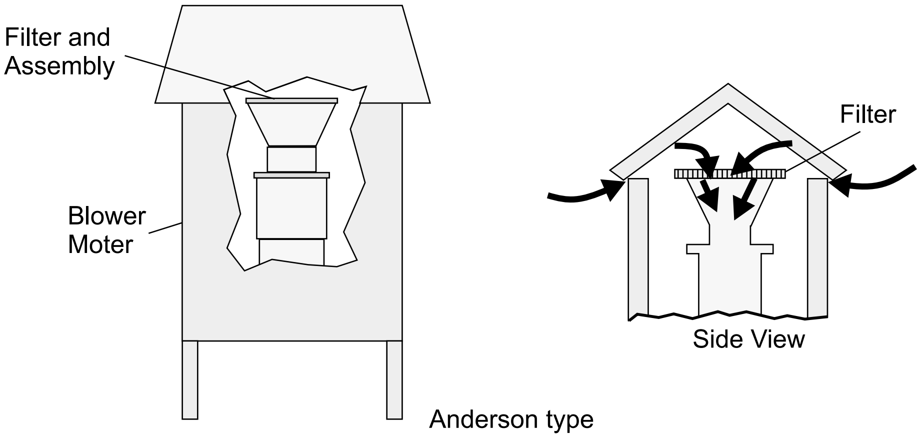
The SS-2000 Series of sequential air samplers are optionally delivered as a wall model or as a bench model with 8 impregnated filters in a sequence

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.

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

6.1.9 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.

6.1.10 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

6.1.11 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 imp actors.

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.

6.2 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 6.1: 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 μg/m^3	60 μg/m^3	35x10^6 μg/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 chemiluminescent 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

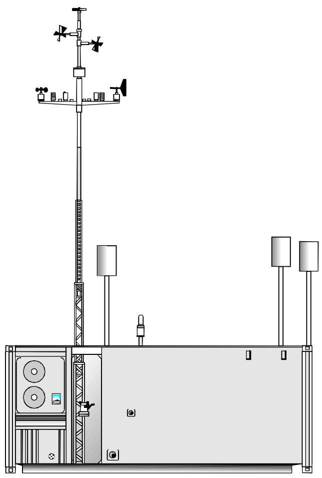
Hydrocarbons (NMHC, Methane and THC) should be measured using a flame ionisation detector (FID). However, problems in +power supplies may interrupt these continuous measurements.

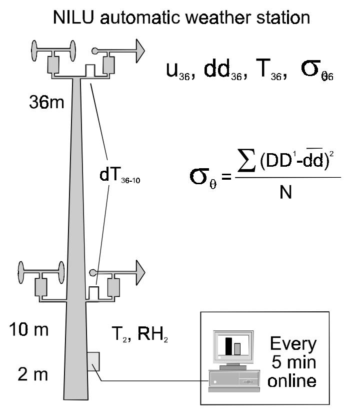
6.3 Meteorological data

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 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.





A complete air quality monitoring station consists of a set of monitors and samplers covering the relevant indicators for the specific site. The instruments are normally placed in an air-conditioned shelter, with telephone communication links to a central computer. For data retrieval and data quality assurance, see next chapter.

7 Data retrieval and QA/QC

When the air quality monitoring programme has 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 trace ability 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

7.1 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 temporal 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.

7.2 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.

7.2.1 Data retrieval via telephone lines

The online monitoring stations need a robust and stable communication network to obtain high frequency of operation. The communication between the various instruments in the monitoring shelters and the central station are normally based on public telephone lines. An Automatic Data Acquisition System (ADACS) can be used for automatic collection of monitoring data, for instance like the one ADACS system developed by NILU. The measurements are transferred to the central station and automatically stored into the AirQUIS database.

The data retrieval and data evaluation routine is described as follows:

- When the first set of data is retrieved at the computer centre daily data evaluation starts. First of all calibration factors will have to be checked. Next span checkpoints, errors, peak values, false data and other peculiarities in the retrieved data have to be taken out.
- Time plots of the data will be produced, to evaluate the diurnal, weekly and spatial variation in concentrations. Training in the judgement of concentration levels and units will be undertaken.

The tools for checking the data quality on a daily basis is part of the AirQUIS system installed at the Central Station.

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.

7.2.2 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.

7.2.3 Data bases

The measurement database is used to store, retrieve and organise measurements. The user can carry out various analyses on data stored in the database, such as statistical calculations and quality assurance tests. Data can also be viewed graphically and printed. The basic database programme used in AirQUIS is Oracle 7.4.

The data in the database are organised in data series (measurement time series). The data series are identified by a set of properties that describe the values. The necessary properties to identify data series in the measurement database are given in the table:

Information	**Properties describing the data series**	**Properties describing each value**
Where are the measurements taken	Station, Measurement position	
What is measured	Medium, Component (Parameter), Unit	
How is this measured	Instrument, Sampling method, Analysis	
When is this measured		From-time, To-time
What was the result		Value
Quality status of the measurements		Quality status flag, Exception flag

7.3 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.

7.3.1 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.

7.3.2 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

7.3.3 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.

7.3.3.1 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.

7.3.3.2 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

7.3.3.3 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,

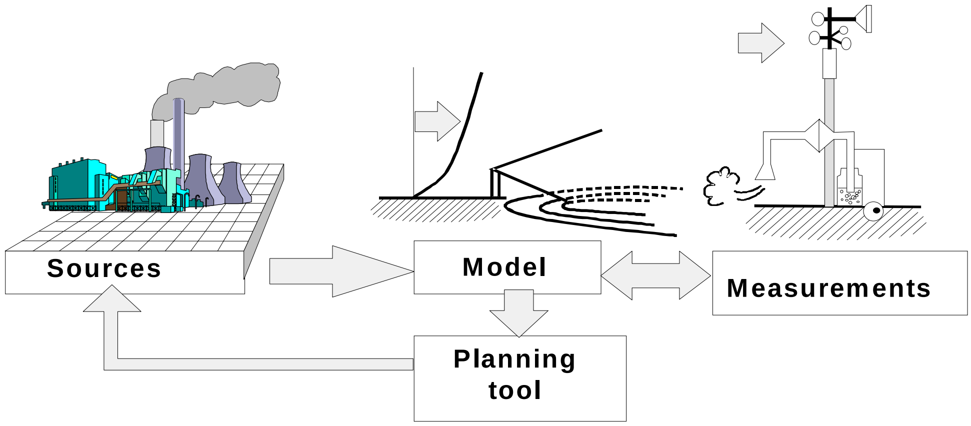
To measure air volumes the reference laboratory must also have available wet gas meters including flow rates of 3 and 20 litres/min. A good calibrated pressure and temperature device is also needed.

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.

Part Two: Modelling and air quality planning

8 Air pollution sources

Information on air pollution sources, meteorological conditions, area and surface conditions as well as observed air pollution is needed as input to perform air pollution modelling.



The dispersion model represents a mathematical description of the physical and chemical processes in the atmosphere, which transport, dilute, transform and deposit air pollutants. Only when all these processes are adequately described and tested have we a system that can forecast air pollution concentrations and may be used as a **planning tool**.

Air pollution is generated from a number of different sources. The concentrations of air pollutants that are measured at the sites will always be a sum of the interactions from different sources. It is therefore important to have some basic knowledge about the characteristics of the sources in the different areas.

Emissions of air pollutant are related to socio-economic activities such as:
- Combustion of fossil fuels (power production),
- Industrial processes of various kinds,
- Road transport,
- Waste burning, open air and in incinerators,
- Solvent use,
- Agricultural activities,

The emissions of air pollutants are normally given by source category or by specific air pollution compounds. Some relevant sources and selected indicators are presented in the Table below:

Source category	SO_x	NO_x	CO	VOC	TSP/PM_{10}
Power generation	**xx**	**xx**	**x**	**x**	**x**
Residential, commercial combustion	**x**	**x**	**xx**	**x**	**xx**
Process industry with combustion	**xx**	**xx**	**x**	**x**	**xx**
Non-combustion industry	**x**	**x**	**(xx)**	**xx**	**x**
Extraction and distribution of fuels	**x**	**x**	**x**	**xx**	
Solvent use				**xx**	
Road transport	**x**	**xx**	**xx**	**xx**	**xx**
Other transport	**x**	**(xx)**	**x**	**x**	**x**
Waste disposal and treatment	**x**	**x**	**xx**	**xx**	**xx**
Agricultural activities				**x**	**x**
Natural sources				**x**	**x**

8.1 Area and point sources

The different air pollution sources are divided into:

- Area sources (e.g. residential heating and other small sources distributed over an area),
- Point sources (emissions from stacks, e.g. power plants and industries),
- Line sources (emission from traffic along a road or a street),

8.1.1 Emission from area sources

Area sources are used to describe sources where geographical distribution is not exactly known and where emissions are small but in large numbers so that they have a significant impact on concentrations. These kinds of emissions can be from house heating, traffic or various type of land use. These emissions are normally connected to use of different fuels in an area that is distributed according to population distribution. It could also be used to model emissions of ammonium from agriculture. The area sources in a city have local influence, they are linked to consumption and emission factors are needed

8.1.2 Emission from stationary point sources

Point sources may be tall stacks emitting pollution from industrial processes or from burning of fossil fuels. When estimating the emission rate, either for statistical reasons or as input to dispersion models, activity data should be linked to the emission generation process as closely as possible.
For performing emission estimates two examples is presented in the following:

- For emission from power plant combustion of certain fuels; (1) fuel input instead of electricity output should be used, and (2) energy units instead of mass units should be used. Consequently, determination of appropriate heat values of fuels may be necessary where fuel data are available in mass units only;

- For combustion related emissions in general: emission characteristics vary from fuel to fuel and hence activities should be reported in this way, instead of using a total energy approach.

One must pay special attention where both combustion and fuels and processing of materials may have effects on emissions. Fuel mixture as well as specific energy demands may change over time. As a consequence, both fuel input and product output need to be accounted.

Whenever point sources are estimated individually, the estimated sum of the activity represented by these sources should be subtracted from the estimated collective activity. This is to avoid double-counting the individually considered point sources when estimating the rest of the source activity emissions (the collective approach).

As in the case of point sources treated individually in the accounting for processes with combustion, attention should be paid to avoid double counting of energy consumption statistics. Reference activity data may be available from public and private statistics, institutions or research projects. Information on fuels should include non-commercial fuels and wastes used for energy generation

8.1.3 Emissions from road traffic

The emission of CO and NO_x from traffic is calculated by multiplying the traffic intensity (cars/hour) with the length of the road (km) and an "emission factor" (g/(km*car)). For CO_2, the emission factor (grams of emission per unit fuel consumption) is multiplied with the fuel consumption (kg/km).

The emission for a given road is a function of:
- speed,
- road gradient,
- year of calculation (this determines the technology level of the vehicle),
- number of cars in each vehicle class.

The emissions increase with the age of the car. There are also increased emissions from cars in cold start mode. Both of these factors can be accounted for in a model.

The total emission from the road network (tonnes/year) is estimated from the mean daily traffic parameters. The peak emission calculations utilise rush-hour parameters.

The calculation of emissions/generation of PM_{10} (road dust) is usually based on a different method than for the other components. The reason for this is that PM_{10} refers to a 24 hour average, whereas CO and NO_2 are one hour averages.

8.2 Undertaking emission inventorying – an example from UK

The London studies established a general methodology now being used in preparing up-dating the London air pollution emission inventory, as well as in the Ten Cities Programme. The geographical framework for data collection and analysis is the 1 x 1 kilometre national grid. Data are collected for three types of sources:

- Line sources including roads and railways;
- Area sources including emissions from agricultural and other land, and low intensity emissions from sources such as building heating systems;
- Point sources including high intensity emissions from industrial plants.

Clearly it is impossible to measure every emission source in an area with a population of 2.5 million. The majority of emissions are therefore estimated from other information such as fuel consumption, vehicle kilometres travelled (VKT), or some other measure of activity relating to the emissions. Emission factors, derived from the results of measurements, are then applied to the activity data in order to estimate the likely emissions:
Activity rate x Emission factor = Emission rate

For many of the pollutants of concern, the major source of emissions is the combustion of fossil fuels. Consequently the collection and analysis of fuel consumption statistics plays an important part in the preparation of emission inventories. However, it is important t consider the differences between consumption and fuel deliveries when making use of the available data. Most of the readily available statistics relate to fuel deliveries which, in many cases, relate closely to consumption. However, in the case of fuels, which may be stockpiled, such as coal, there may be significant differences between delivery and consumption. In the case of transport fuels, there may be significant geographical differences between the point of delivery and where the fuel is used.

The pollutants and pollutant groups included in the present inventories are:

- Sulphur dioxide (SO_2)
- Oxides of nitrogen (NO_x)
- Carbon monoxide (CO)
- Methane (CH_4)
- Non-methane volatile organic compounds (NMVOC)
- Carbon dioxide (CO_2)
- Benzene
- 1,3-butadiene
- Total suspended particulate (TSP)
- Particulate matter less than 10 microns aerodynamic diameter (PM_{10})
- Black smoke

The inventories do not include all pollutants, which may be of concern for health or other reasons. Some pollutants are only emitted from a limited number of sources, or only affect specific areas. Emissions of other pollutants are in decline as a result of established policies. An example of a pollutant in this latter category is lead.

Airborne lead levels have shown a downward trend since 1981, when the amount of lead in leaded petrol was reduced from 0.45 g/l to 0.40 g/l and to 0.15 g/l in 1985. The increase in petrol consumption has offset these reductions to some extent but lead emissions from vehicles in 1994 are estimated to be 18% of those in 1980 Atmospheric concentrations are now well below the air quality limit values. The general reduction in airborne lead levels is expected to continue as cars using leaded petrol continue to be replaced by those with catalytic converters using un-leaded petrol.

Ozone is not included in the inventory because it is not emitted directly into the atmosphere. Ozone occurs as a result of chemical reactions taking place within the atmosphere, and is therefore known as a 'secondary pollutant'. The emission factors now being used in preparing the urban emission inventories are derived from different sources.

9 Meteorology and dispersion

The weather on all scales in space and time acts on the transport and dilution of air pollutants and plays different roles on the air quality that we measure and feel.

Meteorology specifies what happens to a plume (or puff) of air pollutants from the time it is emitted from its source until it is detected at some location (at a receptor). The motion of the air dilutes the air pollutants emitted into it. Given a known emission rate, it is possible to calculate how much dilution occurs as a function of meteorology or atmospheric conditions, and the resulting concentrations downwind of the source. This will require some basic knowledge of meteorology and its effects on the dispersion of air pollutants.

9.1 Wind

Local wind and temperature patterns play a significant role on the dilution of air pollution. The transport of pollutants emitted into the atmosphere is a function of the local (average) wind direction. The dilution of pollution is mainly a function of wind speed and turbulence. This wind is again influenced by:

- Topography, which channels the wind and modify the local wind directions,
- Vegetation and buildings, which influence on the surface friction and reduce wind speed at the surface,
- Net radiation and radiation balance, which influence on the atmospheric stability, and thus on the vertical wind profile,
- Local and mesoscale sources of heating and cooling setting up thermally driven local winds.

All these factors interact to change the dispersal conditions of the atmosphere.

The transport of the emitted air pollution is directed along the trajectory of the air parcel in which the pollutants were emitted. The trajectory is a function of wind direction and wind speed in the wind field. The dilution of pollutants is a function of the atmosphere’s turbulent conditions, which are presented by a 3-dimensional variation in wind direction and wind speed. Turbulence is usually defined by fluctuation of the wind with spatial dimensions less than the pollutant plume.

The variation of wind on all scales is the most important factor deciding the air pollution concentration at a receptor location. The wind observed at a certain receptor is the sum of several effects:

- large scale wind patterns (geostrophic)
- friction (roughness change)
- thermally driven local winds
- radiation balance
- topographical features (deformation, channelling ...)

9.1.1 Large scale wind patterns

Wind is a result of equilibrium produced by pressure, Coriolis and friction forces. Weather maps show regions of high and low pressure and also denote wind direction and wind speed. The pressure forces are caused directly by the existence of high and low pressure regions in the atmosphere. In the Northern Hemisphere the air blows counter clockwise around low pressure centres while in the Southern Hemisphere the air blows clockwise.

High-pressure regions are called anticyclones and these are often the source of temperature inversions. An inversion limits the atmosphere’s potentiality for dilution of pollutant emissions.

9.1.2 Terrain induced air flow

During the diurnal circulation in mountainous regions, three-dimensional circulation can form within and just above the valleys. Complex cross-valley-axis flow (anabatic/katabatic slope winds), and along valley-axis-flow (mountain/valley winds), may be combined to three-dimensional mountainous circulation.

9.1.3 Mountain and valley winds

During the night, radiative cooling of the mountainsides cool the air adjacent to the surfaces, resulting in cold down slope or katabatic winds. These winds are normally very shallow (2 to 20 m), and the normal velocities are within the order of 1 to 2 m/s.

Above the valley floor drainage flow is a gentle return circulation of upward moving air that diverges toward the ridges. The chilled and heavy air flows into the valley and collects as a cold pool. Although some of the cold air flows down the valley axis, some can remain in the valley depending on the topography. The resulting pool is often stable stratified throughout its depth, and is sometimes called a valley inversion. The potential temperature profile indicates the shallow inversion layer that started to build up in the valley bottom during the night. The radiative cooling of the ground continued throughout the night creating a deep cold pool throughout the valley. Pollutants emitted into this inversion can build to high concentrations because of very slow dispersion in the vertical, and can be hazardous to people, animals, and plant life on the slopes.

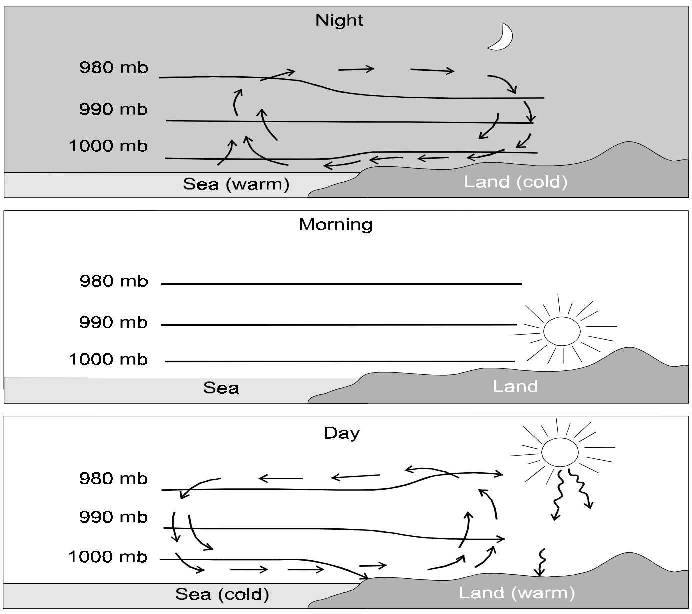
During the sunny hours after sunrise, the incoming solar radiation will warm the mountain/valley sides and the air in contact with it faster than the air at some distance from the slope. This differential heating sets up a circulation, which is akin to the sea breeze and is called the anabatic winds. Because of this instability in the lower layers of air set up by the differential heating, the warm air will stream toward and up the valley sides.

9.1.4 Drainage winds

At night, the cold winds flowing down the valley onto the plains are known as mountain winds or drainage winds. Depths range from 10 to 400 m, depending on the size and flow constrictions of the valley. Velocities of 1-5 m/s have been observed and these winds are occasionally intermittent or surging. The return gentle circulation of warmer air aloft is called the anti-mountain wind, with velocities of about half of the mountain wind, and depth of about twice as much.

9.1.5 Sea and land breeze

The large heat capacity of oceans and lakes reduces water-surface temperature change to near-zero values during a diurnal cycle. The land surface, however, warms and cools more dramatically because the small molecular conductivity and heat capacity in soils prevents the diurnal temperature signal from propagating rapidly away from the surface. As a result, the land is warmer than water during the day, and cooler at night. This situation causes sea breezes.

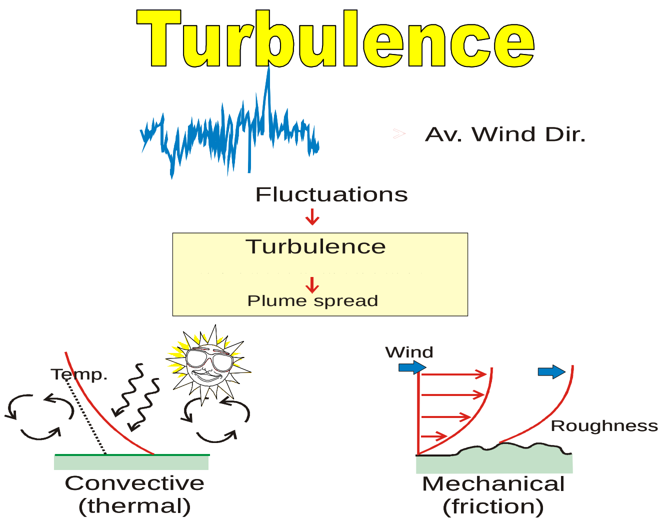


The general feature is that during the morning there is little difference in temperature between land and sea. During mid-morning, however, air begins to rise over the warm land near the shoreline as a result of the solar heating from the sun, and cooler air from the water flows in to replace it. A return circulation (the anti-sea-breeze) aloft brings the warmer air back out to the sea where it descends toward the sea surface to close the circulation. The depth of the sea breeze have been observed to be on the order of 100 to 500 m, and the total circulation depth including the return circulation can range from 500 m to 2000 m.

At night, land surfaces usually cool faster than the neighbouring water bodies, reversing the temperature gradient that was present during the day. The result is a land breeze; cold air from land flows out to sea at low levels, warms, rises and returns aloft towards land (anti-land-breeze) where it eventually descends to close the circulation.

9.2 Turbulence

The atmosphere can disperse gases and particulate matter rapidly because it is turbulent. Turbulent flow can be defined as having the ability to disperse embedded gases and particles at a rapid rate. Turbulence is the primary process by which momentum, heat, and moisture are transported into the atmosphere from the surface of the earth and then mixed in time and space.



Turbulence can be visualised as consisting of irregular swirls of motion called eddies. Usually turbulence consists of many different size eddies superimposed on each other. Thus, a continuous hierarchy exists from the largest down to the smallest eddies, with molecular diffusion occupying the bottom of the scale.

The effect of eddy motion is very important in diluting concentrations of pollutants. An air parcel that is displaced from one level in the atmosphere to another can carry both momentum and thermal energy with it. Obviously it will also carry the pollution emitted into the air parcel. Hence, the turbulent motions in both the horizontal and vertical directions will diffuse smoke and pollution.

Atmospheric turbulence depends in general on the magnitude of three factors: mechanical effects or the roughness of the ground, horizontal and vertical wind shear, and thermal instability. These factors are described separately in the following chapters.

9.2.1 Mechanical induced turbulence

Mechanical induced turbulence is caused by wind flow over uneven and rough surfaces. Turbulence is generated by mechanical shear forces at a rate proportional to $(\partial u/\partial z)^2$ (the wind speed profile). The wind profile gradient is dependent upon the surface roughness and the stability of the atmosphere. The velocity profile can be described using the power law:

$$\overline{U}_z = \overline{U}_0 \left(\frac{z}{z_0} \right)^m$$

where m varies between 0.12 and 0.50, depending on the atmospheric conditions.

9.2.2 Thermally induced turbulence

Convection or thermally induced turbulence is defined as predominantly vertical atmospheric motion resulting in vertical transport and mixing of atmospheric properties. Convective eddies or turbulence arise from hydrostatic instability as the result of surface heating (i.e. solar heating of the ground during sunny days causes thermals of warmer air to rise). These eddies are largest and occurs at a lower frequency than eddies produced by mechanical turbulence. Note that convective turbulence, unlike mechanical turbulence, is indirectly related to wind shear and strongly related to stability

9.3 Atmospheric stability

In its simplest terms, the stability of the atmosphere is its tendency to resist or enhance vertical motion, or alternatively to suppress or augment existing turbulence. Stability is related to both wind shear and temperature structure in the vertical, but it is generally the latter, which is used as an indicator of the condition.

The atmospheric stability, or the atmospheric dispersion conditions, can be classified as unstable (U), neutral (N) or stable (S). A short description of the three individual classes of atmospheric stability is given below.

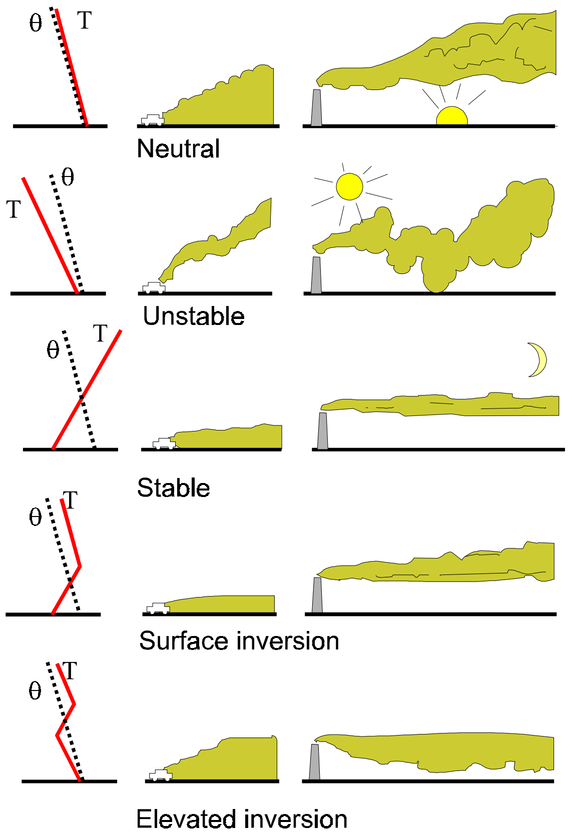


Figure 9.1: Schematic presentation of the atmospheric stability and the corresponding dilution of air pollutants above ground level.

- Neutral atmospheric stability (N) occurs at moderate to high wind speeds that are usually connected to overcast skies. High wind speeds and good mechanical turbulence/mixing result in good horizontal and vertical mixing of the smoke plume.

- Unstable atmospheric stability (U) is common on days with strong solar heating and low wind speed, or when cold air is being transported over a much warmer surface. The sun warms the underlying surface and vertical turbulent eddies are set up causing vertical dispersion of the smoke plume. For emissions at ground level or just above ground level, the concentrations will dissolve quickly. For stack emissions, elevated concentrations may occur at the ground because of the turbulent motion of the lowest level of air.

- Stable stratified atmosphere (Ls, S) is usually confined to clear nights and winter situations with cooling of the ground and the lower layers of air. In a stable stratified atmosphere the temperature increase with height, and hence, the vertical dispersion is poor. In situations when relatively warm air from the sea is transported over land, the lower level of air will be stable stratified. This result in poor dispersion of the smoke plumes both horizontally and vertically. For ground level sources this situation is critical because of poor vertical dilution and hence, enhanced ground level concentrations of pollution. For stack emissions, poor vertical dilution result in high-level pollution concentrations being transported far before it touches ground.

10 Dispersion models

Numerical and statistical models are being used in air pollution studies of various content and complexity. The models can roughly be divided into two main types:

1. Source oriented models
2. Receptor models

Receptor models use measured concentrations of various air pollutants over long time periods and can by statistical analyses identify source impact and the different sources contribution to the concentration measured at specific receptor points.

The source oriented models combine information about sources (emission inventories), meteorology as well as area characteristics, topography, surface roughness etc. to estimate concentration distributions. In this Chapter we will only discuss the source oriented models, as these are the only ones that adequately can be used for planning purposes. Receptor models can mainly be used for explaining measured concentrations, and is useful in such cases.

In the modern multi compartment environmental information system (like ENSIS/AirQUIS) numerical air quality dispersion models are essential parts of the total system. These models are to be used for explanatory purposes and for planning and forecasting purposes.

10.1 Different types of models

The different models may roughly be divided into the following categories:

- Gaussian plume models
- Numerical models
- Trajectory models (puff, segment, etc.)
- Box models
- Statistical models

The models may also be characterised according to the investigated pollutant

- inert passive gas,
- gases influenced by physical processes (deposition, fall-out)
- heavy gas,
- gases subjected to chemical reactions in the atmosphere.

The description of models below is, however, strictly limited to air pollution dispersion estimates and examples are given for various air quality models available. Different types of dispersion models have been developed and applied to estimate the ambient impact of air pollution emissions from point- line and area sources.

The selection of models to be used in a specific case is dependent upon the spatial and temporal scales, complexity of source configurations and chemistry, topographical features, climate and instationarity/inhomogeneity in the meteorological conditions of the area. It is advisable to consult experts in this process.

A variety of different models are available on the market today. However, one should note that it may be a significant step from obtaining a model to actually having an operable modelling tool for a specific area and application.

The following examples of different types of models available are taken from the air pollution surveillance programmes. They range from single quasi-stationary Gaussian type single source models based upon analytical solutions of the mass balance equations, to advanced numerical models, which require large computers.

10.1.1 Single source Gausssian type models

The simplest models can be used on personal computers for impact assessment. These models can estimate 1 h average concentration distributions downwind from ground level, diffusive and elevated single sources. (Sivertsen 1980, Bøhler 1987)

Gaussian type models are based on Gaussian (normal) probability distribution of the concentration (particle density) in both the vertical and horizontal direction perpendicular to the plume centreline. These models represent simple analytical solutions to the continuity equation which require homogenous and steady state conditions. The model concept is presented below

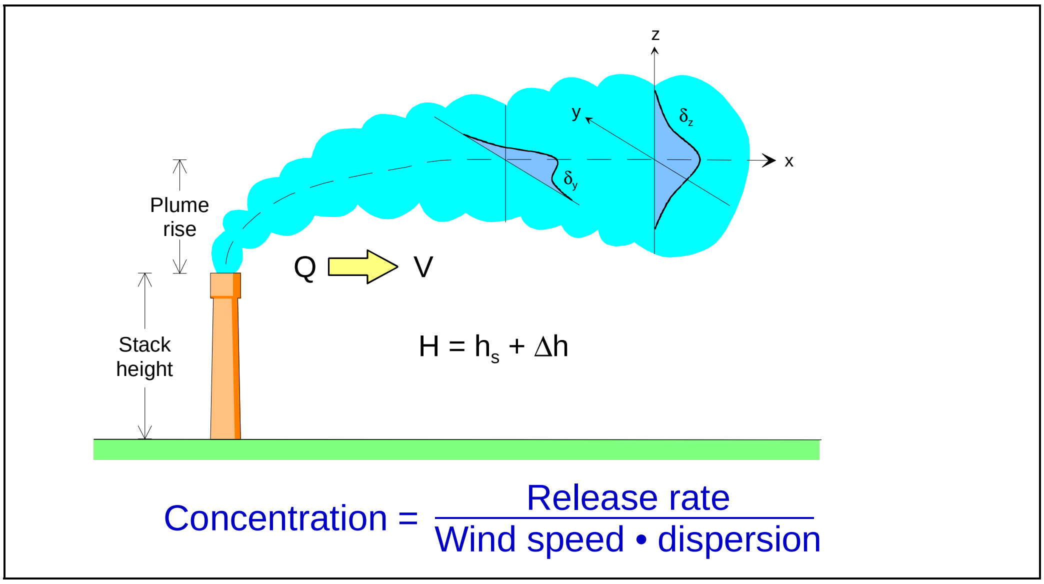


Table 10.1: The concept of the Gaussian plume model.

Gaussian type dispersion models are the most commonly applied models in practical use to day. The equation for calculating the concentration (C) at ground level, assuming total reflection of the plume at the surface, can be written:

$$C = Q\left[\exp\left(-H^2/2\sigma_z^2\right)\cdot\left(-y^2/2\sigma_y^2\right)\right]/\left(\pi\sigma_y\sigma_z\cdot u\right)$$

where Q = release rate (µg/s)

H = effective plume height $(h_s + dh)$

σ_y, σ_z = dispersion parameters (m)

The co-ordinate y refers to horizontal direction perpendicular to the plume axis, and z is the height above the ground. The ground is assumed to be flat and uniform.

The parameters σ_y and σ_z are the standard deviations of the concentration distribution in y and z directions, respectively. The parameters are usually referred to as the diffusion parameters. The values σ_y and σ_z are functions of the turbulent state of the atmosphere, which again is a function of the mechanical induced turbulence (wind shear, wind profile) and the convective turbulence (temperature profile).

10.1.2 Multiple source Gaussian models

One step up represents the short-term model for estimating 1 h average concentration distributions for emissions from multiple source industrial complexes (Bøhler 1987). This includes the multiple source Gaussian type models for estimating short term or long term integrated concentrations in a gridded co-ordinate system. Two different type of such models have been developed at NILU; CONDEP for monthly, seasonal and annual average concentration distribution estimates (Bøhler 1987) and KILDER which is a flexible emission inventory linked to multiple source Gaussian type dispersion models for line, area and point sources. (Gram 1996).

The user to match the specific problem specifies the grid system used by the models and the area considered. The resolution, grid spacing and total area can easily be modified and changed depending upon the specific needs.

These models need as input data some background information on;

- source characteristics and emission data,
- area characteristics (surface roughness, topography etc.),
- measurement data (measurement type, heights etc.),
- meteorological data (wind, stability, mixing height, temperatures etc.),
- dispersion coefficients (type to be used and parameters),
- dry and wet removal coefficients,
- location of receptor points (distances or grid specifications).

All the NILU models have been well documented and are being used for planning purposes and for impact assessments both nationally and internationally.

10.1.3 Traffic models

Small scale models are also available for estimating the air pollution load from traffic in street canyons and along roads. A commercially available model, ROADAIR (Larssen and Torp, 1993), estimates emissions, concentrations and exposure along the road system based upon traffic data. These input data may originate from traffic models or from traffic density data and on-line traffic counting.

The ROADAIR model calculates:

- Emissions of CO, NO_x and CO_2 from the traffic on each road link,
- concentrations of CO, NO_2 and PM_{10} at chosen distance from the road curb for each road link,
- road dust deposition (g/m^2 month) along each road link,
- population exposure to CO, NO_2 and PM_{10} ,
- nuisance from air pollution experienced by persons in their residence.

10.1.4 Numerical models

On a spatial scale from about 1 to 100 km there are several types of numerical models available; both Lagrangian type and Eulerian type models. The Lagrangian type models follow puffs of air pollutants estimating in each puff the turbulent diffusion, chemical reactions and deposition processes. The turbulence description and the diffusion processes may be treated in different ways.

One example is the INPUFF model (Knudsen and Hellevik, 1992) which is based upon Gaussian concentration distributions in the puff. This model also includes chemical and physical reactions and processes. Another model of this type is the Danish operational puff diffusion model RIMPUFF (Mikkelsen et al., 1987). This model was developed by Risø National Laboratory to provide risk and safety assessment in connection with e.g. nuclear installations.

10.1.5 The EPISODE model

One example of a Eulerian type numerical dispersion model is the EPISODE model developed by Grønskei et al. (1993). This is a time-dependent finite difference model normally operating in three vertical levels, combined with a puff trajectory model to account for subgrid effects close to individual sources. When the size of the puffs reaches the horizontal and vertical grid size the transport and dispersion is treated as a numerical box model. The mass of pollutants is then added to the average value for that grid element. The model can thus treat point sources, area/volume sources and line sources. The wind field used as input to the model may be homogeneous or inhomogeneous for each time step dependent upon the meteorological input data available.

The EPISODE model has been tested for a variety of different meteorological and emission conditions. (Larssen et.al. 1994)

10.2 Model applications

For further information on the use of models Hanna et al. (1982) give a good overview of the topic. One important issue when using dispersion models is to obtain adequate meteorological input data. Meteorological pre-processors have been developed during the last few years to handle this problem. (Paumier et al., 1985 and Bøhler et al., 1995). These pre-processors can estimate meteorological dispersion and the basic meteorological variables of interest for diffusion modelling based upon the current concepts regarding the structure of an idealised boundary layer. (Gryning et al., 1987). Methods are also provided for estimating the vertical profiles of wind velocity, temperature and the variances of the vertical and lateral wind velocity fluctuations.

Air quality dispersion models have been and are being used for several purposes. Some of the most important areas in which models are of greatest importance are in

1. siting studies,
2. for environmental planning purposes,
3. environmental impact assessment reporting.

A more detailed list of possible uses of dispersion models may contain

- calculation of stack heights for single sources,
- impact assessment from large point sources,
- estimate results of emission controls,
- accidental release impact,
- deposition of aerosols and gases to vegetation,
- odour evaluation,
- estimate photochemical oxidant potential,
- impact of distant sources,
- land-use planning,
- traffic planning,
- planning of measurement programmes,
- analyses of measurement data,
- forecasting of episodes,
- environmental impact assessment,
- implementation plans.

Operational dispersion models contain the type of input data that has been described earlier in this chapter:

- Emission data,
- meteorology (wind, turbulence, temperature),
- chemical reaction mechanisms,
- deposition mechanisms.

The input to these models may come from a monitoring programme or be taken from historical data records or pre-estimated variables. The figure below indicates the procedures of an operational model.

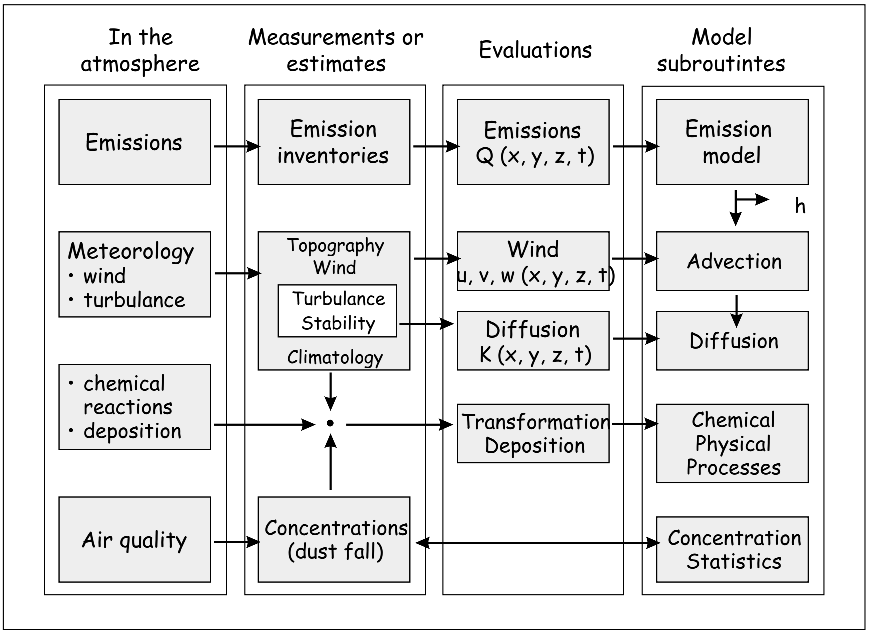


Figure 10.1: The procedure of an operational dispersion model used in practical applications.

A dispersion model is often more useful than a measurement programme. At least together with measured air quality data the model is superior compared to the single point measurement data only. (Slørdal and Walker, 1997).

The type of model to be utilised for a specific application will be dependent upon several factors such as:

- Accuracy
- Available computer capacity
- Economic resources
- Source types (chemical compounds)
- Point source/area source
- Continuous or puff-release
- Terrain (type, complexity, surface)
- Scale (time and space)
- Averaging time for estimated concentrations

A model produces a complete picture of the concentration distribution for an area. A source oriented model can calculate the contribution, and evaluate the importance, of each source to the total picture. Models can also be used to evaluate the representativity of measured data.

11 Air quality – the air we breathe

The air that we breathe consists of a number of naturally occurring and man-made chemical compounds. The polluted atmosphere is generally associated with man's industrial and domestic activities. However, natural processes also emit many of the major gaseous pollutants. On a worldwide basis, the total mass of trace gases emitted by nature may in many cases exceed those emitted by human activities by several orders of magnitude.

Nonetheless, human activities do adversely affect the air quality and the air we breathe, particularly in urban areas and close to large emission sources.

Table 11.1: Typical trace gas concentrations (ppm) in clean and in polluted air.

Compound	Clean air	Polluted air
CO_2	320	400
CO	0,1	40-70
CH_4	1,5	2,5
N_2O	0,25	?
NO_2	0,001	0,1-0,5
O_3	0,02	0,2-0,5
SO_2	0,0002	0,1-0,5
NH_3	0,01	0,02

Air pollution comes from many different sources as we have seen above:
- stationary sources such as factories,
- power plants,
- smelters and different types of industries,
- smaller sources such as dry cleaners and degreasing operations,
- mobile sources such as cars, buses, planes, trucks, and trains,
- and naturally occurring sources such as windblown dust, and volcanic eruptions.

All of these sources contribute to air pollution. Air Quality can be affected in many ways by the pollution emitted from these sources. These pollution sources can also emit a wide variety of pollutants, which have been classified as the six principal pollutants (or criteria pollutants as the US EPA also defines them).

The six criteria pollutants defined by US EPA are:

- Carbon Monoxide (CO)
- Lead (Pb)
- Nitrogen Dioxide (NO_2)
- Ground-Level Ozone (O_3)
- Particulate Matter (PM_{10})
- Sulphur Dioxide (SO_2)

These pollutants are normally monitored by national and international organisations. Environmental Laws, such as the US EPA Clean Air Act and the European Air Quality Framework Directives provides the principal framework for national, state, and local efforts to protect air quality.

11.1 Air quality standards and limit values

11.1.1 WHO air quality guidelines

The World Health Organisation (WHO) has issued air quality standards and guideline values. The 1999 WHO air quality guidelines (Air quality guidelines for Europe) provide a basis for protecting public health from adverse effects of environmental pollutants, and for eliminating or reducing to a minimum, contaminants that are known or likely to be hazardous to human health and well-being.

Air quality guidelines provide background information and guidance to governments in making risk management decisions, particularly in setting standards. They also assist governments to carry out local control measures in the framework of air quality management. Air quality guideline values are levels of air pollution below which lifetime exposure or exposure for a given average time does not constitute a significant health risk; short-term excess do not mean that adverse effects automatically occur; however the risk of such effects increases.

Table 11.2: WHO 1996 Air Quality Guidelines for Europe

	Averaging period	**Concentration (µg/m^3)**
Sulphur dioxide: health	10 minutes 24 hours one year	500 125 50
Sulphur dioxide: ecotoxic effects	annual and winter mean	10 - 30 depending on type of vegetation
Nitrogen dioxide: health	1 hour one year	200 40
Nitrogen dioxide and nitric oxide: ecotoxic effects	one year	30
PM_{10}	24 hours one year	dose/response dose/response
Lead	one year	0.5

Also other international bodies like the European Union are presenting air quality Directives and standards. These are often the basis for standards developed by national authorities like the US EPA and many others.

11.1.2 Air Quality Guidelines for Europe

The major goals for the establishment of guidelines for Europe has been to provide a high level of protection for public health throughout the European Union, and to set for the first time ambient air quality limit values designed to protect the environment.

The new limit values are based on the revised Air Quality Guidelines for Europe adopted by the World Health Organisation. Some main elements of the proposal are:

- Health-based limit values for sulphur dioxide, lead and particulate matter to be met by 2005,
- Health-based limit values for nitrogen dioxide
- A tighter set of limit values for particulate matter to be met by 2010;

- Limit values to protect the rural environment against the effects of sulphur dioxide and oxides of nitrogen;
- Details of how levels of the pollutants should be assessed throughout the European Union; and a requirement that up to date information on all four pollutants should be easily available to the public.

For each of the four pollutants, the proposal sets out new air quality standards as well as the date by which these air quality standards must be achieved. A summary of the air quality standards is presented below.

Table 11.3: Limit values for sulphur dioxide (Europe).

	Averaging period	**Limit value**	**Date by which limit value is to be met**
1. hourly limit value for the protection of human health	1 hour	350µg/m^3 not to be exceeded more than 24 times per calendar year (1)	1 January 2005
2. daily limit value for the protection of human health	24 hours	125µg/m^3 not to be exceeded more than 3 times per calendar year	1 January 2005
3. limit value for the protection of ecosystems	calendar year and winter (1 October to 31 March)	20µg/m^3	Two years from entry into force of the Directive

(1) Designed to protect against exceedances of the WHO 1996 10 minute guideline to protect health

Table 11.4: Limit values for nitrogen dioxide and nitric oxide

	Averaging period	**Limit value**	**Date by which limit value is to be met**
1. hourly limit value for the protection of human health	1 hour	200µgm^{-3} NO_2 not to be exceeded more than 8 times per calendar year	1 January 2010
2. annual limit value for the protection of human health	calendar year	40µgm^{-3} NO_2	1 January 2010
3. annual limit value for the protection of vegetation	calendar year	30µgm^{-3} NO + NO_2	two years from entry into force of the Directive

Table 11.5: Limit values for PM_{10}.

	Averaging period	Limit value	Date by which limit value is to be met
Stage 1			
1. 24 hour limit value for the protection of human health	24 hours	50µgm^{-3} PM_{10} not to be exceeded more than 25 times per year	1 January 2005
2. annual limit value for the protection of human health	calendar year	30µgm^{-3} PM_{10}	1 January 2005
Stage 2			
1. 24 hour limit value for the protection of human health	24 hours	50µgm^{-3} PM_{10} not to be exceeded more than 7 times per year	1 January 2010
2. annual limit value for the protection of human health	calendar year	20µgm^{-3} PM_{10}	1 January 2010

Table 11.6: Limit value for lead.

	Averaging period	Limit value	Date by which limit value is to be met
1. annual limit value for the protection of human health	Calendar year	0.5µgm^{-3}	1 January 2005

In order to ensure that the standards are respected air quality must be monitored on a regular and systematic basis. The directive requires standard methods to be used for measuring pollution and also sets down minimum requirements concerning the design of the air quality monitoring networks (number and location of measuring stations etc).

11.1.3 The US clean Air act

Under the Clean Air Act, the Office of Air Quality Planning and Standards (OAQPS) is responsible for setting standards, also known as national ambient air quality standards (NAAQS), for pollutants which are considered harmful to people and the environment. OAQPS is also responsible for ensuring that these air quality standards are met, or attained (in co-operation with state, Tribal, and local governments) through national standards and strategies to control pollutant emissions from automobiles, factories, and other sources. EPA is also dedicated to monitoring the quality of the air we breathe.

The priority pollutants are:
Carbon Dioxide (CO_2); the principal greenhouse gas emitted as a result of human activity (e.g., burning of coal, oil, and natural gas). If inhaled in high concentrations, CO_2 can be toxic and can cause an increase in the breathing rate, unconsciousness, and other serious health problems.
Carbon Monoxide (CO); an odorless, colourless gas. After being inhaled, CO molecules can enter the bloodstream where they inhibit the delivery of oxygen throughout the body. Low High concentrations are found at idling in enclosed areas such as garages, poorly ventilated tunnels, and even along roadsides in heavy traffic.
Chlorofluorocarbons (CFCs); chemicals used in industry, refrigeration and air conditioning systems, and consumer products. When released into the air, CFCs rise into the stratosphere to reduce the stratospheric ozone layer (ozone-destroying chemicals).
Hazardous Air Pollutants (HAPS); chemicals that cause serious health and environmental effects. Health effects include cancer, birth defects, nervous system problems, and death due to accidental releases.
Lead; a highly toxic metal that produces a range of adverse health effects, particularly in young children. Lead has been phased out of gasoline, but is emitted from other sources such as smelters, manufacture of lead batteries, some ceramic ware and fixtures.
Nitrogen Oxides (NO_x); a major contributor to ozone (smog) and acid rain. NO_x reacts with volatile organic compounds (VOCs) to form smog. In high doses, smog can harm humans by causing breathing difficulty for asthmatics, coughs in children, and general illness of the respiratory system. NO_x are produced from burning fuels, including gasoline and coal.
Ozone (O_3) Ozone forms naturally and is beneficial in the stratosphere, where it filters harmful ultraviolet (UV) rays. However, ozone that is close to the ground can irritate the respiratory tract, cause chest pain and persistent cough, affect the ability to take a deep breath, and an increase susceptibility to lung infection. Ozone can also damage trees and plants and reduce visibility. Oxidation occurs readily during hot weather.
Particulate Matter (PM); Fine solids suspended in the air in the form of smoke, dust, and vapours, which can remain suspended for extended periods. In addition to reducing visibility and soiling clothing, microscopic particles from the air can be breathed in and lodged in lung tissue, causing increased respiratory disease and lung damage. PM_{10} is particulate matter smaller than 10 microns.
Sulfur Dioxide (SO_2). SO_2 is produced by burning coal and oil. Some industrial processes, such as paper production and metal smelting, produce SO_2. SO_2 is a major contributor to smog and acid rain. It can harm vegetation and metals and can cause lung problems, including breathing problems and permanent lung damage.
Volatile Organic Compounds (VOCs), Organic chemicals are the basic chemicals found in all living things and all products derived from living things. VOCs include gasoline; industrial chemicals, such as benzene; solvents, such as toluene and xylene; and perchloroethylene (the principal dry cleaning solvent). VOCs are released from burning fuel, such as gasoline, wood, coal, or natural gas, and from solvents, paints, glues, and other products used at home or work. Vehicle emissions are an important source of VOCs. Many VOCs are also HAPs

12 Presenting Air Quality data

12.1 Air pollution data

Standardised statistical analysis should be performed to assess air quality trends, changes in emissions or impact from specific types or groups of sources. The severity of the air pollution problem or the air quality should be specified relative to air quality guideline (AQG) or limit values, standards or pre defined levels of classification (e.g. good, moderate, unhealthy, hazardous)

The number of hours and days, or percentage of time when the air pollution concentrations have exceeded AQG values should be presented. This will also need minimum requirements of data base completeness. Long-term averages (annual or seasonal) should be presented relative to AQG. In the Norwegian surveillance programme the winter average values of SO_2 and NO_2 are presented on maps in percent of the national air quality guideline values.

Before undertaking statistical evaluations the data should be presented and validated based upon a form of time series. These data must be evaluated logically to correct for drift in instruments, and eliminate data that are identified to be including errors. It is also important that the data are checked with other relevant information.

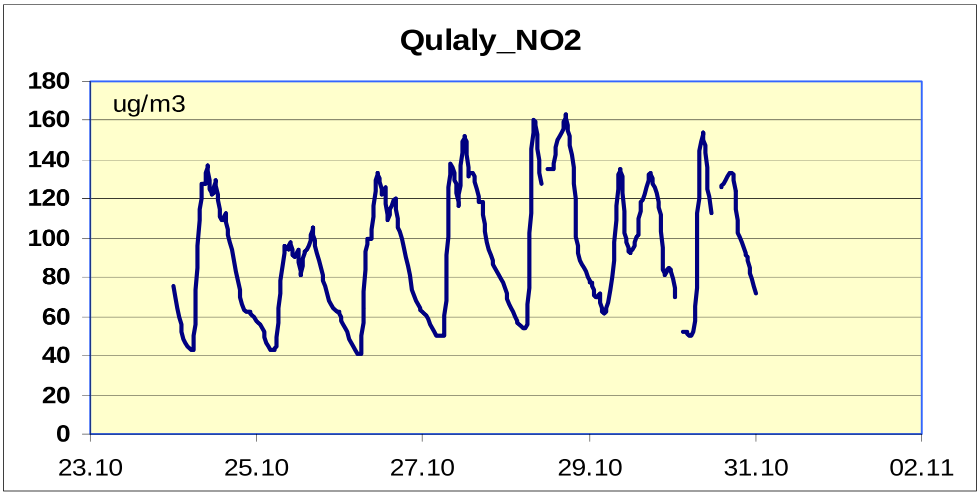


Figure 12.1: Time plot of NO_2 concentrations from Quolaly, Cairo, October 1999.(Sivertsen 1999)

After an analysis of the time plot the approved data can be handled in different ways statistically.

Air quality data are most often presented as

- time series,
- cumulative frequency distributions, where the frequency distribution should be referred to air quality standards,
- average concentration distributions at various monitoring sites as function of wind directions (Breuer diagrams or concentration "roses"),

- Scatter plots which can be used for interrelation between simultaneous air quality measurements, meteorological variables or other relevant data,
- average concentration as function of time of day.

The statistical programmes that are mentioned above are those most commonly used when evaluating measured data. The following chapters will present some examples on how the results can be presented, interpreted and used.

In addition to the measured data, statistical analysis of calculated concentrations can give additional information of the air pollution distribution for areas where measurement data are not available. This is usually done with the same type of statistical methods as mentioned above.

Special statistical analysis of comparison between measured and calculated parameters is available. Different interpolation routines are available for handling of measured data in a grid. One such method, which is frequently applied, is kriging - an interpolation of measured concentrations in a grid. Three kriging procedures are used: simple, ordinary and universal.

Some of these statistical procedures can easily be handled in a normal spreadsheet like EXCEL on a personal computer. But some need special programs. At NILU the AirQUIS system has been developed to take care of the databases and some of the statistics used for presentation of results.

Examples of concentration frequency distribution and the scatter plot are shown in the Figure below.

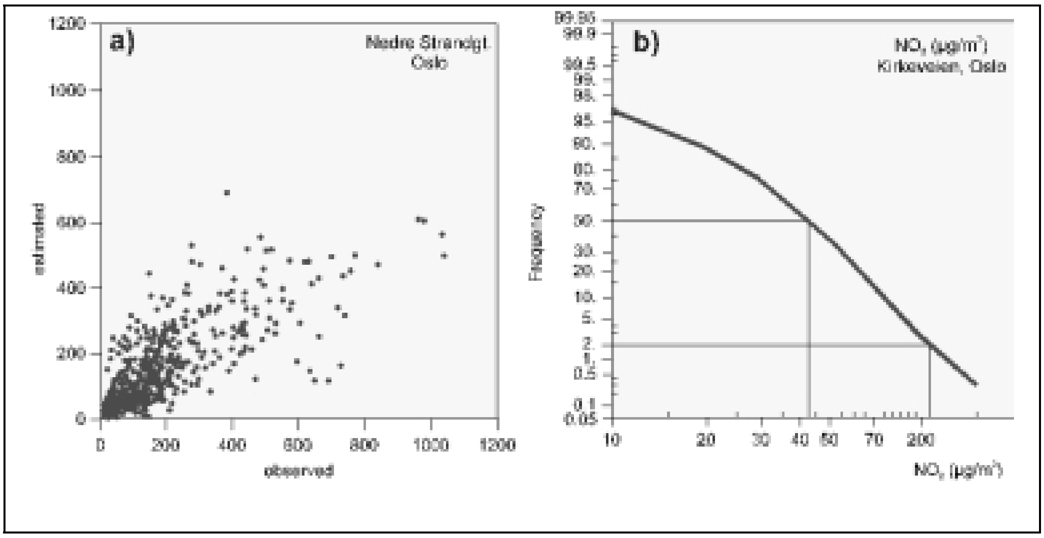


Figure 12.2: a) Scatter plot of estimated vs. observed data.
b) Cumulative frequency distribution of NO_2 concentrations.

The "concentration rose" is handy when investigating the impact of specific sources. These analyses will give the average concentration as a function of wind direction. An example of a "concentration rose" is shown in Figure 12.3.

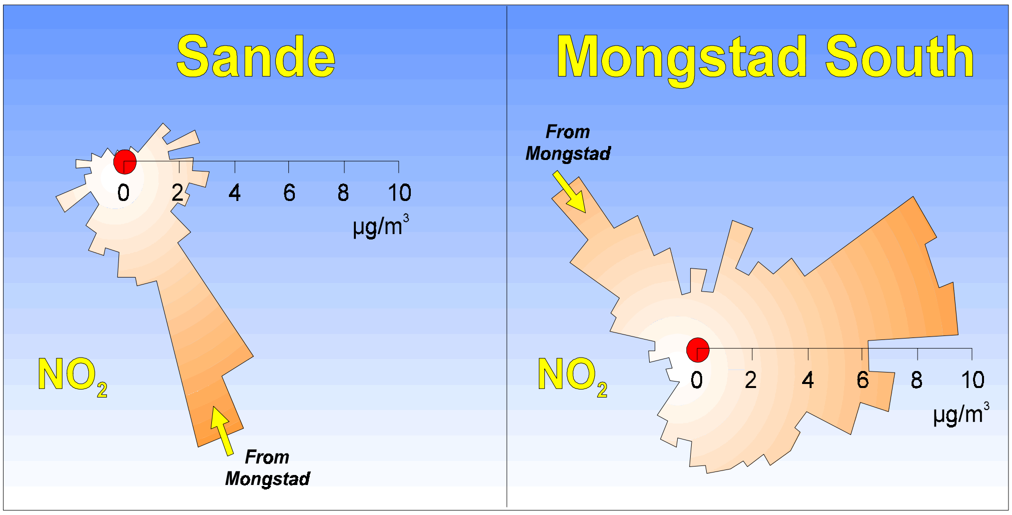


Figure 12.3: "Concentration rose", (Breuer diagram) established for two measurement sites at an oil refinery.

12.1.1 Meteorological data

To produce a Breuer diagram as presented above it is necessary to have access to meteorological data. Different procedures are available to examine the quality and representativeness of meteorological data.

The most commonly used methods are:

- Time series of selected meteorological variables,
- wind roses (wind direction frequency distribution),
- different types of frequency distributions,
- joint frequency distribution to establish the relationships between wind direction, wind speed, atmospheric stability and/or other variables,.
- different types of scatter plots to establish connections between different parameters collected at the same site or at different measurement sites,
- frequency distribution of stability or other meteorological data as a function of time of day and time of year (seasonal)

The presentation of measured meteorological data is of great importance to understand the physical properties of the local atmospheric conditions. A presentation of any kind of data is helpful to visualise to the user the most important features of the data and of the meteorology and climatology of the area. It is therefore important to choose a representative tool.

Results from wind measurements are usually presented in the form of frequency distributions. Frequency distributions are either presented as matrixes (wind speed versus wind direction) or as wind roses. Wind roses are used to visualise the frequency distribution of wind speed versus wind direction for different measurement stations

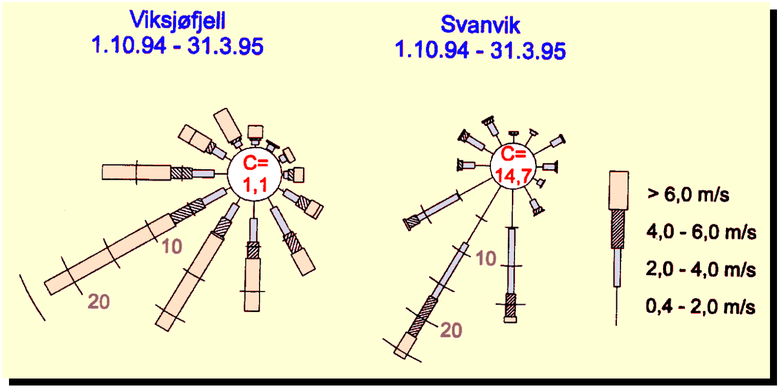


Figure 12.4: Wind roses for two different measurement sites; Viksjøfjell at a hill top (low friction), Svanvik in a valley (high surface roughness).

The thermal stability of the atmosphere is an important factor for the vertical dilution of air pollution. The stability is measured as the vertical temperature gradient of the atmosphere, and is also a measure of thermally induced turbulence. The turbulence is given by the small-scale fluctuations in the wind and is a measure for the dilution of air pollutants.

The atmospheric stability in this example is measured as the temperature difference (DT) between two levels at a tower and divided into 4 classes. Each of these 4 classes indicate the stability of the atmosphere and hence, the vertical dilution of air pollutants. The classes are:

Unstable	$\Delta T \leq -0.5\ ^{o}C$
Neutral	$-0.5\ ^{o}C < \Delta T \leq 0.0\ ^{o}C$
Light stable	$0.0\ ^{o}C < \Delta T \leq 0.5\ ^{o}C$
Stable	$0.5\ ^{o}C < \Delta T$

Neutral atmospheric stability (often characterised by strong winds and cloudy conditions) and unstable atmospheric stability usually results in good dispersion of air pollutants emitted into the atmosphere.

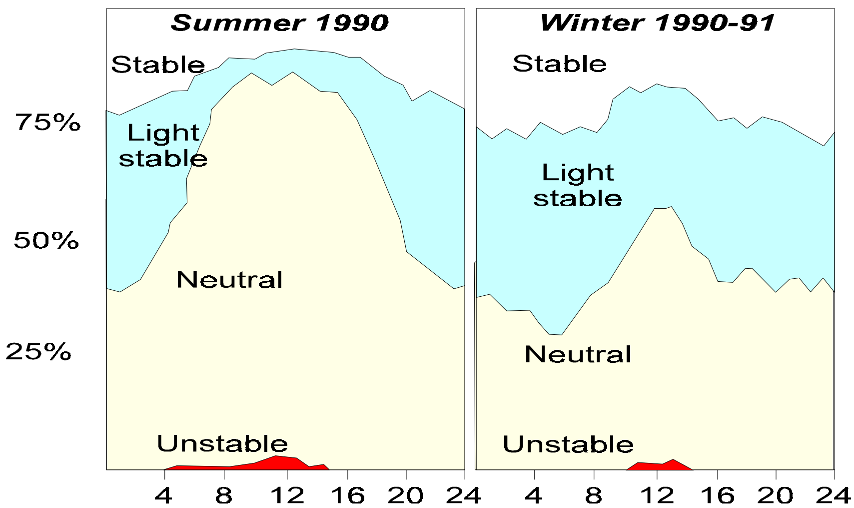


Figure 12.5: Frequency distribution of the four stability classes during the summer and winter season. (Sivertsen et al. 1991 and 1994).

During night-time and winter when there is a net outgoing radiation from the earth, the ground cools off rapidly resulting in cold air at the surface and a temperature increase with height (light stable /stable or inversions). An inversion layer is formed, and the dispersion of pollutants is suppressed.

12.1.2 Air quality statistics

To present trend analyses and air pollution variation over time, box plots have been developed to include average concentrations as well as percentiles and peak values.

The box plot represents a uniform method for pollutant specific (indicator) air quality trends reporting. It increases the comparability, it can present national or international wide trends and represents a standardised reporting procedure.

Boxplot diagrams have been generated for several combinations of regions, site categories and defined pollutant indicators. In cases of insufficient monitoring sites, or unavailability of data, the establishment of trend can be difficult.

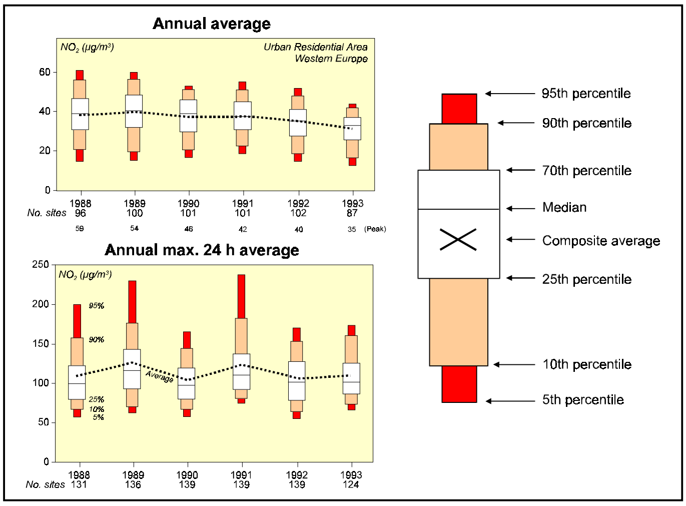


Figure 12.6: An OECD trend analysis presenting annual NO_2 data (average and max. 24 h average) from 1988 to 1993 from up to 139 measurement sites in Western Europe.

Bar charts can also be used to generate urban peak statistics. The bar charts show the highest, composite average and lowest values of annual maximum values for each defined indicator as segments of a bar. The bar chart may represent all recorded data by monitoring sites located in the city or in a country.

When a large number of measurement site data are available it is possible to present a spatial concentration distribution based upon statistical averaging procedures. Such a distribution is shown in for a weekly average SO_2-concentration distribution based upon measurements with passive samplers in Cairo.

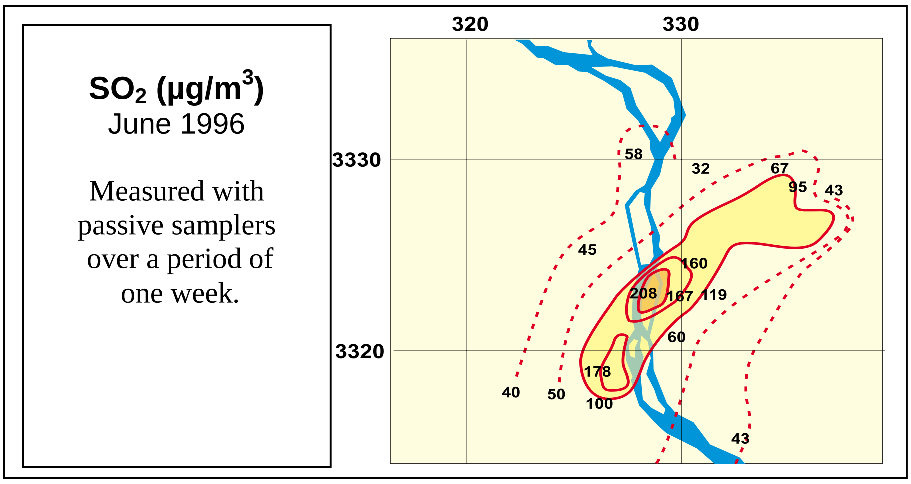


Figure 12.7: SO_2 concentration distribution for Cairo, based upon one week measurements with passive samplers, June 1996.

13 Information to the public

Citizens should have access to information concerning air quality. Air quality directives and standards sets out some basic rules concerning how and when the authorities should provide information on pollution episodes and on air pollution in general.

13.1 Web development

In the modern information society it has been necessary to establish good and easily accessible web solutions as part of international air pollution research programmes. This development has materialised in a broad expertise, giving a great variety of Internet solutions available to the users and to the public. NILU offers simple solutions, for example plots from monitors in the field, as well as fully Internet driven Air Quality Management Systems with Geographical Information System (GIS) interface.

Objectives may be identified by the different users, and include such as:

- Specific layout to meet well defined needs.
- Public section with selected tables/graphs and maps from received data supported with necessary background material and national as well as international links.
- Air quality measurements as well as Air Pollution Index values for all sites. Tables and graphs and some maps are used to present the data.
- Specific text blocks on public area where officials can edit information from their own computer. This is general text for comments on episodes etc.
- Tables and graphs to be kept as simple and straight forward as possible
- Concentration distribution plots on maps where appropriate. Potential for transformation to GIS based Internet system at later stage.

Functionality, menu selections and requirements will be developed in a co-operation between NILU experts and the users. Estimated air pollution concentrations, as well as indexes and forecasts should be made available on the net as soon as they are prepared.

The Internet pages are dynamic, using an Oracle database for storage of information and Cold Fusion as the technical software. A specially designed NILU WEB Desk is used for administrating all the websites/pages.

13.1.1 European development projects

NILU has participated in the European Web application development; IRENIE, which demonstrated and evaluated the telematics options for increasing the efficiency of flows of data and information at the local, national and international levels. The project also aimed at providing European-wide information services for the European Environment Agency and its customers such as the European Commission.

The layout, functions and type of graphs etc. will in many ways by quite similar, but with a own “look”, to the web site developed recently for the atmospheric research station at Spitsbergen: http://www.nilu.no/niluweb/services/zeppelin/

A development project, which may apply to air pollution forecast procedures, is the European research project "*Air Pollution Network based on-line information Exchange in Europe, (APNEE).* APNEE will build, install and evaluate a scalable and transposable information system on air quality within four major European urban agglomerations. The project will focus on the methods of presentation and dissemination of information through different communication channels.

Part of the information system will be an early warning/forecast module based on measurements and modelling results to inform local authorities and public about episode of high impact of air pollution.

The project will develop sophisticated interfaces for following access methods:

- PC’s or IP terminals at home, at the office or in public places enabling WEB access to the Geographical Information System (GIS) of APNEE through standard modem connection over the Internet
- Electronic information panels aside the roads in the city and sub-urban regions enabling access to text based information
- Mobile phone enabling**:**
- passive access through SMS or e-mail messages via subscription to an alert service
- active access through Wireless Application Protocol (WAP)
- active access through voice server after SMS alert message

This project is finalised in year 2001, so advanced methods for information to the public and authorities will be available at the end of the year.

14 Effects of air pollution

The damage caused by pollution in our atmosphere is difficult to assess, especially in terms of human or animal health, since pollution may provide a stress sufficient in itself to cause a reaction (ill health or death) or may be a 'catalyst' in such bodily deterioration.

It is thus time consuming to pinpoint the pollutants of most danger, since their effects may also be slow and/or cumulative and/or synergistic. Damage has been described in terms of the effects on inert material such as fabrics and building stone. The damage may perhaps be easier to quantify in terms of cleaning costs; and the damage to plants and commercial animals. Some uses of experimental animals may be justified if the scaling up to human body weight is feasible.

Many pollutants today are respirable and the biology of the respiratory tract, together with the body's defence and removal mechanisms have been outlined. Odours and reduced visibility have long been regarded as particularly unpleasant aspects of pollution. Only now, with the lowered ambient levels of smoke and

SO_2, can researchers make more thorough quantitative investigations into the possible or actual physically harmful effects of pollutants, whose qualitative nature has been appreciated for some time

14.1 Exposure estimates needed to evaluate the environmental impact

Many of the perceived health effects associated with urban air pollution rely on the tools of epidemiology and toxicology for their identification and quantification. Epidemiological studies still need further development, as they were not yet capable of quantifying the problems.

There were three main reasons for this;

- The air quality data used to provide an explanation for the epidemiological effects are usually flawed by the need to rely on insufficient, badly placed instrumentation.
- The effects observed occurred in a complex environment and increases in risk less than 1.5 could not really be relied upon.
- The concentration on external air quality as a cause of observed factors ignored the importance of indoor air. The elderly, a group specifically studied by epidemiologists, spend 85% of their life indoors. In other words dosage estimates were likely to be very inaccurate. The consequence of this was that indoor air quality needed more study, the validity of epidemiological studies could be improved by modelling the transport of air quality indicators, together with indoor/outdoor activity.

The human response has been examined in terms of individual and population response for the affected senses. Exposure estimates have been a key issue in obtaining the basic information on how much pollution is affecting the population. Legislative limits were introduced as threshold limit values, but it is recognised that different members of a population have their own personal threshold value for each pollutant.

Exposure must not be confused with concentration. Concentration is the amount of substance that exists in the air, while exposure is the product of concentration and time. Since we move constantly, exposure is also the sum of all of the incremental products of concentration times time.

Exposure estimates can be based upon subjective tools such as interviews, questionnaires or diaries. However, these may be bias in that people may lie, underestimate or be unaware of certain elements. The objective approach consists of following a person in order to determine his/her exposure. While more reliable, this method is far more costly and lengthy. Both of the aforementioned methods constitute the basis for exposure distribution charts, which indicate to what extent concentrations are spread throughout the population. Levels can vary according to work conditions, living conditions, etc. As in other scientific areas, we speak in terms of medians, percentiles, average values, etc.

Accurate estimates of exposure to ambient air pollutants are required to answer questions related to air quality guidelines and legislation, and as inputs to environmental assessments related to human health. Studies performed in Oslo

Norway have demonstrated the effects of air pollution from combinations of exposure models and self reported health symptoms. (Clench Aas et.al. 1996)

The concept of microenvironments have been introduced as part of the exposure concept. Today models exists that can estimate the concentrations hour by hour in a selected number of microenvironments, where people stay and move. Diaries or questionnaires can be used together with these models to estimate the exposure to individuals or to the total population in a given area.

14.2 Health impact

Sulphur dioxide's main effect is on respiratory function. High concentrations can affect breathing very quickly. Asthmatics are especially sensitive. A recent study on pollution in European cities, financed by the Commission, also showed that when SO_2 levels increase daily hospital admissions and daily mortality rates are also higher.

Nitrogen dioxide has short-term effects on the respiratory system. Long-term exposure is associated with increased rates of respiratory infection in children.

Several recent studies on particulate matter, including a study financed by the European Commission, have found that there are more asthma attacks, more hospital admissions (especially for respiratory problems) and higher death rates from respiratory and cardiac diseases on days when levels of particles are high. The extent of the effect of these short-term changes in particle levels on life expectancy in particular is hard to interpret. But the results taken together show clearly the large potential impact of particulate matter on public health. Long-term studies suggest that chronic exposure to particles can shorten lifespan significantly.

The most important effects of ambient lead on health are reduced IQ in children and an increase in neonatal mortality owing to maternal exposure.

Air quality standards and guidelines have been established based upon air pollution impact also to the human health and well-being. The best available background material for evaluation of health impacts is the US- EPA criteria documents and the air quality guidelines for Europe (WHO, 1987 and 1995). The air quality guidelines are formulated to ensure that populations exposed to concentrations lower than the guideline values should not inflict harmful effects. In cases where the guideline for a pollutant is exceeded, the probability of harmful effects will increase.

14.3 Impact on the environment

Sulphur dioxide in the air can both cause direct damages to growing plants. Nitrogen dioxide acts together with nitric oxide to damage vegetation. These are also some of the main pollutants responsible for acidification. Lead deposited on the ground accumulates in the soil. It can directly damage soil micro-organisms and plant growth and enters the food chain of animals.

Sulphur dioxide is the most important pollutant in determining the rate of deterioration of a number of materials, including stonework. NO_2 and particles can also damage materials. The old buildings and monuments, which form a vital part of our cultural heritage, are particularly vulnerable.

Studies of plant damage and air pollution impact on plant growth have been performed for several individual air pollutants and for air pollution mixtures. In the discussion of specific air quality indicators considerations of recent scientific results on plant damage have been considered.

Also the consideration of **critical loads** should be taken into account. The critical load values is defined as a quantitative estimate of the exposure to one or more pollutants below which significant harmful effects on specified sensitive elements of the environment do not occur according to present knowledge. The critical level for a given area depends strongly upon geology, vegetation, climatology, and soil properties. It might thus be difficult to generalise. It is possible to extrapolate maps of critical levels and loads for the fresh water system, vegetation and crop.

14.4 Impact on building materials

The concern for our cultural heritage and for the general life time of buildings and constructions have increased during the last few years. Considerations for this part of our environment and for the cost of restoration and rebuilding, should be built into the air quality levels when considering air pollution indicators.

As for human health the impact is usually a result of mixtures of compounds included air pollution, climate, weathering, wind, humidity, temperature, erosion, freezing, etc.

Dose response relationships have been established for a few specific air pollutants. For SO_2 these data have been used in cost/ benefit analyses for sulphur-reduction measures linked to the use of fuel oil in Europe.

15 The Air Quality Management System

15.1 Air quality management

The basic concept for an Air Quality Management Strategy contains the following main components:

- Air Quality Assessment
- Environmental Damage Assessment
- Abatement Options Assessment
- Cost Benefit Analysis or Cost Effectiveness Analysis
- Abatement Measures
- Optimum Control Strategy

The effects of long-term emission changes, as a basis for formulating and evaluating reasonable air pollution abatement strategies has been a type of long term “forecasting”, where different type of models have been most extensively used. The AirQUIS models may be used to estimate concentration distributions and population exposure as input to trend and impact analyses.

A system for air quality management requires continuing activities on the urban scale in the following fields:

- Inventorying of air pollution activities and emissions
- Monitoring of air pollution and dispersion parameters
- Calculation of air pollution concentrations and exposure, by dispersion models
- Inventorying of population, materials and urban development
- Calculation of the effect of abatement/control measures
- Establishing/improving air pollution regulations.

For cases when the national or international air quality limit values are exceeded, we will often have to estimate the population exposure. Demographic data and population distributions will have top be available. The relative contributions from various source categories may also have to be estimated and discussed as a basis for air emission reduction measures.

15.2 Abatement strategies

As a typical application of the AirQUIS system, NILU has been requested by the World Bank and international authorities to use the models as a basis for evaluating scenarios for reducing the air pollution load. Scenarios for different reduction measures that may be implemented in the area have been developed locally. NILU supported the establishment of a Cost Benefit Analysis or Cost Effectiveness Analysis based on Damage Assessment, Air quality Assessment, and Abatement Options. (Larssen et al., 1996)

The elements in an abatement planning process are shown in the figure above. The Air Quality Assessment, Environmental Damage Assessment and Abatement Options Assessment provide input to the Cost Benefit or Cost Effectiveness Analysis, which is also based on established Air Quality Objectives (i.e. guidelines, standards) and Economic Objectives (i.e. reduction of damage costs). The final result of this analysis is Optimum Control Strategy.

15.3 Action plan

Based upon the monitoring system and the analyses and understanding of air quality monitoring data it has been possible to establish action plans that have been prioritised according to the most cost/effective actions. Through the work carried out in local working groups, a large number of proposed actions and measures has been listed, and categorised within the following categories:

- Improved fuel quality.
- Technology improvements.
- Fuel switching.
- Traffic management.
- Transport demand management.

Each of the proposed actions may be described regarding its effect (benefit), costs, policy instruments, time frame of instigation, and institutions responsible.

A selection of “obvious” technical measures for possible short-term introduction has been made, and cost-benefit analysis carried out for each measure separately.

15.4 Forecasts and early warning systems

Procedures and models have been developed for predicting air quality 24 to 48 hours into the future. There are basically two different approaches, based upon:

- statistical methods and
- numerical models.
- There are also combinations of these approaches.

Normally air pollution forecasts for short periods in time should be defined as a process that estimates the time and a value for a pollutant concentration based upon meteorological predictors. The objective of the prediction is to present the concentration level itself, and possibly compare it with some given limit values.

There is a difference between air pollution potential forecasting, which can be performed using statistical methods, and episode forecasting, which normally will have to take into account pollutant emission changes and variations. The first methods are based on weather-pollution interactions. Episode forecasting will normally be based on emission-dispersion interactions and will thus require numerical dispersion models.

15.4.1 Statistical forecast models

Different types of statistical “roll back” models have been applied to forecast the levels of air pollution in urban areas for the next day or two. These forecasts are normally based on historical data, which are used to establish statistical relationships between air pollution concentration measurements and meteorological data. (Sivertsen and Tønnesen 1989).

A “catalogue” of air pollution as a function of forecasted weather conditions has to be developed. The input to this statistical evaluation is normally real time forecasted wind patterns, locally observed winds, turbulence and atmospheric stability as well as air pollution concentrations in selected receptor points. The statistical properties of all these data, selected for a period of at least one year represent the basis for establishing these forecasts.

The simplest and less expensive type of statistical forecast models have been based upon the normal local weather prediction issued by the National Weather Services. A simple meteogram, or similar presentation of the weather forecast, represents the basis for linking local wind and turbulence data to the weather predictions. The local weather pattern is further on linked to concentrations of selected indicators observed in given receptor points in the urban area. The statistics generated this way is, however, normally only representative for the areas or sites where measurements were taken.

15.4.2 Automatic air pollution forecast based on numerical models

Numerical forecast models have been developed to combine estimated wind and turbulence with numerical dispersion models to forecast air quality into the next 24 or 48 hours. At NILU the forecasted wind fields have been used as input to the AirQUIS air pollution dispersion modelling system to estimate concentration distributions for the next 24 and 48 hours.

A direct interface between the weather prediction models, which estimates the wind and turbulence fields and the numerical air pollution dispersion models, has been developed. The NILU/ AirQUIS “Episode” dispersion models are initiated automatic and a pollution prediction for the next 24 and 48 hours is performed. The results may be produced and transferred to the web site.

Weather forecasts

The numerical weather forecast model HIRLAM50 with 50-km resolution has been used to estimate and forecast the weather conditions such as wind and turbulence for the next 24 hours. The 50 km scale winds may be scaled down to 10 km. The results from the HIRLAM 50 model with 50 km or 10-km resolution is then used as input to the MM5 model to produce a more detailed wind field. The procedure requires large computer capacities and is thus fairly cost consuming for routine and daily operations. (Berge et.al. 2000)

In Norway the forecast models are mainly operated during periods of expected high concentrations (“episodes”). They have been operated in Oslo since November 1999. In Bergen the testing has been continued throughout this winter and spring before the models are being made operational for presenting official forecasts. It that case when high air pollution exposures are forecasted measures and immediate actions may be taken.

15.5 The first on-line system in operation in Oslo

The local Health Authorities operate the air quality monitoring system in Oslo. Measurements are also supported from Road Authorities and from NILU. NILU has taken on responsibility for data quality control and has direct access to the collected data. The results are presented daily in the media and are published on Internet and Teletext. (Sivertsen and Bøhler, 2000)

In addition to presenting on line measurements of meteorology and air pollution, the system calculates the pollution concentration distribution and the public’s exposure to air pollution.

For the city of Oslo some acute measures or immediate actions were implemented since 1 November 1999 to reduce the level of suspended dust (measured as PM_{10}) along the main road system of Oslo. These actions are based upon exposure estimates, which means that the Health Authorities have to have an operative dispersion model linked to population distribution information. This model system is part of AirQUIS, which may update the complete concentration field as well as the exposure numbers every hour during periods of special interest.

A second requirement stated by the authorities was that:

"Actions are to be taken if more than 20 000 persons in Oslo experience PM_{10} concentration in excess of 100 µg/m^3. The actions to be taken have to be forecasted about one day ahead of time."

For the winter 1999/2000 it was assumed that the following restriction would be tested:

- speed limitations (max 60 km/h during episodes),
- prevent between 0900 and 2100 hrs:
    - driving cars without catalytic equipment, or
    - cars registered before 1 January 1989.

These measures were also implemented to reduce NO_2 concentrations on days where the concentration forecast indicates that the NO_2 concentrations would exceed 200 µg/m^3.

A combination of the weather prediction model (HIRLAM) and the numerical dispersion models in AirQUIS, was assigned to produce the air pollution forecasts. The decision whether to start running the MM5 model had to be based on criteria given to the meteorologist on duty at the Norwegian Meteorological Institute.

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ABSTRACT
Understanding air pollution represents an introduction of the development of monitoring programmes, as well as the main elements of an air pollution modelling and planning system. The report was prepared for a Seminar held in Jeddah, Saudi Arabia and includes also examples of data presentations, interpretation and information dissimination.

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