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Assessment and Management of Urban Air Quality in Europe

European Environment Agency

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Preface

This report provides an overview of the state of air pollution in major European cities with populations in excess of half a million. Air pollution is a feature of life across Europe, where over 70% of the population live in urban agglomerations. Many air pollution studies have addressed issues at a global level, in particular in relation to climate change, and at regional level, with particular respect to transboundary delivery of acid rain from industrialised areas. However, it is increasingly recognised that population exposure to air pollutants is largely dependent on city-generated air pollution. Therefore, the detailed examination of air quality in European cities presented here is both relevant and timely.

In this report, each city is examined in terms of its potential for air pollution problems. This is partly related to the topography and climate of the city, which may predispose it to the build-up of pollutants at particular times of the year, leading to summer or winter smogs. The nature and amount of pollutant emission in a city depends on the population size, level of industrial activity, traffic density, and the mode and extent of domestic heating and air conditioning use. Thus, in some cities, the dependence on sulphur-rich fuels causes substantial risks of winter smogs. If the emission levels and topographic predisposition for smog-forming conditions are compared with known exceedances of mandatory and guideline health limits, estimates can then be provided of population exposure. From these, it can be seen that nearly all the cities under consideration in this report pose an air pollution health threat to at least some of their citizens; in some cases over two-thirds of the population may be exposed to unacceptable pollutant levels.

Examination of trends in reported data over the years shows that the issue is not static but developing on many fronts. For example, the removal of lead in petrol has greatly reduced the threat of lead toxicity in most cities, although in some an ageing vehicle fleet and the introduction only recently of lead-free petrol means that there is still some way to go. Many cities have reduced dependence on coal as a domestic fuel and have introduced high stacks for power generation plants; this has lead to a reduction in city levels of particulates and SO_2, although it has increased the risk of transboundary pollution. On the other hand, increasing vehicular emissions of NO_x and secondary vehicular pollutants, such as ozone, continue to cause growing concern in many cities.

The capability of Europe's cities to manage the air pollution situation is an essential requirement for its control. A unique feature of this report is the assessment, through questionnaires, of air quality management capability in terms of measurement capacity, assessment capacity, data availability, emission estimation, legislation and the implementation of control measures. The report's results show the considerable variations in management policy and highlight individual cities' strengths and weaknesses within the various components of management capability.

This review concludes that there is capacity for improvement in air pollution management in all of the investigated cities. The report identifies a number of needs which would assist this process – for example, greater harmonisation of measurement and reporting methods, and greater information delivery to populations exposed to health risks during peak air pollution periods. The European Environment Agency, who commissioned this report, are playing an active role in bringing countries and cities together in order to exchange information and discuss the way forward to providing healthy and sustainable cities into the next millennium. The concept of sustainable healthy cities was recognised at the Rio summit and, through Agenda 21, made a priority environmental issue for the future in both Europe and the developing world. It is hoped that by highlighting the European experience, this report will generate management ideas and options world-wide.

Acknowledgements

This report has been written by Dorothee Richter and W. Peter Williams of MARC. However, the report could not have been prepared without the immense help that was received from respondents, too numerous to name individually, from the participating cities. However, special mention is due to Darius Krochmal who helped co-ordinate the Polish city responses and provided much useful information on air quality in Polish cities. In addition, a great deal of data was provided by the European Topic Centre - Air Quality and particular thanks are due to Rob Sluyter and Hans Eeerens who offered unstinting assistance throughout. We are also grateful to European National Focal Points where they have provided information or contacts. At King's College, we should like to acknowledge the assistance of MARC staff, particularly Fiona Preston for secretarial and proof reading assistance and Roma Beaumont from the Geography Department for assistance in the production of maps. We are also grateful to the EEA for entrusting us with the project and, in particular, to Mr. D. Stanners and Mr. G. Kielland who have provided constructive advice and critical appraisal throughout.

Chapter 1

Introduction, Data and Information Sources

Over the last few decades the state of the global environment has become an issue of major concern. All three environmental media – air, water and land – have suffered pollution caused by human activity, and in addition, a wide variety of natural processes can influence environmental quality significantly. Although humans have always had an impact on their surroundings, the deterioration of the environment has drastically accelerated recently, due to rapid population growth and development. Problems have become especially apparent in densely populated areas, such as Europe, and in urban areas in particular. Since we have no choice but to breathe the air surrounding us, air quality is an important issue for the whole population. A variety of guidelines and standards, suggesting upper limits of pollutant concentrations in ambient air, have been developed to protect human health and the environment from adverse effects. Where these levels are breached, negative consequences must be expected, the extent of which depend on the level and the duration of exceedance.

Urban Air Quality – Importance of the Issue

Atmospheric pollution can be investigated on different spatial and temporal scales. On the macro-scale, global problems of importance are the depletion of the stratospheric ozone layer and global warming, which is caused by the emission and accumulation of greenhouse gases in the atmosphere. The meso-scale includes regional and

Evening skies over London

Old industries have a key role historically in air pollution

local air quality and pollution. On a regional scale, the transboundary transport of pollutants can be responsible for acid deposition or the formation of photochemical smog. Air quality on a local and urban scale is closely related to emissions arising from almost all human activities, and to local characteristics such as topography, climate and also economy. Aspects of air quality investigated on a micro-scale include studies on emissions from a single point source, indoor pollution from oil or wood burning stoves, or the dispersion of pollutants in a street canyon.

More than 70% of the European population, which will grow to about 523 million by the year 2000, live in urban areas (UNEP, 1993). They are often exposed to elevated levels of air pollutants, predominantly emitted from a variety of sources concentrated in the city; the most important of these are usually road traffic, domestic dwellings, industrial facilities and power generation plants. Besides the emissions generated within the city limits, transboundary transport of pollutants can cause elevated concentrations, but almost all urban agglomerations are net emitters. Thus cities are liable to have a detrimental effect on the air quality in surrounding areas, particularly downwind from the centre in the so-called city plume.

Many epidemiological investigations have demonstrated that the exposure of the population to air pollution causes adverse health effects, which can be divided into acute or chronic effects. The level of impact will depend on the duration and level of exposure. Recent studies have suggested that even pollution concentrations around and below levels generally considered safe according to current guidelines and standards might pose a risk to human health (Katsouyanni et al., 1995). Thus urban populations are likely to suffer from air pollution and certain groups of individuals such as children, asthmatics and elderly people will be particularly vulnerable. Furthermore, many pollutants affect the vegetation in and around the city as well as building materials and monuments, exacerbating the deterioration of structures and cultural heritage.

On several occasions episodes of poor air quality have caused high numbers of additional deaths, which have been directly related to the elevated concentrations of certain pollutants in the urban air. The best known tragic example is probably that of the so-called London pea-soup fogs, which occurred in December 1952 and were responsible for nearly 4,000 premature deaths. These Londoners were killed by breathing air containing extraordinarily high concentrations of black smoke and sulphur dioxide (SO_2) trapped over the city during a persistent temperature inversion, a weather condition where warm air is blanketed by a layer of cold air and where extremely little movement of air masses occurs; this leads to an accumulation of pollutants as there is no dispersion and dilution *(Box 5)*.

As will be described later in this report, the majority of cities investigated still have incidences of poor air quality where EU or WHO Air Quality Guidelines are exceeded for one or more air quality pollutants, and where large proportions of the urban community are exposed. For some pollutants, particularly those associated with traffic, levels are increasing in many cities and thus air pollution will continue to be a major health issue into the foreseeable future.

Air Quality in European Cities and Their Monitoring and Management Capabilities

The aim of this report on Urban Air Quality is to give a comprehensive overview of the situation in European cities. This will be achieved by reporting current concentrations of major pollutants and by considering the various factors which have an impact on air quality. Analysis of trends and predictions of future air quality, as well as an estimation of the impacts of air pollution, are other important aspects of this report. Additionally, the air quality monitoring and management capability of all major urban agglomerations in Europe is assessed on a city-by-city basis. To enable the formulation of recommendations on how to develop and improve management strategies, and thus air quality in the short and long term, the different components of monitoring and management capabilities are assessed.

The management of air quality is a complex task consisting of several elements which are:

- assessment of air quality including monitoring and appropriate usage of data,
- existence of a legislative framework allowing the control of emissions, and
- enforcement of such legislation in situations where air quality standards or objectives are not being achieved.

Air quality in major European cities, and their capabilities to assess and manage it, will be described and discussed in this report.

Ambient Air Pollutants

Chemical compounds, present in the atmosphere, are considered ambient air pollutants when they occur in unnaturally high concentrations and have the potential to cause harm to the environment. There is a very wide literature on air pollution and only a brief overview is provided here to set the scene for the report. Air contaminants, are often grouped according to their chemical nature, the levels at which they are present in ambient air, or their impacts. Although there are no universally adopted classification schemes, two groups have been identified by the OECD (OECD, 1995):

(i) Traditional air pollutants, which include sulphur dioxide (SO_2), nitrogen oxides (NO_x), carbon monoxide (CO), lead (Pb), particulate matter (PM), ozone (O_3) and volatile organic compounds (VOCs), and

(ii) Hazardous air pollutants (HAPs), forming five distinct categories, which are:

- metals and metalloids, e.g. cadmium (Cd), mercury (Hg) and arsenic (As),
- respirable mineral fibres, e.g. asbestos and glass microfibres,
- inorganic gases, e.g. fluorides, chlorine, cyanides and phosgene,
- non-halogenated organic compounds, e.g. aldehydes, aromatics and polycyclic aromatic hydrocarbons (PAHs), and
- halogenated organic compounds, e.g. vinyl chloride, chlorobenzenes and dioxins.

Some overlap between these two groups exists. Lead, for example, could also be classed with the metals as a hazardous air pollutant, and several VOCs such as benzene and 1,3-butadiene can be considered HAPs. The traditional air pollutants are

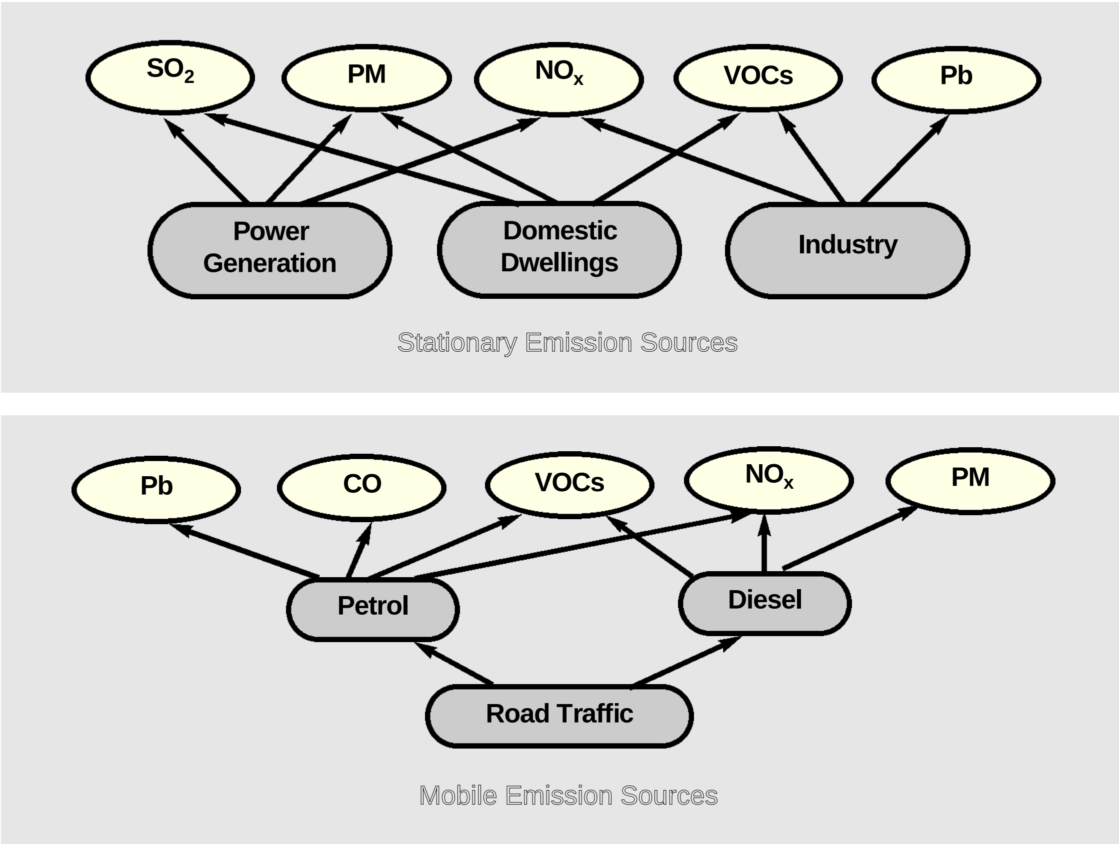


Figure 1.1
Traditional air pollutants and their major emission sources

ubiquitous and their impact on society and the environment is experienced throughout Europe. Thus monitoring efforts generally concentrate on these pollutants and available data are much more complete and up to date. Hazardous air pollutants are often only measured on a spatially and/or temporally restricted scale in monitoring surveys, for example near potential industrial emission sources.

The term particulate matter describes a very diverse mixture of pollutants, consisting of particles suspended in the atmosphere. These cover a wide range of sizes and chemical characteristics *(Chapter 4)*, including PAHs, acid aerosols and diesel particulates (WHO, 1995c). The major sources of the most common air pollutants are depicted in *Figure 1.1*.

Several of these primary emissions take part in chemical reactions in the atmosphere, the principal processes of secondary pollutant production are:

- the formation of ozone (O_3),
- the creation of secondary aerosols, and
- the oxidation of nitric oxide (NO) into nitrogen dioxide (NO_2).

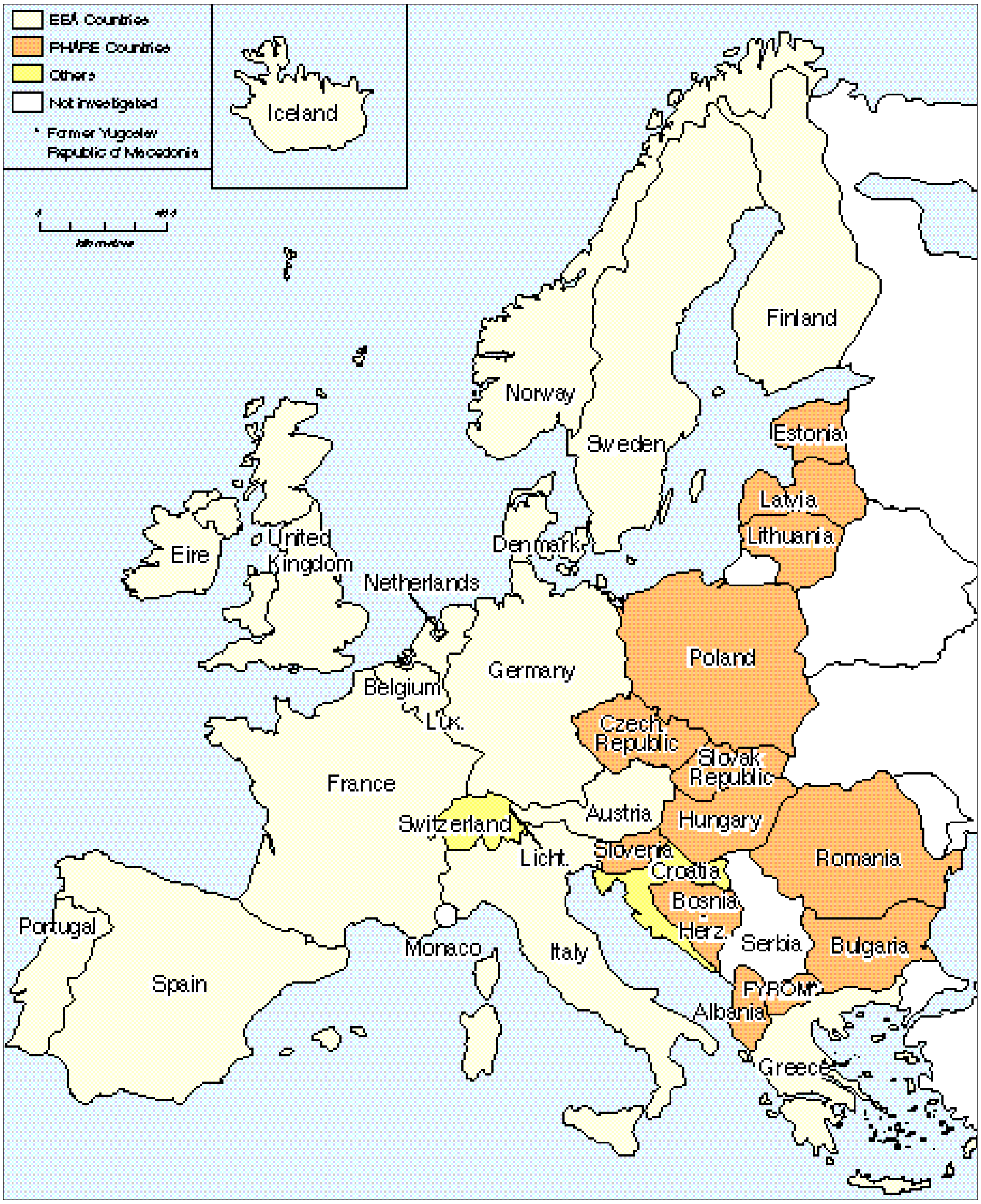
Area of Investigation, Sources of Data and Information

The area under investigation in this report consists of 32 countries, including the Member States of the European Environment Agency (EEA), the Eastern European PHARE countries other than Bosnia Herzogovenia and the former Yugoslav Republic of Macedonia (FYROM), as well as Monaco, Switzerland and Croatia. Non-PHARE European countries were excluded *(Map 1.1)*. A total of 79 cities were selected, which are either those with more than 500,000 inhabitants or the largest agglomeration in the country *(Map 1.2 and Table 1.1)*. In such a large and diverse region, air quality, air pollution problems of major concern, and the capability to monitor, assess and manage air quality will obviously vary considerably. Furthermore, additional factors which can have significant influence on air quality such as topography, economy and climate can also display relatively wide variations.

This report is primarily based on data and information already available within Europe. It builds upon work presented in *Chapter 4*: Air, of the report 'Europe's Environment – The Dobříš Assessment' (Stanners and Bourdeau, 1996). The production of this report was requested in June 1991 at the Ministerial conference held at Dobříš Castle, Czechoslovakia, as a first appraisal of the state of the environment using a pan-European approach. The basis for the chapter on air quality in the Dobříš assessment is the study 'Air Quality in Major European Cities' (RIVM, 1995a,b), which surveys the ambient air quality situation in 105 European cities with more than 500,000 inhabitants, including exposure to air pollution as well as meteorological, topographical and demographic data and emission inventories. Further information sources used in the production of this report were the Air Pollution Information System (APIS) and questionnaires forwarded to National Focal Points or cities directly. APIS is a data base with an associated software package facilitating exploration, statistical treatment and presentation of the material. It contains data which were transmitted by the EC Member States following the Council Decision 82/459/EEC on the Exchange of Information on Air Pollution. A second data base employed is called GIRAFE (Guide d'Information sur les Résaux de qualité de l'Air Fonctionnant en Europe/Information System for Operational European Air Quality Monitoring Networks) and comprises of an inventory of station location and environment, monitored compounds, the techniques used and the organisations responsible for the operation of the networks.

More recent investigations carried out by the EEA's European Topic Centre on Air Quality (ETC-AQ) include the questionnaire-based projects MA1-2 'Report on State of the Air Pollution Monitoring Situation in Europe – Problems and Trends' (ETC-AQ, 1995) and MA2-4 'Air Quality in Europe, 1993 – A Pilot Report' (ETC-AQ, 1996a). The first of these studies catalogues the air pollution monitoring networks currently operating in Europe, their monitoring practices and the availability of data, whilst the second summarises air pollution levels at urban or local and regional scale. Another assessment of monitoring networks was conducted by the WHO Collaborating Centre for Air Quality and Management and Air Pollution Control (WHO CC) at the Institute for Water, Soil and Air Hygiene (Mücke and Turowski, 1995). In addition to details of the monitoring networks, such as descriptions of measurement stations, pollutants and measuring frequencies as well as the methodologies used, information on policy and legal instruments was also collected. Collaboration between the ETC-AQ and the WHO CC, employing a questionnaire survey for data aggregation, was initiated to avoid duplication of effort.

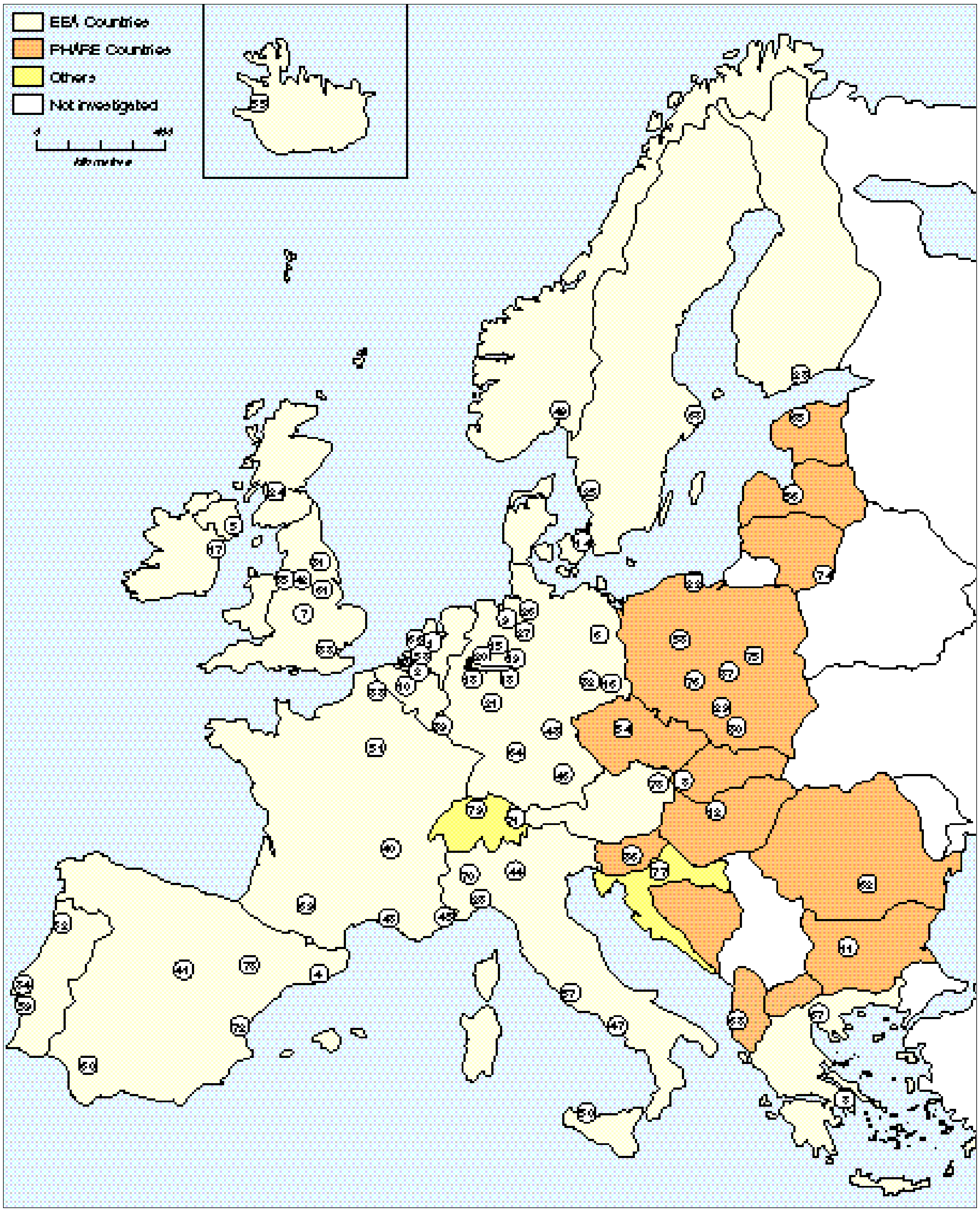
A review of scientific literature was conducted, concentrating on trade journals published after 1992; a literature search including 1992 was carried out in an earlier study (RIVM, 1995a). As a



Map 1.1
Geographic region and European countries included in the Report

result of this review several hundred references were found, of which a large number were investigated more closely. These references covered 48 of the investigated cities and will be mentioned individually in the text below.

An updated version of APIS and GIRAFE, containing air quality data as recent as 1994, was made available on CD-ROM, produced and distributed by the ETC-AQ. Unfortunately, only a few cities, namely Copenhagen, Dublin, Brussels, Antwerp and the three Dutch cities had recently reported their monitoring results. Both systems were recently reviewed and, taking account of the findings, the ETC-AQ developed a revised air quality information system named AIRBASE (Sluyter et al., 1996). From August 1996, AIRBASE was partly accessible by means of a web-application and was loaded with the earlier APIS and GIRAFE data.



Map 1.2
Distribution of the cities investigated, numbered in alphabetical order

New information concerning the state of their monitoring networks was requested from the participating countries, and AIRBASE will be updated continuously. Once completed, AIRBASE will fulfil the requirements under the new Council Decision on Reciprocal Exchange of Information and Data on Air Pollution, which has been adopted by the EU Member States.

The CORINAIR'90 emission inventory for 27 European countries, prepared by the EEA, presents data on national emissions of up to eight pollutants. Emissions are distinguished by source type, and emissions per capita and per square kilometre have been calculated (ETC-AE, 1996a,b). These inventories are also accessible on the internet, where pollutant or country-defined searches can

Country	City	No.	Country	City	No.
Albania	Tirana	68	Latvia	Riga	56
Austria	Vienna	73	Liechtenstein	Vaduz	71
Bulgaria	Sofia	62	Lithuania	Vilnius	74
Belgium	Antwerp	2	Luxembourg	Luxembourg	39
	Brussels	10	Monaco	Monaco	45
Croatia	Zagreb	77	Netherlands	Amsterdam	1
Czech Republic	Prague	54		Rotterdam	58
Denmark	Copenhagen	14		The Hague	66
Estonia	Tallinn	65	Norway	Oslo	49
Finland	Helsinki	28	Poland	Gdansk	22
France	Lille	33		Katowice	29
	Lyon	40		Krakow	30
	Marseilles	43		Lodz	37
	Paris	51		Poznan	53
	Toulouse	69		Warsaw	75
Germany	Berlin	6		Wroclaw	76
	Bremen	9	Portugal	Lisbon	34
	Cologne	13		Porto	52
	Dortmund	15		Setubal P.	59
	Dresden	16	Romania	Bucharest	11
	Düsseldorf	18	Slovak Republic	Bratislava	8
	Duisburg	19	Slovenia	Ljubljana	36
	Essen	20	Spain	Barcelona	4
	Frankfurt	21		Madrid	41
	Hamburg	26		Seville	60
	Hannover	27		Valencia	72
	Leipzig	32		Zaragoza	78
	Munich	46	Sweden	Gothenburg	25
	Nürnberg	48		Stockholm	63
	Stuttgart	64	Switzerland	Zürich	79
Greece	Athens	3	United Kingdom	Belfast	5
	Thessaloniki	67		Birmingham	7
Hungary	Budapest	12		Glasgow	24
Iceland	Reykjavik	55		Leeds	31
Ireland	Dublin	17		Liverpool	35
Italy	Genoa	23		London	38
	Milan	44		Manchester	42
	Naples	47		Sheffield	61

Table 1.1
Countries and cities investigated

be performed (CORINAIR'90, 1996). CORINAIR'94 is currently being produced and total emissions data for EEA member countries are available. The internet is an information source with rapidly increasing importance; several national environmental agencies have web-sites where they display air quality data and further interesting material. These sites are generally updated frequently and can thus contain highly relevant information. In addition, CORDIS (The Community Research and Development Information Service) was explored and valuable material found.

Despite this multitude of information sources, considerable difficulties were experienced with the completeness, age and the reliability of the available data. The air quality situation in several cities had already been thoroughly investigated and detailed information was readily accessible. These were cities which had generally also taken part in earlier surveys. For other cities, hardly any material could be found. Although it was initially intended to use only data from 1990 onwards to ensure that results are representative and up to date, sometimes the only information available was older and had to be used.

Since the aim of this report was defined as not only to describe the air quality and the monitoring network situation in European cities, but also to provide an assessment of their monitoring and management capabilities, additional information was required. In order to obtain this detailed information it was necessary to introduce a questionnaire-based survey of management capabilities. Questionnaires consisting of enquiries into cities' measurement capacity, data assessment and availability, emission estimates and air quality management were forwarded to contact persons in EEA National Focal Points, city councils and organisations responsible for air quality monitoring at local and national level *(Appendix 1)*. In order to simplify the replies, only yes/no answers were necessary and the material analysed in the literature review was used to pre-fill the individual questionnaires as completely as possible before sending them. The returned responses were evaluated using an index scoring system, developed and described in detail elsewhere (WHO/UNEP, 1996) and summarised in *Chapter 9*. In addition, emission inventories were collected from the individual cities by the EEA's European Topic Centre on Air Emissions (ETC-AE). These inventories and all information sources mentioned above were employed to cross check the questionnaire responses before calculating the index score.

Questionnaire responses were received initially from 45 of the 79 cities. A further 17 were eventually returned following reminder letters or by approaching alternative contacts, giving a final reply rate of 80%. Twenty-one cities sent emission inventories or air quality information, and a further 11 indicated in their questionnaire responses that emission inventories had been produced within the last five years. Due to the variety of information sources, contradictory statements and data were found on a number of occasions. Priority was generally given to the newest publication and to responses on the collected questionnaires, since the contact persons in the countries and cities were considered to be the most qualified specialists in providing relevant information. It has to be assumed that those cities which did not take part in this nor any of the earlier studies, possess only limited air quality monitoring, assessment and management capabilities, and are thus less willing to take part in surveys and give information.

From a geographic, climatic and economic standpoint it was decided to link the European countries into four loosely associated groups with similar characteristics; these are described as the eastern, Nordic, southern and western regions *(Table 1.2)*. Albania, Slovenia and Croatia have been grouped with eastern rather than southern countries based on the similarity of past economic systems rather than geographic affinity. In relation to both air quality and management capability, an analysis of the validity of such groupings may provide an insight into causes of problems and the possibility of common solutions.

Overview and Report Structure

A short introduction into general air pollution problems is followed in *Chapters 2, 3 and 4*, respectively, by a summary of air quality guidelines and monitoring and data assessment techniques frequently employed in Europe. In *Chapter 5* a city-by-city analysis of local impacts on air quality, and an investigation into the relative importance of key factors such as climatic, economic, topographic and demographic viewpoints, is conducted; ten case-study cities with relatively complete data sets have been selected for more detailed analysis. The influence of long-range transboundary transport of pollutants on urban environments is examined in *Chapter 6*. Current situation and trends in urban air quality in European cities are reviewed comparatively for all cities in *Chapter 7*. This information is used in *Chapter 8*, to examine the impacts of local air pollution on human health, vegetation, animals and materials. The results of the survey on city capability to monitor, assess and manage urban air quality are presented in *Chapter 9*, which includes

Table 1.2 Europe's four regions and constituent countries used in this Report

Eastern Countries	Nordic Countries	Southern Countries	Western Countries
Albania	Finland	Greece	Austria
Bulgaria	Iceland	Italy	Belgium
Croatia	Norway	Portugal	Denmark
Czech Republic	Sweden	Spain	France
Estonia			Germany
Hungary			Ireland
Latvia			Liechtenstein
Lithuania			Luxembourg
Poland			Monaco
Romania			Netherlands
Slovak Republic			Switzerland
Slovenia			United Kingdom

a further analysis of the 10 detailed case studies, and recommendations on how to improve air quality conditions most efficiently. Finally, conclusions are drawn and a way forward, with recommendations which would lead to better air quality in urban areas, is suggested.

Chapter 2

Understanding Urban Air Pollution Problems - Sources, Impacts and Control Strategies

The primary determinants of air quality are atmospheric emissions, although a wide range of natural factors, such as climate and topography will also have a significant impact. This is particularly true in urban areas, where emission sources are concentrated and where the large number of people present are potentially exposed to poor air quality. The actual pollutant concentrations present in the air we breathe are determined by the dispersion of emissions, and are thus closely related to wind speed and direction as well as local topography. Currently, air pollution control is often achieved by emission reduction, which can be accomplished by various means. It is used to tackle short-term impacts during episodes of particularly high pollution and also as a solution to long-term problems of elevated background concentrations.

Emissions to Urban Air

Emissions can be either of natural or of anthropogenic origin, but human activity, especially the combustion of fossil fuels, is the predominant cause of air pollution. In rural areas agriculture, animal breeding and natural sources contribute large amounts of specific pollutants, mainly ammonia (NH_3), nitrous oxide (N_2O) and methane (CH_4) (ETC-AE, 1996). Urban emission sources are generally divided into mobile or stationary; another possibility is spatial distinction between area, point and line sources. A differentiation between 277 emission source activities according to the SNAP Level 3 code (Selected Nomenclature of Air Pollutants) was undertaken in the CORINAIR'90

Emissions to air from a steelworks in Germany inventory. Total national emissions from the 27 European countries contributing to CORINAIR, distinguished into the 11 main categories (SNAP Level 1), are displayed in *Table 2.1* (ETC-AE, 1996). The CORINAIR'94 inventory is currently being produced *(Table 6.2, Chapter 6)*; so far total emissions for EEA member countries are available and data from the PHARE countries are being collected. The next aim of the ETC-AE will be to fill the gap of emission data for the years between 1990 and 1994 and to update the inventory on an annual basis.

Investigations have shown that certain sources have characteristic emissions with respect to both the type and relative quantities of compounds. It is thus frequently possible, using receptor models, to identify emission sources by determination of the pollutants present in the atmosphere *(Chapter 9)*. However, with increasing distance from the source, dilution with cleaner air and mixing with other pollutants takes place and the 'source-fingerprint' becomes less distinct. Often, emission inventories only contain estimates for those pollutants originating from combustion processes, while other sources are neglected. The calculation of atmospheric emissions from fuel consumption is the most frequently employed concept of emission determination. Emission factors, taking into account the relative pollutant concentrations in flue gases, are used in calculating total emissions from specific source types. In addition to the source type, a variety of factors influence the amount and composition of emissions from fuel combustion and these are summarised in *Figure 2.1*.

In addition to the emissions of substances with detrimental effect on air quality, combustion processes are the major source of the greenhouse gas carbon dioxide (CO_2) which, together with CH_4, N_2O and several fluorinated hydrocarbons (CFCs) such as trichlorofluoromethane (CCl_3F), are responsible for global warming. CORINAIR'90 contains inventories for these compounds on a national and European level. A more detailed introduction into the greenhouse effect can be found, for instance, in UNEP/GEMS (1987).

Emissions from Mobile Sources

In the majority of European cities, and indeed around the world, mobile emitters, particularly road traffic, are the predominant source of atmospheric emissions. Several contaminants, such as atmospheric lead (Pb), nitrogen oxides (NO_x) and carbon monoxide (CO) originate predominantly from road vehicle emissions. This is clearly illustrated by comparison of the detailed emission inventories of four European cities, representative of different climatic and economic regions *(Table 2.2)* and *Figure 2.2*, which compares the proportion of NO_x and CO emissions derived from traffic and non-traffic sources for the same cities. Estimated annual mean concentrations of NO_x and CO for England, Scotland and Wales are shown in *Figure 2.3*. The areas of highest concentrations coincide with the locations of major cities, where dense road traffic generates the highest exhaust emission rates.

Table 2.1 Total estimated emissions of SO_2, NO_x, CO and NMVOC in Europe and the percentage contribution of each Main Source Category (SNAP Level 1) (CORINAIR'90, 1996)

Source Sectors	SO_2	NO_x	CO	NMVOC*
Total emissions (106 tonnes)	27.8	17.8	69.0	21.5
Percentage contribution to emissions	%	%	%	%
1. Public power, co-generation and district heating	54	21	1	<1
2. Commercial, institutional and residential combustion	11	4	14	5
3. Industrial combustion	25	14	12	1
4. Production processes	3	2	5	6
5. Extraction and distribution of fossil fuels	<1	<1	<1	6
6. Solvent use	0	0	0	22
7. Road transport	3	44	56	31
8. Other mobile sources and machinery	2	13	3	3
9. Waste treatment and disposal	<1	1	6	2
10. Agriculture	0	<1	1	4
11. Nature	2	<1	2	20

*NMVOC = non-methane volatile organic compounds.

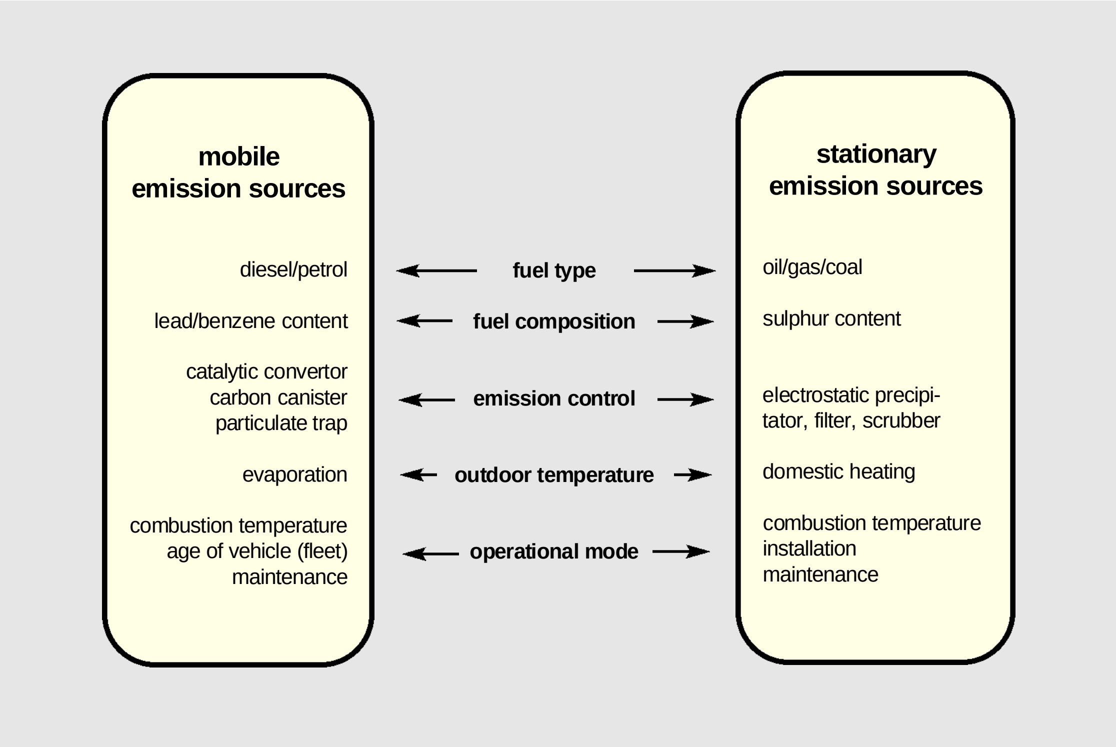


Figure 2.1
Key factors which influence emissions from combustion processes

City		SO_2 (kt/a)	NO_x (kt/a)	CO (kt/a)	VOC (kt/a)	PM (kt/a)
Barcelona [*]	Traffic	0.7	25.6	128.9	26.4	1.2
	Domestic	10.2	7.5	1.1	0.2	0
	Industry/Power	0.5	1.2	0.8	15.0	15.9
	Total	11.4	34.3	130.8	41.6	17.1
Hannover [#]	Traffic	0.7	11.8	34.1	4.3	0.6
	Domestic	1.0	1.3	4.0	0.4	0.1
	Industry/Power	3.9	2.8	0.9	0.3	0.1
	Total	5.6	15.9	38.9	5.0	0.8
Helsinki [§]	Traffic	0.5	15.5	42.0	n.d.	0.9
	Domestic	0.2	0.3	-	n.d.	0.1
	Industry/Power	8.2	10.0	-	n.d.	1.2
	Total	9.0	26.0	42.0	16.0	2.2
Zagreb	Traffic	1.6[+]	7.8[+]	16.0	3.0	0.7[+]
	Domestic	3.6[+]	1.2[+]	7.2	1.2	n.d.[+]
	Industry/Power	5.4[+]	3.1[+]	0.7	0.1	1.6[+]
	Total	10.6[+]	12.1[+]	23.9	4.3	2.3[+]

[*] Costa and Baldasano, 1996
[#] Fritsche and Rausch, 1993
[§] Aarnio, 1996
[+] Jelavic et al., 1995

Table 2.2
Detailed emission inventories for four European cities (RIVM, 1995a)

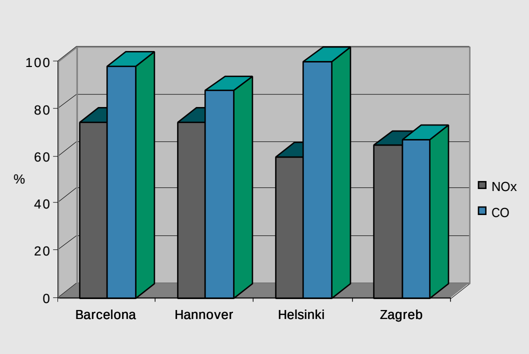


Figure 2.2
Proportion of traffic emissions for NO_x and CO in four cities

Emissions from Stationary Sources

In cities where traffic activity is comparatively low, the proportion of emissions originating from stationary sources gains in importance. Combustion processes for power generation and in industrial facilities are the major point sources either distributed in and around a city or concentrated in industrial areas, whereas domestic dwellings form an extensive area source. In addition to the combustion-based emissions, industry and households generate significant emissions of solvents. Many industrial production processes generate specific emissions (e.g. metals from smelters) and waste incinerators can, if not properly controlled, be the source of a cocktail of highly dangerous substances, including heavy metals and dioxins. Besides emissions stemming from human activities, natural sources can make a major contribution to concentrations of certain substances in the atmosphere, for example, particulates in arid areas and certain biogenic volatile organic compounds (VOCs) emitted from plants.

The emissions from incinerators in residential areas require close monitoring

Urban Air Pollutant Concentrations

The concentration of air pollutants in a city is typically very variable, both spatially and temporally. Spatial variation occurs due to emission source location and climatic and topographical factors which govern the speed and direction of dispersion. On a large scale, stack emission may produce a pollution plume which can extend many miles and indeed give rise to transboundary pollution. Ozone concentrations tend to be higher some distance from city centres as it is a secondary pollutant formed from the oxidation of VOCs and nitrogen dioxide (NO_2). On the other hand, spatial variation in pollutant concentration may occur on a micro-scale, for example from kerbside to a few metres from the road.

Temporal variation in air pollution concentration may similarly occur over an annual or even inter-annual time frame or on a diurnal or hourly scale. Typically, climatic conditions in Europe vary seasonally, giving rise to varying potential summer or winter smogs. Particularly hot summers may give rise to long critical periods which may not occur under more average climatic conditions. Energy use for heating may give rise to high winter emissions, particularly in cities where sulphur-rich coal is used as a domestic fuel. Vehicular emissions are likewise temporally variable but are usually on a diurnal basis related to peak hour traffic commuter levels in the morning and in the late afternoon.

The scale of variation in pollution concentration can be seen from some typical values. During a winter smog incident in Northern Bohemia, daily average sulphur dioxide (SO_2) and particulate matter (PM) concentrations reached maximum values of 825 and 480 $\mu g/m^3$, compared with WHO-AQG for the evaluation of ambient concentrations with respect to their probable effects on human health of 125 $\mu g/m^3$ for SO_2 and 120 $\mu g/m^3$ for PM as 24 hour averages. Maximum 30 minute average concentrations were 1,850 $\mu g/m^3$ for SO_2, 2,600 $\mu g/m^3$ for PM and 760 $\mu g/m^3$ for NO_x. The most severe smog episode ever reported was in London in December 1952 when SO_2 and PM daily average concentrations reached values of about 5,000 $\mu g/m^3$. For summer smogs, excess ozone may be defined as the sum of the concentrations minus a given limit value of 75 ppb. In 1989 most of western Europe had excess ozone levels of over 1,000 ppb between April to September, with an excess in some areas of over 7,500 ppb. Urban street pollution is monitored in many cities; the measurements show that short-term maximum concentrations of CO, NO_2 and particulates may exceed AQGs by a factor of 2 to 4 depending on the actual traffic and dispersion conditions. Figures for the annual average concentration of lead in air at four locations in the UK in 1985 were: rural 100 ng/m^3, suburban 300 ng/m^3, urban 1,300 ng/m^3, and motorway 2,000 ng/m^3. By 1989 these values had all at least halved due to the introduction of unleaded petrol (Stanners and Bourdeau, 1995).

The impact of pollutants on human health will

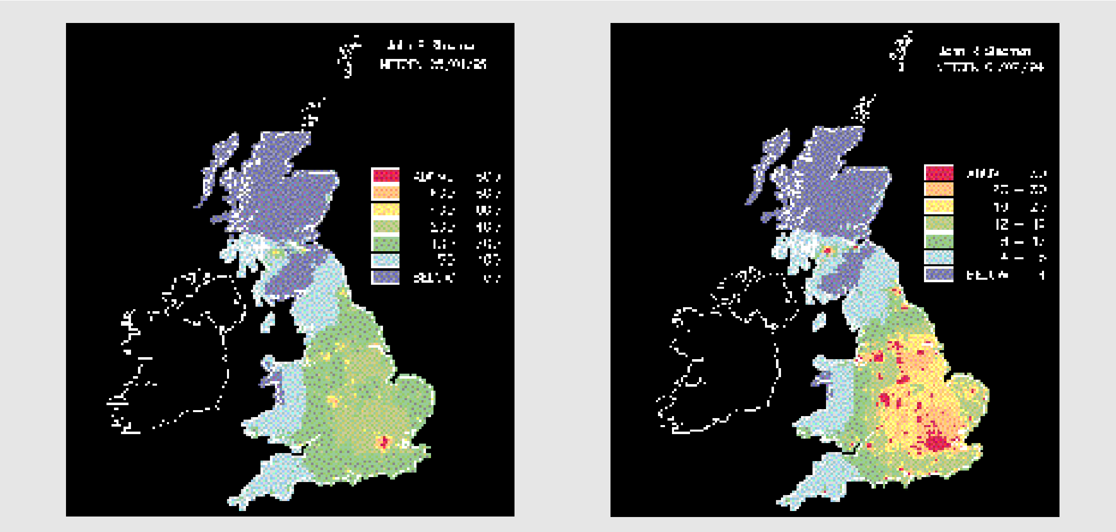


Figure 2.3
Estimated annual mean CO and NO_x concentrations in the UK in 1991 (AEAT, 1996)

depend on the dose-effect relationship of the particular pollutant, hence acute effects may be observed due to high level short-term exposure, and chronic effects from lower level long-term exposure. Individual exposure will depend on exposure to background levels or peak short-term levels depending on activity. For example, traffic wardens may be particularly vulnerable to peak roadside levels. It is on this basis of exposure risk that limits are usually given for both short-term, e.g. 30 minutes or 1 hour or 8 hour averaging times, as well as for long-term annual averages.

Impact of Urban Air Pollution

The impacts of emissions generated within an urban area can be experienced inside the city and on a regional and global scale if pollutants are transported away from the source. Transboundary long-range pollution occurs if compounds are relatively stable in the atmosphere and their transformation takes place over a longer time-scale of weeks to years. This phenomenon will be discussed in more detail in *Chapter 6*.

Human health is generally the issue of highest priority, and most environmental standards are set at levels that should prevent adverse health effects or only pose a risk considered to be acceptably low. Depending on pollutant type, concentration, and exposure duration, an affected individual can suffer acute or chronic health effects. Current guideline and standard values for ambient air quality are summarised in the *Tables 3.2* to *3.6*; considerations taken in to account in setting these values are discussed in *Chapter 3*. These guideline values relate to pollutant concentrations in ambient air, which can be greatly exceeded in 'hot spot' areas near busy roads or industrial facilities.

Exposure to air pollution is not restricted to outdoor environments but also takes place indoors, although this is generally not perceived as harmful by the general public. Where sufficient ventilation ensures the exchange of outdoor and indoor air, strong relationships between the two air qualities have been established (Perry and Gee, 1994), although, under some circumstances, the predominant pollutants and concentrations may differ. Specific indoor emission sources, such as heavy smoking or the use of solvents and cleaning agents, can pose additional health risks. Exposure to air pollutants at the workplace, which is regulated by a different set of standards and guidelines, will also add to the total pollution load a person has to tolerate. The amount of time an individual spends in environments with elevated pollution levels is thus of prime importance for the assessment of total exposure and the associated effects.

Human health is no longer the only matter of concern when the topic of poor air quality is con-

Campaigners protesting about traffic pollution in London sidered, as vegetation inside and outside urban areas has suffered severe damage from air pollution. Forest damage in many parts of Europe and the acidification of fresh waters in Scandinavia *(Chapter 6)* initiated measures to protect the environment from detrimental impacts of atmospheric emissions (Stanners and Bourdeau, 1995). It is now accepted that the long-range transport and subsequent deposition of air pollutants on soils have contributed to both acidification and eutrophication in several areas (UNEP, 1992). Many plant species, especially mosses and lichens, are very sensitive to certain pollutants and their presence in biotopes or their appearance can indicate the air quality. This fact is exploited in the application of biomonitoring techniques, where bioindicators are either intentionally distributed in the environment, collected and analysed after a certain exposure period, or naturally-occurring plants are investigated. The advantages of biomonitoring are its low cost and flexibility, but standard monitoring programmes have yet to be developed (UNEP/WHO, 1994a).

Air pollutants can also attack building materials and increase the deterioration rate of buildings and cultural heritage *(Chapter 8)*. Black smoke and particulate matter can soil the surface of buildings, ruin their appearance and necessitate frequent cleaning. An even worse effect is the destruction of calcareous sandstone which, in many European cities, is the predominant construction material of monuments. Corrosion of metals used as structural material or for roofs and facades is accelerated by elevated sulphur dioxide and chloride deposition levels (RIVM, 1995a). The economic costs involved in the restoration of cultural heritage can be enormous, but they are easily exceeded by the damage the economy suffers from health effects in humans, particularly in the workforce. In addition to emission of air pollutants, other environmental impacts with negative effects on the quality of life, such as noise and odour, often originate from the same source.

Swedish spruce, showing the effects of acid deposition

Current Control Strategies

Without control and management of urban air quality, standards and guideline values are frequently breached. The development and application of strategies to improve and sustain air quality is therefore required. The pollution abatement strategies most often practised with the intention of reducing the exposure of the population to harmful substances are:

- emission reduction,
- land-use changes, and
- wider dispersion of emissions.

The reduction of pollutant concentrations in ambient air and near 'hot spots' can, in most cases, obviously be achieved by emission reduction. Methods of emission reduction for the various combustion sources are outlined in *Box 1*.

For secondary pollutants, like ozone, the situation is different and more difficult to control *(Chapter 6)*. Emission limits can focus on individual pollutants or total emissions, the production of polluting compounds can be reduced, or they can be prevented from reaching the atmosphere by cleansing of flue gases *(Figure 2.4)*. Measures can be proactive, aiming at prevention of the occurrence of pollution episodes by cutting the long-term emission pressure, or reactive, by employing ad-hoc initiatives in situations of deteriorating air quality. Different strategies to curb emissions have been applied separately or in combination with varying success. The implementation of pollution abatement is generally connected with major capital investments. Thus, the effectiveness of possible measures in relation to their costs must be inspected before a decision on which strategy to employ can be made. Although there is now considerable experience with various methods of air quality management, and expertise in how to develop and accomplish strategies is readily available, each specific situation still needs thorough consideration. Measures, which have been implemented successfully in one or several areas, might not prove feasible in other parts of Europe or the world. Besides topographic, climatic and demographic factors, the economic, social and cultural backgrounds of the population are extremely important (Elsom, 1996). If the general public does not support pollution abatement programmes then their success will be very limited. Economic instruments applied cover emission charges, taxes and fines. If they are comparatively high, they will encourage investment into emission reduction by other means.

The enforcement of emission reductions can meet strong opposition, especially when high costs or the restriction of the individual's freedom of choice are involved. The extent to which measures have to be applied depends mainly on the nature of the air quality problem. During short-term episodes of high air pollution, when a larger part of the population experiences health problems, more drastic solutions can and have to be chosen, and will be more readily accepted by the public. To decrease long-term mean concentrations of pollutants in ambient air, gradual and sustainable approaches, such as changes in land use, can be applied. Another means of achieving gradual change is the adoption of new legislation, which permits certain periods of time before full compliance has to be achieved.

With respect to mobile emission sources, several new laws and regulations have been introduced in recent years to reduce emissions from road traffic. These have operated at different levels either by controlling the amount and flow of traffic on a local basis, or by limiting the amounts of certain pollutants emitted by individual polluters (EC Directive 94/12/EC). However, investigations into the effectiveness of these measures showed that up to 80% of the CO and VOC emissions are caused by only 20% of the vehicle fleet. These so-called gross polluters are the vehicles which do not comply with the set standards (Rayfield et al., 1995).

An important step towards better air quality was the introduction of unleaded petrol in most European countries in 1989 (EC Directive 85/210/EEC) combined with catalytic converters (EC Directive 91/441/EEC). The removal of lead anti-knock compounds and their replacement by aromatic hydrocarbons, which maintain the high octane number in petrol and thus guarantee knock-free combustion, can, however, create new problems. Lead compounds were banned from petrol after a relationship between impaired intelligence development in children and high levels of atmospheric lead had been established. Financial incentives strongly encouraged the use of unleaded petrol, quickly increasing market shares. Unleaded petrol is also required by catalyst-equipped cars, since free lead would poison the catalysts and render them ineffective. However, unleaded petrol is being used in cars without catalytic converters, increasing the emissions of volatile organic compounds (VOCs), particularly benzene, a proven genotoxic carcinogen which can increase the risk of developing leukaemia (EPAQS, 1994). In this case, the removal of one harmful compound and its replacement by others might have shifted, rather than removed, the problem.

The introduction of three-way catalytic converters, which reduce amounts of CO, HC and NO_x in the exhaust gases of new petrol-driven cars registered after 1 January 1993 (EC Directive 91/441/EEC), will lower atmospheric concentrations of these pollutants. However, the turnover of the vehicle fleet will take several years, and any increase in number of journeys undertaken in private cars will reduce and eventually offset improvements (Elsom, 1996).

A reduction of air pollutant concentrations in the vicinity of industrial facilities or waste incinerators can be achieved by regulating minimum stack heights, thus ensuring a wider distribution and dilution of the pollutants. The temperature of the gases is also important, since warmer gases will rise as they leave the stack and thus the plume will be dispersed over a larger area. This approach is the strategy most often applied since it does lower the impact on individuals and the environment in the vicinity of the plant, although it does not reduce the total emissions and simply disperses the pollutants over a larger area. Unfortunately, this approach may thus lead to transboundary long-range pollution problems. Several international agreements have been signed by a majority

BOX 1: METHODSOF EMISSION REDUCTIONFROM COMBUSTION SOURCES

- **Fuel composition:** Specific compounds contained in fossil fuels may be responsible for certain air quality and health problems. The limitation of the lead content of petrol (78/611/EEC), replaced by Directive 85/210/EEC which also regulates the benzene content of unleaded and leaded petrol, is an example of the reduction of individual chemicals.
- **Flue/exhaust gas treatment ('End-of-pipe' treatment):** The treatment of flue gases from industrial and power generation facilities with electrostatic precipitators, filters or scrubbers, and of vehicle exhaust gases with catalytic converters and particulate traps, reduces emissions of one or several harmful substances.
- **Fuel type:** The combustion of different fuels can result in a considerable change in the emission profile. Switching domestic fuel consumption from coal to natural gas, for example, greatly reduced black smoke and SO_2 in urban atmospheres.
- **Reduction of traffic or output of industrial facilities:** Road traffic can be reduced using a variety of measures: through restricted access to defined areas and periods, decreased need of transportation for people and goods, improved and more attractive public transport, provision of walking and cycling facilities and many other options. Cutting down production rates of industrial facilities can only be employed in short-term situations of extremely serious air pollution because of the economic aspects involved.
- **Energy efficiency:** The increasingly efficient use of primary energy and energy-saving are not only ways of emission reduction but also save natural resources and all impacts related to their exploitation and can bring major financial benefits. The installation of combined heat and power systems can raise the efficiency rate significantly, as co-generation saves about 15% primary energy.
- **Economic instruments:** Application of the polluter pays principle, which can be achieved by the introduction of emission charges, taxes or fines, encourages investment into low emission equipment and processes in order to avoid such payments.

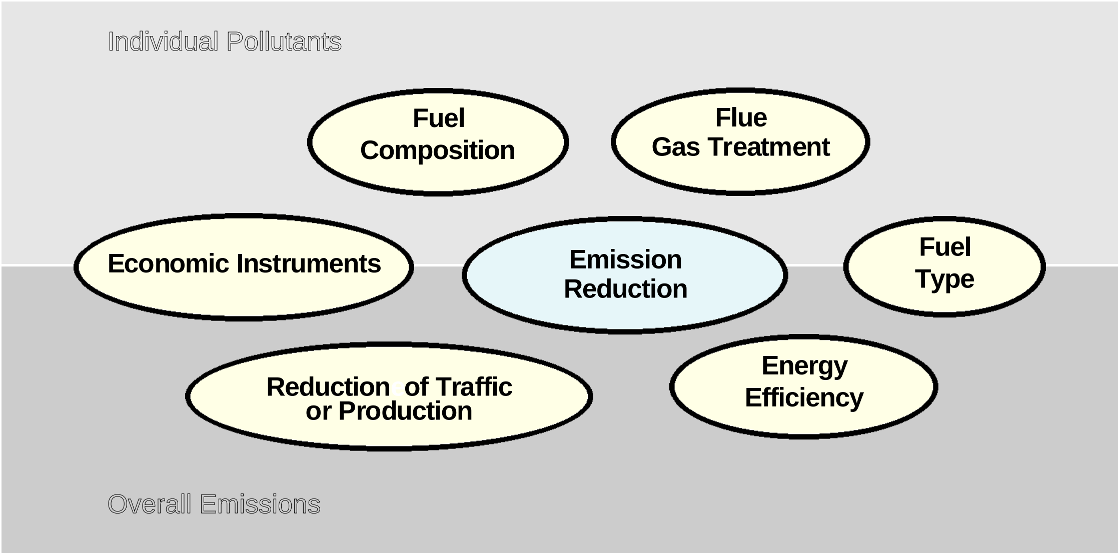


Figure 2.4 Possible approaches towards emission reduction

of European countries in order to limit emissions of compounds involved in these transboundary problems *(Box 5, Chapter 6)*.

An important aspect to be borne in mind is the concept of integrated pollution control, which implies that the improvement of one environmental sector must not cause the deterioration of another. For example, the removal of pollutants from flue gases using electrostatic precipitators, filters or scrubbers reduces their concentration in the atmosphere, but generates solid or liquid wastes which have to be disposed of in a sound manner without posing any risk to the receiving environmental media.

Under the title 'Towards Sustainability', the EU designed the 5th Environmental Action Programme as a community-wide approach to improve the environmental situation. Five target sectors were selected, namely manufacturing industry, energy, transport, agriculture and tourism, which are all relevant to current and future air quality. The mechanisms by which sustainable development will be reached include the integration of environmental considerations into other policy areas and a broadening of the range of instruments, particularly economic instruments such as the internalisation of external costs (COM(95) 624, 1995).

Chapter 3

Air Quality Standards and Guidelines

The relationship between air quality and human health and the state of the environment as a whole has been recognised for a long time. In order to protect humans, animals and vegetation from adverse effects that are caused by elevated concentrations of air pollutants, limit values for pollutant concentrations have to be set and enforced. The acute and chronic health effects of the major air pollutants are described in *Table 3.1*. A first set of European air quality guidelines covering 28 compounds was suggested by the WHO in 1987 (WHO, 1987). Currently these guidelines are being revised and amended, and will be extended to 38 individual and mixtures of air pollutants. Although these guideline values have no legal power, many countries have based the development of national air quality standards on them (WHO, 1995a). Summaries of guidelines, limits and thresholds for the major air pollutants are given in *Tables 3.2* to *3.5*.

Formulation of Air Quality Standards

The level at which air quality standards are fixed, are generally a compromise between maximum protection and technically and economically feasible limits. The implementation of air pollution abatement measures can involve major capital investment, but this should be balanced against the advantages of clean and healthy air. This cost benefit analysis is hardly ever carried out. The protection of human health is the aspect of predominant concern in the process of setting guideline levels. Toxicological information derived from

Cyclists protect against exhaust pollution in London

Pollutant	Acute health effects	Chonic/Toxic health effects
Sulphur dioxide	Narrowing of the airways, particularly in sensitive individuals, producing symtoms ranging from coughing and wheeze to bronchitis and asthma; no observable threshold.	Increased prevalence to chronic bronchitis and other respiratory diseases; differences in lung function.
Suspended particulate matter	Increased mortality from cardiovascular and respiratory diseases; no observable threshold.	Increased respiratory mortality and morbidity; decreased pulmonary function; no observable threshold.
Nitrogen dioxide	Sensitizes lungs to other pollutants and allergens; increases frequency of eye irritation, sore throat and phlegm.	No definite effects from outdoor exposure but indoor exposure suggests a range of effects upon lung function; in animal studies morphological, biochemical and immunological changes were detected.
Ozone	Powerful oxidant reacting with most biological substances; a lung irritant and sensitizer to other pollutants and allergens; can produce runny eyes and sore throats.	It has recently been suggested that ozone is a genotoxin but adequate investigatons are not available; high level long-term exposure in animal studies induced morphological changes in the lung.
Carbon monoxide	Reduces oxygen carrying capacity of the blood by binding with haemoglobin.	Excess risk from arteriosclerotic heart disease; affects developing foetus.
Lead	None known.	Neurotoxin (suggestion of impaired cognitive development); affects blood biochemistry and can raise blood pressure.
PAHs	None known.	Benzo-a-pyrene and certain other species are carcinogenic.
Benzene	None known.	Genotoxic carcinogen linked to leukaemia.
1-3 Butadiene	None known.	Genotoxic carcinogen, increases risk of cancer of the lymphoid system and bone marrow.

Table 3.1
Acute, chronic and toxic health effects of common air pollutants

epidemiological studies is evaluated, the nature of the health effect is taken into account *(Box 2)*, and additional safety factors are used, taking into consideration more vulnerable members of society and assuming a lifetime exposure, to calculate an acceptable value (Nilsson, 1995). *Box 3* summarizes different approaches to the definition of air quality standards. It is important that those levels eventually adopted are, on the one hand, achievable but, on the other, pose a challenge for constant improvement of air quality. They must not be perceived as upper limits which may be reached if that entails a deterioration of present air quality.

Compounds are generally treated in isolation, whereas possible interactions, which can cause additive, synergistic or antagonistic effects, are generally ignored. Few toxicological studies on combined exposure have been undertaken and the lack of data makes evaluation virtually impossible. Exposure to the same substance by one or more routes, e.g. by inhalation and consumption of food, is assumed to have no more than an additive effect. So far, only one air quality standard governing the simultaneous occurrence of pollutants has been set in the EU. The compounds are sulphur dioxide (SO_2) and particulates which are thought to have synergistic effects (Nilsson, 1995). Historically, they were often present at the same time, since their common source is domestic and industrial combustion of coal. On the whole, knowledge of the effects of mixtures of pollutants is very restricted; intensive research and the development and enforcement of guidelines, to protect humans and the environment from the toxic cocktail of pollutants sometimes present in ambient air, is clearly necessary (AGMAAPE, 1995).

Compounds	1987 Guideline value	1987 Averaging time	1996 Guideline value	1996 Averaging time
Lead	0.5-1.0 µg/m3	1 year	0.5 µg/m3	1 year
Nitrogen dioxide	400 µg/m3	1 hour	200 µg/m3	1 hour
	150 µg/m3	24 hours	-	-
	-	-	40-50 µg/m3	1 year
Ozone	150-200 µg/m3	1 hour	-	-
	100-120 µg/m3	8 hours	120 µg/m3	8 hours
Sulphur dioxide	500µg/m3	10 minutes	500 µg/m3	10 minutes
	350 µg/m3	1 hour	-	-
	-	-	125 µg/m3	24 hours
	-	-	50 µg/m3	1 year
Total suspended particulates	120 µg/m3	24 hours	-	-
Carbon monoxide	-	-	100 mg/m3	15 minutes
	60 mg/m3	30 minutes	60 mg/m3	30 minutes
	30 mg/m3	1 hour	30 mg/m3	1 hour
	10 mg/m3	8 hours	10 mg/m3	8 hours

Table 3.2
WHO Air Quality Guidelines for Europe 1987 and the 1996 update (WHO, 1987, 1995c,d)

BOX 2: CATEGORIES OF HEALTH EFFECTS (QUARG, 1993)

- **Non-carcinogenic effects:** The No Observed Adverse Effect Level (NOAEL) or the Lowest Observed Effect Level (LOEL) found in the evaluation of epidemiological studies is divided by uncertainty factors to find the recommended guideline or limit value.
- **Non-genotoxic carcinogenic effects:** For several non-genotoxic carcinogens, the way in which they cause the disease is well understood. This makes it possible to define a level of exposure below which no adverse effects should be observable. For substances where the carcinogenic action is not known, the no-safe-level approach is used.
- **Genotoxic carcinogenic effects:** The generally accepted assumption is that no threshold exists and thus no safe level of exposure can be defined. Therefore, air quality standards can only be set at levels where the risk of developing a disease is thought to be exceedingly small. This risk estimation approach has been accepted by WHO. Another method is to calculate the level of exposure likely to cause a defined disease with a given excess risk (e.g. one additional person in one million dies of leukaemia).

The member countries of the European Union have recently adopted the Framework Council Directive on Ambient Air Quality (EC Directive 96/62/EC). Daughter directives for individual compounds are to be developed setting new air quality limit values (AQLVs). In addition to SO_2, lead (Pb),

BOX 3: TYPESOF AIR QUALITY STANDARDS (NILSSON, 1995)

- **Limit values:** Levels of pollutants are legally binding and may not be exceeded. Close definitions are required, including the description of monitoring methods. Often no absolute maximum levels, but rather percentiles, are set; the 98th percentile (P_{98}) for instance, may be exceeded by no more than 2% of the measured levels during a certain reference period.
- **Guidelines, target values:** Not legally binding and generally more stringent than limit values. Long term target values intended to set a goal influencing land-use planning and concessions to industries.
- **Threshold values:** Threshold values can be set to protect human health or vegetation, or threshold concentrations can be set above which specific actions must be taken, such as warning the public if the ozone levels are breached.
- **Critical loads and critical levels:** the critical load can be defined as the greatest addition of a pollutant an ecosystem can support without suffering damage in the long term. Critical levels are levels in the ecosystem which will cause long term impact. Using this concept, no fixed limit values are set for pollutant concentrations in the environment, but the characteristics of a specific receiving environment are taken into account. For example, the impact of acid deposition on an ecosystem is dependent on the buffering capacity of the soils and waters. Calculations are made of the acidic load that can be buffered, i.e. the critical load, and attempts are made to ensure that this capacity is not exceeded, or the acidic emissions are reduced if the critical level is already being exceeded.

Table 3.3
EC Limit and Guideline values for SO_2 and suspended particulates (EC Directive 80/779/EEC)

Pollutant	Reference period	Limit values (to be met by 1.4.83)
Sulphur dioxide	1 year (median of daily values)	120 μg/m^3 if smoke < 40 μg/m^3
		80 μg/m^3 if smoke > 40 μg/m^3
	Winter (median of daily values)	180 μg/m^3 if smoke < 60 μg/m^3
		130 μg/m^3 if smoke > 60 μg/m^3
	1 year, peak (P_{98} of daily values)	350 μg/m^3 if smoke < 150 μg/m^3
		250 μg/m^3 if smoke > 150 μg/m^3
Smoke	1 year (median of daily values)	80 μg/m^3
	Winter (median of daily values)	130 μg/m^3
	1 year, peak (P_{98} of daily values)	250 μg/m^3
	Reference period	**Guide values**
Sulphur dioxide	24-hour mean	100-150 μg/m^3
	1 year mean	40-60 μg/m^3

suspended particulate matter (SPM), nitrogen dioxide (NO_2) and ozone (O_3), which were covered by earlier compound-specific directives (*Tables 3.3* to *3.5*), new compounds will be included, namely: benzene (C_6H_6), carbon monoxide (CO), cadmium (Cd), arsenic (As), polycyclic aromatic hydrocarbons (PAHs), and those nickel-containing compounds which are classified as carcinogens. Further amendments for acid deposition and fluorides have been under consideration, but agreement has not been reached. Action plans for areas that do not comply with the standards will have to be drawn up and annual reports will be prepared. Monitoring will become mandatory in urban agglomerations with more than 250,000 inhabitants and areas with high pollutant concentrations; however, under certain conditions, modelling will be allowed to replace monitoring.

It has not been considered possible to set a limit value for the secondary pollutant ozone as it is formed at some distance from the sources of primary emissions *(Chapter 6)*. Thresholds for the protection of human health and vegetation, population information thresholds and population warning were adopted (EC Directive 92/72/EEC) *(Table 3.5)*. If an hourly mean of 180 μg/m^3 O_3 is exceeded the population should be informed, whilst if the hourly mean concentration of 360 μg/m^3 O_3 is

Table 3.4
EC Limit and Guideline values for NO_2 (EC Directive 85/203/EEC) and lead in air (EC Directive 82/884/EEC)

	Reference period	Limit value (to be met by 1.7.87)
Nitrogen dioxide	1 year (P_{98} of 1-hour means)	200 μg/m^3
	Reference period	**Guide values**
	1 year (P_{50} of 1-hour means)	50 μg/m^3
	1 year (P_{98} of 1-hour means)	135 μg/m^3
	Reference period	**Limit value (to be met by 9.12.87)**
Lead	1 year	2 μg/m^3

Objective	Threshold concentration ($\mu g/m^3$)
Health protection	
8-hour mean	110
Population information	
1-hour mean	180
Population warning	
1-hour mean	360
Vegetation protection	
1-hour mean	200
24-hour mean	65

Table 3.5
Threshold concentrations for O_3 (EC Directive 92/72/EEC)

Country	Reference period	Limit value
Czech Republic	1 year (P_{95} of half-hour means) *	10 mg/m^3
	1 year (P_{95} of 24-hour means) *	5 mg/m^3
Germany	1 year #	10 mg/m^3
	1 year (P_{98} of half-hour means) #	30 mg/m^3
	half hour +	50 mg/m^3
	24 hours +	10 mg/m^3
	1 year +	10 mg/m^3
Slovenia	half hour *	60 mg/m^3
	1 hour *	30 mg/m^3
	8 hours *	10 mg/m^3
	24 hours *	5 mg/m^3
	1 year (P_{95} of 1-hour means) *	20 mg/m^3

* MA 1-2
# TA-Luft #86 (Technical Instructions)
+ VDI-Richtlinie 2310

Table 3.6
Examples of CO guidelines in Europe

breached, warnings must be issued to the public and advice on how to avoid excessive exposure, and the possible consequences, should be given. In 1994, this was the case in Athens, on the Setubal Peninsula and in rural Sicily (ETC-AQ, 1996a).

In addition to the compounds regulated by the EU Directives, several countries have adopted limit values for other common pollutants, often CO *(Table 3.6)*. The member states also have the right to tighten the limits. All investigated European countries outside the EU have comparable legal frameworks in place, except for Monaco, where no air quality standards have been laid down (Questionnaire response). In addition, pollutants, such as heavy metals, are frequently regulated in areas where local problems may be present.

Chapter 4

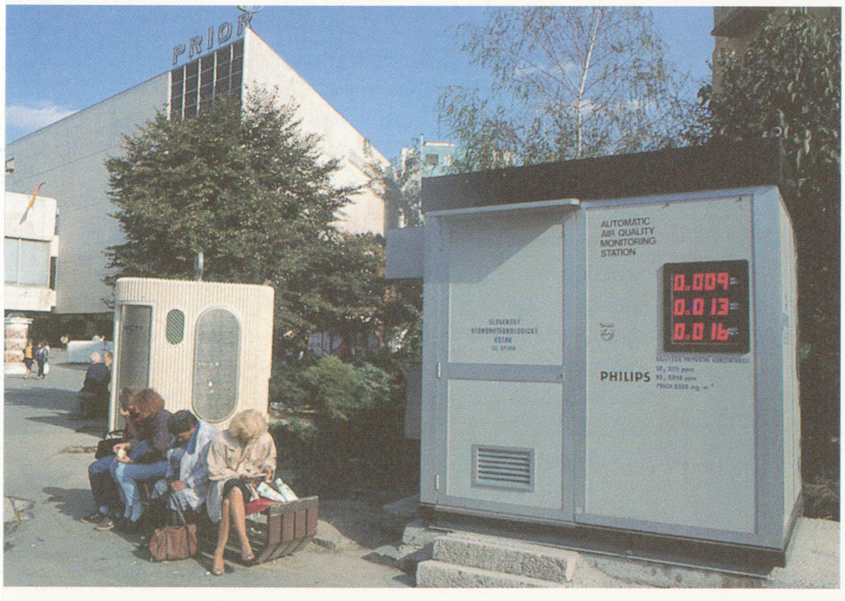
Urban Air Quality Monitoring and Assessment

Measurement of the concentrations of individual chemical species or a mixture of these in the atmosphere over a period of time, and the recording of data, are the basic steps in air quality monitoring. Statistical analysis and evaluation of the collected data and the application of quality assurance and quality control (QA/QC) systems are essential to affirm the validity and reliability of the monitored data. The generation of decision-relevant and reliable information, with a sufficient temporal and spatial resolution that allows the identification of problems, is fundamental for successful air quality management.

Design of Air Quality Monitoring Networks

The design and subsequent implementation of a new air quality monitoring network, or the review and adaptation of an existing system, is a complex task. Finding the most appropriate and cost-effective solution under the special circumstances, which govern the process of establishing and running a specific network, starts with setting the monitoring objectives. These will help to determine the sampling equipment, site selection and the overall network design. Typical monitoring objectives are (UNEP/WHO, 1994a):

- establishing a sound scientific basis for policy development,
- determining compliance with statutory criteria,
- assessment of population/ecosystem exposure,
- public information,
- identification of pollution sources or risks, and
- evaluation of long-term trends.



Automatic monitoring station, Bratislava

Definition of priority pollutants, necessary data accuracy and time resolution, and consideration of available resources (capital, manpower, space), will restrict the choice of employable measurement methodologies and thus aid the selection of monitoring equipment. Air monitoring methods form five groups:

- passive samplers,
- active samplers,
- automatic analysers for on-line information,
- remote sensors for multi-component measurements, and
- bioindicators.

Samples taken using both passive and active samplers, as well as several biomonitoring techniques, require subsequent laboratory analysis, which can be labour intensive and expensive.

A detailed description of these methods and a consideration of their advantages and disadvantages, as well as a comparison of the capital cost, can be found elsewhere (e.g. UNEP/WHO, 1994a,b,c). The density of the monitoring network and the location of the individual sites are the next points to be decided. Requirements which have to be taken into account are (UNEP/WHO, 1994a):

- monitoring objectives,
- pollutant sources and emissions in the area,
- meteorology and topography,
- existing air quality data,
- model simulations,
- demographic/health/land use data,
- access (and potential vandalism),
- site sheltering, and
- infrastructure (electricity, telephone, etc.).

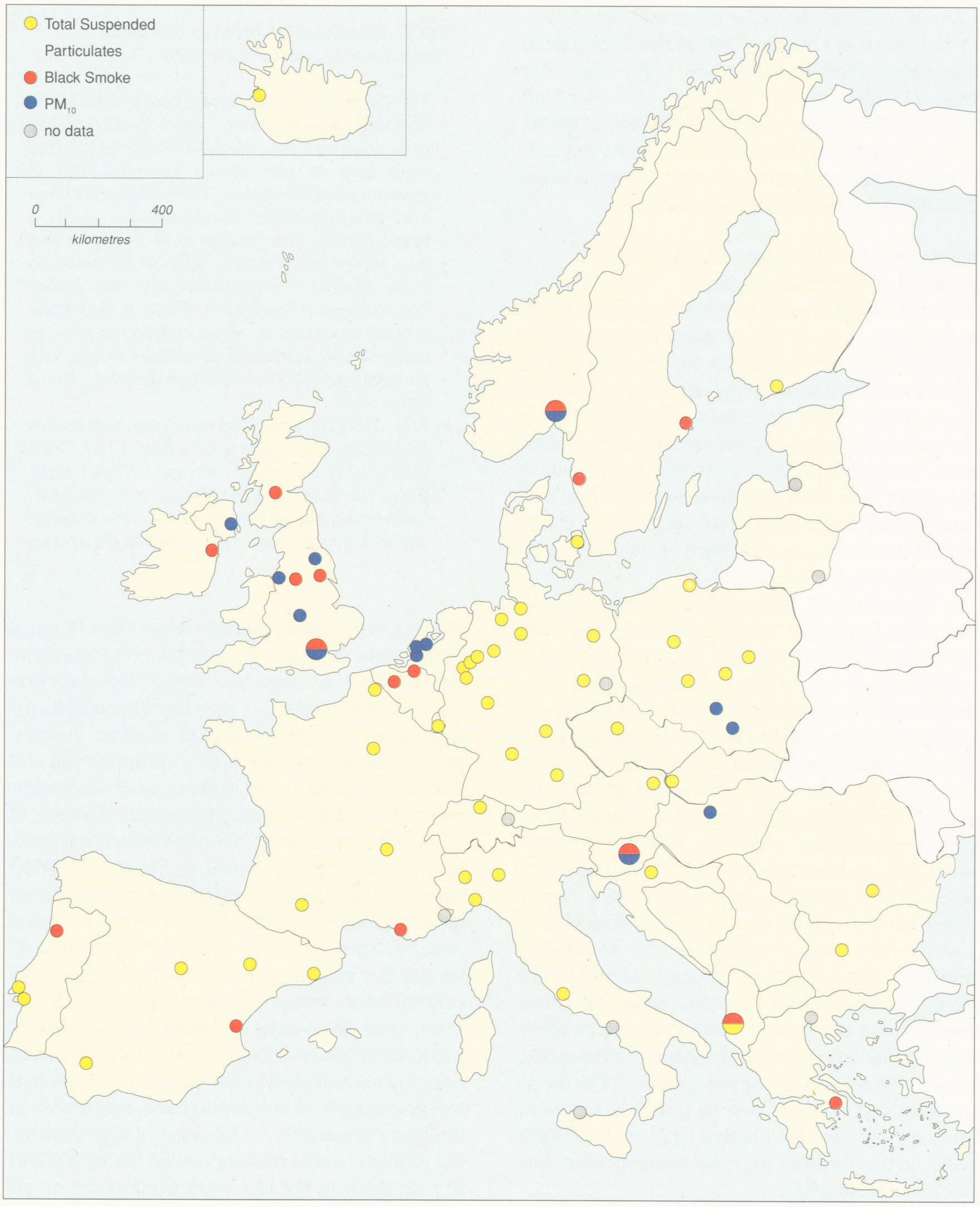
Once the implementation of the monitoring network is completed and is in operation, quality assurance and control programmes have to be applied to the generated data and the measurement equipment, using regular maintenance and calibration procedures. Only the use of set data quality standards will guarantee the production of accurate, representative, inter-comparable and reproducible information on a local and international level. The harmonisation of monitoring and assessment systems is thus an important step towards an easier exchange of information and the determination of the pan-European air quality situation and trends. This does not imply that the same measurement and analysis methods have to be employed. The production of consistent, representative data of known quality and accuracy can be achieved using either reference or equivalent techniques. The equivalence of procedures has to be established by inter-comparison of different monitoring and QA/QC methods.

Public display of information on air pollution monitoring, Dresden

Current State of European Air Quality Monitoring and Information Exchange

Two interconnected surveys of air quality monitoring networks in Europe, from international down to local level, have recently been conducted (Mücke and Turowski, 1995 and ETC-AQ, 1995). In addition to the monitoring practices, the network objectives and the national and international monitoring requirements were reported. Monitoring practice is defined as the way air pollution monitoring is carried out in terms of compounds measured, methods used, site representativeness, spatial and temporal coverage of stations and networks, availability of the data, and how data are reported.

A large number of monitoring sites for different pollutants, generally covering the compounds regulated by EU legislation and focusing additionally on particular local air quality problems, are in operation throughout Europe (ETC-AQ, 1995). In



Map 4.1 Monitoring techniques used by investigated cities for particulate matter

most cases, the applied technology and legal framework seem to be appropriate for effective air quality management but both data assessment and policy enforcement may show gaps. Specific problems will be discussed on a city-by-city basis in the following chapters. The availability and time resolution of monitored data is also not always sufficient. In order to issue warnings to the public, on-line data, or even better air quality forecasts, are necessary. Assessment of acute health effects for some pollutants requires short averaging periods, for example, the WHO Air Quality Guidelines suggest a maximum allowable sulphur dioxide (SO_2) concentration of 500 µg/m^3 over an averaging time of 10 minutes (WHO, 1995c).

The definition of monitoring practice demonstrates that information availability and reporting are seen as core components of good practice.

Current amendments to the existing EU legislation, as described in *Chapter 3* and in the Exchange of Information (EoI) Decision (C30, 1996) which has replaced the old EoI Decision (EC Decision 82/459/EEC), will increase the availability of recent air quality data. Furthermore, an improved network information service via the web-application AIRBASE is being developed by ETC-AQ.

Box 4: Monitoring Methods for Suspended Particulate Matter (EPAQS, 1995)

- **TSP (Total Suspended Particulates):** High volume samplers are commonly used to accumulate particulates on a filter, the determination of collected mass and air flow allows the calculation of atmospheric concentration. TSP samples are often used for subsequent chemical analysis.
- **Black Smoke:** The passage of air through a filter for a certain period of time, generally 24 hours, will create a stain of accumulated particulate matter. The darkness of this stain is related to the particle concentration in the air, where emission sources are predominantly combustion of diesel fuel and coal, particles originating from other sources may have a lighter colour.
- **PM_{10} and $PM_{2.5}$:** Samplers collect the mass fraction of particles which pass a 50% inlet cut-off at the aerodynamic diameter of 10 µm or 2.5 µm, respectively. The levels of these thoracic and respirable fractions are relevant for the assessment of health effects, since they penetrate deeply into the airways.

Monitoring Development – an example: Suspended Particulate Matter

With the development of sophisticated, automatic monitoring devices, many older systems were replaced. It is very important, however, to ensure that old and new monitoring results are comparable, and that existing long time-series, essential for the calculation of trends, are not interrupted. One major problem encountered in the assessment of air quality is the determination of suspended particulate matter concentrations, since three different methods, briefly described in *Box 4*, are in general use in Europe *(Map 4.1)*.

Methods using TSP and Black Smoke measurements are gradually being replaced by the measurement of PM_{10} and $PM_{2.5}$. The latter measures are thought to more accurately reflect health risks associated with inhaled particulates. However, the changing methodology does make comparisons between datasets within and between cities difficult.

Map 4.1 shows that TSP sampling still is the most frequently applied method in Europe. However, several cities might use monitoring equipment with an inlet cut-off at a certain particulate size, but the available data do not state clearly which measurement approach was selected. In several cities, where more than one monitoring network is in operation, different methods are used. Levels measured using either of these methods are not readily comparable, since there are no standard conversion factors. Furthermore, it has to be noted that the composition of airborne particles has changed due to a shift in emission sources, and thus the relation between the 'blackness' of the samples and the concentration has altered in most areas.

The size of aerosol particles is a very important aspect related to their health-threatening impact. Finer particles penetrate more deeply into the lung, whereas the fraction larger than 10 µm is held back in the upper parts of the respiratory system, where they cause less harm. Thus measurements of PM_{10} and $PM_{2.5}$ are more appropriate for application in epidemiological studies. Furthermore, coarser particles tend to comprise soil and dust, particularly in arid regions, whereas smaller respirable matter with an aerodynamic diameter of <5 µm consists of more harmful combustion products (Elsom, 1996) *(Chapter 6, Figure 6.2)*. WHO has not defined any new guidelines for particulate matter *(Chapter 3, Table 3.3)*, since the evidence collected from a number of epidemiological studies did not suggest the existence of a threshold concentration or exposure duration (WHO, 1995c). Thus, even short-term exposure to low levels of particulates has to be associated with a significant risk. This is reflected by the common opinion that the assessment of fine particulates suspended in the lower atmosphere is an issue of high priority. For example, initial reviews carried out by ETC-AQ to help develop the EEA work programme on air quality have highlighted particulate matter as one of the priority areas for further work (ETC-AQ, 1996b).

Chapter 5

Analysis of Local Impacts on Air Quality

Every city has its individual and distinct characteristics, and their influence on urban air quality will vary in relative importance, but several key factors can be identified. Emissions from local or distant sources are fundamental determinants of the pollutant concentrations which can occur in an area, whilst dispersion determines the levels actually present. Emissions and dispersion again depend on numerous parameters, frequently summarised as topographic, societal and climatic. This chapter will investigate these factors in more detail and present the results for all major European cities in several maps, in order to allow comparisons to be made and to support the understanding of current and future pollutant levels, which will be presented and discussed in *Chapter 7*.

The primary information sources employed to compile this chapter were the two parts of the study 'Air Quality in Major European Cities' (RIVM, 1995a,b). Where additional material was used, individual references will be given. The most up-to-date information has been used wherever possible. Considerable problems were experienced with data gaps and inconsistency. The comparative maps have been supplemented by the more detailed analysis of 10 case study cities. A primary criterion for the selection of these cities was that they offered good data sets and that they had responded also to the Management and Assessment Capability questionnaire which is discussed in *Chapter 9*. It is a reflection of the gaps in the data sets that there were few cities that met this criterion. However, those cities selected display a wide

Air pollution obscures the view of the Acropolis, Athens

Amsterdam shows that road vehicles are not the only form of transport causing air pollution

range of geographic, social and economic conditions and provide data that throw considerable light on the range of air quality problems experienced by cities in Europe.

The City and Its Population

This study aimed at investigating European cities with more than 500,000 inhabitants. However, in some smaller countries, where urban populations do not reach this number, the largest city, often the capital, was selected. It is difficult to define boundaries of a city and various approaches considering administrative units (municipalities), population density or building density have been attempted, but none of these was entirely satisfactory. The concept of morphological city boundaries defining a conurbation was adopted, making the assessment of large urban agglomerations possible. London and Paris are examples for this type of extensive urban areas, where a prime (core) city is surrounded by secondary satellite towns and suburbs. Thus a core municipality together with its morphologically integrated neighbouring cities/towns, or a city and its suburbs, excluding secondary towns or suburbs separated by more than 2.5 km from the prime city, is termed a conurbation (RIVM, 1995a). Where possible, the built-up area of the city has been obtained or estimated as well as the total area, since emission sources and potentially exposed population are concentrated in the former.

Urban areas, which fall under this definition in the parts of Europe investigated, are inhabited by about 100 million people, 19% of the total population. London is spatially the most extensive conurbation considered with 1,580 km^2 and, with 10.6 million inhabitants, it also has the largest population. The distribution of inhabitant numbers and built-up or total areas is shown in *Figure 5.1*. This shows a wide diversity of city area for each population category, but most cities with populations of over 0.5 million cover an area of more than 100 km^2, with 28 cities occupying areas of greater than 200 km^2.

In several cases, highly industrialised areas, consisting of more than one municipality, with large total populations were considered relevant for this report. So the Katowice region with about 3 million inhabitants, only about a tenth of which live in Katowice itself, and the Setubal Peninsula with a total population of 650,000 in nine municipalities including Barreiro/Seixal and Setubal which is inhabited by 105,000 people, were taken into account as well. Both areas are pollution hot spots with industrial facilities of national importance.

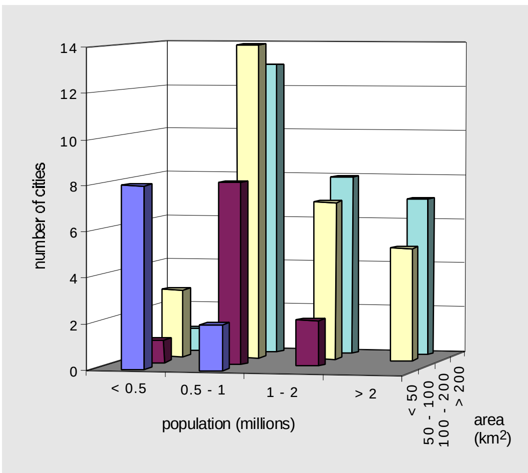


Figure 5.1
Distribution of population size and area of investigated cities

Environmental Indicators

In recent years there has been a perceived need for data analyses that address management needs for decision-making. Increasingly, the use of aggregated data to produce numerical environmental indicators has been seen as a useful management tool. An environmental indicator should have a number of attributes including:

- its base parameters should be measurable in a reliable and quality controlled manner, and
- the indicator should be responsive to the range of environmental conditions that it describes.

A number of air quality indices have been designed to express key determinants of air quality in an accessible and understandable manner. In this chapter the indices developed and used in ‘Air Quality in Major European Cities’ (RIVM, 1995a,b) are briefly described and used to examine air quality determinants in the investigated cities. Other indices developed in the ‘Air Quality Management and Assessment Capabilities in 20 Major Cities’ (UNEP/WHO, 1996) are used in *Chapter 9*.

Description (nominal classes)*		Population density and Vehicle Smog Index	Other indices
most favourable	(++)	$< D - 0.8\sigma$	$< M - 1.5\sigma$
favourable	(+)	$\geq D - 0.8\sigma$ and $\leq D - 0.3\sigma$	$\geq M - 1.5\sigma$ and $\leq M - 0.5\sigma$
neutral	(o)	$\geq D - 0.3\sigma$ and $\leq D + 0.3\sigma$	$\geq M - 0.5\sigma$ and $\leq M + 0.5\sigma$
unfavourable	(-)	$\geq D + 0.3\sigma$ and $\leq D + 0.8\sigma$	$\geq M + 0.5\sigma$ and $\leq M + 1.5\sigma$
most unfavourable	(--)	$\geq D + 0.8\sigma$	$\geq M + 1.5\sigma$

*Emission index range = o (less unfavourable) to ---- (most unfavourable)

Table 5.1
Description and calculation of Index classes (after RIVM, 1995a)

Of the many possible indices which could be employed to describe the determinants of urban air quality, the following were selected for a comprehensive and comparative analysis on a local and regional level:

- population density,
- average dispersion (mean of average wind speed index and topographic siting index),
- winter smog emissions,
- vehicle smog emissions,
- summer smog emissions,
- meteorological winter smog potential, and
- meteorological summer smog potential.

The indices were ranked in five classes ranging from lowest (1) to highest (5) for environmental pressures or climatological impacts such as population density, topographic siting, average wind speed and average dispersion index. The number 1 corresponds to the least pressure, or most favourable climatological conditions, and 5 refers to the most unfavourable. For some of the descriptive indicators, an arbitrary ++ to -- scale, from most favourable to most unfavourable, was used. For quantitative indices, the values and classes bandings were calculated, as shown in *Table 5.1*, from mean values for the key determinants, i.e. mean population density (D) and mean emission density (M) and class intervals of the standard deviation (σ). For emission indices, the classes were described as ranging from 1 (least unfavourable) to 5 (most unfavourable) relative to the average emission conditions in the cities for compounds with summer (VOCs and NO_x) and winter (SO_2 and PM) smog-forming potential.

Population density has an indirect influence on the air quality since emissions are, to a significant extent, correlated with populations – more humans generate more emissions. On the other hand, skilful land-use planning, concentrating homes, work-places and shopping and leisure facilities in small, compact areas can dramatically decrease the necessity for road traffic and thus reduce total vehicle emissions (Elsom, 1996). In *Map 5.1*, the average population densities in the European cities is shown grouped into 5 classes *(Appendix 2)*, although it has to be noted that these vary considerably within the conurbation, and are generally significantly higher in central areas than in the suburbs. *Figure 5.2* illustrates the percentage of cities in each population density class range, and shows that 25% fall into the highest two categories.

Climate and Meteorology

The climatological conditions prevalent in a region determine the population's activity patterns and thus, to a certain extent, the generated emissions. For the city-specific assessment, four climatic conditions with indicator capability for their influence on air quality were identified:

- average temperature, indicating amount of emissions generated through heating requirements,
- total precipitation, indicating the capacity of atmospheric scavenging,
- average cloud cover, indicating insolation and thus the significance of photochemical reactions, and
- average wind speed, indicating the potential for pollution dispersion.

The meteorological conditions in cities are often dominated by urban scale aspects, rather than

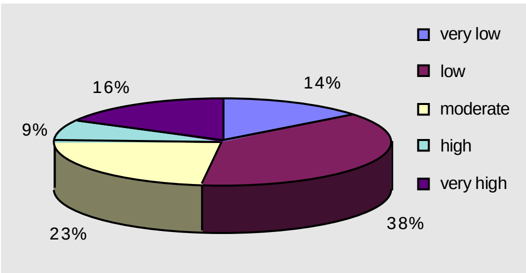
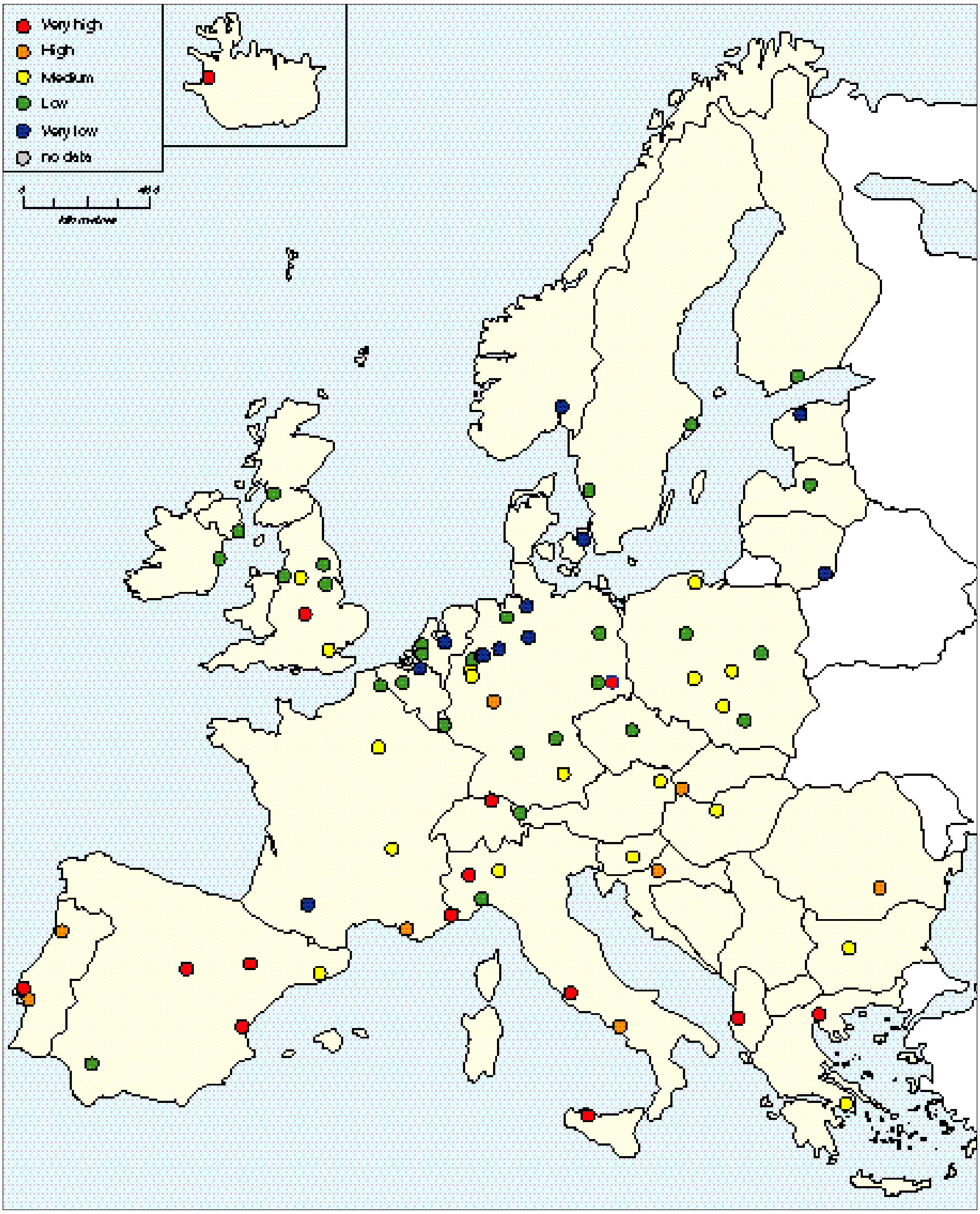


Figure 5.2
Distribution of city population densities in five classes



Map 5.1
Distribution map of cities showing population density classes

solely by the broad climatological situation. Characteristics of the local topography, man-made and natural, and including building height and density, mountains and hills, lakes, rivers and sea, and vegetation, all affect the movement of air masses and cause turbulence. The dilution and dispersal or accumulation of pollutants emitted into the urban airshed are ruled by atmospheric stability and wind velocity. The mixing depth, which is the thickness of the atmospheric layer taking part in the dispersion, varies with weather conditions and is influenced by the heat production of the city itself. Certain topographic configurations support the formation of low-level temperature inversions, creating highly stable air layers of low depth near the ground, leading to smog events *(Box 5)*.

Box 5: Seasonal Smog Episodes

- **Summer smog:** A complex chain of photochemical reactions involving the primary pollutants NO_x and volatile organic compounds (VOC) takes place in the lower atmosphere, induced by solar radiation, and produces excess amounts of the aggressive oxidant, ozone (O_3). The speed of O_3 generation depends on the amount of insolation; in warm and sunny climates it takes place more rapidly. In situations where the primary pollutants react at a slower rate, the precursor substances will be transported away from their emission sources, while the O_3 generation continues. In those environments with high nitric oxide (NO) concentrations, for example, near major roads with high levels of vehicle exhaust, the O_3 is used up in the oxidation of NO to nitrogen dioxide (NO_2). However, in rural environments which show otherwise generally better air quality, O_3 accumulates in the lower layer of the atmosphere.

  Under certain topographic and climatic conditions, which make it impossible for the O_3 precursors to escape the urban environment, summer smog is experienced in city centres. For example, Athens and Barcelona are surrounded by hills and close to the coast, where sea-land breezes recycle polluted air. They frequently suffer long and heavy smog episodes. A short-term reduction of road traffic in urban areas under summer smog conditions would limit NO concentrations and consequently inhibit the O_3 removal process in city centres. Hence O_3 levels in densely populated central areas would rise temporarily, whereas the O_3 formation in suburban areas would be reduced immediately. The distances over which precursor substances are transported vary from a few to several hundred kilometres, and thus elevated O_3 concentrations can occur in the suburban and rural areas downwind from a city centre in the so-called city plume, and even in another country.

- **Winter smog:** The pollutants involved in episodes described as winter smog are a mixture of SO_2, NO_x and particulate matter (PM), generated predominantly in the combustion of oil, coal, lignite and wood for domestic heating or industrial and power generation facilities, or from petrol and diesel oil used by road transport. In adverse weather conditions these pollutants accumulate in the lower atmosphere under the influence of persistent high pressure systems over the European continent (anti-cyclonic conditions), when low wind speeds and temperature inversion restrict the mixing depths often lasting for several days. A temperature inversion is characterised by a layer of cold air which blankets warmer air near the ground, where the trapped pollutants reach dangerously high concentrations without being dispersed. These situations occur most frequently in cities such as Krakow and Ljubljana which are located in river valleys or surrounded by hills or mountains. It is interesting to note that in many parts of Europe, SO_2 concentrations remain low even during conditions which, in the past, have led to high levels of SO_2 and PM. For example, in the Netherlands, only PM concentrations are now used as an indicator for winter smog type episodes. In addition to these local, fairly restricted pollution episodes, when a city suffers the accumulation of "its own" emissions, long-range transboundary transport can move polluted air masses for long distances *(Chapter 6)*.

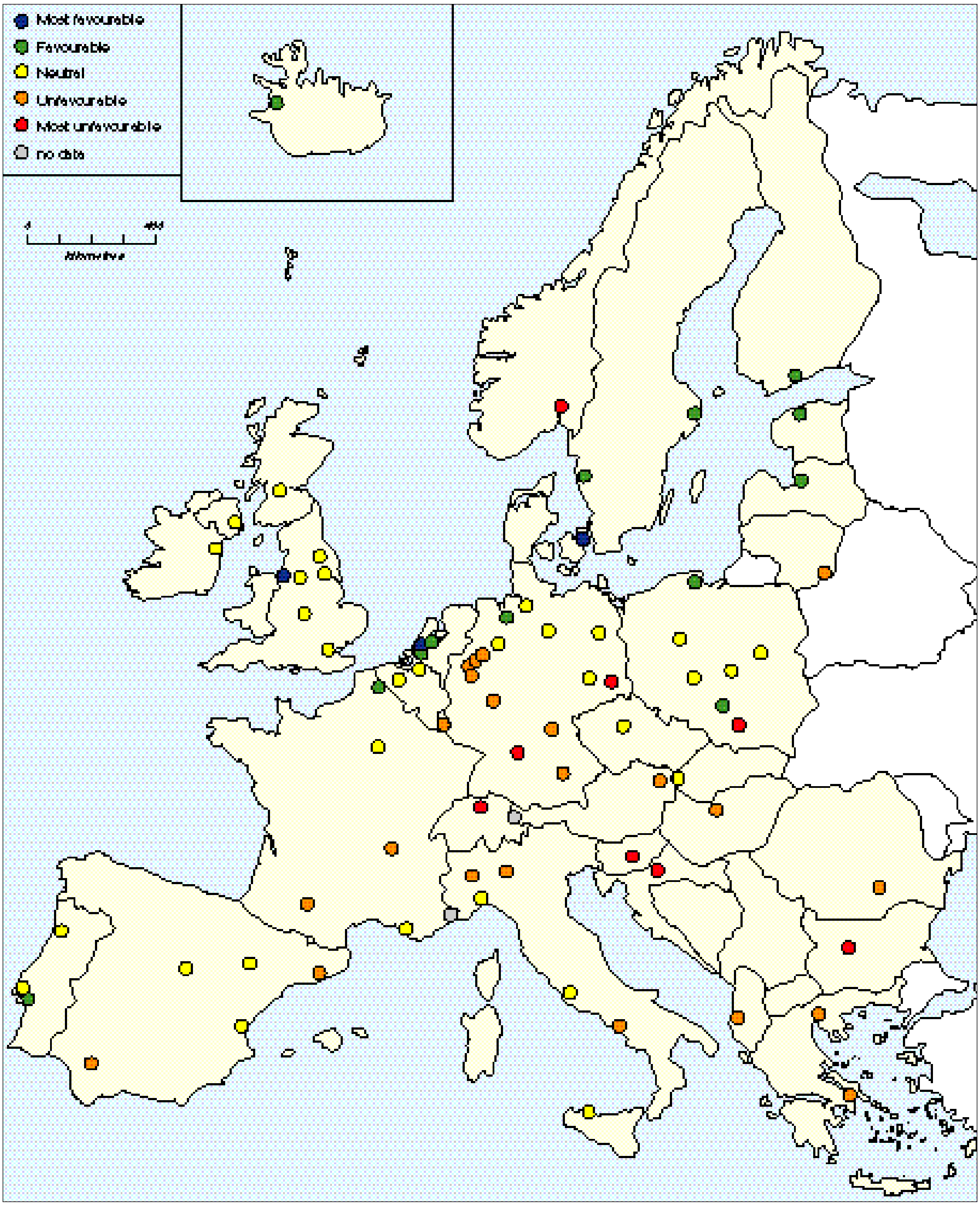
It is important to note that for both types of pollution event, long-range transboundary transport of more stable compounds can be responsible for elevated concentrations, but it is local emissions which almost always contribute to poor air quality in situations when guideline values are exceeded. Thus, local air quality management should take the potential occurrence of these episodes into account and increase and manage air quality to an extent which leaves a margin for pollution impacts outside local control, in order to ensure that breaches of limit and guideline values do not arise.

The Average Dispersion Index

The wind speed, together with the wind direction and the local and regional topography determine the average dispersion. Topographic characteristics have a long-term to permanent influence on the dispersion capacity, whereas the impact of meteorological conditions tends to be temporally restricted and follows seasonal patterns with significant variations. For the calculation of the average dispersion index, the very general indicator of annual average wind speed is used in this study. Annual average wind speeds have been grouped into five classes ranging from the least favourable for dispersion – less than 1.9 m/s – to the most favourable – >5.0 m/s. For the topographical component of the average dispersion index, the five siting classes used by RIVM (1995a) were used and also ranked from most favourable to most unfavourable *(Table 5.2)*. Descriptions of the impacts on dispersion associated with these topographic sitings are summarised in *Table 5.3*.

Topographic siting classes		**Description of topographical types**
most favourable	++	coastal (C), coastal-plain (C,P)
favourable	+	plain (P)
neutral	o	coastal-hills (C,H), plain-river basin (P,RB), plain-hills (P,H)
unfavourable	–	coastal-valley (C,V), river basin (RB)
most unfavourable	– –	valley (V), river basin-hills/valley (RB,H/V)

Table 5.2 Topographical Siting Index (after RIVM, 1995a)



Map 5.2
Average Dispersion Index for investigated cities

The average dispersion index for the cities was calculated as the mean of the wind speed index and the topographic siting index; the results are presented in *Map 5.2*. As can be expected, wind speeds tend to be higher in coastal regions and in flat landscapes, whereas hills and mountains restrict the movement of air masses. For many cities the wind speed classification and the topographic siting index are similar, but for several southern European agglomerations, such as Milan, Valencia and the Setubal Peninsula, wind speeds are low and the siting index is more favourable. The distribution of the average dispersion index shown in *Map 5.2* emphasises the generally more favourable values obtained by cities in coastal areas and the northern part of Europe. In the densely populated Rhine-Ruhr valley and in mountainous central European regions the dispersion index values are more unfavourable.

Emission Indices

The importance of the emission density for air quality and the potential development of pollution episodes has been pointed out in previous chapters. Different emission sources contribute specific compounds and seasonal variations in amounts, and composition of pollutants are often experienced. The UK Advisory Group on the Medical Aspects of Air Pollution Episodes investigated human health effects caused by the exposure to mixtures of air pollutants and identified three types of smog events common in the UK, which are also prevalent in the rest of Europe (AGMAAPE, 1995):

- summer smog, where the photochemically produced ground level ozone (O_3) is used as an indicator,
- vehicle smog, characterised by heavily elevated concentrations of oxides of nitrogen (NO_x) originating from vehicle exhaust and
- winter smog, the indicator pollutants being mainly sulphur dioxide (SO_2) and, to a lesser extent, oxides of nitrogen generated in the combustion of fossil fuels.

Since these air pollution episodes occur in periods of low dispersion the accumulation of particulate matter in the atmosphere, leading to dangerously high concentrations, may occur during all three types.

The indicators describing the smog formation potential due to the specific pollutants, were derived from local emission densities divided into five classes using the method outlined earlier and summarised in *Table 5.1*. Emission densities used for the calculation of summer and winter smog indices were calculated either from data supplied by the cities in the questionnaire survey, or they were estimated, differentiating between the three source categories: industry/power generation/ industrial solvent use, transport, and non-industrial combustion processes/solvent use.

Relevant Pollutants

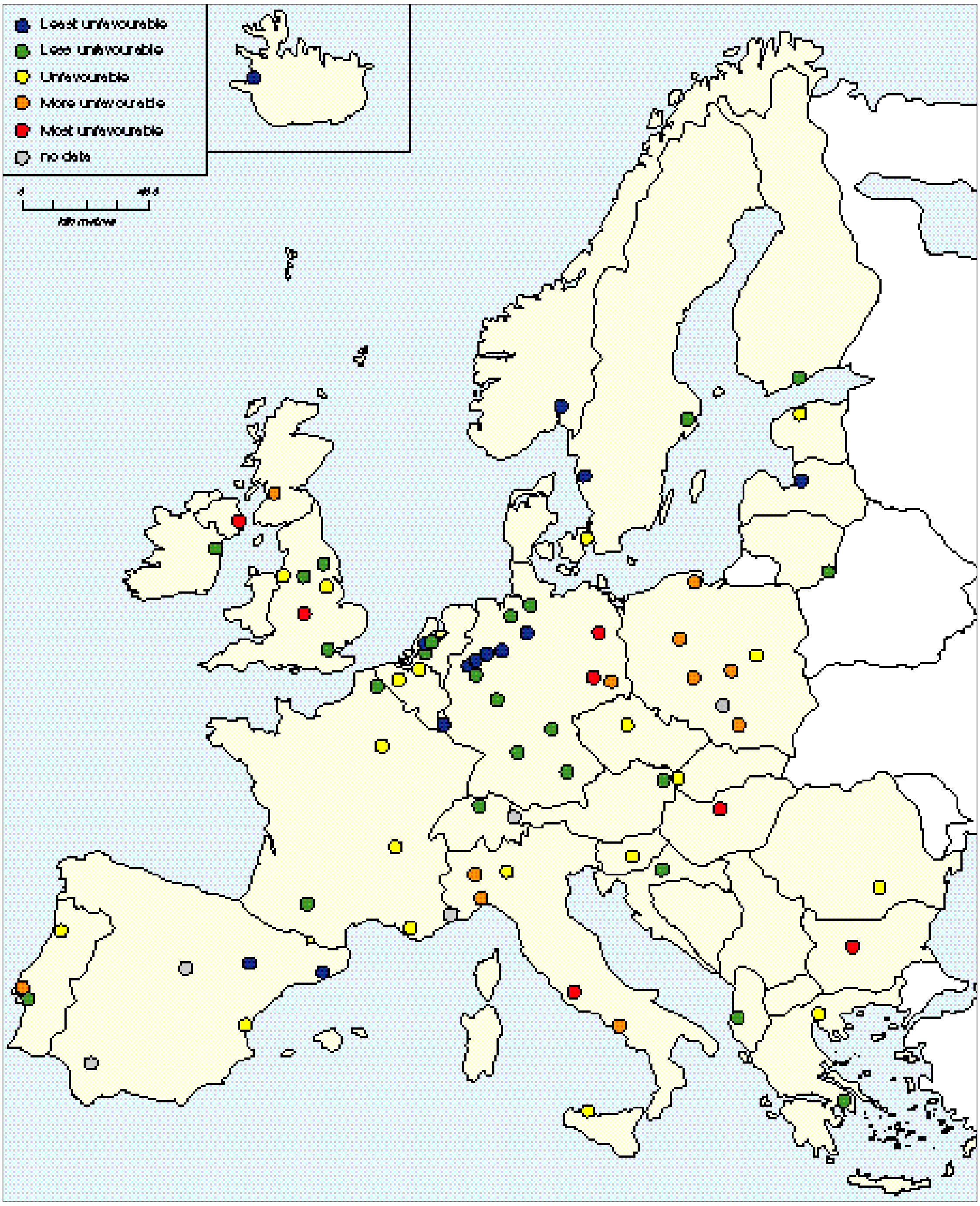
The substances, which have been identified as indicators for the different types of smog episodes formed the basis for the determination of the smog emission indices. If available, emissions data for both SO_2 and particulate matter (PM) were used in the calculation of the winter-smog index for each city *(Map 5.3)*, otherwise the single compound for which emissions were known was used.

Summer smog type emission indices *(Map 5.4)* were calculated from emitted amounts of VOCs and NO_x, while VOCs were weighted with a factor two (RIVM, 1995a). The predominance of road traffic as a source for NO_x and carbon monoxide (CO) pollution in cities has been shown in *Table 2.2* and *Figure 2.2*. Thus, both or either of these compounds, depending on data availability, can be used to calculate a vehicle smog type emission index.

Flat plain	(Flat or undulating) No local wind effects to be expected.
Coastal	Coastal cities will be influenced by land/sea breeze systems during the summer half year in situations characterised by high pressure on the synoptic scale. Average wind speed is generally higher than it is for inland locations.
River basin	In the river basins diurnal local wind systems may develop. The driving forces for local/scales winds diminish in situations with cloud cover. Stagnant air and inversions may develop at night and during the winter half year.
Valley	Horizontal winds are channelled along the valley axes. Local wind systems may develop as a result of differential solar heating of mountain slopes. Persistent stagnant air and inversions may develop at night and during the winter half year.
Hills	Hills at one side, the city is located on a plain. Local wind systems may develop as a result of differential solar heating plain/hill slopes. Average wind speed can be relatively low if the hills are located upstream of the main wind direction.

Table 5.3
Expected effects of siting on dispersion characteristics (RIVM, 1995a)

Diesel exhaust can be an important contributor to smog

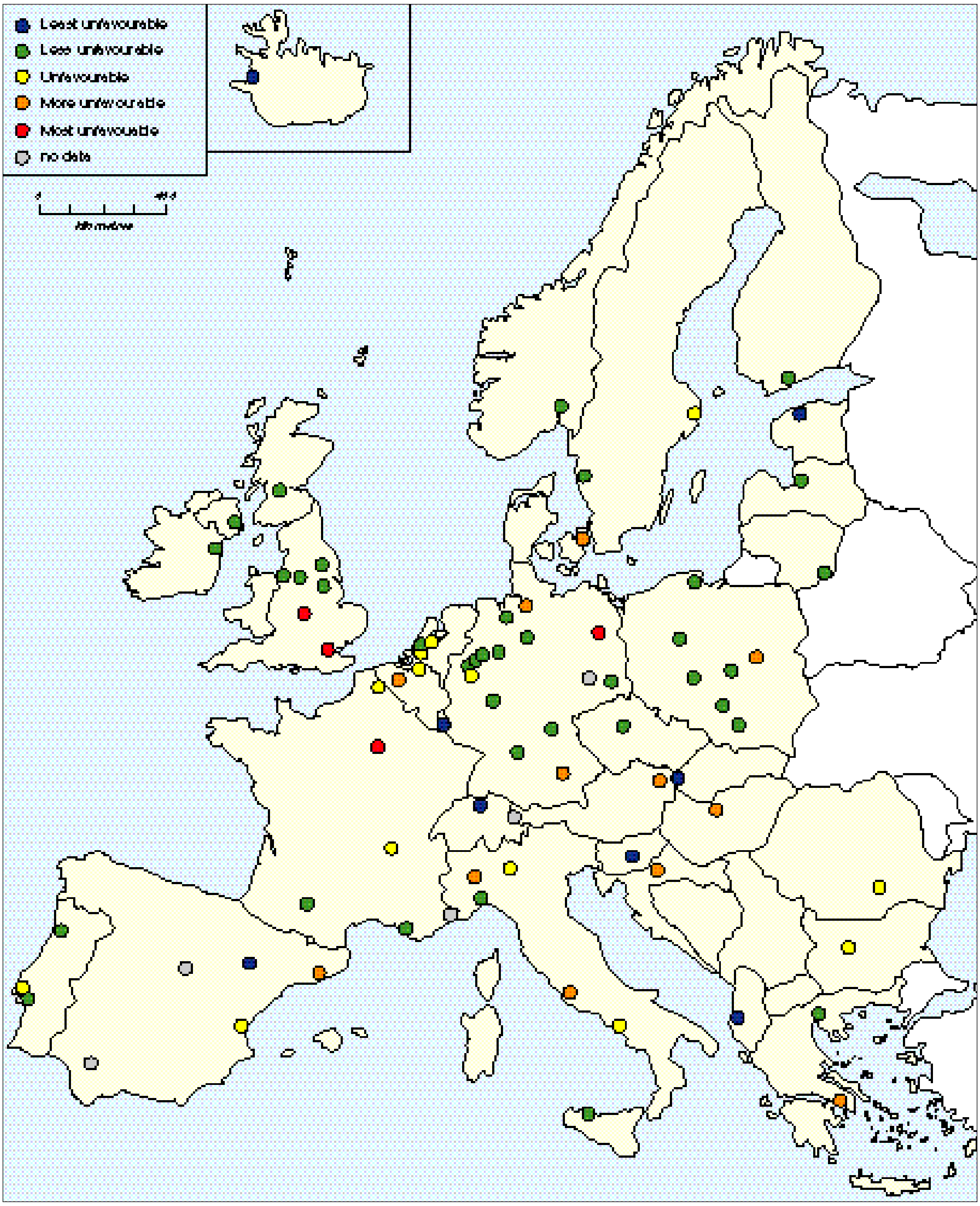


Map 5.3
Winter Smog Emission Index for investigated cities

Occurrence of Emission Source Classes

The distribution maps of emission classes enable a comparison between Europe's major cities, and show that high emission rates of those compounds responsible for the formation of winter smogs occur in those cities in the eastern region of Germany, Poland and the UK where coal combustion is widely used for energy production *(Map 5.3)*. The summer type smog emission index does not exhibit any regional preference. However, emissions of pollutants relevant in photochemical reactions tend to be especially high in the largest cities, such as Athens, Berlin, London, Paris and Rome *(Map 5.4)*.

The vehicle smog emissions indices calculated for the two pollutants NO_x and CO show good correlation for most cities, which confirms that both compounds are useful for the assessment of



Map 5.4
Summer Smog Emission Index for investigated cities

vehicle emissions *(Appendix 3)*. The number of results for emissions of either NO_x and/or CO was limited and was available for only 40 cities. It was also judged that there were significant variances in data quality that probably influenced the results; it is concluded that a pan-European assessment is currently impossible. The available emission data for Tallinn, for example, relates to stationary sources only, which explains why very good results are achieved. Overall, cities with high traffic densities, such as Athens, show high vehicle smog emission indices, whereas cities in eastern Europe with lower traffic density are expected to be less affected. It is worth noting, however, that poorly maintained vehicles can significantly raise emission levels in a city even though traffic density may not be particularly high. Lower than expected vehicle smog potentials found for London and

Paris could be explained by the relatively good public transport systems in both cities, which reduce road traffic. A more detailed investigation, enabling the differentiation between stationary and mobile emission sources for all cities is necessary.

Emission Control Strategies

Various cities have undertaken considerable efforts to curb emissions on a local level. Since mobile sources and, in particular, road traffic have such an enormous impact on urban air quality, attempts are being made to encourage a shift away from individual passenger cars to more environmentally friendly modes of transportation. Mass public transport schemes, pedestrian areas and the designation of safe cycling routes are options that are being employed in the attempt to improve air quality. In addition to the emission reduction, lower noise levels, less congestion and accidents are direct gains. Although the EU-wide development and use of alternative fuel vehicles still has to be considered minimal (COM(95) 624, 1995), the motor industry, particularly in Italy, are carrying out major work on the design electric vehicles and cleaner buses. Several cities, including Vienna and Sheffield, have introduced electrically-powered public transport systems. London unfortunately withdrew its electrically-operated tram and trolleybus system in the 1950s.

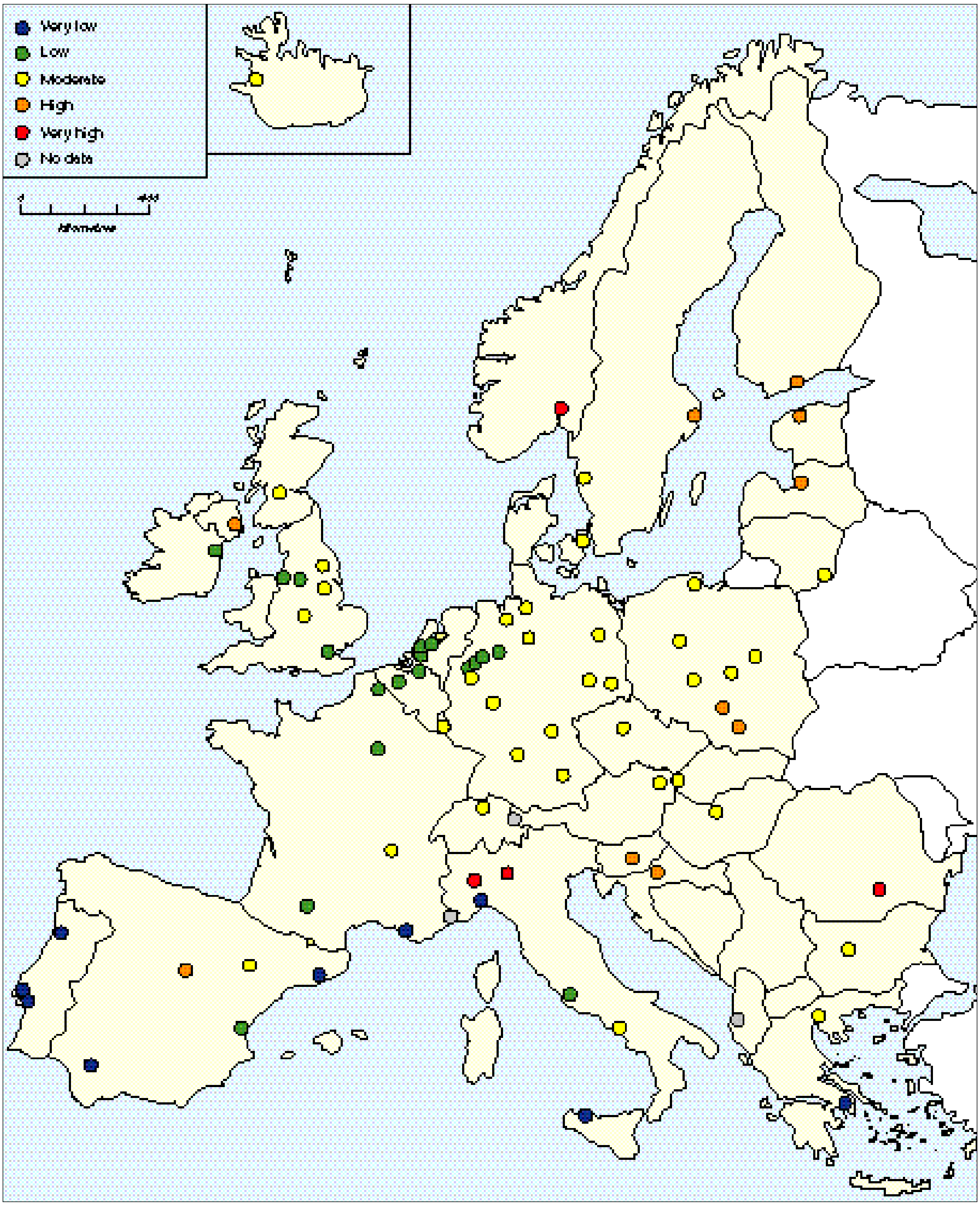
Super-trams, such as this in Sheffield, can help to relieve air pollution in cities

Experience with the construction of new ring roads, aimed at reducing congestion in inner cities by diverting the traffic, has often shown that these roads attract more vehicles and thus create additional problems rather than solving any (Elsom, 1996). The Dublin Transport Initiative consists of a comprehensive long-term transportation strategy dealing with all modes of surface transport. The enhancement of public transport and interchange facilities, traffic management measures and road projects will cost over 800 million ECU, of which the last element will only receive just under half. Priority lanes for buses and taxis have been established in many cities, such as London, Athens and Hamburg. Furthermore the expansion of safe and attractive cycling networks has been integrated in traffic management plans of various cities, although this solution is generally only adopted by cities in the northern part of Europe. In Athens, infamous for its photochemical smog episodes caused by vehicle traffic, the construction of a metro system and renewal of the bus fleet will be major steps towards better air quality, once the systems are in operation.

A further option is a reduction in the vehicle accessibility to inner cities; this can be achieved by control of entry under certain conditions or the restriction or introduction of high charges for the use of parking space. In this context park and ride systems form a reasonable alternative to private cars. Optional schemes which support the commuter's use of public transport have been introduced by several companies, such as offering interest-free loans for season tickets to the employees or restricting parking space on the company ground. Strict speed limits of 30 km/h have been enforced in residential areas in many German cities, redirecting through traffic and reducing local congestion.

Development and Use of Smog Potential Indices

In addition to pollutant emission densities, topographic setting and average wind speed, several meteorological characteristics influence the formation of smog. To facilitate the assessment of frequencies of air pollution episodes during the summer and/or winter season, indices termed meteorological smog potentials were developed (RIVM, 1995a). The accumulation of regionally or locally produced emissions in the atmosphere of a city is, to a large extent, determined by the local meteorology. The smog potential is the probability of the occurrence of situations that favour the development of stable, low dispersion conditions and is thus a number between 0 and 1. If pollution

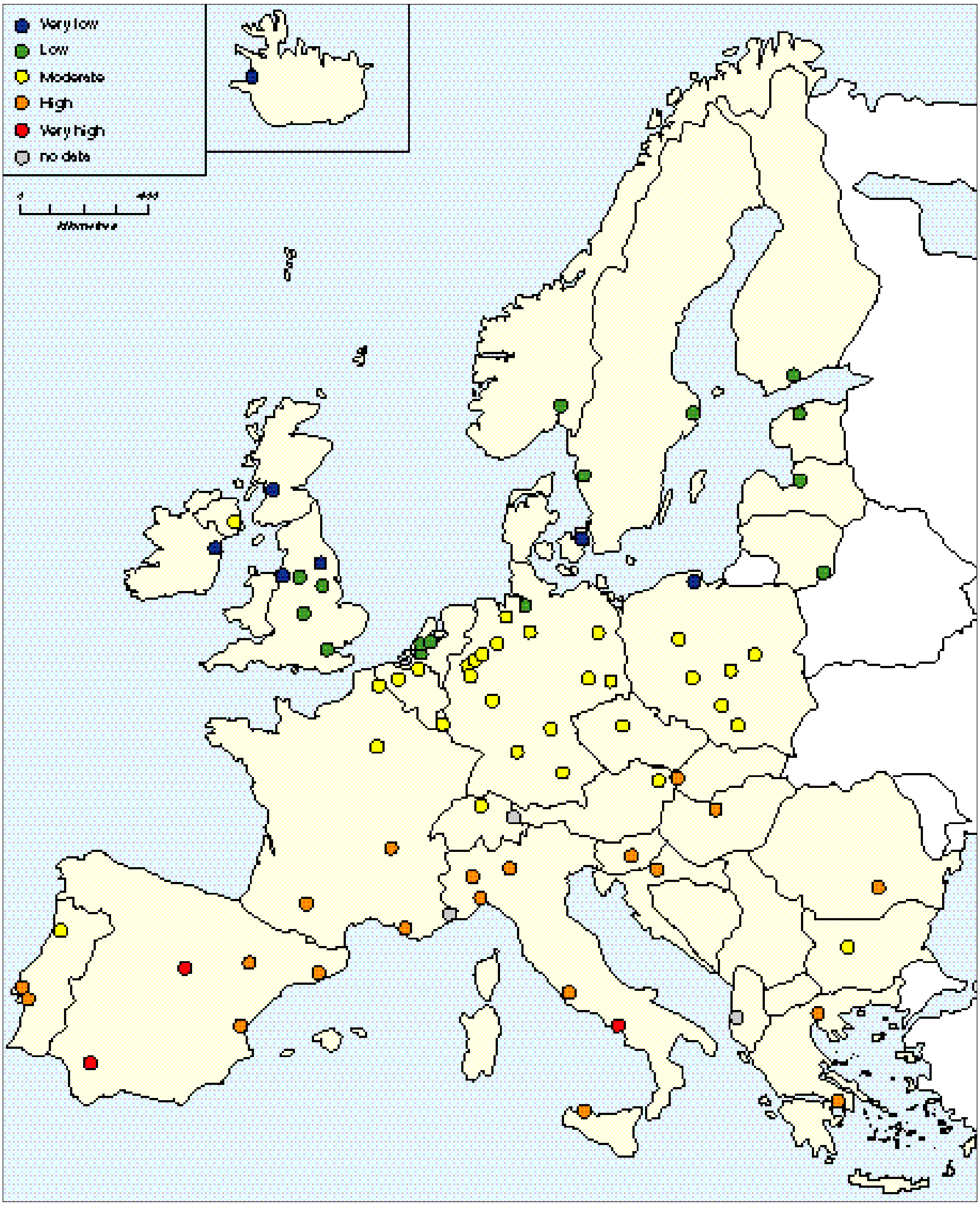


Map 5.5
Meteorological Winter Smog Potential Index for investigated cities

accumulation is very likely to occur the smog potential takes a value near 1, a value near 0 indicates situations where smog episodes are unlikely. Seasonal differences in prevailing weather conditions responsible for the specific smog formation necessitate a division of the year into a summer and winter half-year, lasting from 1 April to 30 September and 1 October to 31 March, respectively. Vehicle smog forms during stable weather conditions independent of the season (AGMAAPE, 1995).

Meteorological Winter Smog Potential Index

Winter smogs occur when emissions are not vertically or horizontally diluted and pollutant concentrations in the near ground atmospheric layer rise quickly. Energy demand for space and domestic heating is high when outdoor temperatures are low and thus pollutants are emitted in large amounts. Precipitation would bring about scavenging of accumulated pollutants from the atmosphere, but does not typically occur under these conditions.



Map 5.6
Meteorological Summer Smog Potential Index for investigated cities

The four meteorological conditions with predominant impact on smog formation during the winter half-year are:

- high atmospheric stability (described by the Monin-Obukhov length),
- low precipitation,
- low temperature and
- low wind velocity.

The probability functions of these factors are combined to form the overall meteorological winter smog potential, rated in five classes between very low and very high (RIVM, 1995a).

Map 5.5 clearly shows that the meteorological winter smog potential is lowest in many southern European cities where high average annual temperatures prevail. However, this may be an oversimplification as, for example, Milan, Madrid and

Valencia do experience winter smog under particular climatic conditions. Cities in western Europe, which are located in coastal areas with higher wind speeds, also possess more favourable conditions. Towards eastern Europe meteorological parameters become more unfavourable, indicating that the probability of winter smog formation in this region is higher.

An improvement of the accuracy of the index could be achieved by using the temperature-lapse rate near the ground rather than the Monin-Obukov length and replacing annual average temperatures by values for winter months only. At present, such data are not widely available but should be considered for future investigations.

Meteorological Summer Smog Potential Index

During the summer half-year, high pressure systems bring spells of sunny, warm and wind-still weather to Europe. Since high temperatures and prolonged insolation enhance photochemical reactions in the lower troposphere, causing the rapid formation of ozone, and the wind velocity in combination with the diameter of an urban area determines the residence time of an air parcel in the urban airshed, the probability function for the meteorological summer smog potential contains the following four components:

- maximum temperature,
- cloudiness,
- residence time and
- wind velocity.

Examination of the distribution of summer smog potential index categories over Europe *(Map 5.6)* shows an obvious gradient with lower potentials in the Nordic countries and the northern parts of western and eastern Europe and a distinct increase towards highest potentials in the south. This picture is to be expected since temperature and solar radiation is higher in the southern European region. The influence of the wind velocity can be seen, for example, in Madrid and Naples where lowest average wind speeds and highest meteorological summer smog potential occur. The same relation can be observed for the Nordic countries.

While concentrating on the meteorological summer smog potential associated with each European city, it has to be remembered that the ozone formation process more often than not gives rise to dangerously high concentrations at some distance from the original pollution source. This turns management and control of the problem into a complex task which often requires international agreements *(Chapter 6)*.

A band of pollution spreads across the evening sky over Manchester

Index Performance

The indices described and applied in the earlier sections were designed to enable a comprehensive and easily understandable assessment of the various impacts on air quality. A comparison of a combination of these indices with the actual air quality situation in the investigated cities *(Chapters 6 and 7)* will show that they are capable of representing the issue in an appropriate manner. By calculating, on a city-by-city basis, the mean of the results for three components:

i) average dispersion index,
ii) summer/winter smog emission index, and
iii) meteorological summer/winter smog potential,

it is found that, for many cities, an estimated smog occurrence index is very similar to the observed value.

A comparative assessment of the vehicle emissions index and the occurrence of vehicle smog episodes is not possible from the available material as information would be needed on simultaneously elevated levels of NO_x and CO to confirm the traffic related source of the pollutants. However, it would, in future, be interesting to collate traffic data, such as traffic density, technical and maintenance standard of the vehicle fleet and travelled mileage, as an independent assessment of traffic-related pollution; this should correlate with vehicle smog occurrence in cities and with elevated NO_x and CO concentrations, and thus confirm the relevance of these compounds as indicator emissions for vehicle smog episodes.

Smog at dusk over Paris

For about 85% of the cities, the difference between calculated and reported winter smog occurrence lies within plus/minus one class. Results for measured and estimated summer smog occurrence differ more significantly than for winter smog, but the variation was less than one class for over 65% of the cities where sufficient information was available. *Figure 5.3* shows the number of cities in each class of smog occurrence difference, attained by subtracting the monitored value from the calculated index. More cities achieved negative results which indicates that the calculated indices are more likely to underestimate summer and winter smog occurrence.

Divergence between predicted and calculated winter and summer smogs can be caused by a wide variety of factors, including unrepresentative data for emissions and/or maximum pollutant concentrations or the impact of specific local conditions on summer and winter smog formation, which cannot be assessed by the three indices used. Material used for the calculation of the indices frequently relates to years other than those when smog occurrences were observed; thus, annual variations may give rise to the differences found. The poorer correlation of calculated and observed results for summer smog episodes may be explained by the strong impact of meteorological conditions on ozone formation. In years where cities experience hotter and sunnier summers, high ozone concentrations and frequent exceedances of guideline values are recorded, whereas in cooler years fewer summer smog episodes occur (AEAT, 1996). Another explanation for the differences could be offered by the fact that calculated indices are based on annual average emission values, which might not be representative of the emissions during a particular episode.

For Prague, significant under-estimations of both smog occurrences were found. Pollution episodes were reported for both the summer and winter half-year, whereas the calculated indices indicated only a moderate likelihood of smog conditions. Data used for emission estimates and summer smog occurrence for 1994 were taken from a recent report (CHMI, 1995), winter smog data were available for 1993 (ETC-AQ, 1995) and the dispersion index and meteorological smog indices were calculated for the period 1985–1989 (RIVM, 1995a). The fact that both calculated smog indices do not represent the actual situation indicates that dispersion conditions during pollution episodes differ significantly from the theoretical average dispersion index. A more detailed assessment of the relevant meteorological data in combination with recent emission and air quality data could explain the divergence.

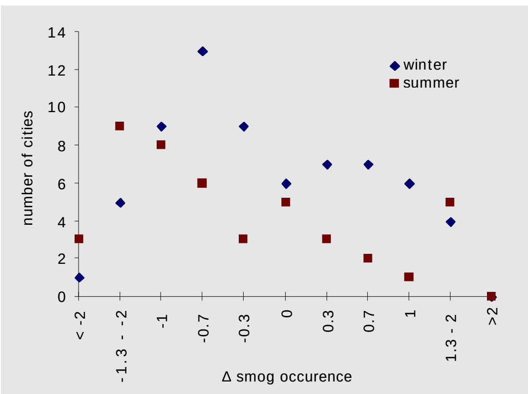


Figure 5.3 Comparison of calculated and monitored smog occurence

Case Studies

In this section the different indices developed and assessed for all major European cities will be discussed in more detail using the examples of ten cities. These cities were selected because of their widely varying characteristics and their location in

Index/City	Barcelona	Belfast	Bucharest	Gothenburg	Hannover	Lisbon	Paris	Rome	Vienna	Warsaw
Population Density	3	2	4	2	1	5	3	5	3	2
Topographic Siting	3	1	2	1	2	3	2	3	5	2
Wind Speed	4	4	5	2	3	4	3	3	3	3
Average Dispersion	4	1	4	2	3	3	3	3	4	3
Winter Smog Emissions	1	5	3	1	1	4	3	5	2	3
Summer Smog Emissions	4	2	4	2	2	3	5	4	1	4
Vehicle Smog Emissions	1	2	3	2	3	5	3	-	3	2
Meteorological Winter Smog Potential	1	4	5	3	3	1	2	2	3	3
Meteorological Summer Smog Potential	4	3	4	2	3	4	3	4	3	3
Winter Smog Occurrence	3	4	3	1	3	2	2	3	2	2
Summer Smog Occurrence	5	1	–	1	5	4	4	2	5	2
Δ Winter Smog Index	-1	0	1.0	1.0	-0.7	0.3	0.7	-0.7	1.0	1.0
Δ Summer Smog Index	-1	1.7	–	0.0	2.3	-0.3	-0.3	-0.3	-1.3	1.3

Table 5.4 Summary of Index results for the 10 case study cities

different regions of Europe. Furthermore all ten cities responded to the questionnaire survey and will thus also be used as case studies in *Chapter 9*, to explain the air quality management and assessment index. *Table 5.4* contains a summary of the index values as developed in the previous sections of this chapter. Data were mainly taken from 'Air Quality in Major European Cities' (RIVM, 1995a,b) and updated where new information was available.

Barcelona

Statistical Summary

Country: Spain
Population: City – 1,687,000
Conurbation – 3,097,000 (1995*)
Map Reference: 41°25'N, 2°10'E
Area (km²): Built-up area – 91
Conurbation – 457

* date of census/reference, see Appendix 2.

Situational Analysis

Barcelona is situated in north-eastern Spain on the Mediterranean coast bordered by a mountain range on the landward side. The climate is typically Mediterranean with a dry hot summer. There is no prevailing wind direction and average wind speeds are low 2.0–2.9 m/s (Class 4).

Air Quality Risk Assessment

The reasonably favourable coastal location for dispersion is countered to some extent by generally low wind speeds particularly in summer months, which could be exacerbated by recirculating sea-land breezes. Thus the dispersion index is rated as unfavourable (Class 4). The meteorological conditions in the winter are, however, relatively favourable and there is little likelihood of conditions leading to the build-up of winter smog pollutants. Conversely, in the summer, the periods of prolonged hot sunny periods with low wind speed make summer smogs highly likely (Class 4).

Sulphur dioxide emissions are very low, particularly as in winter there is little requirement for space and domestic heating. The major incinerator, burning 1,000 t of municipal waste daily, has a chimney height of 98 m and is equipped with an electronic filter system. The major thermal power stations burn fuel oil and natural gas and have tall stacks of 80–200 m. The winter smog emissions index is in the least unfavourable class although the trend for SO_2 is upward. In summer, vehicular emissions provide major outputs of NO_x and CO and lead to summer smog emissions, giving an unfavourable Class 4. A factor increasing the likelihood of air quality problems is the high population density of Barcelona of 6,074 inhabitants/km^2 which implies high emission densities.

The exceedance classification of Barcelona for winter smog periods is relatively high with exceedances observed of 1–3 times the Air Quality Guidelines (Class 3). This is rather surprising considering the low emissions and the prevailing winter climatic conditions. A detailed investigation on the reasons for these values would be worthwhile particularly as SO_2 levels are reported to be increasing. In summer the exceedances are close to prediction, with the poorest index rating giving indications that exceedances of EU short-term ozone threshold values by some 3–5 times the Air

Quality Guidelines have been observed. It is estimated that over 66% of the population are affected by O_3 levels in excess of 180 µg/m^3, with concentrations possibly up to 270 µg/m^3, and that over 66% of the population have been exposed to maximum NO_2 levels in excess of 200 µg/m^3.

Barcelona reports several local policies to reduce air pollution, with all new industry required to present an environmental impact report and an inspection programme for already established industry. All domestic/space heating systems must carry a certificate of yearly inspection. There is an environmental control service that controls the emissions from cars in the city.

Belfast

Statistical Summary

Country:	United Kingdom
Population:	City – 295,000
	Conurbation – 392,000
Map Reference:	54°40'N, 5°50'W
Area (km^2):	Built-up area – 106

Situational Analysis

Belfast is situated on the east coast of Northern Ireland and lies in an enclosed basin where hills on the west act as a barrier to dispersion. The climate is classified as moderate, coastal with a mild winter and warm summer and no dry season. Hot sunny spells are rare but can cause photochemical smog formation whilst low wind speeds can hinder the dispersion of emitted primary pollutants. The prevailing wind direction is westerly (SSW-NNW 59%, 17% still, 24% other directions).

Air Quality Risk Assessment

Factors which influence the risk of serious air quality problems in Belfast include the coastal location and prevailing wind direction which will generally disperse emissions away from the city out to sea in a westerly direction. However, the western hills surrounding the city and the east coast location protect the city from strong westerly winds and give a low average wind speed (the wind speed index is an unfavourable 2.0–2.9 m/s). These conditions lead to a Class 3 dispersion index which indicates that climatic and topographic conditions are average for the dispersion of air pollutants away from the city.

A favourable factor is that Belfast has a relatively low population density of 2,783 inhabitants/km^2. However, the pattern of fuel use in Belfast is far from favourable since approximately 70% of homes use coal for heating (compared with 12% in the UK as a whole) and similarly the main power generation station is fuelled by bituminous coal with an annual consumption of 341,305 t/a (1990–91). This places Belfast in the most unfavourable winter emissions category (Class 5) whilst the summer emissions index is considerably less unfavourable (Class 2). Vehicular emissions in Belfast are classified as fairly low.

With an average dispersion index it can be expected that, under particular weather conditions, the high level of emission from coal burning will lead to pollution episodes. Closer examination of the meteorological data indicates that there is a high meteorological potential for winter smog due to periods of climatic stability and a medium potential for summer smog. Regionally this places Belfast as an outlier since these values are more typical of central and eastern Europe.

The high level of winter emissions is thus exacerbated by the high meteorological winter smog potential, and this is confirmed by records of poor air quality. This is reflected in a high winter smog exceedance category (Class 4), based on 1990 data on the occurrence of highest observed concentrations of SO_2 and particulate matter (black smoke) exceeding twice the WHO Air Quality Guidelines on 6 and 8 days respectively (RIVM, 1995). In terms of the number of inhabitants exposed to these exceedances, it is estimated that over 66% of the population were exposed. For particulates it was estimated that over 66% of the population were exposed to levels over 120 µg/m^3 and up to 33% to the higher level of 180 µg/m^3.

Belfast has an on-going smoke control programme which was started in 1967 and will be completed in 1997. Since 1955, smoke levels have been reduced by around 80%. Sulphur dioxide levels dropped steadily until the early 1980s but showed a slight increase in the late 1980s (RIVM, 1995). More recent data show that since 1992/3 there have been no breaches of EC limit values, although most sites still regularly exceed guide values. The number of hours of poor air quality for SO_2 has declined steadily since 1991 (BCC, 1995).

In view of the low summer smog potential and emissions, exceedance of O_3 levels have not been observed and are unlikely to occur.

Bucharest

Statistical Summary

Country:	Romania
Population:	Conurbation – 2,388,000
Map Reference:	44°28'N, 26°07'E
Area (km^2):	Built-up area – 182
	Conurbation – 228

Situational Analysis

Bucharest is situated on a flat plain in south-east Europe, 225 km from the Black Sea and 120 km from the Carpathian mountains. It is described as having a Mediterranean climate with a dry hot summer. Average wind speeds are very light in the range 1.0–1.9 m/s.

Air Quality Risk Assessment

Factors which influence the risk of air quality problems in Bucharest include the location on a flat plain, which will favour dispersion, but this is countered by the generally low wind speeds, which will enhance accumulation of pollutants over the city. This gives an unfavourable dispersion index (Class 4). The calculated meteorological risks of summer and winter smogs are very unfavourable (Class 5) and unfavourable (Class 4) respectively. These calculations are based on the likelihood of summer and winter temperature inversions.

The emissions inventory for 1990 shows large outputs of SO_2 mainly from heavy industry and power plants. Bucharest is responsible for approximately 13% of the total industrial output of Romania. Oxides of nitrogen emissions are seen to derive primarily from industry and power plants with traffic contributing about 15% of the total. Winter smog emissions are classified as fairly unfavourable (Class 3) and summer smog emissions as more unfavourable (Class 4).

Exceedance of short-term WHO-AQG of 1–3 times AQG have been reported for winter smog but no data are available for summer smog occurrence since O_3 concentrations are not currently monitored. However, NO_2 levels above a maximum of 200 µg/m^3 are reported to affect over 66% of the population. For all pollutants, the high population density of 13,121 inhabitants per km^2 would lead to very high percentage population exposure if limits were exceeded.

Bucharest is one of the cities of the former Eastern Europe COMECON group which have only very recently introduced unleaded petrol, and cars with catalytic converters are not common. There are relatively few cars and the public transport system is well developed with approximately 1,556,700 passengers km/a by electric-powered public transport, with non-electric transport at about 310,000 passengers km/a (1990). There is also widespread provision of district heating (30%). These factors may have served to reduce the risk of poor quality air pollution in the past. Recently, with the break up of the Soviet Union and the east European economic partnership, there has been an economic downturn, which has led to a reduction in emissions. New policies include plans to modernise emission control systems and to stimulate the use of low-sulphur fuels. Access for heavy freight traffic to the city centre is restricted and more restrictions are planned. Car owners will be encouraged to install catalytic converters. Further development of central heating using natural gas and decreased reliance on wood/coal are planned.

Gothenburg

Statistical Summary

Country:	Sweden
Population:	City – 514,000
	Conurbation – 734,000
Map Reference:	57°43'N, 11°58'E
Area (km^2):	Built-up area – 132
	Conurbation – 654

Situational Analysis

Gothenburg is situated on the Gotä älv estuary surrounded by hills, with three to four valleys leading into the city centre. The climate is coastal with relatively warm summers; there is no dry season and, despite the northerly latitude, there is seldom snow or ice due to exposure to warm westerly winds. The city is an important administrative centre with major industrial activities, including the largest car factory in Sweden. In addition, there are petrochemical industries on the north side of the harbour.

Air Quality Risk Assessment

The average wind speed is favourable for pollutant dispersion and this, with the coastal location, gives Gothenburg a favourable dispersion index (Class 2). The meteorological potential for winter smog and summer smog has been classified as moderate (Class 3) and low (Class 2) respectively.

Emission inventories are available and these show that SO_2 from traffic is equal to that produced by heating, industry and power plants combined. Recorded levels of ambient SO_2 have shown a major decrease over a long period. Particulates too have declined significantly but recent levels show an increase. For NO_x, CO and VOC, the emissions from traffic are, as would be expected, by far the major source of pollution.

The total emissions are quite small and those likely to cause winter smog are rated as least unfavourable (Class 1) whilst the largely traffic related emissions give a more unfavourable summer smog emissions index (Class 2). It is interesting to note that, in 1992/3, 40% of cars already had catalytic converters. Data indicate that WHO and

EU-AQG have not been exceeded for either winter smog or summer smog-forming pollutants. The city is classified in the lowest exceedance class for both types, i.e. exceedances and exposure of the population to high pollution levels are unlikely although it is considered likely that the O_3 threshold value of 180 µg/m^3 could be exceeded.

Gothenburg has adopted numerous policies to reduce air pollution: emission constraints are placed on new or rebuilt power plants of over 50 MW output. Traffic emissions of VOC were targeted to be reduced by 40% and NO_x by 30% by 1996 compared with 1988 values, and total emissions of NO_x from combustion and space heating must not exceed 1,200 t/a.

Hannover

Statistical Summary

Country:	Germany
Population:	City – 514,000
Map Reference:	52°33'N, 9°44'E
Area (km^2):	Built-up area – 204

Situational Analysis

Hannover has a central European location on the north-west European plain in Lower Saxony. The climate is classified as coastal with warm summers with the hottest month exceeding 22°C. The lowland open location with exposure to winds from north, east and west leads to relatively high wind speeds averaging 3.3–3.4 m/s (wind speed index 3).

Air Quality Risk Assessment

The location and wind speed analysis, and the resultant average dispersion index (Class 3), suggest that the risk of poor air quality will be related to specific periods of wind-still rather than likely to occur under average conditions. A further factor reducing risk is the very low population density of 2,520 inhabitants per km^2. Climatic data indicate a medium vulnerability to both winter and summer smogs. The former is due to the winter occurrence of periods when a high pressure system above Europe persists for several days. The likelihood of these episodes increases along a W-E axis across Europe, and Hannover is typical of its region. Summer smogs also tend to occur during episodes of high pressure and low wind velocities, leading to high urban concentrations of ozone. The potential for this to occur generally increases along a N-S axis and again Hannover is typical of a central European belt of intermediate potential. Hannover is a thriving industrial city with several important industrial activities including railway engineering, cars, engines, electrotechnics, synthetic materials and food generation. There appears to be an increasing tendency for summer smogs and a reducing tendency for winter smogs, which is probably due to increasing vehicular emissions and more control of SO_2 and particulates. In 1989 there were six days in which observed levels of SO_2 exceeded WHO-AQG and 1 day of exceedance of twice the WHO-AQG. The figures for TSP were 15 and 10 days respectively. This placed Hannover in an unfavourable exceedance Class 3 for winter smogs but the available data are relatively old (1989) and further improvements are believed to have occurred. The estimated proportion of population exposed to SO_2 and particulate matter exceedances is in the 33–66% band.

For O_3 the WHO-AQG were also exceeded, with observed exceedance but of unknown number and duration of episodes for summer smogs. It is also estimated that more than two thirds of the population are affected by O_3 concentrations in excess of 180 µg/m^3.

Lisbon

Statistical Summary

Country:	Portugal
Population:	City – 1,329,000
	Conurbation – 2,000,000
Map Reference:	38°44'N, 9°08'W
Area (km^2):	Built-up area – 100

Situational Analysis

Lisbon is both the most southerly and most westerly of the cities considered in detail in this report. It has a Mediterranean climate with a hot dry summer season. The highest monthly mean temperature exceeds 22°C. Lisbon is situated on the west bank of the River Tagus and is protected to the west and north by a range of coastal mountains reaching an altitude of 866 m.

Air Quality Risk Assessment

The population density of the built-up area of Lisbon is estimated to be 20,000 per km^2 which ranks amongst the highest in Europe. The situation is less favourable than one might expect for a city so close to the Atlantic Ocean because it lies behind a range of coastal hills and effectively lies in a river valley. Wind speeds are fairly low (Class 4) on average and the overall dispersion index is rated as Class 3. The high population density gives rise to high winter, and very high vehicular, emissions; those emissions involved in the formation of summer smogs are average.

Despite the stronger winter winds, winter smogs do occur and exceedance of short-term

WHO-AQG for SO_2 has been observed; between 33–66% of the population are believed to have been affected by levels exceeding 125 µg/m^3. The risk of summer smog is substantially higher (Class 4) and maximum ozone levels reached 341 µg/m^3 in 1990, which is double the WHO-AQG and close to the EU population warning limit (1h 360 µg/m^3). It is estimated that over two-thirds of the population are affected by levels exceeding 270 µg/m^3. There is no available information on the number of days on which exceedances occurred. It is also worthy of note that the trend for NO_2 is strongly upwards, which indicates that increasing traffic in the future is likely to exacerbate current problems unless further stringent action is taken.

Paris

Statistical Summary

Country: France
Population: City – 2,189,000
Conurbation – 8,510,000
Map Reference: 48°52'N, 2° 20'E
Area (km^2): City – 105
Conurbation – 1,200

Situational Analysis

The conurbation of Paris lies in the depression of the Paris Basin. The climate is classified as a marine west-coast climate typical of western Europe. Paris is about 160 km from the coast and is therefore not directly influenced by coastal diurnal wind changes. The conurbation is surrounded by wind-shielding hills which can prevent the dispersion of air from the basin during wind-still periods and temperature inversions.

The average wind speed is a relatively strong 3.5 m/s. The strongest winds come from the south-south-west followed by north-north eastern and western winds. Wind speeds are generally lowest in summer.

Air Quality Risk Assessment

Factors that influence the risk of air quality problems in Paris include the topography of a sheltered basin but the generally high wind speed tends to assist dispersion. In the winter, episodes likely to lead to winter smog may occur, particularly in January and February. There are relatively short periods of anti-cyclonic conditions with temperatures in the range of, or slightly below, 0°C, clear sky and very light, mostly easterly winds; this combination gives rise to stable atmospheric conditions with low-altitude inversion layers which sometimes include dense low-level fog (winter smog potential Class 2). In summer, the generally lower wind speeds also provide some meteorological potential for summer smog. Emissions are particularly high in summer (Class 5) whilst the winter smog emission index is a more moderate Class 3.

These combinations of emission, climatic and topographic indices for smog potential agree with the observed occurrences of episodes of poor air quality. Exceedances of WHO-AQG were still being observed for SO_2 in the 1980s. However, SO_2 levels have been measured in Paris since the 1950s, from which point values have fallen by almost 80% and are now below the EC limit values. No exceedances have been reported recently, although exceedance and population exposure is still considered possible.

Summer smog emissions are very high, as evidenced by the need to control city traffic flows during the summer smog of 1997. Over two-thirds of the population are estimated to be exposed to NO_2 values above 200 µg/m^3 and an increase in concentrations was reported in recent years. Similarly, O_3 levels exceed EU guidelines on 1–5 days a year during which time over two-thirds of the population have been affected at the lower 180 µg/m^3 threshold and up to one-third may have been affected by the higher 270 µg/m^3 level.

Rome

Statistical Summary

Country: Italy
Population: City – 2,830,000
Conurbation – 3,710,000 (1991)
Map Reference: 41°53N, 12°30' E
Area (km^2): Built-up area – 125

Situational Analysis

Rome is situated on the River Tiber where the valley opens out on to the coastal plain. The climate is classified as Mediterranean temperate rainy. Winters are wet and summers dry due to an alternation of moist polar air masses in winter with dry maritime tropical air masses in summer.

Air Quality Risk Assessment

Rome is regarded as having a moderate situation in terms of risk of poor air quality as it is situated at the widest part of the Tiber valley and is not closely surrounded by mountains. The average wind speed is broadly within the range 3.0–3.9 m/s (Class 3). These two factors give a moderate (Class 3) dispersion index. However, in the summer months prolonged hot sunny spells provide conditions for photochemical smog and the summer drought favours episodes of dust pollution. The potential for summer smog is placed in the

Rome, through a haze of fumes from vehicles

unfavourable category (Class 4), while the potential for winter smog is low, placing Rome in the more favourable Class 2.

Rome has two major problems with respect to human influence on air quality. Firstly, the population density at 21,544 inhabitants/km^2 is very high and secondly, the traffic conditions can be extremely congested. There is a metro but it consists of only two lines. However, there is also a bus network (Roma 2000, 1996). There are no major individual industrial emissions but, nevertheless, winter emissions are rated at a very poor Class 5 and summer emissions at a poor Class 4.

Despite the fairly low meteorological potential for winter smog, the high emissions lead to observed exceedances of some 2–3 times AQG (exceedance Class 3). For summer smog, the situation is also poor, with smog classification in the highest exceedance class, reflecting the fact that ozone levels have been observed to exceed 3–5 times AQG. The built-up nature of the city and high population density means that the proportion of the population affected by ozone exceedance in the summer is estimated to be over two-thirds. Over the past few years there have been substantial reductions in SO_2 levels in Rome and hopefully this will reduce the occurrence of winter smogs. The prognosis for summer smogs is not so positive as traffic congestion is still very great.

Vienna

Statistical Summary

Country:	Austria
Population:	1,564,000
Map Reference:	48°12'N, 16°22'E
Area (km^2):	Administrative area – 415
	Built-up area – 190

Situational Analysis

Vienna, the capital of Austria, is located in central Europe on the north-east edge of the Alps, near the Pannonian Lowland. The river Danube runs through the city, which has large parks, and there are woods and hills mainly to the west. The climate is classified as transitional between marine and continental Mediterranean. However, Vienna's location in central Europe obviously reduces the marine influences, and rainfall is moderate and the summers are warm.

Air Quality Risk Assessment

Unfavourable topographic siting and average wind speed (2.8–3.0 m/s) result in a low dispersion index (Class 4). Meteorological conditions responsible for the formation of summer and winter smogs occur with moderate frequency compared with other investigated cities.

Although the city possesses a good public transport network with an underground system, trams and buses, the number of registered cars has nearly tripled over the last three decades, exacerbating road congestion and related emissions (at-net, 1996).

Emission estimates for 1990, from transport, domestic and industrial sources, lead to calculated summer, vehicle and winter type smog emission indices of very low, moderate and low respectively. Expected frequencies of winter smog and summer smog episodes are moderate and high respectively. These differ by about one class each from the observations in the selected years. In 1994, monitored ozone concentrations exceeded the EU threshold values of 180 µg/m^3 (1-hour average) and 110µg/m^3 (8-hour average between 12.00 and 20.00) on 14 and 35 days respectively; over two-thirds of urban inhabitants were exposed to these elevated concentrations. Comparably high ozone levels were also experienced in 1990 and 1992, whereas in 1993, 1995 and 1996 concentrations were significantly lower (Schneider, 1997). These exceedances are among the highest reported by European cities *(Chapter 7)*, and are clearly indicated by the high estimated summer smog occurrence index (Class 5), although the summer smog potential index was only Class 3. The calculated winter smog occurrence index was Class 2. The more frequent occurrence of summer smogs than predicted is probably due to the particularly poor dispersion of pollutants from the city during the quite frequent and long lasting periods of stable summer air conditions which occur in this part of Europe. Detailed investigations of more data and analysis of longer time series may allow the explanation of these discrepancies.

Warsaw

Statistical Summary

Country: Poland
Population: 1,653,000
Map Reference: 52°13'N, 21°01' E
Area (km^2): Built-up area – 495

Situational Analysis

Warsaw, the capital of Poland, lies in the valley of the River Vistula which flows through the city. Hills surround the city on all sides but they do not exceed an altitude of 200 m and thus present only a minor windshield. Warsaw is classified as having a humid continental climate with precipitation in all months and no dry season. The temperature range is sub-arctic with the coldest month averaging less than -3°C but with relatively warm summers where the warmest month is less than 22°C.

Air Quality Risk Assessment

The climatic typology of Warsaw can give rise to prolonged cold winter periods with stagnating air and inversions favouring pollutant accumulation whilst, in the short summer, conditions can be favourable for photochemical smog formation.

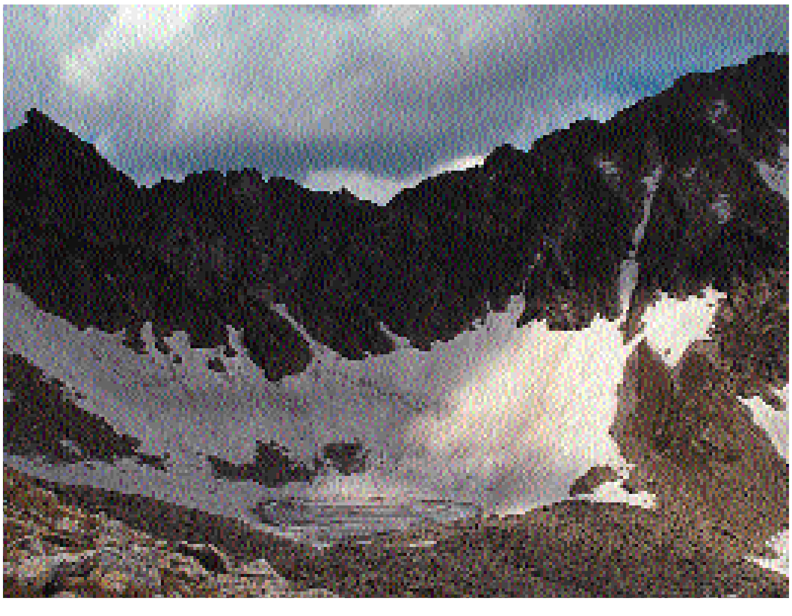
The topographical situation of Warsaw is favourable since it is surrounded by only low lying hills and this, combined with a moderately high average wind speed of 3.9 m/s, leads to a moderate dispersion index (Class 3). However, the average wind speed in some years falls into the higher category of 4.0–4.9 m/s indicating that the dispersion index may sometimes be more favourable.

The winter smog potential of Warsaw is average (Class 3) and the winter smog emissions are also classified as average (Class 3). The meteorological summer smog potential is also average but the summer smog emissions index is more unfavourable (Class 4), thus indicating an above average risk of summer smogs. The data on actual air quality conditions in Warsaw suggest that SO_2 maximum city background levels do not exceed WHO-AQG and hence the winter smog potential was not realised in the year under investigation. For summer smog the exceedance class is rated as Class 2, i.e. no days of exceedance recorded, but levels suggest that there is a possibility that they may do so from time to time.

Warsaw is an interesting example of a city from eastern Europe where the apparent potential for the risk of poor air quality is moderate but actual exceedances did not occur in the investigated year. The current population density is low; the vehicles present and their emission index is also quite low. Several cities from eastern Europe have reported reduced economic activity in recent years and this may have offered a temporary respite from smog risks. The implications of this, however, may be that the main future risk will be linked to increased standards of living which may generate increasing emissions – particularly those associated with summer smog, i.e. vehicular emissions. Any major increase would almost certainly lead to the realisation of the high meteorological summer smog potential.

Chapter 6

Long-range transboundary air pollution in Europe



Long-range transboundary pollution may be defined as pollution that arises from distant emission sources and is transported across regional and national boundaries. It is not generally possible to distinguish individual sources. Emissions from power stations burning sulphur-rich fossil fuels make significant contributions to transboundary air pollution, and regions such as the Black Triangle (Poland, Czech Republic and eastern Germany) and the United Kingdom have been identified as major sources of such transboundary pollution. The potential recipients of pollution impact extend from living resources to legitimate uses of the environment (Barrett et al., 1995). Most primary pollutants emitted into the atmosphere undergo chemical reactions and change their properties, they are then called secondary pollutants. The speed at which these reactions take place depends on various factors, such as compound concentration, availability of reactants, insolation and temperature. Average residence times of different chemical species in the atmosphere vary considerably; nitric oxide (NO), for example, is almost immediately oxidised to nitrogen dioxide (NO_2), whereas others remain unchanged for days, months and even hundreds of years. While the pollutants prevail in the atmosphere they are transported with the air masses and can affect air quality and deposition rates in regions and countries far away from their emission source.

In the Dobríš Assessment the pollutants of main importance in a European context with

Polluted snow on the Tatry mountains

atmospheric residence times between days and months and the regional pollution problems they are responsible for, were identified and are summarised below (Stanners and Bourdeau, 1995):

- Sulphur dioxide (SO_2), nitrogen oxides (NO_x) and ammonia (NH_3) are the predominant compounds causing acidification of water and soil after their deposition on the earth's surface. The scavenging from the atmosphere can occur as wet or dry deposition. Whether or not an adverse impact on the ecosystem occurs depends not only on the total deposition load, but also on its capability to absorb the pollutants, expressed as critical loads and levels *(Box3)*.
- Volatile organic compounds (VOCs) and nitrogen oxides (NO_x) are the major precursors in the formation of photochemical smogs, which are characterised by elevated levels of the aggressive oxidant, ozone (O_3).
- Aerosol particles can be primary or secondary pollutants and include solids and liquids suspended in the air covering a wide range of physical and chemical properties. The chemical composition and atmospheric lifetime of particulates depend greatly on their size and source, which can be anthropogenic or natural and show major spatial variation *(Figures 6.1 and 6.2)* (EPAQS, 1995). Harmful pollutants such as heavy metals and persistent organic pollutants are often bound to aerosol particles. The most obvious consequence of raised suspended particulate concentrations in the atmosphere is the reduction of visibility. In addition, serious effects on public health and the environment are caused by the compounds adsorbed on the particle surface. Reflection of solar radiation by the particulate haze reduces global warming.

Forest destruction resulting from acid rain

International Initiatives

Due to lack of harmonisation of national and local monitoring programs, which makes it difficult or impossible to assess environmental problems on a transboundary scale, several attempts to set up pan-European and global monitoring networks of transboundary pollution have been made. Two such networks of considerable relevance to air quality in European cities are:

- EMEP (Co-operative programme for monitoring and evaluation of the long-range transmission of air pollutants in Europe): Established to provide information about distribution, transport and deposition of pollutants responsible for acidification and VOCs on a continental scale. EMEP employs modelling tools to calculate transboundary fluxes, and a monitoring network to collect data for model control. To accommodate the request for adequate spatial coverage, distances between monitoring sites in central Europe are 150–200 km, and in other parts about 300 km. Since stations are intended to produce data representative of the whole region they cover, they are generally located at remote positions. Thus, focusing on urban air quality, EMEP sites are only relevant as providers of background pollution levels (ETC-AQ, 1995).
- BAPMoN (Background Air Pollution Monitoring Network): A network established in 1969 under the auspices of the World Meteorological Organization (WMO) for the measurement of precipitation chemistry in response to concern at enhanced rates of acid deposition. Currently, there are 152 precipitation chemistry stations throughout the world which provide useful data for the evaluation of transboundary transport of air pollutants. BAPMoN is now incorporated in the Global Atomosphere Watch (GAW)-Programme of WMO.

Other international organisations, such as the Oslo Paris Commission (OSPARCOM) and the Helsinki Commission (HELCOM) which deal with transboundary issues in relation to the North Atlantic and Baltic Sea respectively, have produced useful information relevant to long-range transport of pollutants, and member states have reached agreements on pollution reduction. The WHO/UNEP Urban Air Quality Monitoring Programme (GEMS/Air) has produced a series of assessments of urban air quality involving European cities and has developed the Air Quality Management and Assessment Capability Approach used in this report.

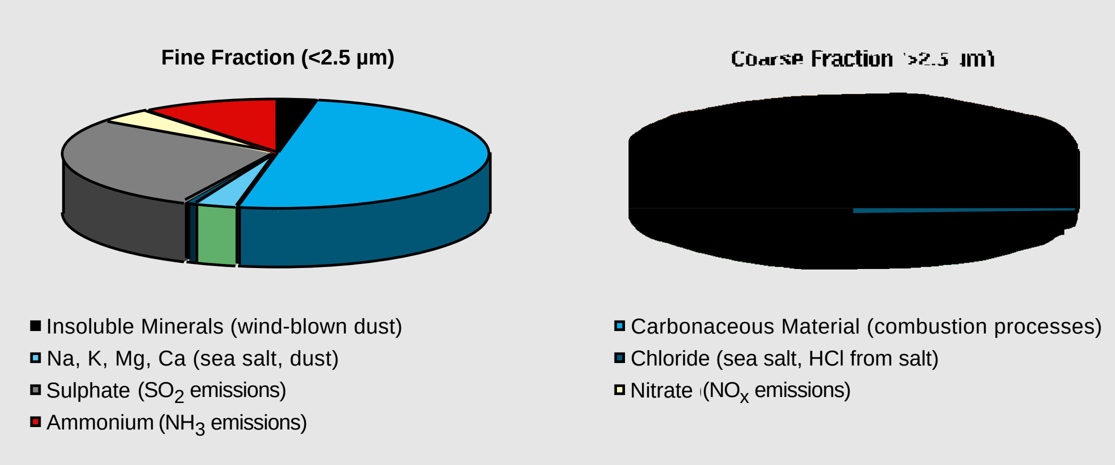


Figure 6.1
Chemical composition of particulates (EPAQS, 1995)

The topics of major concern regarding regional and transboundary pollution are acid deposition, long-term ground level ozone concentrations, photochemical smog episodes and winter smog episodes. The latter two have been identified as conditions where mixtures of air pollutants pose a major risk to human health (AGMAAPE, 1995). The recognition of these acute health effects has prompted many national and local authorities to establish smog warning systems, and several impose short-term measures to reduce emissions from road traffic and/or industry *(Figure 6.3)*. Additionally, international agreements on the reduction of the relevant pollutant levels in the atmosphere, have been ratified by many European countries *(Box 6)*.

Acid Deposition

The prime issue discussed in connection with acid deposition is the destruction of ecosystems, particularly freshwater biotopes and forests, where the critical loads of SO_2, NO_x and NH_3 scavenged from the atmosphere exceed the capacity of the environment to utilise or buffer them. *Figure 6.4* shows exceedances of critical loads for acidity in ecosystems. Calculations are based on SO_2 and NO_x depositions only. In some parts of Europe, NH_3 depositions contribute considerably and exacerbate exceedance of the critical load (RIVM/CEE,

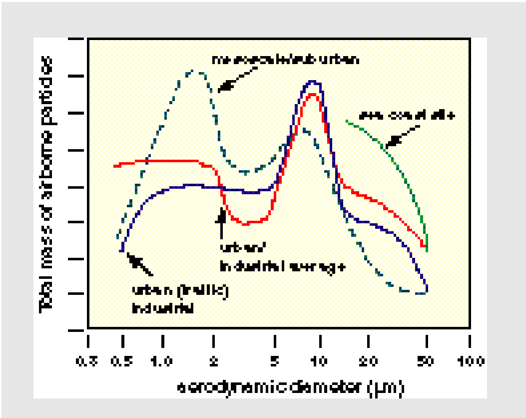


Figure 6.2
Physical composition of particulates (UNEP/WHO, 1994b)

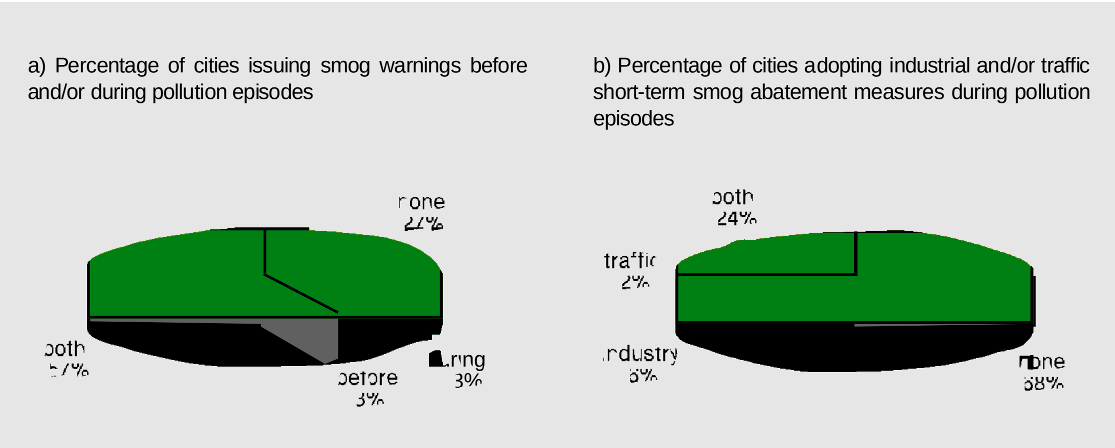


Figure 6.3
Short-term smog management measures

1995). Damage is also caused in urban areas; the pollutants attack vegetation and increase the deterioration rate of building materials and monuments *(Chapter 8)*.

The predominant emitters of sulphur are large combustion plants, responsible for 80–90% of total anthropogenic emissions in Europe. These plants, mainly power stations, industrial plants, refineries and district heating plants, are generally equipped with tall stacks. This restricts their local impacts, even though they tend to be clustered around cities, but the emissions are liable to be widely dispersed and transported over long distances. The application of emission controls at these large point sources is generally the most cost-efficient option in the reduction of total emissions. Control methods include 'end-of-pipe' flue gas desulphurization (FGD), fuel switching and increased energy efficiency. FGD is frequently applied but can be comparatively expensive and decreases the energy efficiency of the combustion plant by 1–2%, resulting in an increase of CO_2 emissions by some 2–8%. Furthermore, the environmental impacts of limestone mining, used as sorbent in the scrubbing process, and disposal of potentially contaminated waste material have to be taken in consideration since an integrated impact assessment approach should be used.

A map with the 100 largest point sources on the European continent *(Figure 6.5)* shows concentrations of emitters in the so-called Black Triangle, where lignite and coal with a very high-sulphur content are combusted, and also in the UK. The largest single source, the power station Marits East in Bulgaria, is alone responsible for 5% of the total sulphur emissions from large point sources in this region (Barrett and Protheroe, 1995). In the Black Triangle *(Figure 6.6)* great devastation has been caused, with large areas of forest almost totally dead and human health effects ranging from cardiovascular diseases, chronic bronchitis and lung cancer to impaired foetal development and elevated infant mortality. Life expectancy in Krakow is shortened by six to eight years in comparison to the European average (Guminska in Pape, 1993).

In response to the different protocols of the Convention on Long-Range Transboundary Air Pollution, the EU's 5th Environmental Action Programme (EAP) set reduction targets for the components of concern *(Table 6.1)*. These total reductions will be achieved by imposing strict emission limits on predominant sources, such as large combustion plants. Member States have incorporated these targets into their national

BOX 6: INTERNATIONAL AGREEMENTS TO TACKLE AIR POLLUTION (MURLEY, 1996)

- **Framework Convention on the Atmosphere (Climate Treaty, 1994):** Following the UN 1992 Framework Convention on Climate Change, the Framework Convention on the Atmosphere (Climate Treaty,1994) was agreed. This treaty requires the reduction of greenhouse gas emissions with particular emphasis on carbon dioxide. By autumn 1995 it had been ratified by 135 countries world-wide including the EU.
- **Agreement on Substances that Deplete the Ozone Layer (Montreal Protocol, 1987):** The Vienna Convention on the protection of the ozone layer was signed in 1985. Under this convention the Montreal Protocol (1987) was agreed and subsequently ratified by about 100 countries world-wide. The Protocol committed industrialised nations to control production and consumption of chlorofluorocarbons (CFCs), which are the compounds largely responsible for the depletion of the stratospheric ozone layer. The Protocol was reviewed in1990 and again in 1992 and, in the light of scientific evidence, revised and strengthened.
- **Convention on Long-Range Transboundary Air Pollution:** This convention came into force in 1983 after it was adopted in Geneva in 1979 under the auspices of the UN ECE. Besides the compounds covered in daughter Protocols, which are summarised below, the framework convention deals with the long-range transport of nitrogen and chlorine compounds, PAHs, heavy metals and particles.

  Helsinki Protocol (1985), prescribing reductions of sulphur emissions or their transboundary fluxes by at least 30%.
  Oslo Protocol (1994), regulating further reductions of sulphur emissions.
  Sofia Protocol (1988), concerning the control of emissions of nitrogen oxides and their transboundary fluxes.
  Geneva Protocol (1991), dealing with the emissions and transboundary fluxes of volatile organic compounds (VOCs).

Tree destruction by acid rain in Bohemia

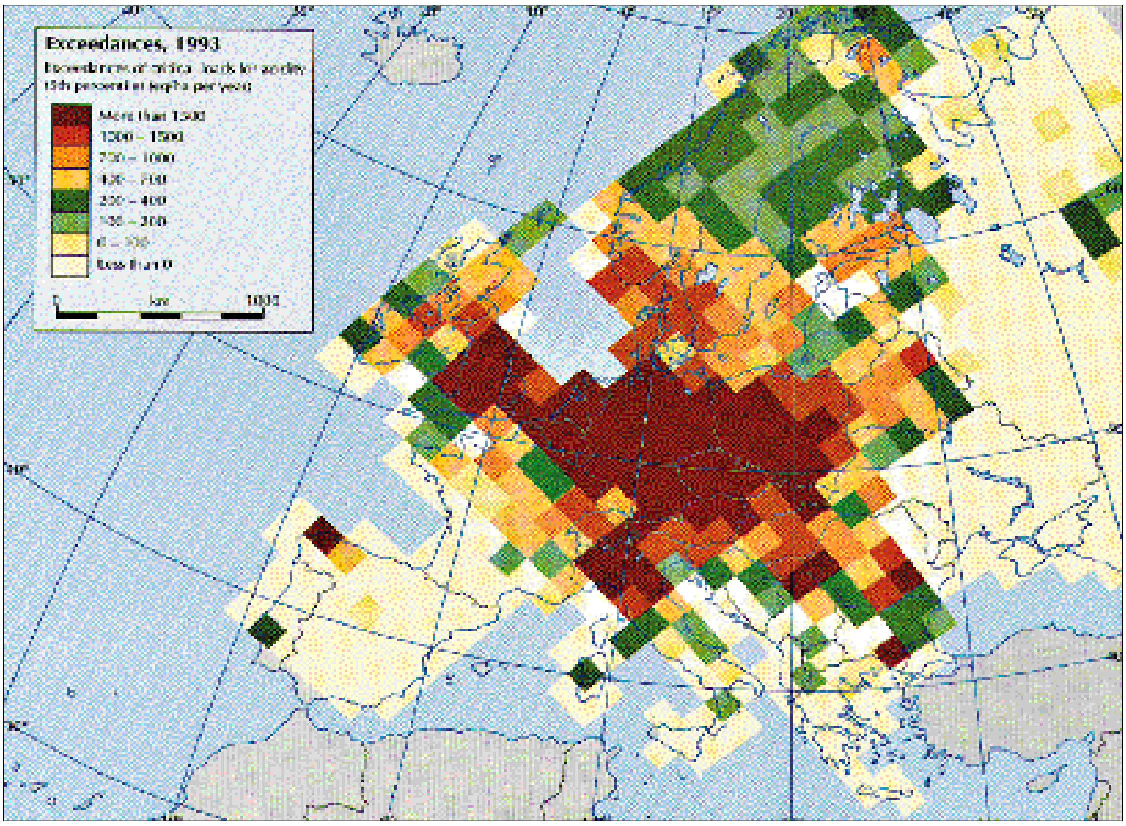


Figure 6.4
Exceedance of critical loads for acid deposition in Europe (RIVM/CCE, 1995)

strategies and specified ways of how to accomplish them. Several states have even increased the required reductions considerably (COM(95) 624, 1995).

The success in reaching these targets varies from compound to compound. The decrease of SO_2 emissions of 35% by 2000 on 1985 levels had already been achieved by 1994 and it is very likely that an agreement on further cuts will be reached. This will be necessary, since, although acid deposition levels will fall significantly, exceedances of critical loads will still be common over large areas of northern Europe. Despite the introduction of catalytic converters for passenger vehicles and emission control in energy and industry sectors, the targetted reduction of NO_x will most probably not be attained. A conclusive assessment of ammonia emissions was not possible, due to lack of reliable data (COM(95) 624, 1995). A comparison of the results for total emission estimates for the 18 EEA Member States and Switzerland, collected in the CORINAIR'90 and CORINAIR'94 inventories shows that, up to now, overall aims have been reached *(Table 6.2)*.

Between 1990 and 1993, the proportion of ecosystems on the European continent where exceedances of critical loads for acid depositions were encountered decreased from 36% to 34%.

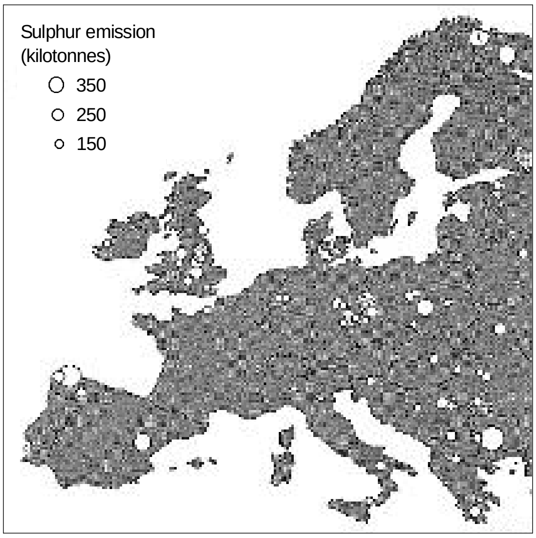


Figure 6.5
Large sulphur-emitting point sources in Europe (Barrett and Protheroe, 1995)

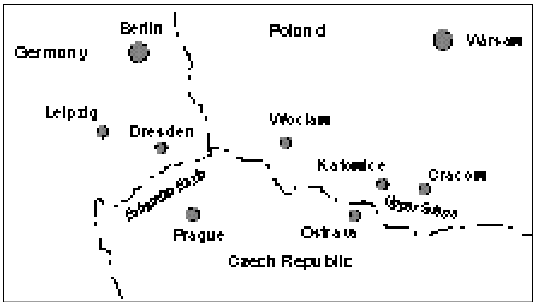


Figure 6.6
The Black Triangle (Budnikowski in Pape, 1995)

Table 6.1
EU Air Pollutant Emission Reduction Targets (COM(95) 624, 1995)

	Emission Reduction Target
SO_2	35% reduction from 1985 level by 2000 55% reduction from 1985 level by 2000
NO_x	Stabilisation at 1990 level by 1994 30% reduction from 1990 by 1999
NH_3	National targets according to problems identified
VOCs	10% of man-made emissions from 1990 level by 1996; 30% of 1990 levels by 1999

Table 6.2
Comparison of total emissions in the CORINAIR'90 and '94 inventories of the 15 EU countries

	Pollutant Emissions (t/a)			
	SO_2	NO_x	NMVOC	CO
1990	17.2	14.0	18.3	54.6
1994	14.3	12.6	16.4	45.1
Reduction	17%	10%	10%	17%

Further decreases to 25% are expected by the year 2000 if air quality targets are met, but additional reductions will certainly be necessary if the protection of all European ecosystems from excessive deposition of acidifying compounds is to be achieved (Wieringa, 1995).

Photochemical Smog Episodes – Summer Smog

The formation of the aggressive secondary pollutant ozone, as described in detail in *Box 5*, is a process occurring in large parts of Europe. This pollution phenomenon results, at least in part, from vehicle emissions concentrated in urban areas, but owing to the often slow atmospheric reactions the major impact and peak levels are often experienced at some distance downwind from the emission source. The influence of insolation on ozone generation causes typical diurnal patterns with highest concentrations during the afternoon. Both effects can be seen in two maps of Austria where peak levels are observable in the afternoon in rural areas leeward of Vienna *(Figure 6.7)* (UBA, 1996).

The occurrences of photochemical pollution episodes in the UK, sometimes covering all of southern England, are generally restricted to episodes of adverse meteorological conditions. Peak ozone concentrations can be reached when the prevailing western winds, which would carry emission away, are reversed and pollutants emitted on the continent are transported across the Channel. A trajectory model for air quality forecasts has been developed by the Atmospheric Measurement and Process Department of AEA Technologies, National Environmental Technology Centre (AEAT, 1996). The results for the prediction of ozone concentrations for one day in early May 1995 are shown in *Figure 6.8*. Light easterly winds moved air masses, containing ozone precursor compounds, to the UK, and poor air quality with levels above 180 µg/m^3 was predicted to occur across large parts of England. In these circumstances, in compliance with the EC Directive on ozone threshold values (92/72/EEC), warnings to the public would have to be issued.

Elevated ozone concentrations have considerable impact on human health *(Table 3.1)* and ecosystems. In many urban and rural areas of Europe an increase in the number and duration of guideline exceedances is now being experienced. Thus several programmes aimed at developing cost-effective abatement methods have been initiated. Ground level ozone formation and photo-

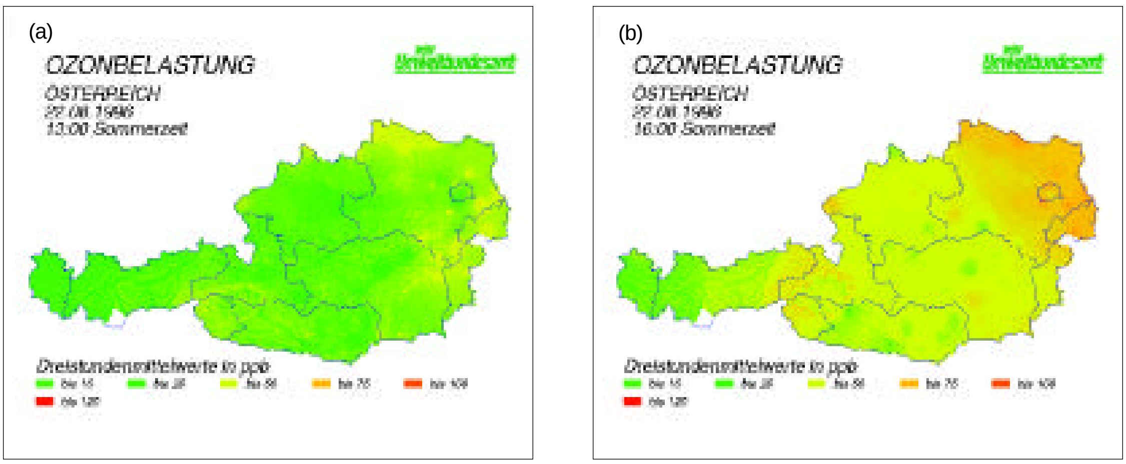


Figure 6.7
Concentrations of ozone in Austria at (a) 13.00 and (b) 16.00 hours on 22nd August 1996 (UBA, 1996)

chemical pollution are considered a priority issue, for which solution strategies need to be determined and implemented. The emissions of the summer smog precursors, NO_x and VOCs, need to be controlled according to the 5th EAP *(Table 6.1)*, but the measures planned so far will not be sufficient to reach the NO_x target specified. The data available on VOCs has not been sufficient to allow an assessment of the feasibility of attaining the specified reductions (COM(95) 624, 1995).

Assessment of Summer Smog Occurrences

Based on the assumption that maximum hourly ozone concentrations can be used as an indicator for the occurrence of photochemical smog episodes, *Map 6.1* shows the incidence and, for some cities, the duration of summer smog events in recent years for which data are available. The assessment of smog frequencies is not possible for several European cities, since ozone concentrations are not monitored adequately, if at all, and the reporting of the duration of exceedances can vary. For example, the cities located in the Rhine-Ruhr valley publish the total number of half-hour values exceeding threshold levels. But there is no indication of whether these were recorded on consecutive days during one long smog episode or whether only one value per day exceeded the guideline as a result of frequent short episodes (LIS, 1992).

EU Directive 92/72/EEC requires the reporting of concentrations and duration in number of days, when threshold value exceedances occur (ETC-AQ, 1995). These data were used for the compilation of *Map 6.1*, in combination with data available from several other sources. The total length of smog episodes per year was calculated by averaging the number of days on which the 180 µg/m^3 ozone threshold value for 1-hour average concentrations was exceeded and those on which the 8-hour average concentration between 12.00 and 20.00 exceeded 110 µg/m^3. Most values used refer

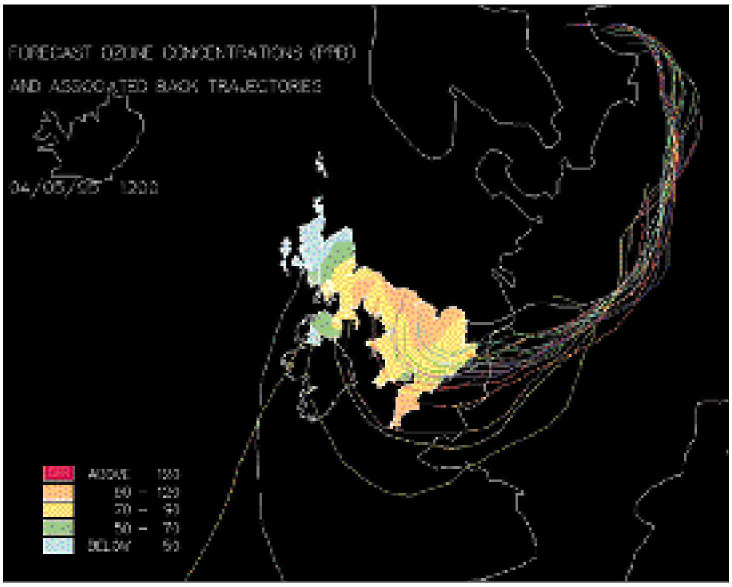


Figure 6.8
Result of ozone concentration prediction for the UK on 4th May 1995 using a trajectory model

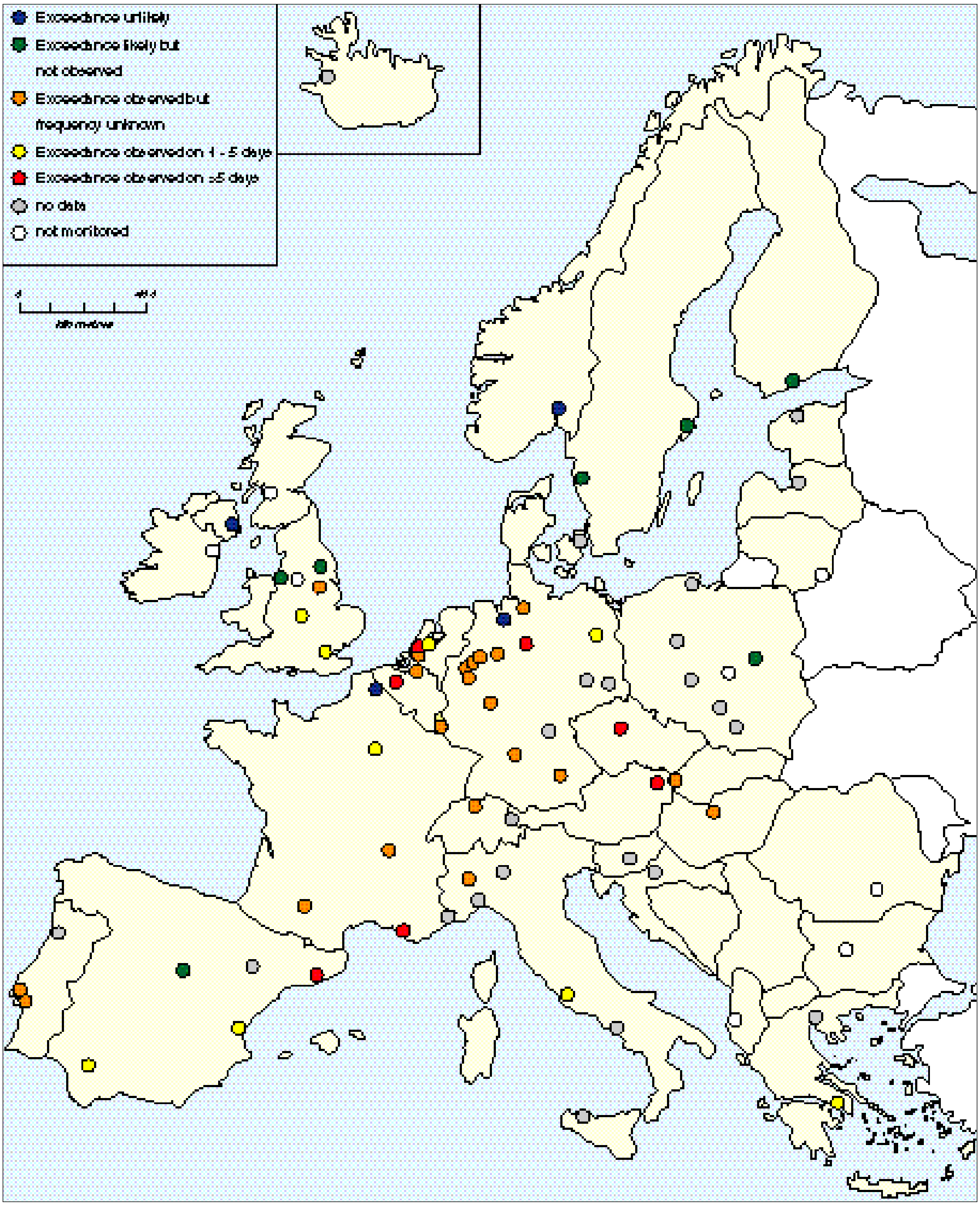
to 1994. *Map 6.1*, shows a north-south gradient similar to that shown by meteorological summer smog potential *(Map 5.6, Chapter 5)*. The restricted data availability for Southern and Eastern Europe complicates an interpretation of the situation. However, it can be seen that summer smog episodes occurred in most European cities. The highest number of days with exceedances of the 8-hour threshold took place in Brussels and Vienna, with 35 and 28 days respectively in 1994.

One of the most comprehensive reports on summer smog episodes is available from the Czech Republic for 1994 (CHMI, 1995). The report contains tables summarising the periods during which exceedances of guidelines were experienced, their duration, how many monitoring stations recorded these elevated levels, the maximum concentration, and the regions in which these stations are located. The results for late July and August for monitoring stations in Prague are shown in *Table 6.3*.

Guideline	Period	Duration (days)	Number of stations reporting exceedance ave - min - max	Maximum O_3 concentration (µg/m^3)	Region
1 h (180 µg/m^3)					
	21/7 - 10/8	21	8 - 1 - 13	180 - 337	all regions*
	22/8 - 23/8	2	1	183-191	Ph**, NM^
8 h (160 µg/m^3)					
	21/7 - 10/8	22	8 - 2 - 13	173 - 303	all regions
	17/8	1	4	179	Ph, NB"
	22/8	1	1	162	Ph

* Prague, Central/Eastern/North/South Bohemia, North/South Moravia
** Prague ^ North Moravia “ North Bohemia

Table 6.3
Reported exceedances of ozone guideline values in the Czech Republic (CHMI, 1995)

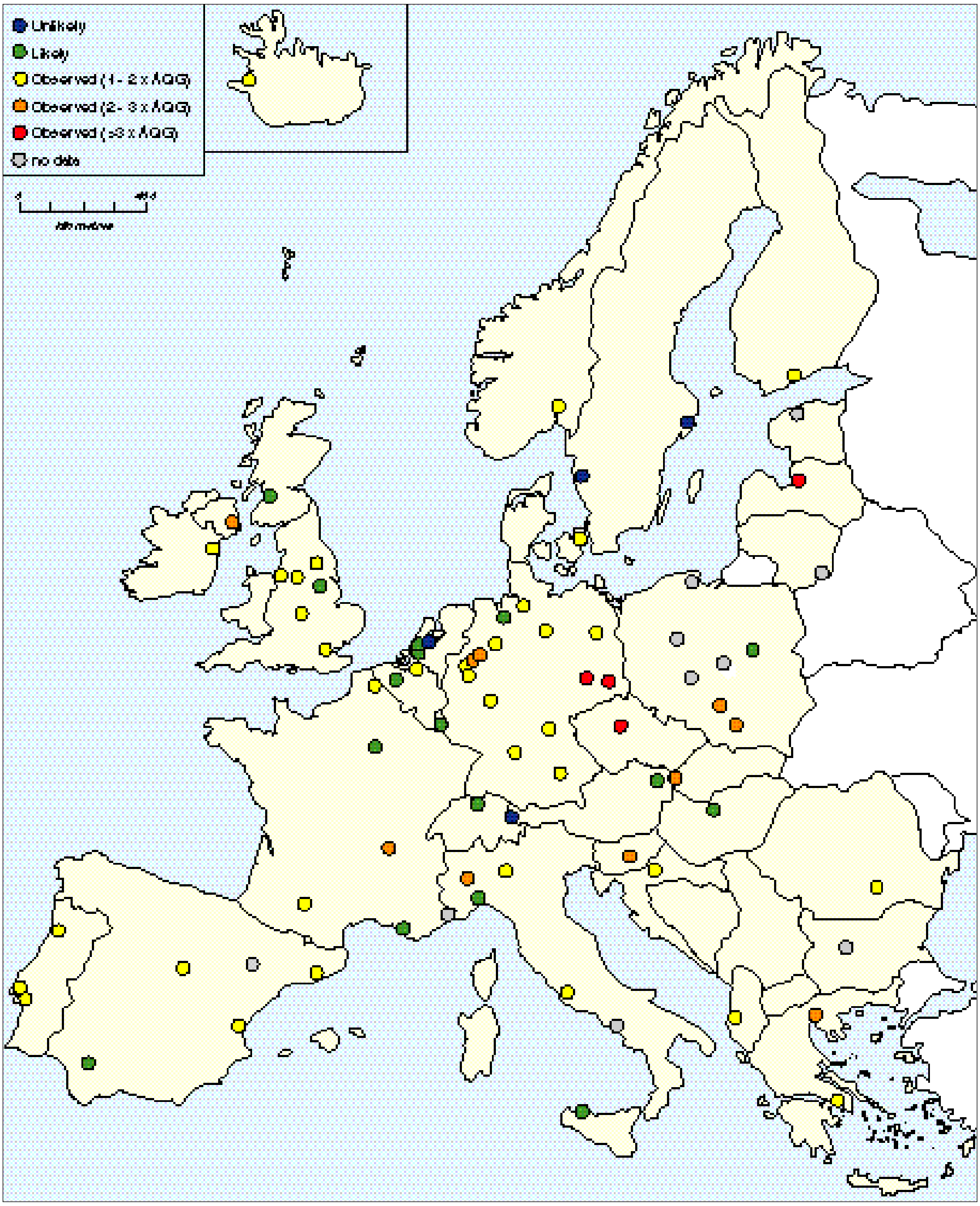


Map 6.1
Frequency of summer smog conditions with exceedance of O_3 guidelines for city background levels

Winter Smog

Although in many areas of Europe emissions of the indicator pollutant for winter smog (sulphur dioxide) have been drastically reduced over recent decades *(Map 6.2)*, the winter smog type emission index is still rated as high in several European cities, particularly in the area known as the Black Triangle *(Map 5.3, Chapter 5 and Figure 6.6)*. The use in this area of local, sulphur-rich lignite, as a major primary energy source, which also has a high ash content and a low calorific value, has given rise to major concern.

The impacts of winter smog episodes are often not locally restricted, since tall stacks of industrial facilities and power plants contribute to the long-range transport of pollutants. This pollution may then accumulate in another part of

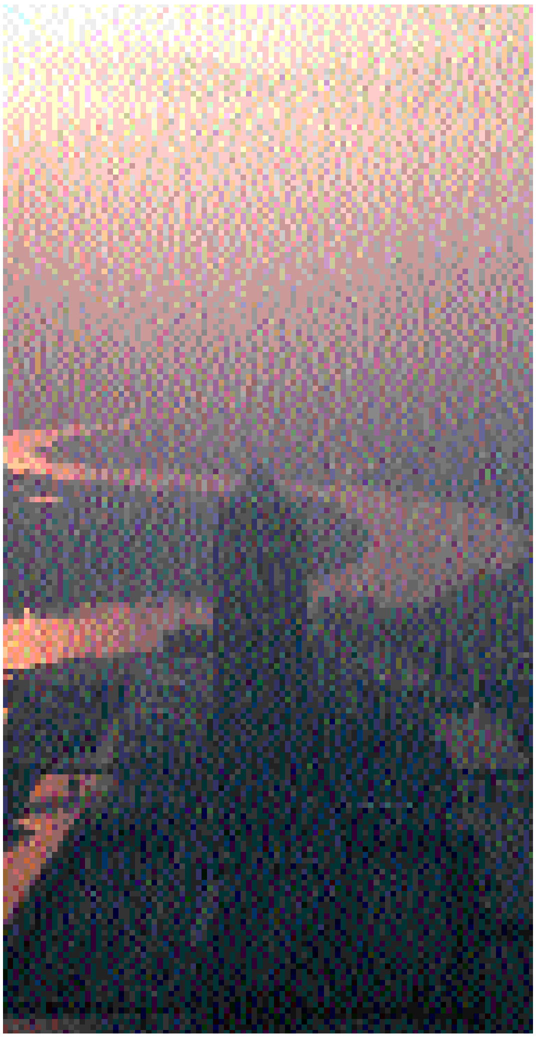


Map 6.2
Occurrence of winter smog conditions and the reported exceedance levels of Air Quality Guidelines for SO_2

Europe, where local emissions raise the concentrations even further. This situation occurred during several winters of mid- and late 1980s. In contrast to the normal conditions of west to east movement of air masses, on these occasions air containing high concentrations of SO_2 was transported from eastern Europe westwards, where it induced dense smogs over Germany, Belgium, the Netherlands and parts of France (Elsom, 1996).

Assessment of Winter Smog Occurrence

Episodes of poor air quality with exceedances of WHO short-term guideline values for the pollutants SO_2 and particulate matter, have been experienced in most European cities in recent years, as can be seen in *Map 6.2*. The relationship between the severity of the event and the use of coal as a primary energy source can be seen in the examples of Belfast and cities in the Black Triangle, where



A winter smog hangs over Canary Wharf and the River Thames, London

exceedances of air quality guidelines by a factor between 2 and 4 were observed. For most cities, elevated SO_2 concentrations occur in combination with high particulate levels, although sometimes data for only one of these pollutants are available. The introduction of smoke control zones in most major UK cities following the Clean Air Act 1956, amended in 1968 and re-enacted in 1993, has reduced winter smog occurrences significantly (Murley, 1996). Many countries or regions have adopted threshold values for different stages of warning issued to the public (*Table 6.4*).

Table 6.4
Examples of pollutant concentrations ($\mu g/m^3$) which trigger smog warnings

Greece	Period	Pre-alert	A!	B!
SO_2	24 hours	250	300	400
Smoke	24 hours	250	300	400
Germany	Period	Pre-alert	1. Alert stage	2. Alert stage
SO_2	3 hours	600	1,200	1,800
SO_2 + SPM	24 hours	1,100	1,400	1,700

Control of Transboundary Air Pollution

The adoption of several international agreements, summarised in *Box 6*, with the aim of controlling emissions of the substances responsible for transboundary air pollution, obliges the countries who ratified them to take action. Since the solution to these large scale problems can involve the use of enormous financial resources, the cost-efficiency of any strategy will have to be investigated before they can be implemented. Thus, a number of research projects concentrating on the economic evaluation of proposed control strategies have recently been established.

The Auto Oil programme, launched in 1994 as a collaborative initiative between the European Commission and the motor and oil industries, is aimed at supplying policy makers with objective information about cost-efficient measures necessary to attain new air quality standards. In the case of ground-level ozone formation, seven major European cities were selected for representative pollutant modelling, and from these models a pan-European approach to pollution reduction was chosen. The measures suggested, which would result in a 60–70% reduction in VOC and NO_x emissions from road transport, were recently adopted by the European Commission (IP/96/631, 1996) as part of the concerted action to reduce ground-level ozone formation. This package also includes reduction targets of 70% for urban CO and particulate matter. The baseline for reductions refer to today's levels and should be achieved by the year 2010. These measures, the costs of which are estimated to amount to 11.5 billion ECU, include action on emission reduction by both the motor and oil industries (IP/96/526, 1996):

- a new fuel quality Directive would set harmonised limit values for unleaded petrol and diesel fuel, leaded petrol should be phased out by the year 2000,
- new vehicle emission limits of between 20 - 40% below today's levels would be introduced in another Directive, applicable to new vehicle types and all new vehicles from the year 2000 and 2001, respectively.

Further legislative procedures will be presented next year concerning the emissions standards for light duty and heavy duty vehicles and vehicle inspection and maintenance.

The models developed by Auto Oil predict that significant reductions in air pollution will be achieved under present regulations by the year 2010, but that additonal measures to curb non-traffic emissions will have to be taken to meet ozone air quality standards. The Auto Oil programme has examined a wide range of different emission reduction measures which covered:

- improved vehicle technology;
- improved fuel quality;
- better vehicle maintenance and annual inspection tests;
- local initiatives such as road pricing and public transport.

The results show that very strict standards for vehicles and severe fuel measures would be needed to reach emission targets using transport measures alone. Clearly, these will be very costly to implement. Auto Oil suggest that a far more certain and, indeed, necessary path to attaining air quality targets in Europe is to tackle emissions from stationary sources. The European Commission has suggested a follow-up to the Auto Oil programme to evaluate the need for further measures, and other EU initiatives are under way which target stationary source emission controls (CONCAWE, 1996).

The problems of acidification and ground-level ozone formation in Europe will be addressed in a study evaluating the cost effectiveness of different control techniques. Least cost solutions for transboundary air pollution issues, including meeting critical loads and levels, must be identified. The preparation of a number of directives, including the review of the 'Large Combustion Plants' Directive (EC Directive 88/609/EEC), will be influenced by the results of this study; cost-efficiency will thus be a major aspect in policy formulation (S216, 1995).

Chapter 7

Urban Air Quality in Europe

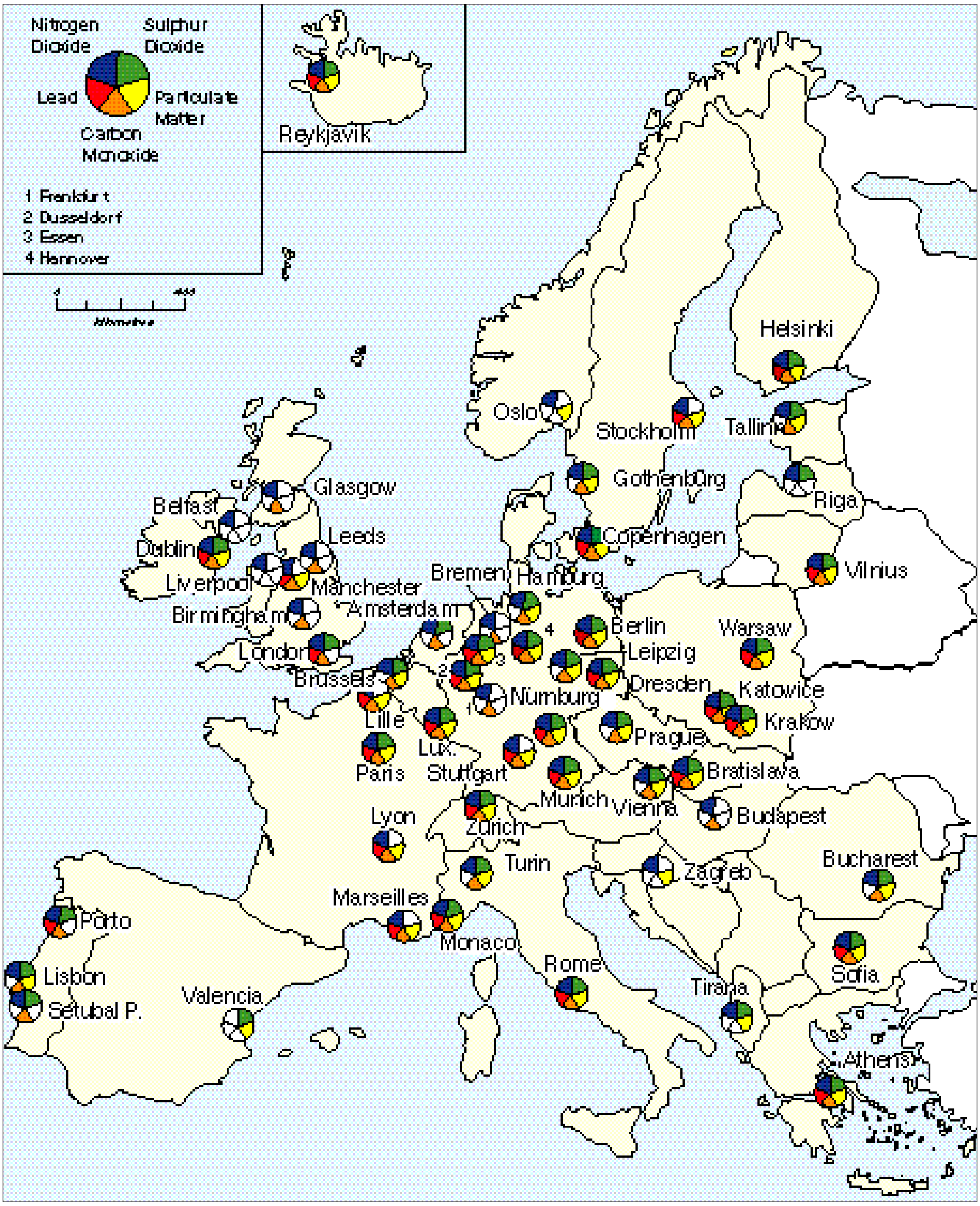
Poor air quality over London

This chapter presents the current air quality situation in the investigated cities, as well as an analysis of recent trends and, where possible, a forecast of expected developments in air quality. It is thus based on recent inventories of air quality monitoring networks and collections of up-to-date air quality data. Although monitoring of air quality is conducted all over Europe and numerous international, national and local networks are in operation, the availability of comparable air quality data is restricted. Various strategies can be followed in the design and implementation of monitoring networks and further differences exist in methods of analysis and assessment of the measured data *(Chapter 4)*. Many approaches to air quality determination are equivalent and can be used, if the meta-information, essential to compare different measurement results, is made available at the same time to facilitate the necessary comparison; unfortunately this is not always the case.

Underlying Aspects

Parameters of predominant influence on the monitored pollutant concentration and the reported results are summarised below.

- **Location of the monitoring site:** Of particular importance is the distance of the monitoring device from specific emission sources. Stations are generally divided into background and hot-spot sites, with a further differentiation between regional/urban and industrial/roadside monitors respectively. Furthermore, the height of the



Map 7.1
Kerbside monitoring programmes for air pollutant compounds in investigated cities

sampling inlet above the ground and the position with respect to climatic impacts will affect monitoring results. Road traffic is now becoming an increasingly significant component of urban pollution. For this reason, many cities have introduced a kerbside monitoring programme. *Map 7.1* shows the cities that have kerbside monitoring stations and indicates the parameters being measured (Questionnaire responses).

- **Monitoring technique:** Two aspects – namely, the monitoring equipment used and temporal resolution of data – are necessary to enable an evaluation of, for example, particulate matter. The influence of the sampling method was described earlier *(Chapter 4)*; time-integrated results with sampling periods of a day or longer will not show diurnal variations and potentially relevant maximum pollution levels *(Figure 7.3)*.

- **Statistical analysis and reported values:** The averaging time, whether hourly or daily mean values are released and particularly the reporting of extreme values, either as absolute maxima or as percentiles, and the reference period *(Chapter 3)* are all aspects which also determine the equivalence of monitoring results.

The expected impact of a certain pollutant and its occurrence in relation to the emission sources determine which monitoring approach to select. If the monitoring objective focuses on the assessment of acute health effects of pollutants, such as sulphur dioxide (SO_2) and ozone (O_3), data with short averaging periods of several minutes to hours and values of extreme concentrations are necessary requirements. Chronic exposure, on the other hand, can be appraised from monthly or annual mean levels. In the case of monitoring networks which are set up to enable the issuing of warnings and smog alerts to authorities and the public, real-time data of high quality is essential.

Examples of simultaneously monitored concentrations of SO_2 and carbon monoxide (CO) at two urban sites, one influenced by heavy traffic (Patission), the other one near to a road with moderate use (Pireas), and a suburban station with only light traffic in the vicinity (Smyrni), illustrate the importance of the position of a monitoring site (APIS, 1996). Differences are obvious between the behaviour of the two pollutants and depend on their predominant emission source; the CO concentrations originating from vehicle exhaust are relatively higher near the road *(Figure 7.1)* than the SO_2 levels which are contributed to by various sources besides road traffic *(Figure 7.2)*. Ratios of average contaminant concentrations for the three sites are (Patission:Pireas:Smyrni) 3:2:1 for CO and 2:1.5:1 for SO_2. Furthermore, the dissimilarity of the two CO curves, with averaging periods of one and eight hours, and the different maximum and percentile values derived from these data, are shown in *Figure 7.3*.

A further problem of comparability arises when data collections are used from previous studies which had differing objectives. Such divergence of aim is often reflected in the type of data and material requested from the cities and reported in the inventories. For instance, levels of the compounds carbon monoxide and airborne lead, as summarised in 'Air Quality in Major European Cities', were predominantly monitored at traffic sites (RIVM, 1995a), whereas 'Air Quality in Europe' contains data from all urban stations (ETC-AQ, 1996a).

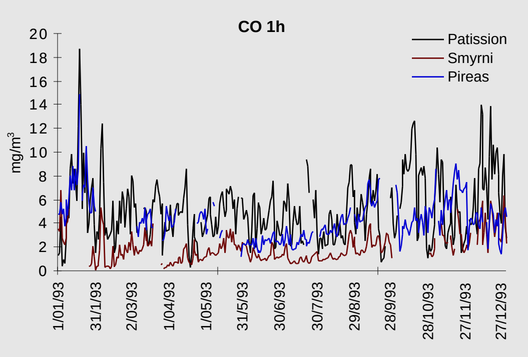


Figure 7.1
1-hour CO concentrations at three different sites in Athens

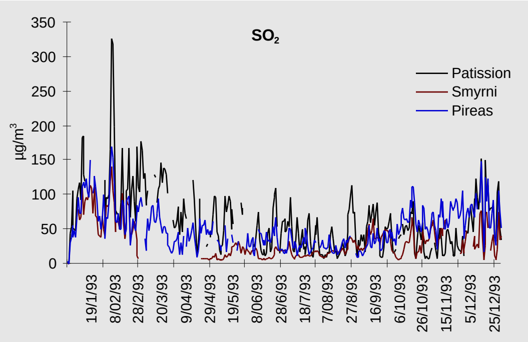


Figure 7.2
Concentrations of SO_2 at three different sites in Athens

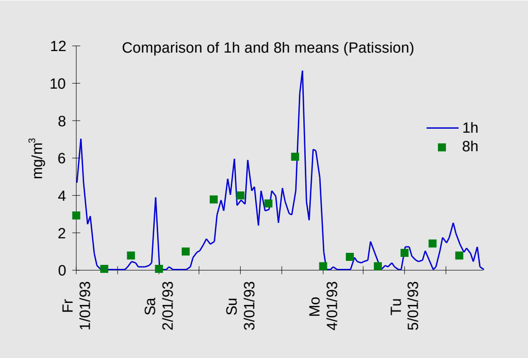


Figure 7.3
Concentrations of CO 1 hour versus 8 hour mean

Data Availability

Figures 7.4 and 7.5 provide a summary of data availability for concentrations of those traditional air pollutants, monitored in recent years, which will be investigated in the following sections. These results are based on a total urban population of 100.3 million and 79 cities in the region of Europe investigated. It can be seen that concentrations of SO_2 are most frequently reported. For suspended particulate matter (SPM), a combination of the three predominant monitoring methods *(Box 4)*, and for CO and O_3 various averaging periods of reported values, were used. This analysis does not take into account whether the data sets provided for each pollutant and city are complete, since the data availability per monitoring site is not always known.

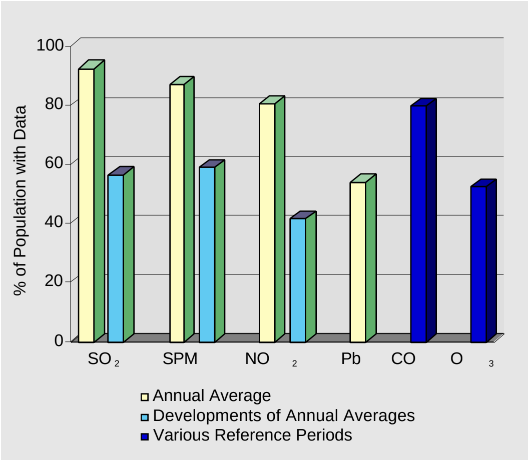


Figure 7.4
Air pollution data availability per % population

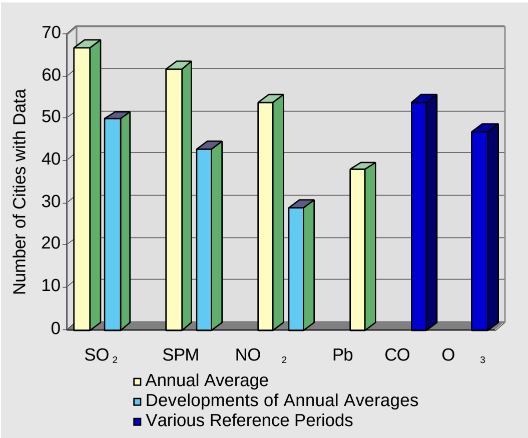


Figure 7.5
Air pollution data availability per number of cities

Traditional Air Pollutants – Current Concentrations and Trends

For the assessment of local air quality and the Europe-wide comparison of the conditions to which city inhabitants are exposed, annual average pollutant concentrations monitored at urban background stations located in a central area were selected for most pollutants. These monitoring sites should not be directly influenced by emissions originating from major roads or industrial facilities, where concentrations can be significantly higher. Where several stations in one city fulfilled these specifications, mean annual levels measured at each station were averaged to provide one representative value for the central area of the city.

The year of collection of the data used to produce the following maps generally ranges between 1990 and 1994 although, on a few occasions, older data had to be included. Data upon which all necessary quality assurance and control procedures had been applied (so that it could be considered as fully verified) were available from only a few cities, for instance, Paris. In Sweden, monitoring networks for most compounds are not in operation during the summer half-year, although nitrogen dioxide (NO_2) is monitored all the year and O_3 during the summer months only (SCB, 1995). It should be noted, therefore, that the concentrations reported by Gothenburg and Stockholm for most pollutants relate to a limited period of the year, normally October–March.

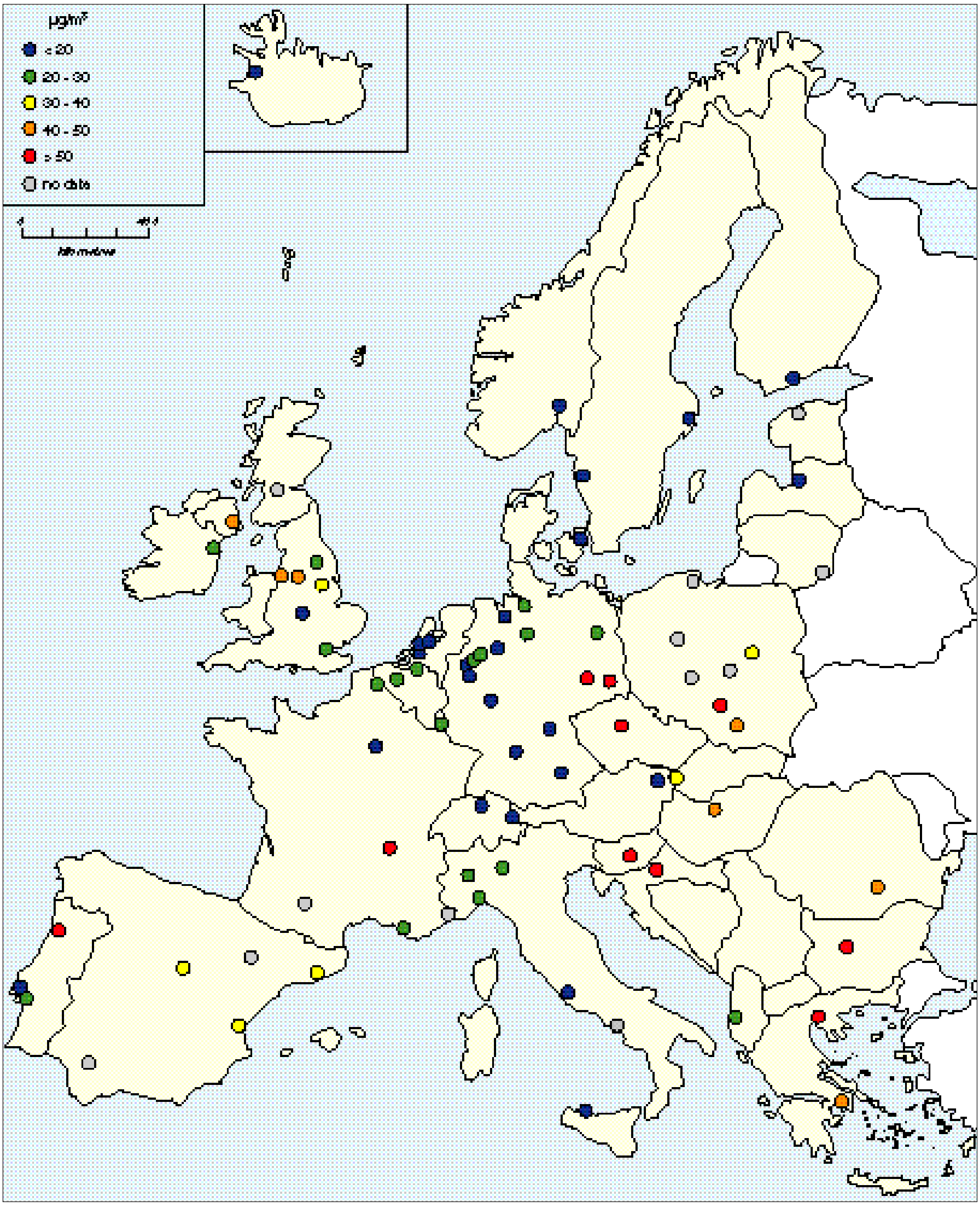
A frequent objective of air quality monitoring is the assessment of concentration trends, in order to predict future problems of air quality or to observe the effectiveness of implemented air quality management measures, such as emission reductions. Thus, the study and interpretation of long time-series is frequently conducted to detect trends. However, data availability is often restricted or inconsistent. Data inconsistencies in long time-series can be introduced by a variety of factors such as changes in the location of monitoring stations or the equipment used.

For several cities and air pollutants, annual average concentrations over two or three years between 1985 and 1994 were available. These figures were used to identify any improvements or deterioration in air quality in the investigated cities. In the absence of long time-series, which would allow a sound statistical analysis, this was felt to be the best approach. The results are of fairly restricted value, particularly in cases where contradicting trends, such as sharp decreases in pollution levels followed by increases, were found. Keeping these limiting points in mind, it is still possible to see that European air quality has improved significantly.

Sulphur dioxide

Sulphur dioxide is probably the most frequently monitored compound; large amounts of data are produced from extensive networks and the interactions of this compound with the environment have been investigated in detail. Annual average concentrations from central urban monitoring sites were available for most European cities and are summarised in *Map 7.2*. Highest concentrations and several exceedances of the WHO air quality guideline value of 50 µg/m^3 annual average concentration are observed in the Eastern region, particularly in the Black Triangle.

The levels shown for Lyon, Porto and Thessaloniki were taken from an EU report, which contains only data on exceedances of the EU guide value for annual average SO_2 concentrations of 50 µg/m^3 (COM(95) 327, 1995). These exceedances occurred in Porto in 1989, and in 1990 in the other two cities. Since then, mean levels remained below the guide value and thus the reported data might



Map 7.2
Annual average SO_2 concentration reported by investigated cities in recent years

not be representative for recent years. Relatively high levels of SO_2 in Belfast can be readily explained by the fact that combustion of coal is still an important source of energy in domestic heating (*Chapter 5*). An extension of the smoke-controlled areas and the implementation of several other regulations are planned. Some progress has already been made and since 1992/93 the EC limit values have not been exceeded (BCC, 1995).

Mapping of pollution concentrations for SO_2 and total suspended particulates (TSP) was performed in Prague; the distributions of annual mean and the 95th percentile (P_{95}) of daily levels for 1994 are shown in *Figures 7.6 and 7.7*. The red, brown and black zones signify areas where the air quality limits for the Czech Republic were exceeded. It can clearly be seen that excess concentrations of particulate matter are present in large parts of the

Figure 7.6

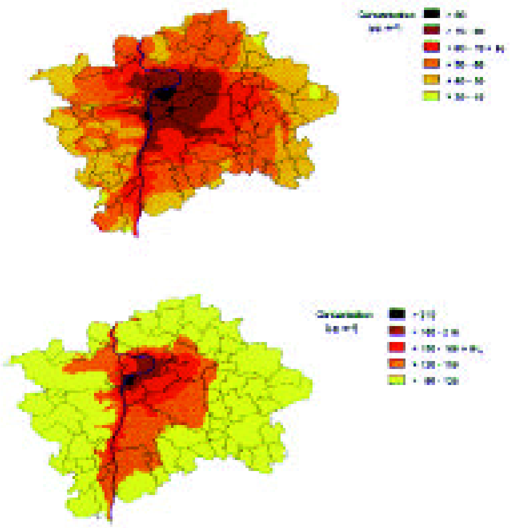
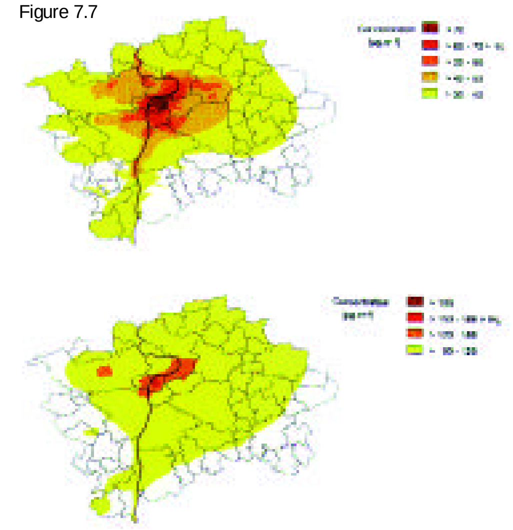


Figure 7.7



Figures 7.6 & 7.7 Mapping of annual mean and P_{95} daily concentrations of particulate matter and SO_2 in Prague in 1994 (CHMI, 1995)

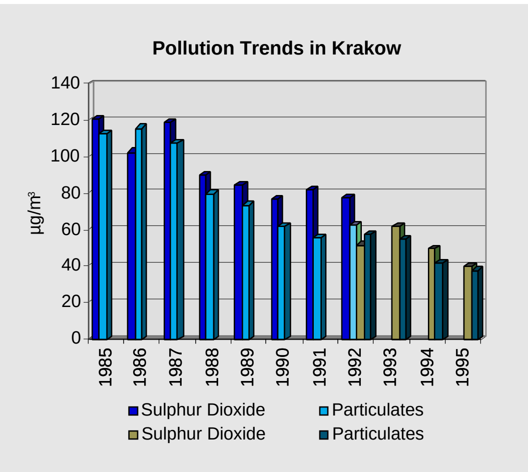


Figure 7.8 Pollution trends in Krakow (VIEPC, 1996)

city, whereas breaches of SO_2 guidelines are restricted to the city centre (CHMI, 1995).

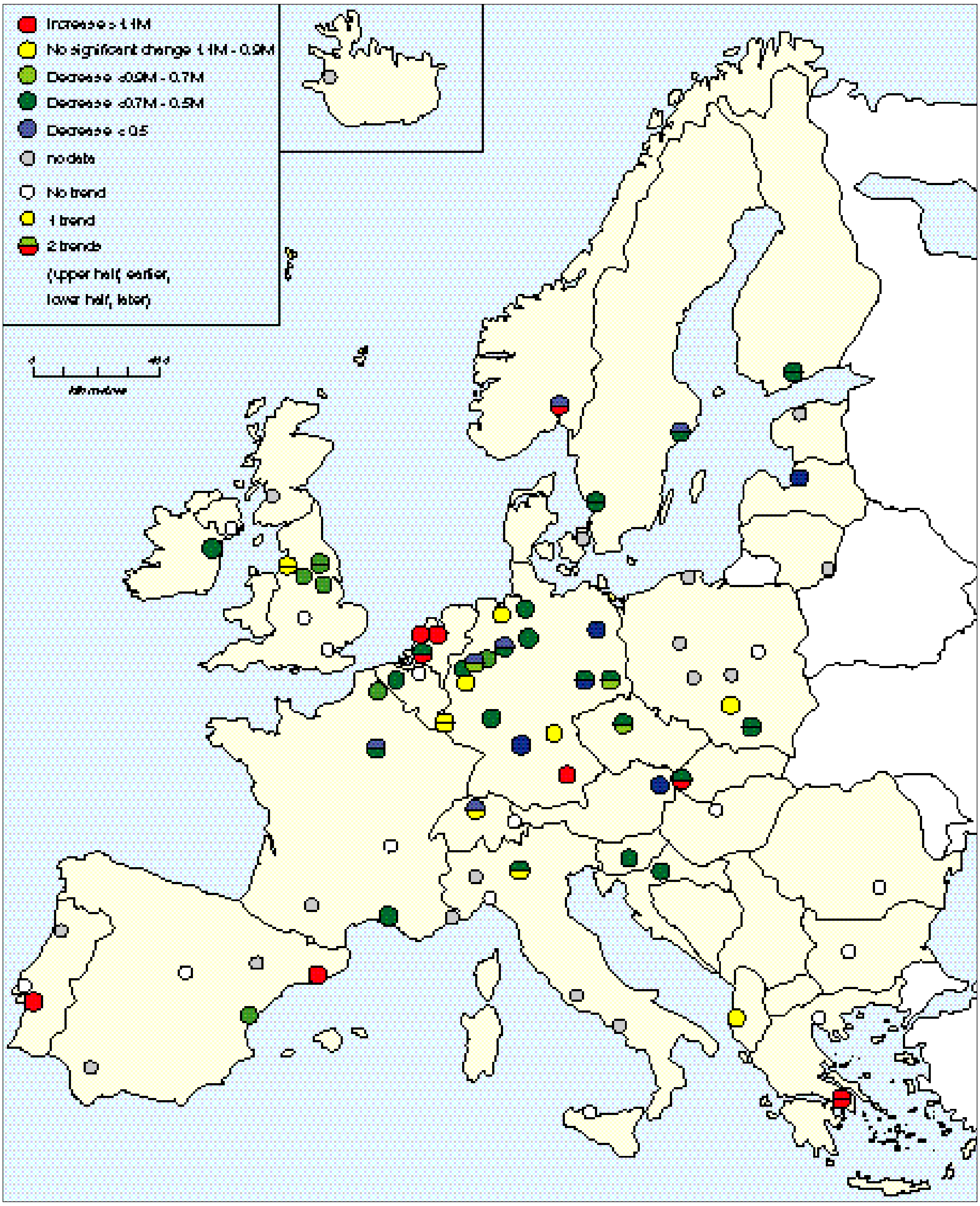
An analysis of available SO_2 concentrations results in the identification of a strong downward trend for the majority of investigated cities *(Map 7.3)*. On many occasions the annual average concentrations have been more than halved and further decreases are to be expected. A comparison with *Map 7.2* shows that in a number of cities these decreases have brought about a major improvement in air quality, lowering concentrations below current guideline values. This is, for example, the case in the Rhine-Ruhr valley, Milan and Paris. In other areas, particularly in the Black Triangle, even drastic decreases have still not been sufficient to stop breaches of limit values, but if the positive developments continue at this rate compliance with guidelines will soon be achieved.

These improvements are clearly illustrated by the city of Krakow, where a three-fold decrease in SO_2 and suspended particulates concentrations has been observed over the last decade *(Figure 7.8)*. The introduction of new automatic monitoring devices in 1991, replacing the wet chemical method, created a step in 1992 in both concentration curves, but the downward trend clearly continues. The collection and analysis of data in a central database facilitates forecasting of pollution episodes, thus smog warnings can be issued to the public and pollution abatement measures can be imposed (VIEPC, 1996).

These trends demonstrate that the technical know-how is available to deal with SO_2 as an urban pollutant and that appropriate action can have major beneficial effects. Lower SO_2 concentrations over wide regions of Europe show the success of emission reductions, which were brought about by switching fuel from sulphur-rich coal to natural gas and desulphurization of flue gases. A further factor involved in these improvements is that economic change and recession has caused the closure of many industrial facilities, particularly in eastern Europe. Further improvements of air quality are to be expected, since many of the remaining plants are being modernised to enhance their efficiency and to adapt them to the latest relevant emission standards.

Particulate Matter

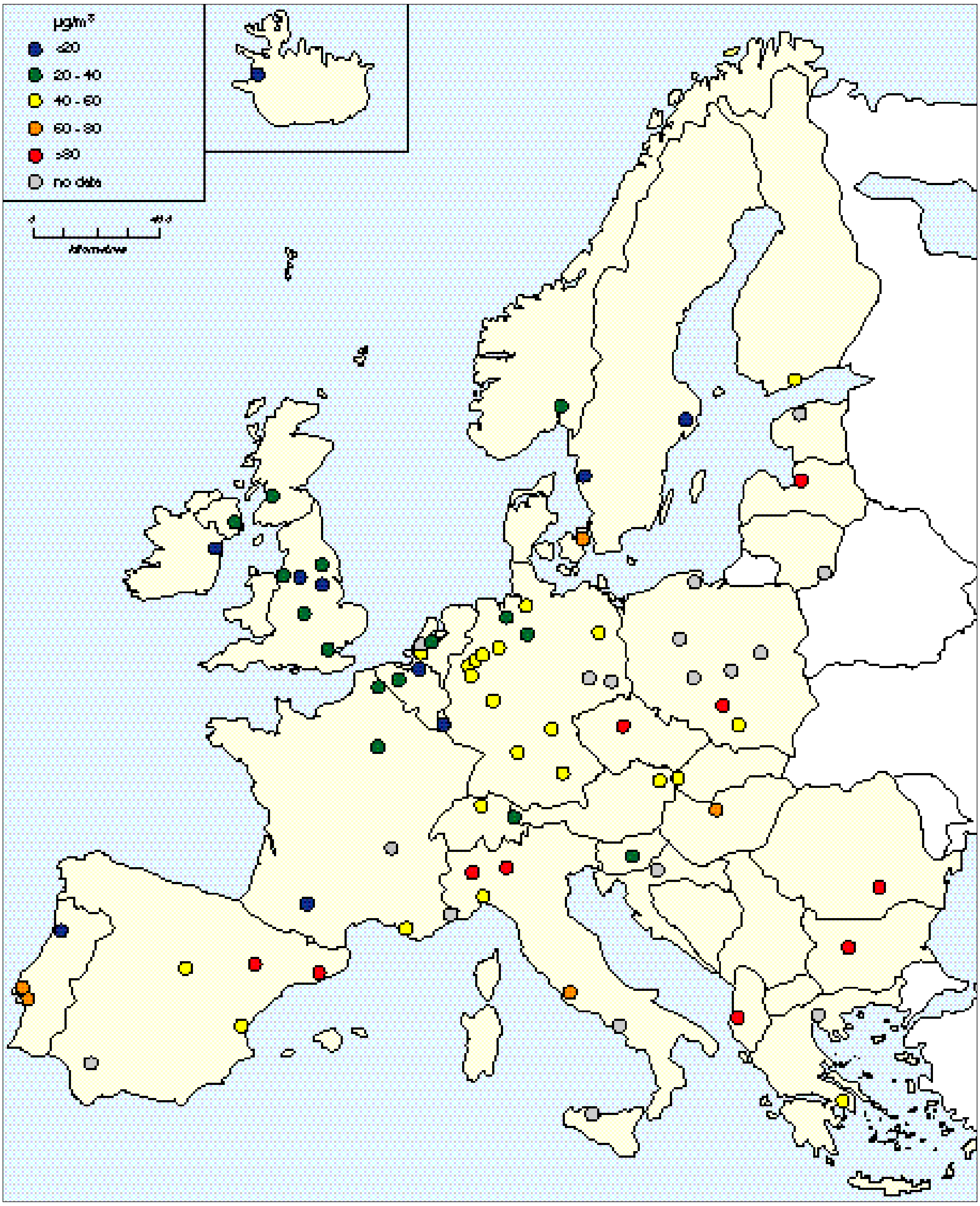
Although the monitoring method is always one of the factors to be considered in the comparison of concentrations measured for any pollutant, its impact on the reported level of particulate matter is probably most important. The three methods predominantly employed in Europe are described in *Box 4*, and *Map 4.1 (Chapter 4)* indicates which



Map 7.3
Trends in annual average SO_2 concentration reported by investigated cities in recent years

method is used in each city. Since the monitoring devices with a cut-off inlet only sample the smaller particulate fraction (e.g. PM_{10}), and if the concentrations are then determined by applying a mass-flow rate relation after weighing the samples, these concentrations will be significantly lower than those simultaneously monitored with the TSP method, since the large heavy particulates are excluded from the PM_{10} samples.

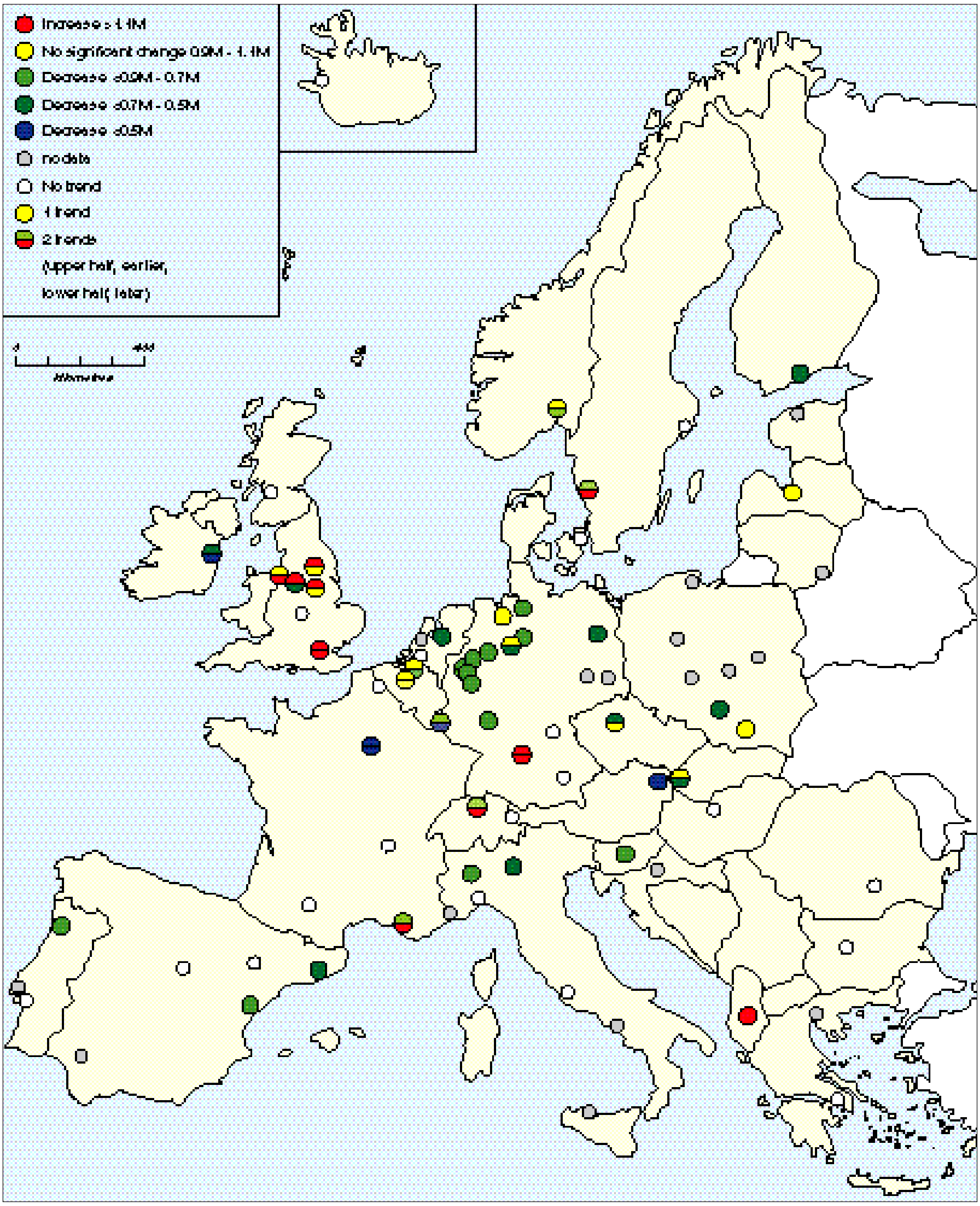
An overall increase in particulate concentrations from north-west towards south-east can be seen in *Map 7.4*. However, a relationship between monitoring method and concentration can also be found. Concentrations are lower in those cities where the black smoke or the PM_{10} method is applied. Thus the high concentrations of particulate matter reported as PM_{10} for Budapest and Katowice are particularly significant. A further complication in



Map 7.4
Annual average particulate matter concentration reported by investigated cities in recent years

comparing the variation in particulate matter composition was previously mentioned in *Chapter 6 (Figure 6.2)*, namely higher concentrations in arid or coastal areas, where more wind-blown dust or sea salt aerosols respectively are suspended in the lower atmosphere, but do not necessarily cause significant health impacts.

A comparison of *Map 4.1* and *Map 7.4* also shows that, although for most cities the method of monitoring is known, annual average levels of particulate matter are not always available. EC Directive 80/779/EEC sets an air quality standard of 80µg/m³ smoke for the median of daily values and the reference period of one year. This value is exceeded in several eastern and southern European cities. The concentration shown for Zaragoza was taken from an EU report containing guideline exceedances only, and might thus not represent



Map 7.5
Trends in annual average particulate matter concentration reported by investigated cities in recent years

usual conditions (COM(95) 327, 1995). The overall pattern of higher concentrations of particulate matter in eastern regions is the same for SO_2, as was expected, although several cities, such as Ljubljana, Porto and Riga, do not follow this rule and data gaps obscure a comparison.

The particular problems encountered in the comparison of concentrations of SPM in European cities make it obvious that a certain harmonisation of monitoring methods and data reporting is essential. This includes the necessity of making meta-information available in combination with the actual air quality data to enable a pan-European assessment of air quality.

A comparison of several annual average concentrations of particulate matter, monitored in European cities over the last decade, shows mainly downward trends *(Map 7.5)*. In some areas these are still not sufficiently low to eliminate exceedances of current guidelines, and the perception of no threshold level adopted by the WHO has to be kept in mind.

The diversity of data sources and availability does not allow a direct comparison between progress in the reduction of annual average SO_2 and particulate matter concentrations, as comparable data are only available for a few cities. A parallel development would be expected, due to the common nature of emission sources for these pollutants, although the construction of tall stacks will tend to remove SO_2 from the immediate area whilst heavier particulates may still be deposited locally. It has been observed *(Chapter 5)* that the reduction of SO_2 is more marked than that of particulates in many cities, and the Netherlands now only uses the latter as a winter smog indicator.

Oxides of Nitrogen

Although primary emissions of oxides of nitrogen consist mainly of nitric oxide (NO), it is quickly oxidised to NO_2 if reactants such as O_3 are available; this NO_2 is the pollutant of concern in terms of human health and is therefore generally monitored and reported. This oxidation reaction causes significant concentration variations in micro-scale investigations, depending on distance from the emission source. On the meso-scale, this effect is eliminated through consideration of monitoring sites that provide urban background concentrations rather than strongly emission-influenced roadside stations. In several cases the distinction between the two types of oxides of nitrogen is not made, but the combined value for NO_x is reported.

Increases in road traffic continue to cause air pollutant levels to rise in some cities

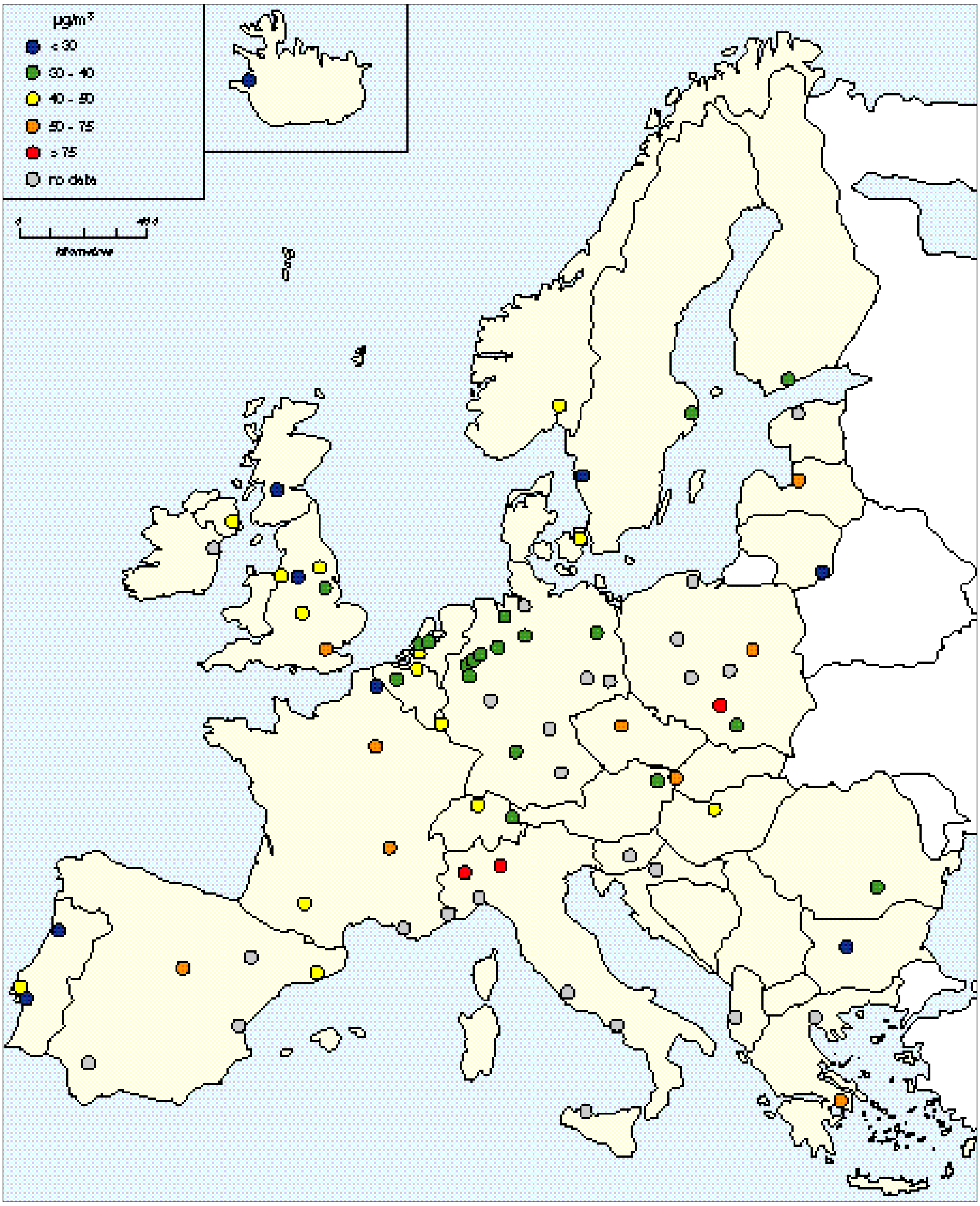
The revised WHO air quality guidelines propose an annual average value of 40–50 µg/m^3 (WHO, 1995c) and the current EU guideline level is set at 50 µg/m^3 as the median of hourly means for a reference period of one year (EC Directive 85/203/EEC). *Map 7.6* summarises annual average NO_2 concentrations, monitored in European cities in recent years. As can be seen clearly from the map, exceedances of these guideline values have occurred in many cities all over Europe, although the highest values predominate in southern and eastern European countries.

Although road traffic is known to be the major emission source for NO_x, high concentrations of these compounds in ambient air do not necessarily indicate highest traffic densities in these cities. The introduction of catalytic converters causes a decrease in NO_x emissions and the state of maintenance of vehicles influences significantly the amount of emitted pollutants. The higher NO_2 concentrations in southern and eastern Europe might thus reflect less tight emission controls as well as a situation where a lower percentage of the vehicle fleet is equipped with catalytic converters.

An assessment of the development of the NO_2 concentrations in recent years *(Map 7.7)* again shows a predominantly downward trend, although the improvement is not as impressive as for SO_2. The highest decreases can be found in Brussels, Manchester and northern Germany, particularly in Dortmund where a reduction by the factor 1.6 was recorded. Conversely, significant increases in annual average concentration were reported from a number of cities. These increases are, at least partially, caused by an increase in road traffic. In Athens, a three-fold rise in the annual average NO_2 concentration was observed between 1985 and 1993, leading to a dramatic decrease in air quality. In the majority of cities, where up-to-date results are available, it can be seen that decreases in NO_2 have taken place and air quality guidelines for this pollutant are no longer exceeded.

Carbon Monoxide

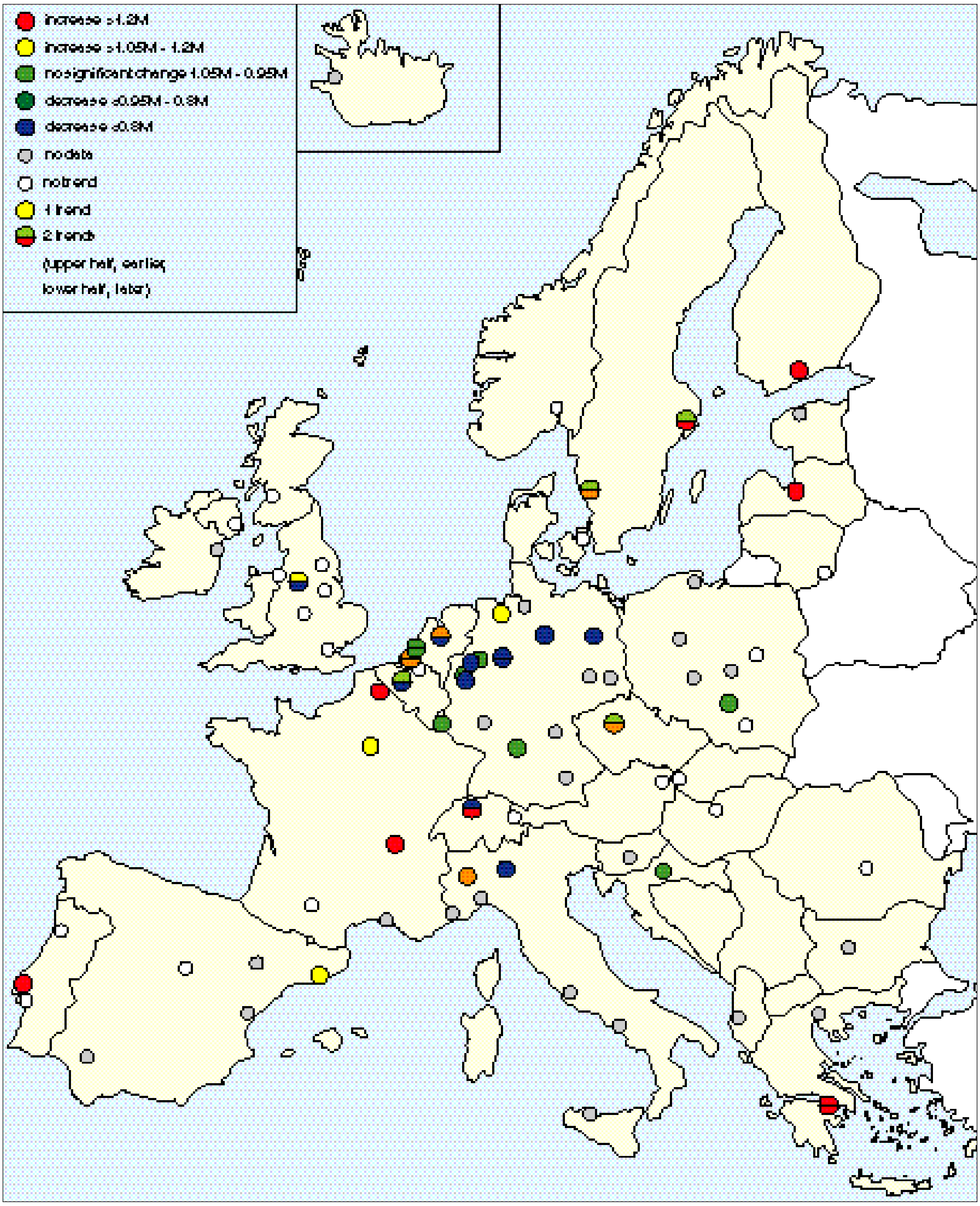
Annual average concentrations of CO are rarely reported, since most attention is often given to the acute health effects of this pollutant. This also explains why values monitored at kerbside stations, as opposed to urban background stations, were preferred in an earlier study (RIVM, 1995a). Carbon monoxide concentrations, and the exposure of the population, are higher at traffic-related sites. *Map 7.8* presents mainly recent maximum 8-hour carbon monoxide concentrations measured



Map 7.6
Annual average NO_2 concentration reported by investigated cities in recent years

at urban background and roadside monitoring stations. For most German cities, and also for several others, available data relate to averaging periods of one or half an hour. The relevant WHO guideline values for these exposure durations are listed in *Table 3.2*.

As expected, the higher concentrations were measured at traffic sites, and maximum values for shorter averaging periods are also generally higher. Yellow and red points as well as red triangles signify cities where the WHO guidelines were exceeded. These breaches are not related to the geographic region in which the city is located. The situation is particularly alarming for those cities, namely the three Italian ones, where the breaches were reported for urban background stations and for longer averaging periods, because it has to be assumed that concentrations in hot-spot areas are even higher, posing an acute health risk to the population.

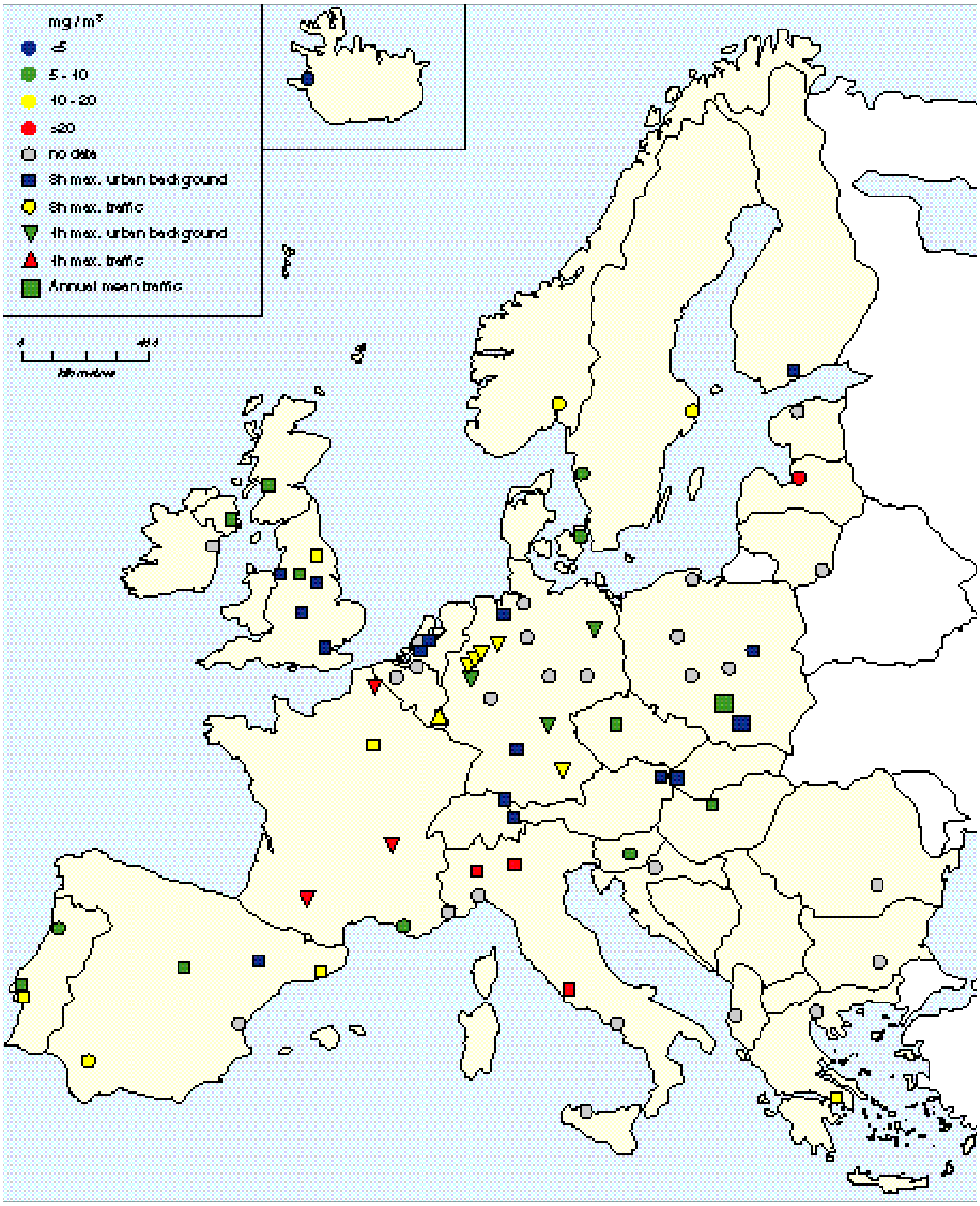


Map 7.7
Trends in annual average NO_2 concentration reported by investigated cities in recent years

Airborne Lead

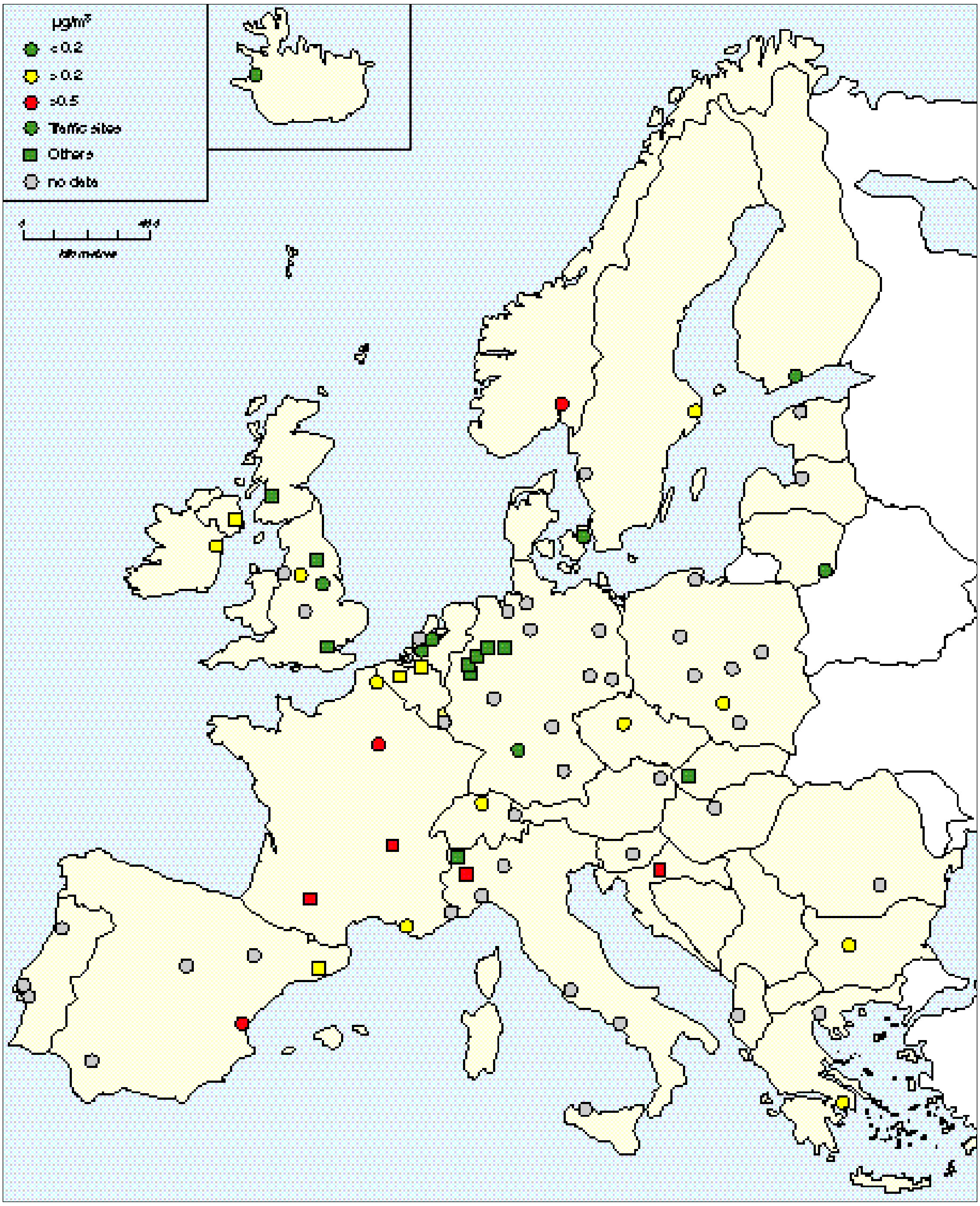
The lead content of suspended particulate matter was commonly determined in many cities through the 1970s and 1980s. *Map 7.9* shows a summary of available annual average concentrations, but once again levels derived from a combination of urban background and kerbside monitoring stations had to be used which reduces rather the comparability of the data. Exceedances of the air quality standard of 0.5 μg/m^3 proposed by WHO (1995d) were observed in several cities, whereas the EU limit value of 2 μg/m^3 (EC Directive 82/884/EEC) was not exceeded between 1985 and 1994 in the investigated cities for which data were available.

It must be noted that highest levels reported here were not necessarily measured at kerbside stations; this could indicate that significant emission sources besides road traffic exist in these



Map 7.8
Urban CO concentration reported by investigated cities in recent years

cities. However an investigation of the age of the data concludes that all levels above 0.5 µg/m^3 were obtained from monitoring in 1990 and earlier, when a large proportion of the vehicle fleet still used leaded petrol. Thus it is probable that since 1990 further reductions in these concentrations have taken place, and will continue as the lead emissions from vehicle traffic decrease further. Since the introduction of unleaded petrol in many countries, lead levels are no longer regarded as a major problem and monitoring is no longer carried out. In parts of eastern Europe, the introduction of unleaded petrol is still in an early phase and it is reasonable to assume that lead levels here will fall rapidly as more of the vehicle fleet changes over to using unleaded fuel.



Map 7.9
Average annual lead concentration reported by investigated cities in recent years

Volatile Organic Compounds

Data on concentrations of volatile organic compounds (VOC) in urban areas are relatively scarce. The determination of VOC levels poses high requirements on monitoring equipment and analytical methods. Monitoring devices that produce on-line data are very costly and are therefore not yet applied on a regular basis. A further difficulty in the interpretation of VOC concentration is stems from the fact that for existing data it is not always clear whether measurements of total hydrocarbons include methane. Benzene (C_6H_6) is the most frequently monitored individual compound, since there are important health effects related to this substance, and these have caused major concern in recent years (EPAQS, 1994). Furthermore, benzene concentrations have increased in many urban atmospheres with the introduction of unleaded petrol leading to high emissions from vehicles not equipped with catalytic converters. The assessment of levels of benzene in ambient air is therefore of considerable current interest.

The available data did not make it possible to prepare a VOC concentration map for Europe. Furthermore, few cities have monitored VOCs for more than five years, thus long time-series are rare. Examples for benzene concentrations monitored in recent years in three European cities are shown in *Figure 7.9*. In Berlin and Hannover, data obtained from roadside monitoring sites were used, whereas the Rotterdam site represents urban background concentrations. So far no European standards for benzene have been set, but several countries have developed guidelines; for example, the UK Expert Panel on Air Quality Standards proposed an annual average of 16 µg/m^3, which should be reduced in time to 3.2 µg/m^3. Since 1990 the higher level was not exceeded in any of the three cities, but the lower guideline was only achieved in Rotterdam in the last two years. The exceptionally high concentrations reported for Hannover in 1989 are due to the fact that only data for the last three months of the year were available and benzene levels tend to be higher in winter. Thus, the annual average for the whole year would be expected to lie below 21 µg/m^3.

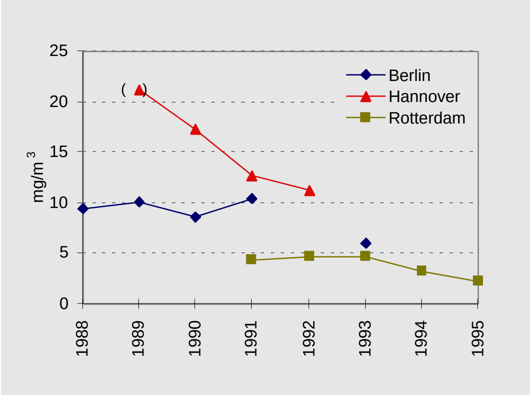


Figure 7.9 Comparison of benzene concentrations in three cities

Map 7.10 summarises 1-hour maximum ozone concentrations monitored between 1989 and 1994. Data availability from southern and eastern European countries is very limited, thus the expected north-south gradient, which is indicated by the meteorological summer smog potential *(Map 5.6, Chapter 5)*, cannot be seen clearly, although the levels measured in several cities agree with this expectation. The lowest concentrations occur in

Ozone

Concentrations of the secondary pollutant ozone show extreme seasonal and even diurnal variations, thus the assessment of annual average concentrations is not particularly useful. *Figure 7.10* displays the ozone concentrations monitored at an urban station in a Brussels residential area with moderate traffic. The annual time-series shows a rise in spring, reaching highest levels in July and early August; diurnal variations with characteristic peaks in the afternoon, when ozone generation is highest, can be seen during the ten selected days in July (APIS, 1996).

For these reasons, as was the case for CO, annual average ozone concentrations are not of relevance for the assessment of adverse impacts on the population and the environment, and no guideline or limit values have been set *(Table 3.5)*. Reporting of ozone levels concentrates on maxima and threshold exceedances. In compliance with EC Directive 92/72/EEC, the EU Member States report ozone concentrations monitored at stations where threshold exceedances occur, as well as the duration of these exceedances in number of days *(Map 6.1, Chapter 6)*.

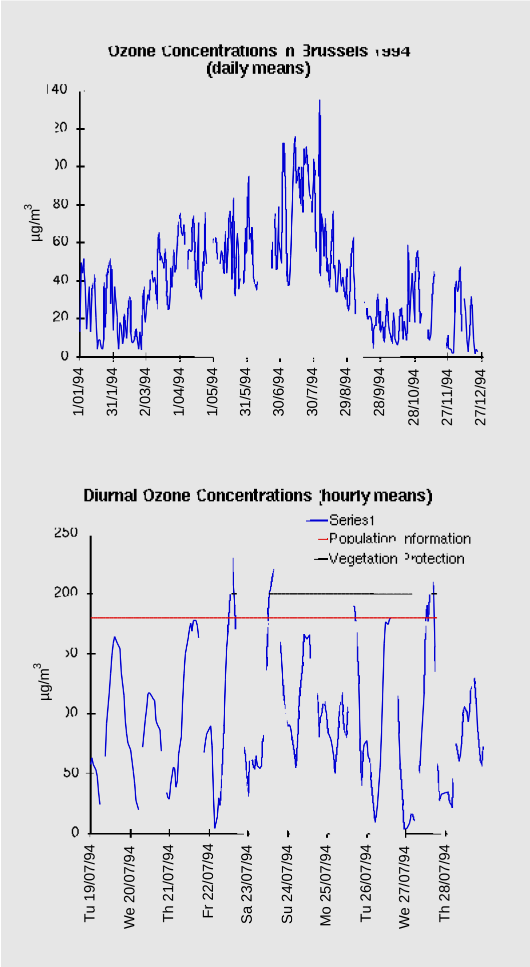
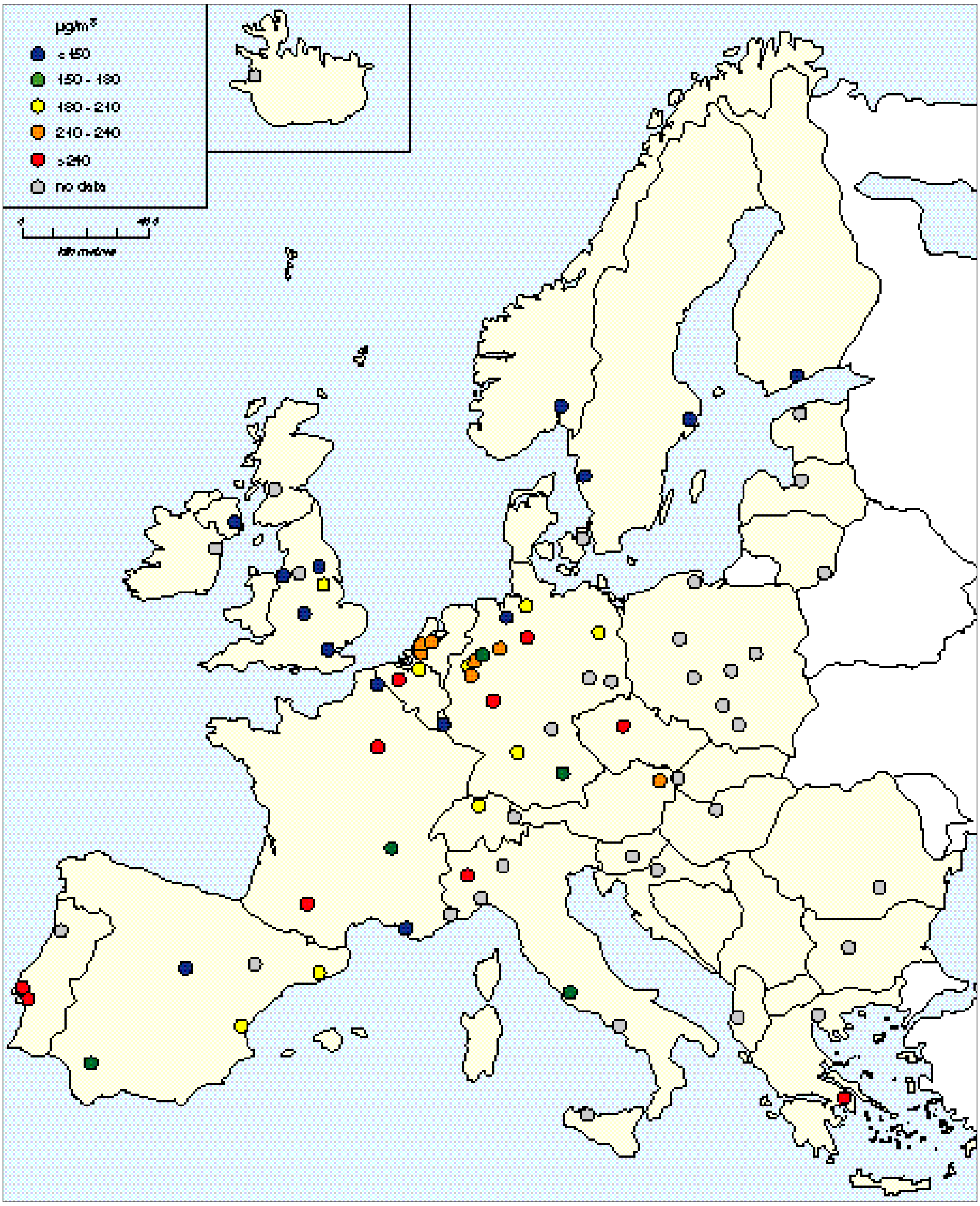


Figure 7.10 Seasonal and diurnal variations of O_3 in Brussels (APIS, 1996)



Map 7.10
1 hour maximum O_3 concentration reported by investigated cities in recent years

the Nordic countries and in the UK, where lower temperatures and insolation restrict the ozone generation. The extremely low value reported for Marseilles in 1991 might not be representative, since in 1994 1-hour maximum values exceeded 180 µg/m^3 and 200 µg/m^3 on 15 and 7 days, respectively, but the actual levels are not known. For Bratislava and Warsaw, 24-hour maximum values had to be used, which implies that those values monitored and reported for shorter averaging periods will be significantly higher and probably exceed guideline values.

Values shown for the UK refer to 1994, which was a year of average ozone concentrations in comparison to the previous seven years. Under specific weather conditions in particularly hot summers, as occurred in 1989 and 1990, these average levels can be greatly exceeded (Bower et al., 1995). On the other hand, the generation of very high concentrations in large cities such as Paris and Hamburg, and in the densely populated areas of Holland and the Rhine-Ruhr valley, shows that the movement of air masses containing ozone precursors from one city to another has an important impact on maximum levels in areas where the photochemical reactions take place at a slower rate.

Furthermore, the involvement of ozone and ozone precursor substances in long-range transboundary transport and the occurrence of peak levels mainly outside cities was previously described in *Chapter 6.*

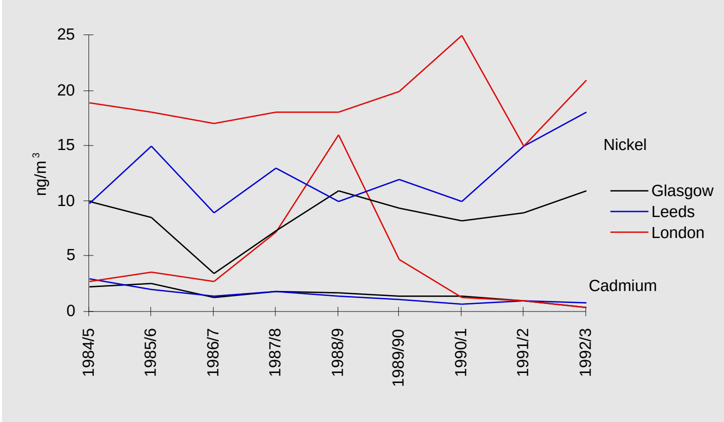


Figure 7.11
Average concentrations of cadmium and nickel (DoE, 1995)

Hazardous Air Pollutants

The term hazardous air pollutants, as opposed to traditional air pollutants, includes a wide variety of substances *(Chapter 1)* which are referred to as a single group only because they pose a risk to human health and the environment, even when they occur at low concentrations. High emission and population densities in urban areas lead to exposure of city inhabitants to elevated levels of a mixture of these potentially toxic compounds. Information and data on emissions, ambient concentrations and the effects of hazardous air pollutants are still very sparse and imperfect with substantial uncertainties. International efforts to harmonise monitoring and assessment methods are once again essential to facilitate the establishment of a pan-European database which would allow the development of source and distribution maps (OECD, 1995). This has been confirmed as a priority by the EEA at the recent workshop on Air Quality Monitoring and Assessment (ETC-AQ, 1996b).

The scarcity of data can be seen in the fact that national monitoring networks in the UK, for instance, measure concentrations of metals other than lead in only three of the eight investigated UK cities. The national multi-element network covers eight important metals (Cd, Cr, Cu, Fe, Mn, Ni, Pb, and Zn), and has been in operation since 1976 (Bower et al., 1995). The curves for cadmium and nickel at all three monitoring sites for the last 10 years show an overall decrease for cadmium *(Figure 7.11)*, whereas nickel seems to increase. These compounds are included in the Framework Directive on Urban Air Quality, which means that daughter Directives with limit values will be developed, and their assessment will become obligatory (EC Directive 96/62/EC, 1996).

Dioxins are a group of pollutants causing local, regional and global pollution problems. Following current concerns over their potential toxicity, it is clearly desirable to reduce their concentrations as much as possible. It is generally accepted that they are very persistent compounds and thus liable to take part in long-range transboundary transport, and, since they are not broken down by biological processes, they accumulate in the food chain and in ecosystems. On the basis of this knowledge, the EU target for dioxin emissions was set at a 90% reduction of 1985 levels from identified sources by 2005 (COM(95) 624, 1995). The predominant sources of dioxins in the atmosphere are waste incinerators and steel works. These sources are both frequently located in the vicinity of cities; urban waste incinerators can shorten distances of refuse transportation and facilitate supply of surplus energy to local communities; steel works were historically located near residential areas for the work force. Stack emissions have a potentially strong harmful impact on the local environment under conditions of low dispersion.

Assessment and control of persistent organic compounds and other hazardous air pollutants are becoming increasingly recognised as international priority issues. As an example of new measurment

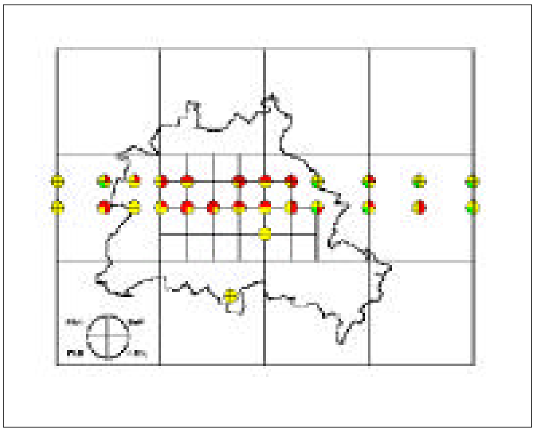


Figure 7.12
Curly Kale - Bio-monitoring Network in Berlin (UISonline, 1996)

systems, Berlin has established a comprehensive biomonitoring programme consisting of several active and passive monitor species for pollutant accumulation and reaction indication. The objective of the network is aimed at assessing the ecological impact of air quality and characterising the effects of regional short- and long-term exposure to atmospheric pollutants. The network covers central and suburban parts of the city. In hot spot areas, close to motorways for example, the density of monitors is increased. Curly kale *(Brassica oleracea acepala)* is used for cumulative determination of PAHs, using the indicator pollutants benzo[a]pyrene (BaP), PCBs and PCDD/PCDFs (dioxins and furans). Results for 1993/94 are displayed in *Figure7.12*, where green, yellow and red indicate low medium and high exposure stress, respectively (UISonline, 1996).

Chapter 8

Exposure Assessment

The assessment of the impact of air pollution on the global environment is generally split into three different sectors, namely human health, ecosystems and building materials. An economic value can be given to all three fields and thus the conservation of clean and healthy air should be not only a prime medical and environmental issue, but also an economic issue. Costs are associated with:

- raised numbers of respiratory and cardiovascular diseases, leading to higher numbers of visits at general practices and increased application of medication, reduced well-being and stress, reduced life expectancy, development of chronic diseases and cancer as well as genotoxic effects;
- reduction of crop yield and loss of biodiversity in combination with decrease in recreational value of a landscape;
- cleaning, restoration and replacement of buildings and structures and the irreversible loss of cultural heritage.

In combination with the recent adoption of the EU Framework Directive on Ambient Air Quality Assessment and Management (EC, 1996), an economic evaluation, with the aim of identifying the least-cost solution to meet the limit values, will be conducted. This evaluation will cover the substances sulphur dioxide (SO_2), nitrogen dioxide (NO_2), fine and suspended particulates, as well as lead (Pb). Analysis based on costs and benefits, with emphasis on the estimation of monetary gain

Cyclist in smog, London

from reduced harm to human health, but also paying attention to damage of ecosystems and materials, will be carried out. The impact on ecosystems and material welfare should, where possible, be expressed in monetary terms as well, otherwise physical terms will be used. The cost assessment will include capital and operating costs for mobile and stationary sources, expressed per ton of abated emission, employing technical and non-technical emission control methods (S030, 1996).

Public Health Effects

Although in certain areas specific pollutants may play a predominant role in the exposure pattern and even in pollution episodes some indicator pollutants have been identified, a mixture of harmful substances is generally present in the ambient air. Thus the assessment of the impact that individual substances have on their environment is often difficult and a wide range of confounding factors has to be considered. The interactions of pollutants, which may occur together in the atmosphere, have hardly ever been investigated. The effects on organisms and materials, caused by two or more chemicals attacking them simultaneously, can be additive, synergistic or antagonistic, yet investigations, particularly controlled-chamber studies, usually concentrate on single pollutants.

On the other hand, in epidemiological studies, the effects of individual pollutants are difficult to distinguish since the concentration curves of several pollutants, originating mainly from the same source or generated under similar conditions, can follow a parallel course; this is the case for SO_2 and suspended particulate matter (SPM) emitted from coal combustion facilities. Another problem encountered in epidemiological studies is the possible presence of unidentified (and thus not measured) confounding factors, which could have some impact on the selected health criteria under investigation. Confounding factors of particular importance in air quality investigations, for which controls are generally applied, are:

- meteorological variables, such as temperature, humidity, wind velocity,
- personal variables, such as smoker/non-smoker, education, income,
- seasonal or other chronological variables, such as day of the week, holidays, and
- others, such as influenza epidemics and pollen levels.

Epidemiological Studies

Two types of epidemiological studies can be differentiated; one investigates single air pollution episodes, whereas in the other, daily health events are computed. In the first type, the derivation of direct evidence for the occurrence of health effects and suggestions on how to practice abatement, is possible from the data. The second type, time-series studies, either focuses on panels or uses the whole population. They allow control for confounding factors and result in the definition of a coefficient, which describes the relationship between health effects and air pollution (AGMAAPE, 1995). Such a coefficient can then be used in the definition of air quality standards.

Many earlier studies suggested that the pollution concentrations normally experienced in the major part of Europe, even during episodes of elevated contaminant levels, do not cause harm to otherwise healthy individuals, but can have a major impact on sensitive individuals. Persons with respiratory diseases, such as asthma, will generally increase the administration of medication to compensate for the effects. If this is not possible or not successful, deterioration of health (morbidity) may occur and, in extreme cases, mortality rates will increase. A Europe-wide study on short-term effects was recently initiated and preliminary results indicate that even levels around or below current guideline values could be harmful to health (Katsouyanni et al., 1995). This project, called APHEA (Air Pollution on Health: European Approach), analyses epidemiological time-series data in combination with monitored air pollution levels and information on potential confounders. By aiming to harmonise analytical techniques, and enhance the comparability of epidemiological studies conducted in different parts of Europe and the world, this collaborative project will contribute to the standardisation of methodology and the exchange of expertise. Furthermore, the findings will be advantageous in the revision and update of current air quality guidelines. The application of meta-analysis to results of individual studies will create even more valuable information than could be achieved from the separate investigations.

Guideline values are generally adopted according to the state of current knowledge, under the assumption that even lifetime exposure to these concentrations will have no, or only acceptably low, adverse effects *(Chapter 3)*. The effect of a pollutant does not necessarily show a linear rise in relation to its concentration; in the case of ozone (O_3), for instance, higher levels will cause more harm than expected (WHO, 1995c). Another unresolved problem is the behaviour of the exposure-impact curve in the low concentration zone. It is widely discussed whether threshold values can and should be defined; for instance, the impact of particulate matter does not indicate the existence of a threshold value, thus no guideline level is set.

The survey conducted as part of this study inquired about air quality and emission assessment, but also requested the contact persons to answer the following questions:

- have epidemiological studies been conducted?
- has exposure of specific parts of the population been investigated?
- are exceedances of WHO or national guidelines assessed?
- have the spatial distributions of air quality and emissions been mapped?

Answers collected from 64 of the 79 cities are shown in *Figure 8.1*.

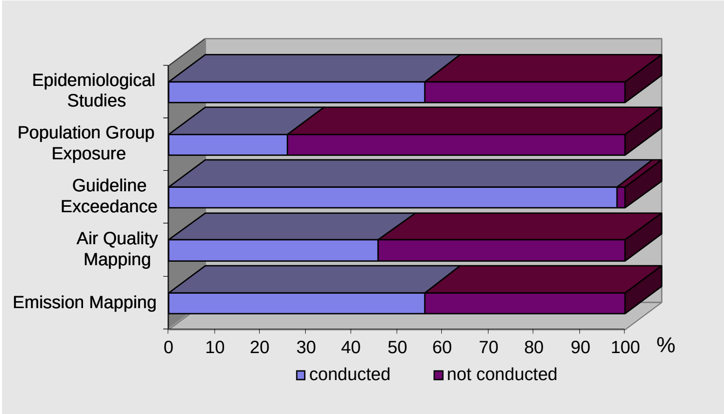


Figure 8.1
Types of assessments conducted in European cities to determine air quality impacts on public health

Findings of Past Research

Two major pan-European studies assessing the health effects of air pollution have recently been conducted. The first is part of 'Air Quality in Major European Cities', prepared for the Dobríš Assessment (RIVM, 1995a,b). The other study was carried out by the WHO in connection with the compilation of 'Concern for Europe's Tomorrow' (CET) (WHO, 1995a). Here different methods of exposure estimation for rural and urban populations (cities >50,000 inhabitants) were employed. The calculations were based on outdoor ambient pollutant concentrations to represent the actual exposure levels experienced by the population. The study concluded that almost half the inhabitants of the European continent (314 million) live in urban areas where they inhale polluted air.

Since the concentrations of air pollutants show a considerable spatial and temporal variance *(Chapter 7)*, the same has to be noted for the exposure of humans to these pollutants. People who spend longer periods of time near emission sources, such as major roads or industrial hot-spots because they live or work there, will be at higher risk of suffering adverse health effects than people who breathe cleaner air. In a detailed assessment of population exposure, the spatial and temporal distribution of pollutants and people has to be conducted in order to correctly estimate the number of inhabitants exposed to particular concentrations.

A method, which facilitates an estimation of the portion of the population within one city exposed to certain pollutant concentrations above air quality guidelines at any time, was developed and applied by RIVM (1995a) and used in the Dobríš Assessment. Again, the calculations were based on maximum city background levels, since data on pollutant concentrations in hot-spot areas and population distribution was too sparse to allow a detailed analysis in all cities. Thus, the minimum exposure of the residential population was determined; higher levels will be experienced by individuals during travelling and near emission sources. Three basic assumptions were made:

- the concentrations monitored at the selected stations for each investigated compound represent the poorest air quality,
- the higher the exceedance of the guideline values at the selected sites the higher the exposure of the total population, and
- the number of monitoring stations is directly related to the capacity to model the population exposure.

This method is very flexible and can be applied to different pollutants and their relevant guideline values, but in the interpretation of results great care has to be taken and several points have to be kept in mind. If the monitoring stations are located in areas of relatively poor air quality this method tends to overestimate the population exposure for primary pollutants, hence the first assumption was made to eliminate this effect. On the other hand, are the concentrations of the secondary pollutant O_3 lower in polluted urban environments, since it reacts with the newly emitted nitric oxide (NO), forming NO_2? This leads to a potential underestimation of the exposure to ozone for the urban population (Eerens, 1996).

The estimations used in the Dobríš Assessment indicate the percentage of city inhabitants breathing air containing pollutant concentrations higher than those suggested in the WHO guidelines for the compounds SO_2 and/or particulate matter. However, these two pollutants were the only ones where sufficient data were available to provide reasonable results.

Table 8.1 Percentage of city population exposed to elevated NO_2 concentrations in cities with data after 1985 (WHO, 1995a)

	Annual mean NO_2 concentration ($\mu g/m^3$)			**Daily NO_2 concentrations (> 150 $\mu g/m^3$)**		**Inhabitants (millions)**
	< 60	**60–100**	**> 100**	**At least 1 day**	**Average duration (days/a)**	
Western Countries	76.1	23.9	0.0	27.9	13.4	56.2
CCEE Countries	75.9	15.4	8.7	24.1	32.4	13.2

Estimates of urban population exposure to further pollutants, such as oxides of nitrogen (NO_x), lead and O_3, without detailed spatial resolution, can be found in 'CET'. Data availability for these compounds was very restricted. Monitored ambient concentrations of NO_x and lead were used in towns inhabited by 30% and 15% respectively, of Europe's total urban population (cities >50,000 inhabitants). For the cities with data, the percentages of people exposed to certain NO_x levels after 1985 are summarised in *Table 8.1*.

Estimation of Urban Population Exposure

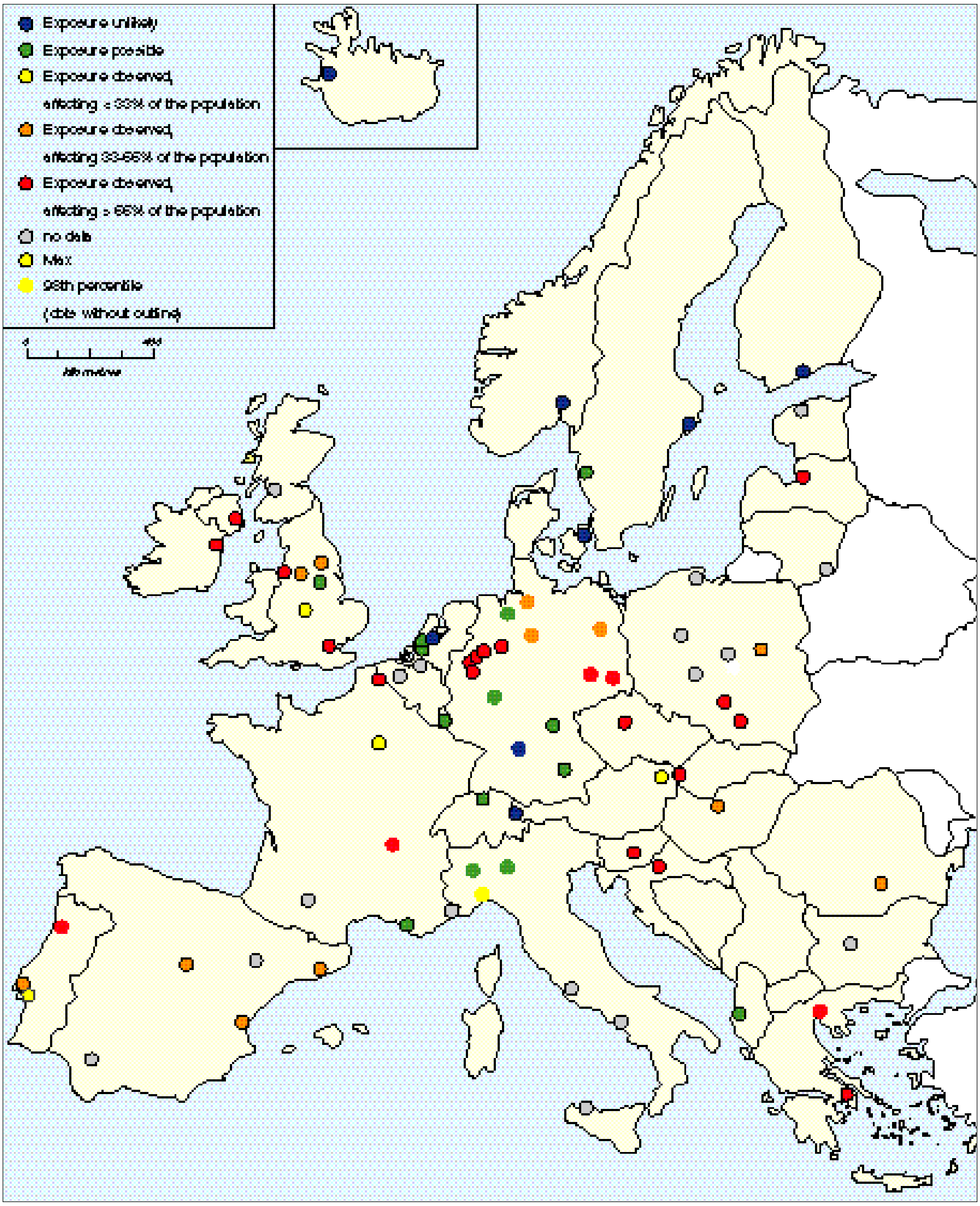
Recent improvements in data availability on a European basis make it possible to produce estimates for the proportions of urban populations exposed to certain concentrations of all major pollutants. Short-term WHO guidelines were selected, since these are of relevance for the whole region under investigation and for pollution episodes. Furthermore, this facilitates a comparison of the results with earlier studies. Using the method briefly described above, which was developed at RIVM, exposure of urban inhabitants to elevated SO_2, particulate matter, NO_2, carbon monoxide (CO) and O_3 concentrations was determined *(Maps 8.1 to 8.5)*. The diversity of information and the problems with reliability and representativity of data again influence the capability to produce adequate results. Whenever possible, maximum pollutant concentrations were used in the assessment of population exposure, but often the 98th percentile (P_{98}) had to be used instead. Depending on the compound under investigation, maximum values will be up to a factor of 3 higher. Thus, results based on the P_{98} will underestimate the proportion of exposed population in comparison to those cities where maxima were employed.

Population exposure to pollution concentrations above the guideline levels was considered unlikely in cities where the highest reported monitoring result was less then half the relevant guideline value. In cases where no exceedance had been observed in the year under investigation, but the highest reported concentration was higher than half the guideline value, exposure of at least a part of the population is considered to be likely under conditions which might occur during other years. If the data indicate guideline exceedances, an assessment of the number of monitoring stations, the highest reported value, and the average of highest values measured at all stations, results in an exposure group. This means that either up to one-third, up to two-thirds or the total urban population, is likely to have been exposed.

Map 8.1 shows the proportions of inhabitants in each city who experienced maximum average daily SO_2 concentrations greater than the WHO guideline of 125 $\mu g/m^3$ in recent years. A comparison of these results with the annual average concentrations displayed in *Map 7.2 (Chapter 7)* shows that exceedances generally occur in cities with high mean levels, indicating a relationship between average and maximum concentrations. A noticeable concentration of short-term guideline exceedances occurred in the Rhine-Ruhr valley, where average values are well below air quality standards. It is unclear whether these exceedances took place at the same time in all cities, but if this was the case it would indicate the occurrence of a winter smog episode over this densely populated area.

An extremely wide range of maximum particulate matter concentrations has been reported, including concentrations that vary by a factor of up to 20 between Gothenburg and Prague. In view of this, the exceedance of the former WHO guideline value of 120 $\mu g/m^3$ for daily mean concentrations is supplemented by an examination of the exceedance of the 50% higher level of 180 $\mu g/m^3$. *Map 8.2* shows that both levels are exceeded in many cities and often, particularly in eastern and southern Europe, the total population is exposed to the poor air quality. Differences in monitoring methods *(Map 4.1, Chapter 4)* may again, to a certain extent, affect the reported concentrations. The correlation between annual average *(Map 7.4)* and maximum concentrations, which was observed for SO_2, can also be seen for particulate matter.

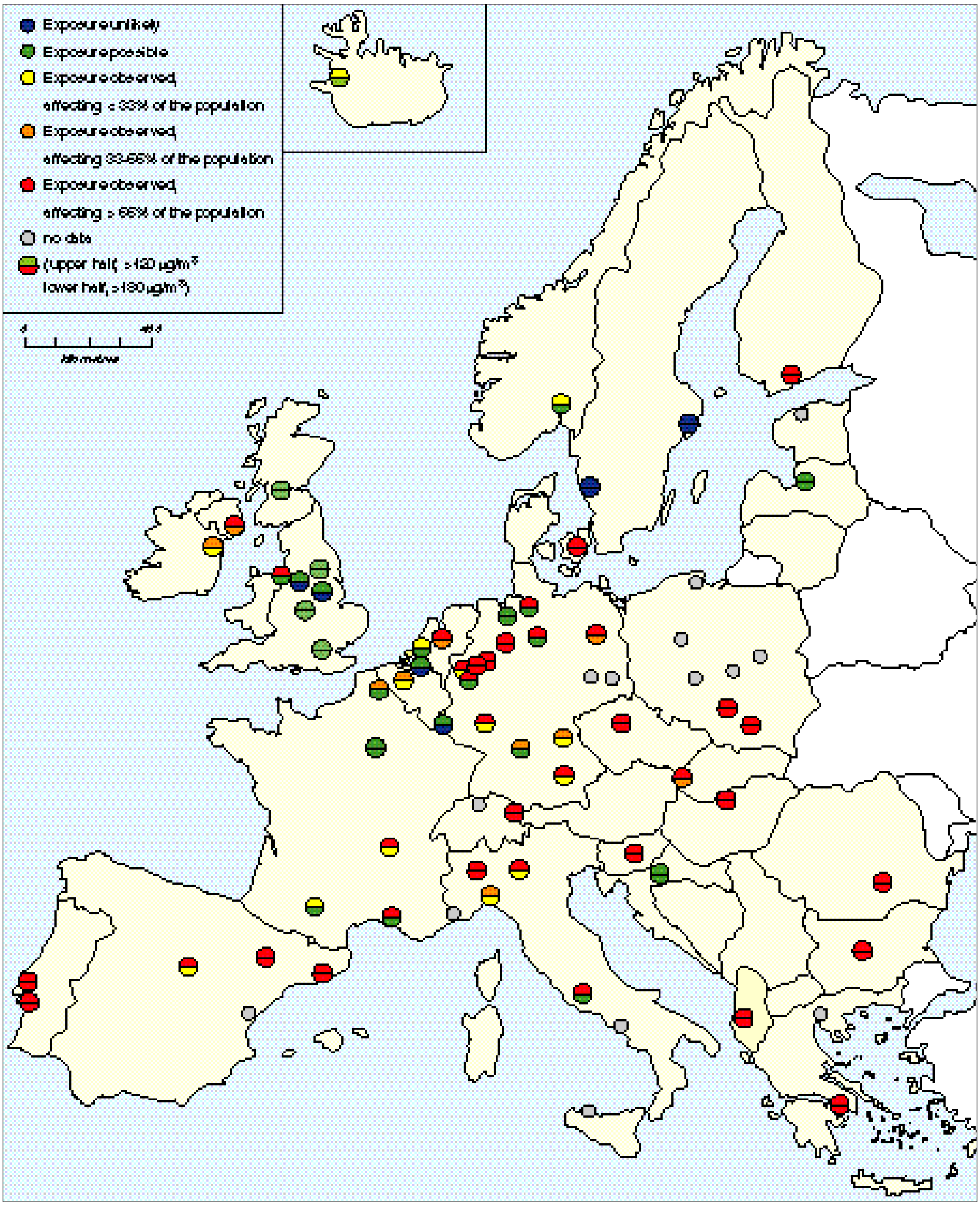
Exposure to maximum one hour NO_2 concentrations above 200 $\mu g/m^3$, the value proposed in the updated WHO air quality guidelines for Europe, is shown in *Map 8.3*. A similarity in the distribution of urban inhabitants, who experienced



Map 8.1
Proportion of urban populations exposed to SO_2 concentrations >125 $\mu g/m^3$

guideline exceedances for the three pollutants SO_2, particulate matter and NO_2 can be detected when comparing *Map 8.1 to Map 8.3*, with lowest levels in the northern region of Europe. The relationship between annual averages *(Map 7.6, Chapter 7)* and maxima is less pronounced for NO_2.

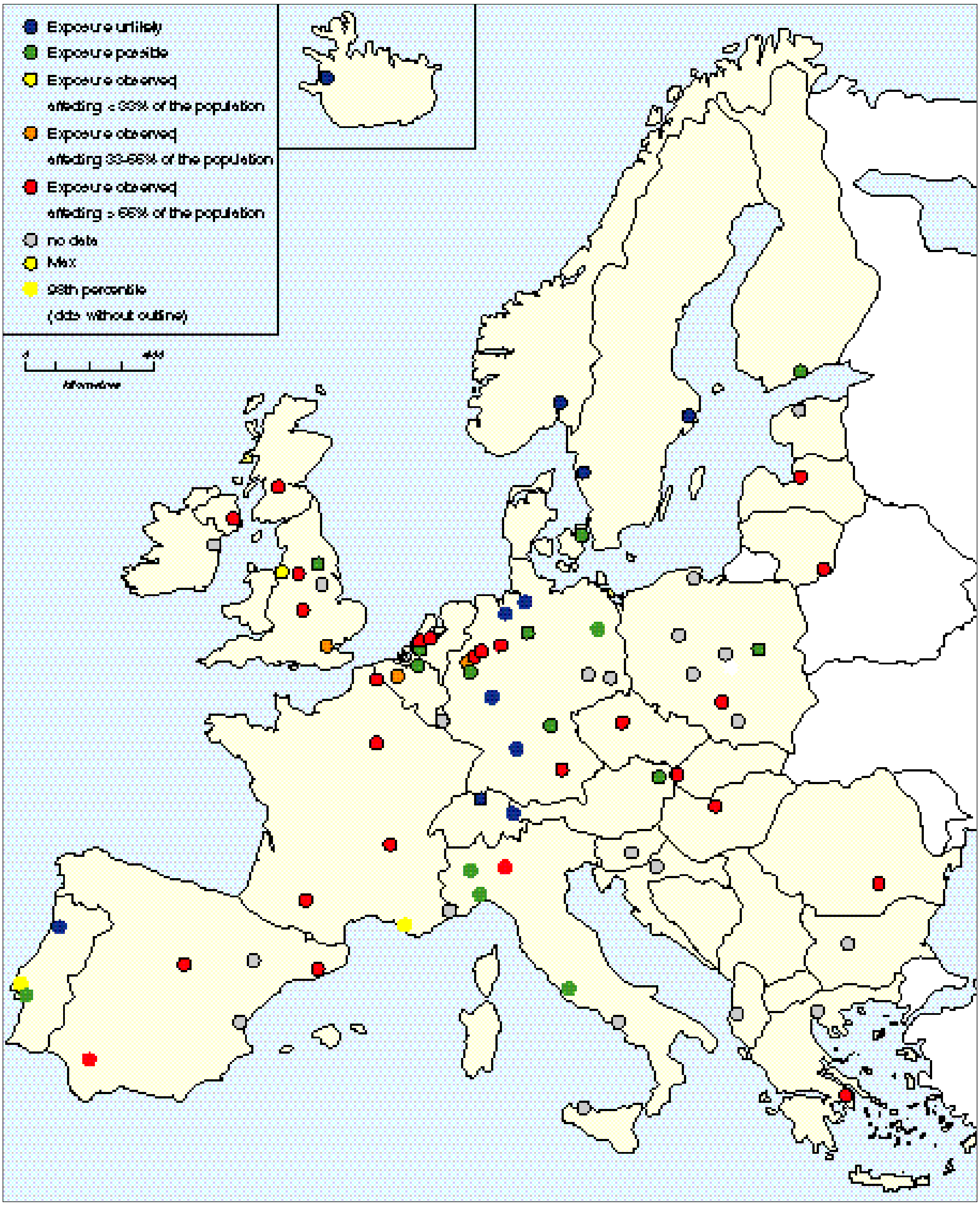
Map 8.4 shows a combination of population exposure to maximum 1-hour and 8-hour average concentrations of CO *(Table 3.2)*. Data availability is very limited, particularly in eastern Europe. So far, no EU air quality standard for CO has been set, however the EU Framework Directive on Ambient Air Quality Assessment and Management includes CO in the list of compounds for which limit values have to be set and monitoring has to be conducted (EC, 1996). Few cities reported maximum 1-hour and 8-hour concentrations; generally only one value is available. Another inconsistency is introduced into the data set by the different location types of the monitoring stations; several are



Map 8.2
Proportion of urban populations exposed to particulate matter concentrations >120/180 µg/m^3

classed as traffic sites and others as urban background *(Map 7.5, Chapter 7)*. The restricted number of results shows that maximum 8-hour concentrations more frequently reach levels considered harmful to the population and that more people are exposed to exceedances of this value *(Figure 8.2)*.

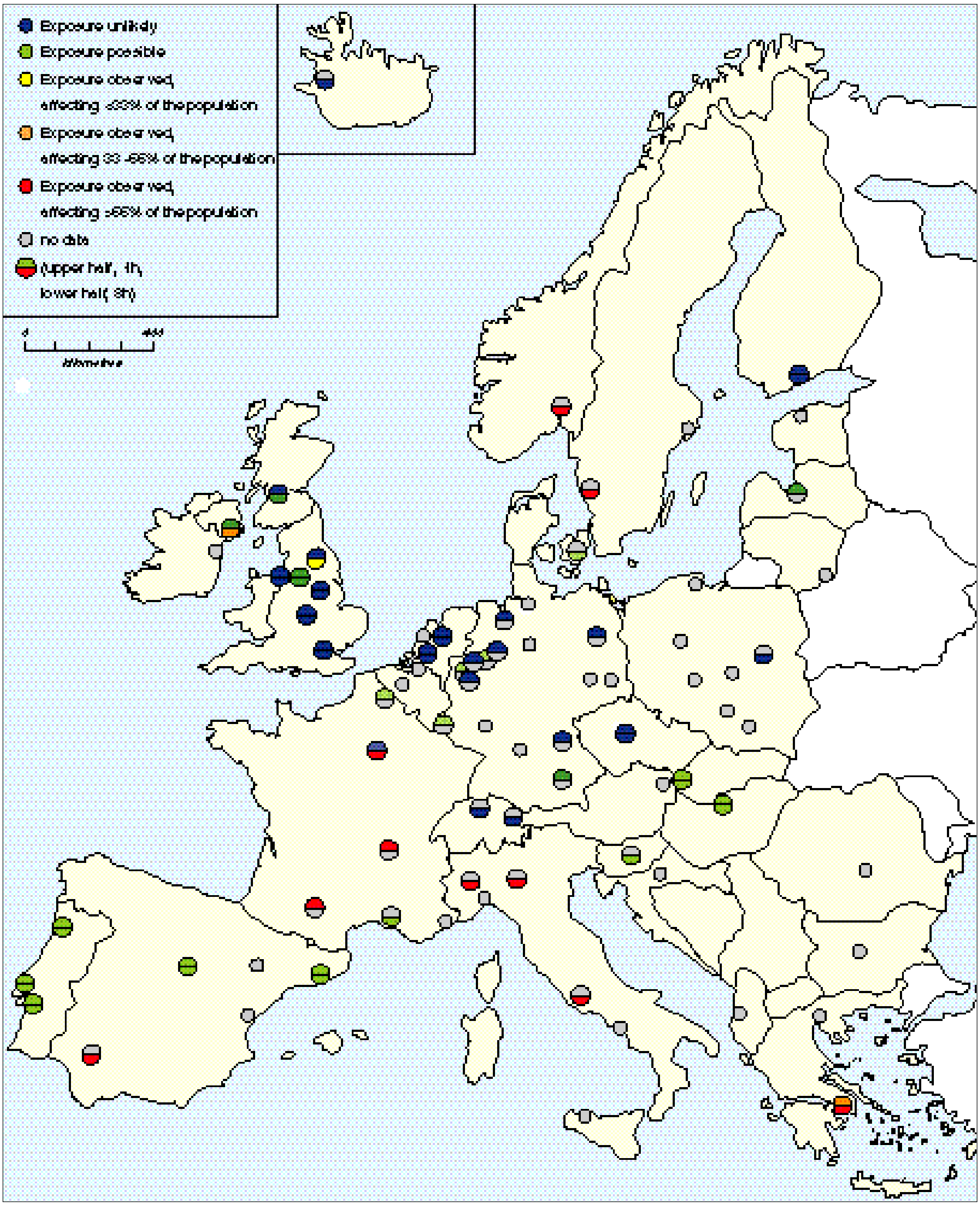
A summary of proportions of urban inhabitants exposed to O_3 concentrations exceeding the EU threshold value for population information of 180 µg/m^3 and a 50% higher level, can be found in *Map 8.5*. Unfortunately, only restricted amounts of data are available for southern Europe, where exceedances and high population exposure are expected. Although in many cities the total population suffers elevated O_3 concentrations above 180 µg/m^3, breaches of 270 µg/m^3 have been observed only rarely. For people in the Nordic countries, the



Map 8.3
Proportion of urban populations exposed to NO_2 concentrations >200 µg/m^3

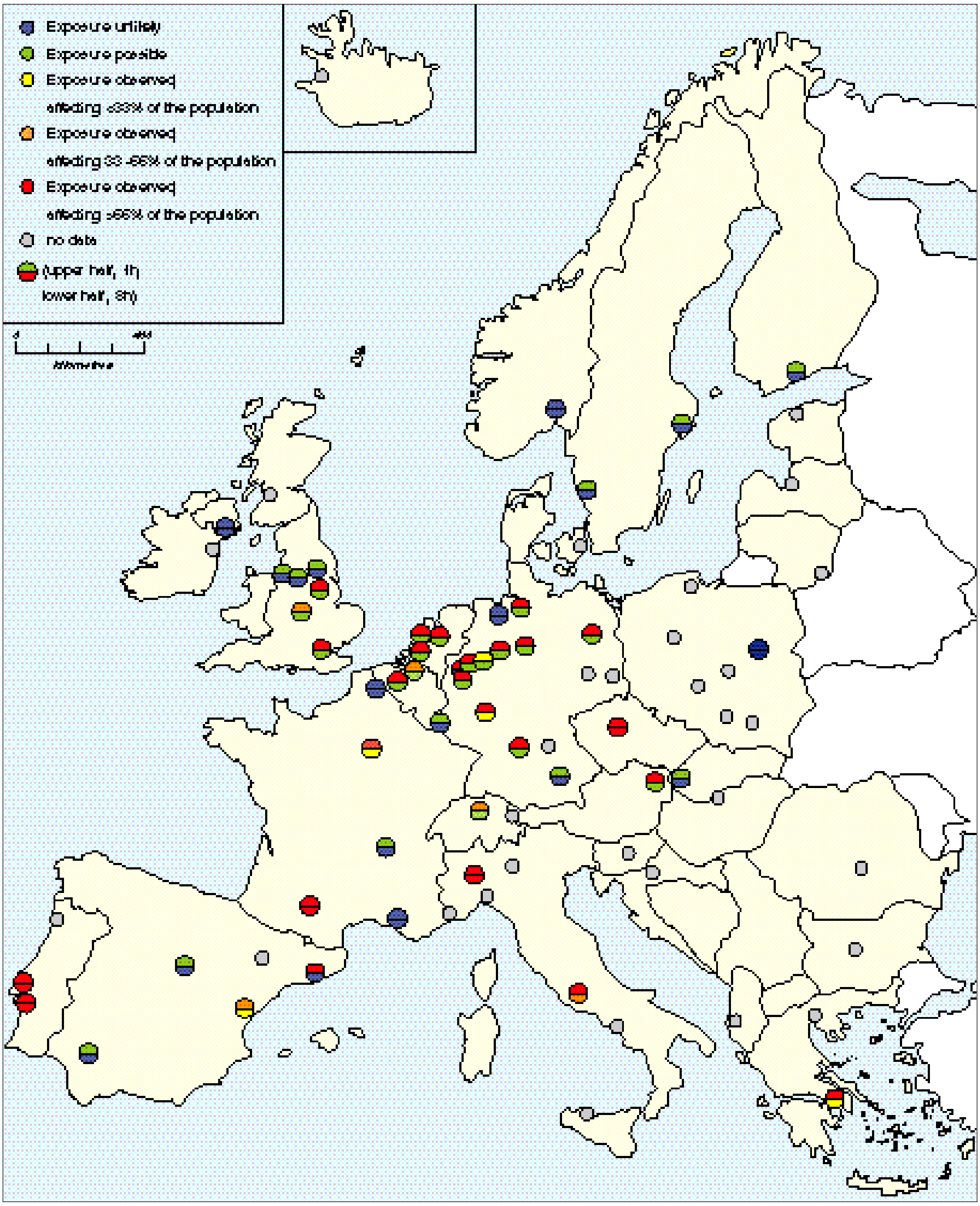
likelihood of O_3 threshold exceedance episodes is relatively low.

It has to be emphasised that, in general, O_3 concentrations in suburban and rural areas are significantly higher than in city centres, thus affecting rural populations and ecosystems more seriously; this is not taken into account in this assessment. Taking Athens in 1994 as an example, a separate estimation of population exposure based on the seven central urban monitoring stations and the three suburban sites has been conducted. The results for the stations located in the inner city are shown in *Map 8.5*; the data for the suburban area indicate that the total population is exposed to O_3 concentrations above 270 µg/m^3. The threshold level for population warning of 360 µg/m^3 was exceeded at one of these stations.



Map 8.4
Proportion of urban populations exposed to CO concentrations >10/30 mg/m^3

Figures 8.2 and 8.3 summarise data availability, expressed as the proportion of European urban population for which the relevant concentrations of the various pollutants are known. The availability of 1-hour and 8-hour carbon monoxide maxima is coincidentally the same, although different cities are included. The information about maximum and annual average SO_2, particulate matter and NO_2 concentrations, between 80% and 92%, is fairly good. The data availability for CO and O_3 levels needs to be increased, especially from eastern and southern European cities. Estimates indicate that, for most pollutants, about 50% or above of the investigated urban populations are exposed to concentrations exceeding short-term guideline values. Furthermore, a significant number of people live in areas exposed to concentrations higher than 150% of the selected guideline values.



Map 8.5
Proportion of urban populations exposed to O_3 concentrations >180/270 µg/m^3

The percentage of residents of large European cities who are exposed to annual average concentrations exceeding long-term limits suggested by the WHO for SO_2 and particulate matter are relatively low at 10% and 14% respectively *(Figure 8.3)*. The results for NO_2 give cause for concern; the WHO guideline for annual means is exceeded in almost half the cities investigated. The percentages of exposed population are taken as the proportion of the entire urban population, rather than city centre residents alone, since the annual averages used are the means of concentrations measured at all urban background monitoring stations. Obviously not every section of the population will breathe air of the identical quality. However, since people move through their city and pass through areas with better and poorer air quality, an application of these long-term average concentrations

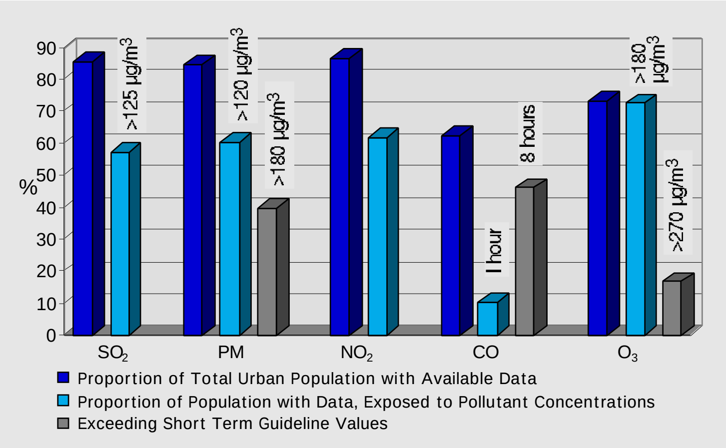
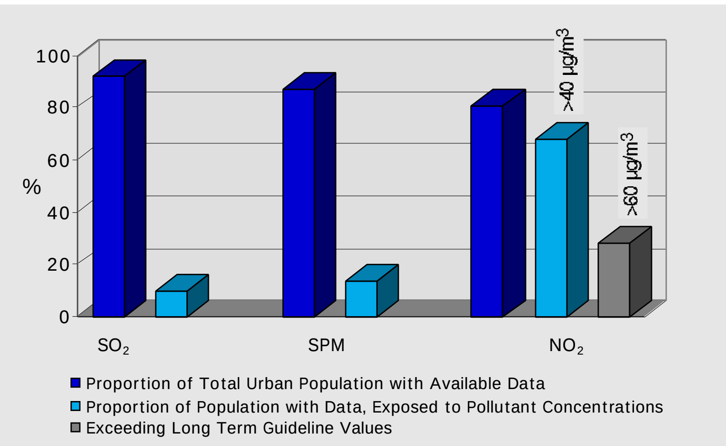


Figure 8.2
Proportion of population with data exposed to pollutant concentrations exceeding short-term guideline values

Figure 8.3
Proportion of population with data, exposed to pollutant concentrations exceeding long-term guideline values



to the total population probably gives a relatively good approximation of the real exposure situation.

Furthermore, the estimates indicate that 28% of urban inhabitants suffer annual average NO_2 concentrations greater than 60 µg/m^3, a result that corresponds well with the estimates from an earlier study *(Table 8.2)*. The 'CET' study assessed the population exposure in urban areas with 50,000 inhabitants; a combination of the results for western countries and those located in central and eastern Europe covers a geographic area similar to that investigated in this study, with an urban population of 212 million. The pollutant concentrations used in the 'CET' study are an aggregation of data reported after 1985. Since this study is generally based on pollution levels monitored between 1990 and 1993, an increase in NO_2 concentrations originating from vehicle traffic may be the reason for the slightly higher results in population exposure. Although, so far, no long-term epidemiological studies of elevated NO_2 concentrations in ambient air have proved definite human health effects *(Table 3.1)*, animal studies suggest that chronic impacts on human health have to be expected.

Table 8.3 summarises findings for SO_2 exposure to elevated annual average and 24-hour average maximum concentrations in relation to the WHO guidelines of 50 µg/m^3 and 125 µg/m^3, respectively. The large variation between the RIVM study (RIVM, 1995a) and this study is surprising because the same estimation methodology was used. However, more complete recent data sets have been used for the current estimates and there is a difference in geographic coverage.

The variety of monitoring methods applied in the determination of particulate matter levels makes an interpretation of results regarding population exposure more difficult *(Table 8.4)*. However, it can clearly be seen that concentrations exceeding recommended short and long-term standards were experienced by large parts of the urban population. As pointed out in the earlier chapters, a consistent approach of measuring particulate matter in ambient air will significantly improve the comparability of different studies.

A detailed comparison of the population exposure to elevated O_3 concentrations is not possible. The only available data are estimates for all urban inhabitants in continental Europe, thus covering 656 million people. Of these, 56% were estimated to be exposed to maximum O_3 concentrations above 200 µg/m^3 in 1989. However, 1989 was a particularly hot and sunny year, whereas estimates for 1985 with comparatively cold and wet weather resulted in exposure estimates of only 22% (WHO 1995a). An investigation of population exposure to concentrations exceeding 180 µg/m^3, combining data from several years, found that 72% were affected. The difference in relevant guideline value and estimation method can explain the divergence of the results. An assessment of population exposure to CO on a European level has not been attempted in any previous study. Unfortunately, the current data on population exposure to 10/30 mg/m^3 is still too patchy to give a pan-European estimate.

Ecosystems

The destructive impact of air pollution on ecosystems takes place in the vicinity of emission sources or after long-range transboundary transport of primary and secondary pollutants. Compounds suspended in the lower atmosphere, as well as those deposited on the earth's surface, are harmful to aquatic and terrestrial biotopes. Environmental parameters, as well as pollutant concentrations, determine the extent of damage, which is the reason for the adoption of the critical load/ critical level approach *(Chapter 3)* for several issues.

NO_2	Guideline value	Population with available data (millions)	Population exposed (millions)	Population exposed (%)
CET	>60 µg/m³ annual average	69.4	16.2	23
	>150 µg/m³ daily average	69.4	18.9	27
This Study	>40 µg/m³ annual average	81.0	55.2	68
	>60 µg/m³ annual average	81.0	22.9	28
	>200 µg/m³ hourly average	87.0	54.0	62

Table 8.2
Comparison of exposure estimates for NO_2
(WHO, 1995a)

SO_2	Guideline value	Population with available data (millions)	Population exposed (millions)	Population exposed (%)
CET	>50 µg/m³ annual average	78.0	10.6	13.5
	>125 µg/m³ daily average	78.0	34.5	44.0
RIVM	>125 µg/m³ daily average	116.0	27.8	24.0
This Study	>50 µg/m³ annual average	93.0	9.3	10.0
	>125 µg/m³ daily average	86.0	49.6	57.6

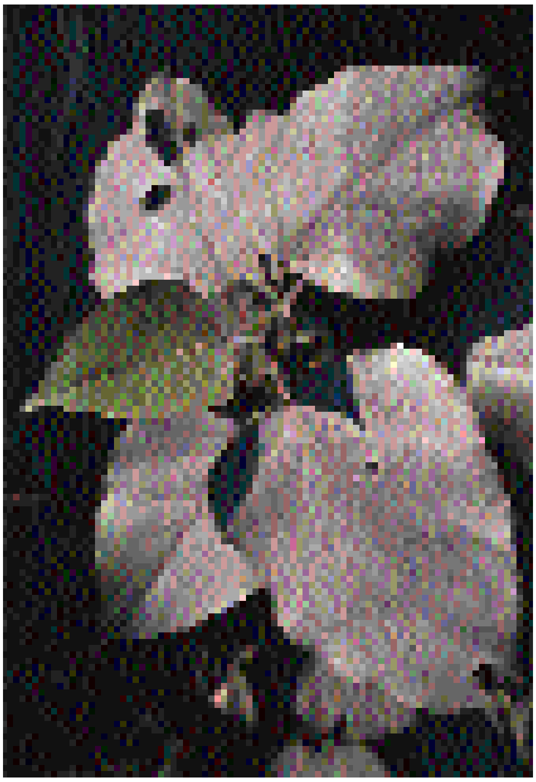
Table 8.3
Comparison of exposure estimates for SO_2
(WHO, 1995a, RIVM, 1995a)

Particulate matter	Guideline value	Population with available data (millions)	Population exposed (millions)	Population exposed (%)
CET Black Smoke	>50 µg/m³ annual average	56.9	13.4	23.6
CET SPM	>60 µg/m³ annual average	29.1	17.2	59.1
RIVM Black Smoke	>125 µg/m³ daily average	116.0	50.0	43.0
This Study TSP/BS/PM_{10}	>80 µg/m³ annual average	87.7	12.1	13.7
	>60 µg/m³ annual average	87.7	19.6	22.3
	>120 µg/m³	84.7	51.4	60.6

Table 8.4
Comparison of exposure estimates for particulate matter
(WHO, 1995a, RIVM, 1995a)

The major environmental issues are:

- forest damage due to acid deposition and ozone,
- pollution of coastal seas by the deposition of heavy metals,
- acidification of surface waters and
- nutrient input into soils, freshwaters and coastal seas causing eutrophication.



Coal dust on leaves close to a coal-fired power station in Poland

The importance of each problem in different parts of Europe varies, depending on pollution loads and a multitude of environmental factors. In general, the effects experienced cover the loss of biodiversity, crop yield, aquatic life and forest decline. A determination of dose-response curves for certain pollutant levels and specific impacts on ecosystems is equally difficult, as it is in the case of epidemiological studies on human health effects, where complex natural systems are involved.

Terrestrial Biotopes

A number of hypotheses have been developed in order to explain forest decline, and it has yet to be determined what impact mixtures of pollutants have on the environment (Wellburn, 1994). In combination with pollutant concentration, various biological stresses, such as humidity, fungal or insect attack and availability of nutrients, will determine the extent of injury. The forest condition in Europe has been thoroughly investigated. The damage of coniferous and broad-leaved species was assessed by determination of defoliation and discoloration of thousands of representative sample trees. *Figure 8.4* shows the distribution of forest condition expressed as the percentage of damaged trees (EC-UN/ECE, 1996). The survey concludes that although sulphur emissions have dramatically reduced over much of Europe over the last 20 years, forest damage has continued to increase. The reason for this apparent contradiction may be the result of many different factors. Sulphur is only one of several different key pollutants, the majority of which have not been subject to emission reductions. Furthermore, there may be a considerable time lag between cuts in emissions and subsequent reductions in soil sulphur levels.

Aquatic Biotopes

The acidification of surface waters, resulting from wet and dry acid depositions, has been observed since the early 1970s. In southern Scandinavia, significant losses of fish populations from lakes also occurred. A number of formerly local species are unable to tolerate pH levels under 5.5, which are now common in many freshwater systems. From *Figure 8.5*, it can be seen that those areas where surface water acidification has actually been

Oak trees showing the damaging effects of exposure to air pollution

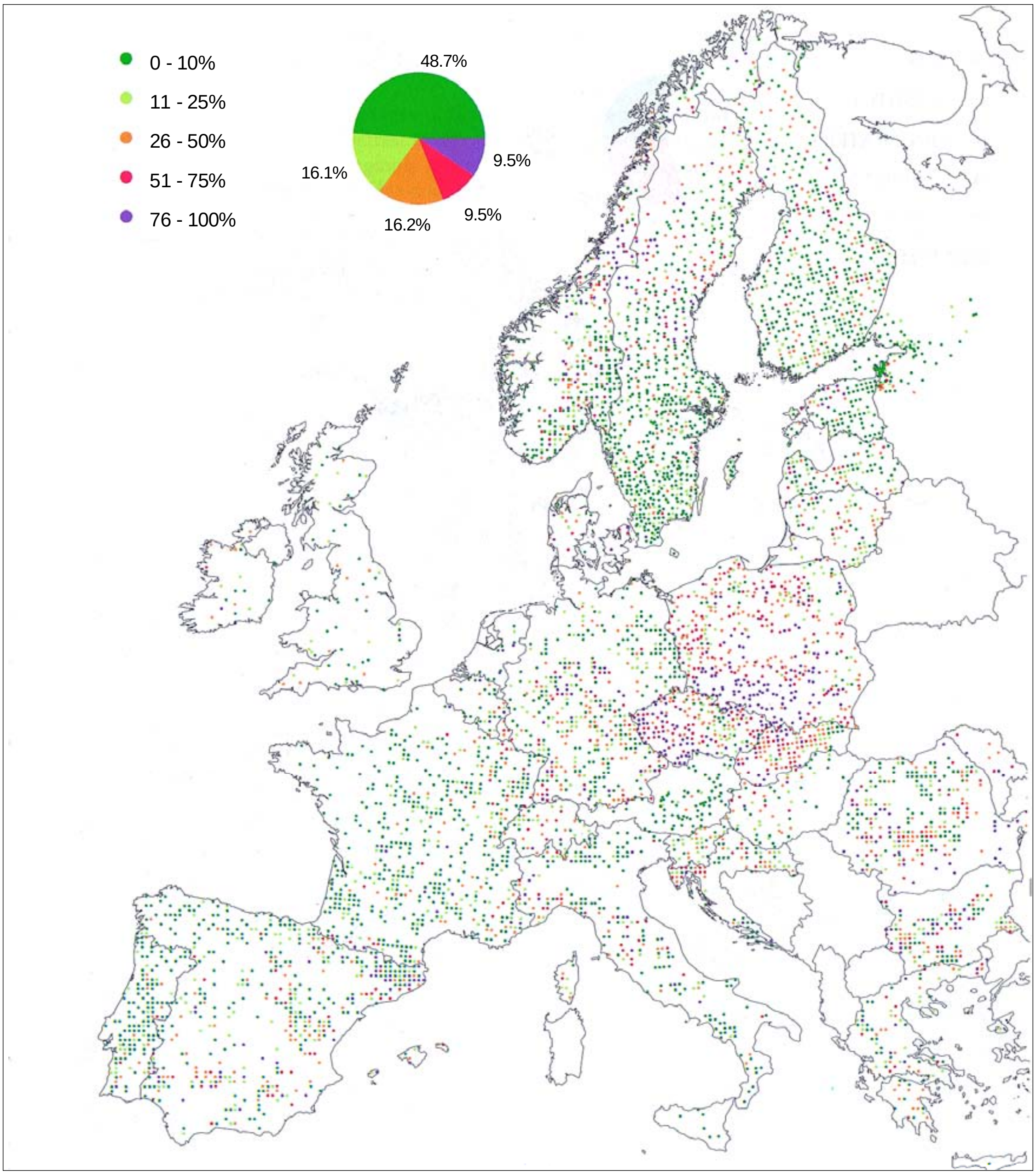


Figure 8.4
Forest condition in Europe (EC-UN/ECE, 1996)

observed are located mainly in southern Scandinavia, Germany and the UK, although areas sensitive to acidification do occur more widely. The distribution of acidification is due to a combination of acid deposition levels in the area, arising from local and transboundary long-range transport of pollutants (particularly from the UK and the Black Triangle), together with the poor buffering capacity of the soils in the affected region. Well-buffered soils have the capacity to neutralise acid depositions and thus prevent or limit harmful impacts (Kristensen and Hansen, 1994).

Loch Fleet is one of many northern UK lakes showing the classic features of acidification

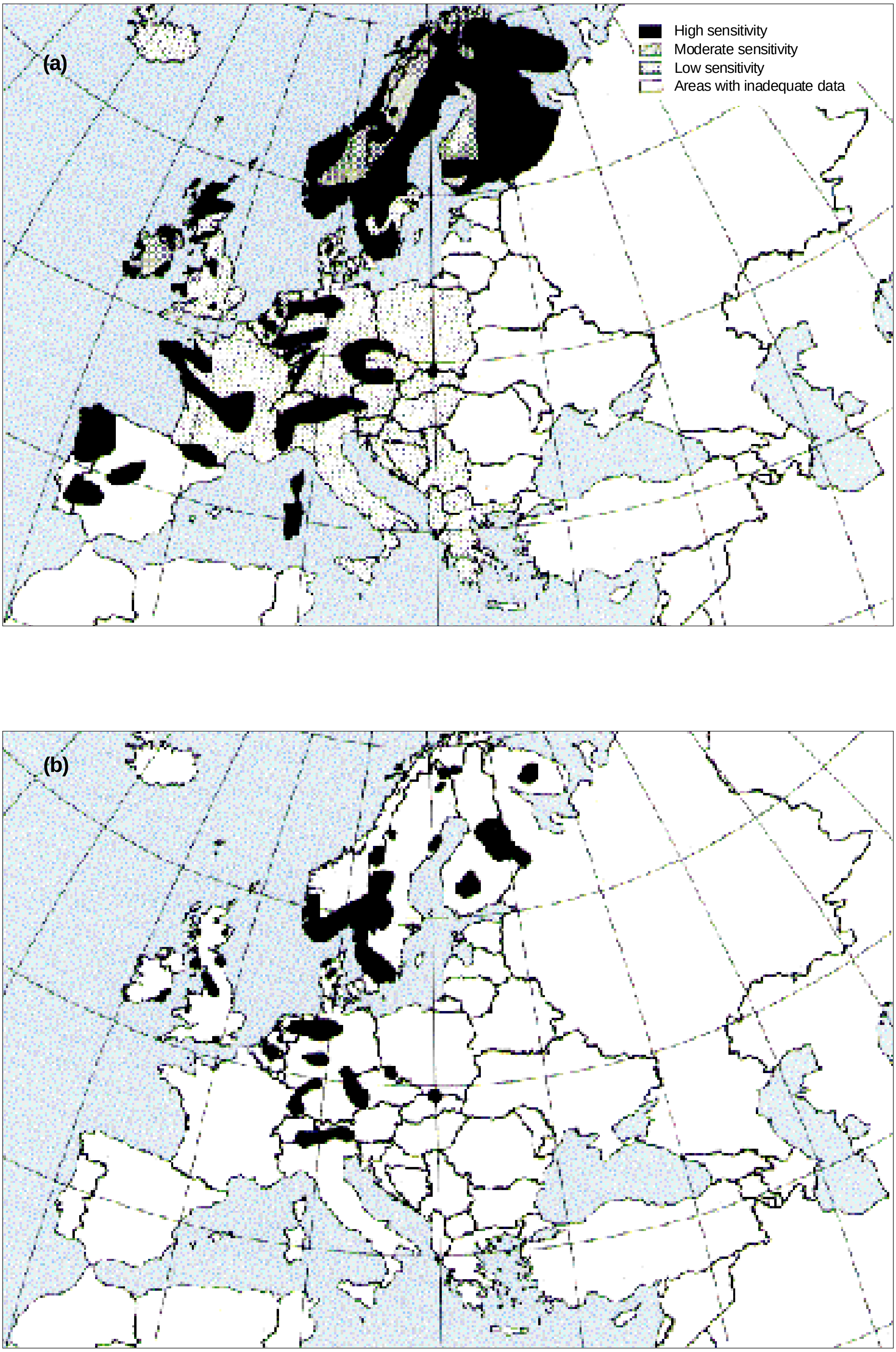


Figure 8.5 Zones with (a) potential and (b) observed freshwater acidification (Kristensen and Hansen, 1994)

Materials

The detrimental effect of air pollution on building materials and monuments has been recognised for a long time and still causes major concern (see *Box 7*). Early studies on these effects concentrated mainly on the corrosive effects of SO_2 on metals. More extensive long-term studies were initiated after the adoption of the Convention on Long-Range Transboundary Air Pollution in 1979 *(Chapter 6)*. These so-called International Co-operative Programs (ICP) investigate the effects of pollutants on different parts of the ecosystem. The ICP on materials was launched in 1985 in order to assess deterioration of various building materials, with some emphasis on the degradation of historical buildings and monuments. The impact of several common air pollutants and important meteorological factors were studied; the different variables are summarised in *Table 8.5*. Exposure of material samples at 39 European sites in sheltered and unsheltered positions for periods between one and eight years allowed the subsequent formulation of dose-response curves, which describe the effects of individual and combined pollutants on the various materials (Kucera and Fitz, 1995).

The presence of pollutants in the atmosphere accelerates natural corrosion, which depends on a variety of meteorological, physical, chemical and biological aspects such as:

- temperature,
- wind speed and turbulence,
- relative humidity,
- precipitation,
- airborne salts,
- UV-radiation,
- effects of freezing, and
- microbiological activity.

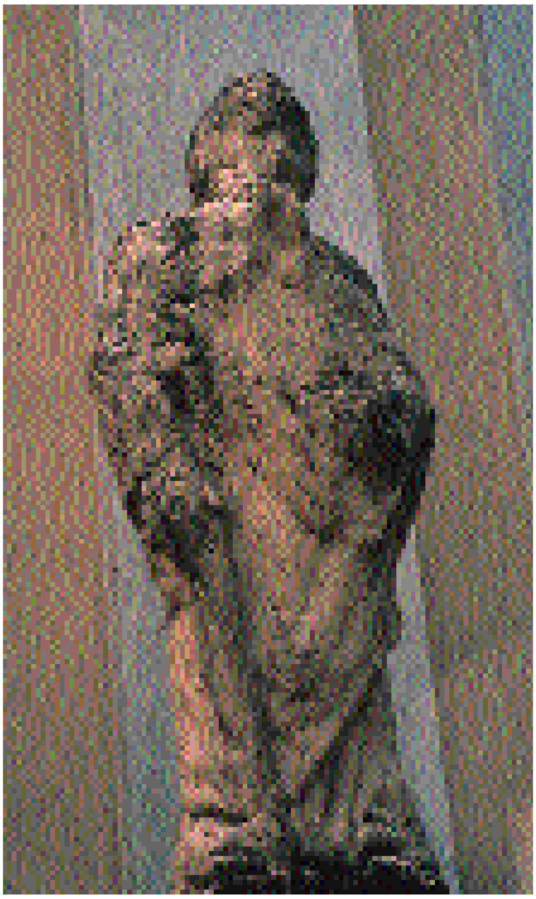
Several material and structural parameters are of importance; these are for instance:

- surface wetness, which strongly influences the dry deposition rate of gaseous air pollutants, as well as surface roughness and composition (Spiker et al., 1995),
- surface alignment, and whether the material is placed in a sheltered or exposed position.

Another long-term project, the UK National Material Exposure Programme (NMEP), investigated material deterioration at 30 sites, four of which were also part of the ICP, representing all climatic and pollution conditions present in the UK. In addition to those materials tested in the ICP, glass and mortar samples were displayed. Furthermore, the impacts of O_3 on several organic materials were assessed in a desktop study. Results showed that some substances are O_3 resistant, but this aggressive oxidant can degrade rubber, other polymers and bituminous materials, with ultra-violet light having an synergistic effect (Butlin, 1995). After establishing the dose-response curves for the various materials and the substances attacking them, the damage done by the presence of certain pollutant concentrations has to be assessed. The formulation of an "acceptable" rate of deterioration, to a certain extent higher than the one which would

Box 7: Effects of Air Pollution on Building Materials, Historical Buildings and Monuments

- soiling of surfaces
- discoloration
- failure of protective coatings
- loss of detail carvings
- failure of structure
- salt efflorescence
- cracks



A statue on an exterior wall of Kohn Cathedral illustrates the effects air pollution can have on monuments

	Materials	Pollutants
Metals	Steel, weathering steel, zinc, aluminium, copper, cast bronze	SO_2 NO_2
Stone materials	Portland limestone, white Mansfield dolomitic sandstone	O_3 $SO_2 + O_3$
Paint coatings	Coil coated steel with alkyd melamine, steel with silicon alkyd paint, wood with alkyd paint system and wood with primer and acrylate	$NO_2 + O_3$
Electric contact materials	nickel, copper, silver and tin as metallic strips, Eurocard connectors of different performance classes	

Table 8.5
Materials and pollutants investigated in the ICP (Kucera and Fitz, 1995)

occur under the impact of “clean” air only, facilitates the determination of critical pollutant loads for wet or dry acid deposition. Mapping procedures including air quality data and meteorological parameters then allow the identification of areas where critical loads are exceeded. Maps produced in this manner present a helpful tool for any cost benefit assessments and maintenance planning (Haagenrud et al., 1995).

Research Findings

Detailed investigations into the effects of air pollution on materials in specific areas and on individual buildings and monuments have been undertaken, for example, for the city of Oslo (Haagenrud et al., 1995), the Royal Palace and the Riddarholm Church in Stockholm (Nord and Tronner, 1995), limestone structures in London (DoE, 1989) and the marble Arch of Titus in Rome (Metallo et al., 1995). The latter study includes a detailed emission inventory that facilitates the modelling of various pollution abatement strategies and the evaluation of their effectiveness.

Furthermore, it was shown that differences in micro-climate occur in different positions of a building or monument, and that differences in meso-climate occur between central and suburban parts of a town. The end results are variations in exposure and thus deterioration. The investigation of various positions and materials in the St. Vitus Cathedral in Prague Castle demonstrated different deposition and corrosion rates in more- or less-sheltered places. A comparison of material damage was conducted in central and suburban parts of Berlin, where mean annual SO_2 concentrations of 100 µg/m^3 and 60 µg/m^3 respectively were measured in the mid 1970s. The expected higher deterioration rate in the centre was not found; this could be explained by meteorological variances. Due to the city heat island effect, the temperature in central Berlin is 2–3 degrees higher, and the humidity lower, than in the suburbs. This results in shorter periods of wetness of material surfaces and thus relatively lower corrosion rates (in Kucera and Fitz, 1995).

The costs of damage to materials due to air pollution can be assessed once inventories of pollutants concentrations, meteorological parameters and building materials have been established and the appropriate dose-response curves determined. Economic benefits of pollution reduction can then be calculated and weighted against the costs of the abatement measures. Decreasing SO_2 concentrations below 20 µg/m^3 would cause savings on corrosion remediation of 125 ECU and 23 ECU per inhabitant and per year in Prague and Stockholm respectively. Under the assumption that (i) the Stockholm data are representative for western Europe, (ii) results from Prague can be used to assess corrosion costs in eastern Europe, and (iii) combination of these numbers with population data acts as indicator for material at risk of deterioration, then calculation of potential total savings for Europe lead to a figure of 10,800 million ECU/year, with eastern Europe benefiting from the larger portion (6,600 million ECU/year) (in Kucera and Fitz, 1995).

In addition to the negative effects on the building or structure itself, corrosion products released from the material surfaces can also cause damage to their immediate and more distant environment. Heavy metals, for example, dissolved and washed off a surface by rainwater can accumulate in sewage sludge and/or river sediments, where their ecotoxological effects may then be experienced.

Chapter 9

Urban Air Quality Management

Traffic-free zone, Amsterdam

There are a wide range of factors which can influence air quality, and various predominant emission and pollution problems in different parts of Europe have been identified and described in earlier chapters. It has been shown that all major cities experience episodes of inadequate air quality and this creates the need for appropriate management of air quality. The 'Concern for Europe's Tomorrow' (CET) study, recently conducted by the WHO, concluded that pollution incidents occur in all European urban areas with more than 50,000 inhabitants (WHO, 1995a).

Before an effective and efficient air quality strategy can be developed, the current situation has to be assessed in detail, and all influential aspects and available resources have to be taken into account. The fundamental tool in air quality assessment is monitoring of pollutant concentrations in different locations in combination with determination of emissions, meteorological data and societal factors. It is important to take seasonal variances, trends and economic aspects, as well as existing and planned legislation, into account. However, the role of monitoring does not end after one air quality problem has been correctly identified and assessed; continuous provision of reliable data is necessary for any successful longer-term environmental management.

A four-phase management cycle, starting with the identification of an environmental problem, has been developed (in WHO/UNEP, 1996). In the case of urban air quality the capability to monitor pollutant concentrations is a basic requirement for

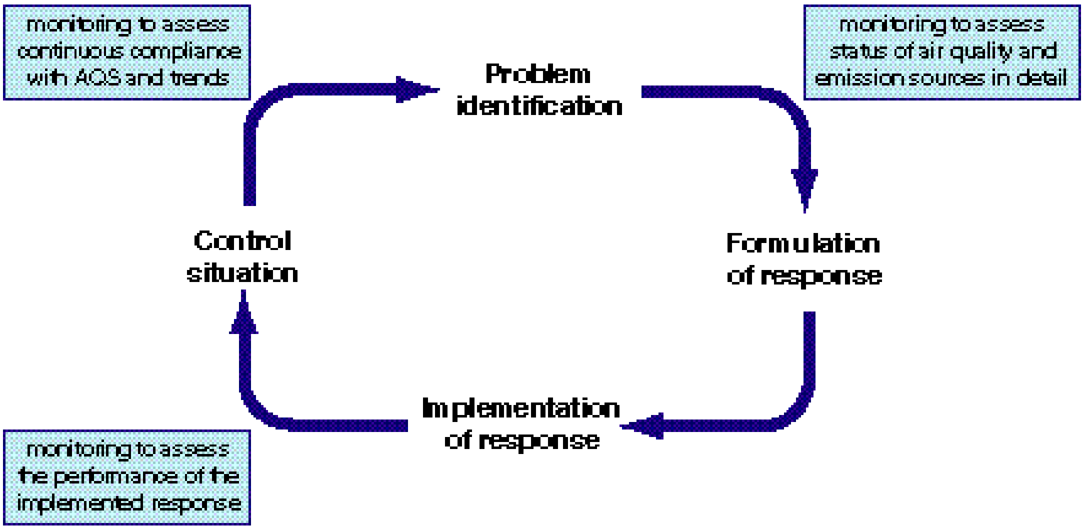


Figure 9.1 Air quality management cycle (after UNEP/WHO, 1996)

each stage of this cycle. The initial recognition of an air quality problem is feasible before a formal monitoring network has been established, and sometimes this awareness functions as the trigger to commence monitoring (WHO/UNEP, 1996). *Figure 9.1* shows the four stages of the cycle and how monitoring capabilities are essential in the process of achieving and maintaining acceptably clean air.

Indicators of Air Quality Management Capabilities

In Europe, as elsewhere, a variety of air quality management systems have been developed by cities in response to their perceived needs. These management strategies are at different stages of implementation and enforcement, and this gives rise to considerable differences in the capacities of cities to control air pollution. The assessment and comparison of air quality management capabilities is a complex task which needs to take a wide range of aspects into account and must avoid oversimplification, which would distort the actual picture. If air quality management is defined as the capability to generate and utilise appropriate air quality information within a coherent administrative and legislative framework, to enable rational management of air quality, it can be assessed by answering the key questions (UNEO/WHO, 1996):

- Were appropriate air quality objectives set?
- Is representative and dependable data available and used in a suitable manner?
- Does the administrative and legislative framework allow the implementation and enforcement of control strategies?

Finding the answers to these three questions will indicate how the use of existing management capabilities and available human, technical and financial resources can be optimised. However, due to its diversity, the subject does not lend itself to finding easy and straightforward solutions. Answering these questions for all major European cities is an exercise that requires the application of a technique which facilitates an assessment on a qualitatively and quantitatively appropriate level. The evaluation of large and diverse data sets calls for tools which enable the objective and consistent interpretation of material. Frequently, indicators are employed to fulfil this task, since they are capable of summarising information and adding an intrinsic interpretative value. In the following paragraphs an indicator framework developed and tested in the report 'Air Quality Management and Assessment Capabilities in 20 Major Cities' (UNEP/WHO, 1996) will be outlined.

The proficiencies required in any successful attempt to manage the various components of air quality are presented in *Figure 9.2*, and can be assessed using four indicators:

- air quality measurement capacity index,
- data assessment and availability index,
- emissions estimates index, and
- management enabling capabilities index.

These indices are described in *Box 8* and together they comprise an overall composite index – the air quality management and assessment capability index. The advantage of such an index is that it provides an objective and comparable overview of each city's capacity to formulate and implement

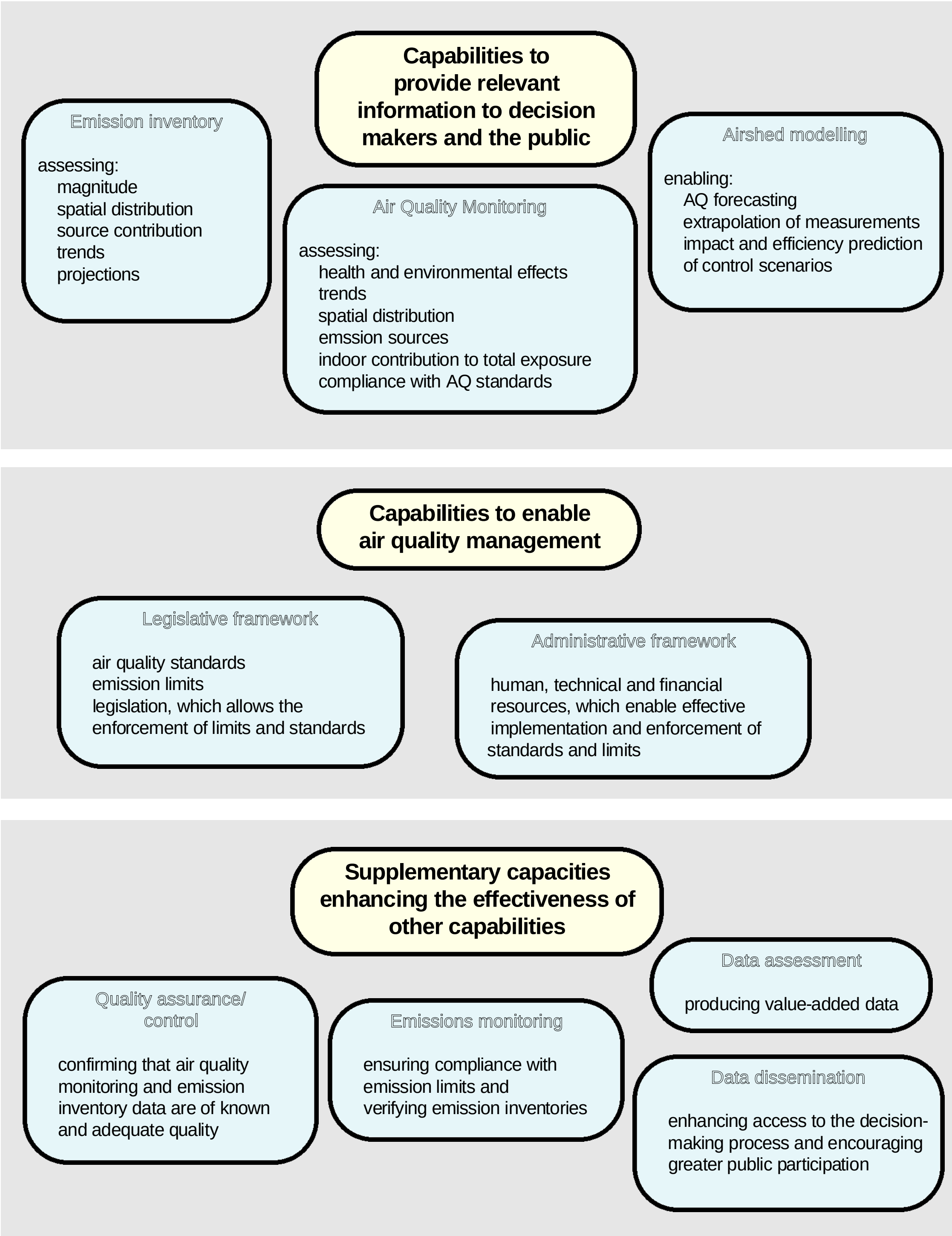


Figure 9.2
Fundamental capabilities required for successful air quality management

air quality management strategies. Such an indicator-based assessment is particularly appropriate for air quality management since it can provide decision-relevant information from large, complex data sets.

The assessment of the four indices can be made from the answers to a series of indicator questions. A questionnaire, with the questions framed to require simple yes/no answers, was designed and sent to all participating cities. Different weighting was given to some of the questions since some air quality management actions were regarded as more important than others, or involved more complex management capability.

The calculation of annual mean values of pollutant concentration is, for instance, less complicated and involves fewer significant management capability criteria than the conduction of epidemiological studies. A copy of the questionnaire used in the survey can be found in *Appendix 1*. For each responding city, a score was obtained for each index (25 points maximum) and an overall index score (100 points maximum) was calculated from the four indicator components, as described in *Box 8*.

The overall index score for a city will thus be a number between 0 and 100. Grading bands have been assigned to each component index as well as to the overall index score, as shown in *Table 9.1*. The air quality management capabilities of each city can thus be expressed using a readily understandable system which facilitates the comparison of overall capabilities and specific components. In this way, the index provides relevant, value-added information to decision makers and enables them to initiate cost-effective investments in the areas where greatest improvements can be achieved.

It is important to point out that the indicator questions and the index score were developed on a basis that represents the minimum capability required to generate air quality information useful for decision makers. Thus, no inquiries were made about many of the tools, procedures and techniques frequently employed in the sophisticated assessment and management of air quality. In a large number of investigated cities, certain areas of air quality management capabilities surpass the aspects assessed in this study and fulfil more than the minimum requirements for effective air quality management.

The obvious danger of unacceptable simplification and loss of valuable, decision-relevant information was avoided by developing the indicators in a way which assures scientific validity, sensitivity towards changes in the system and a realistic, transparent depiction of the system. Furthermore, it was necessary to ensure that a meaningful index score was readily derivable from available data (WHO/UNEP, 1996).

Table 9.1 Bandings of individual and overall index scores (WHO/UNEP, 1996)

Capabilities	Component index score	Overall capability index score
Minimal	0-5	0-20
Limited	6-10	21-40
Moderate	11-15	41-60
Good	16-20	61-80
Excellent	21-25	81-100

Box 8: Indicators of Air Quality Management and Assessment Capabilities

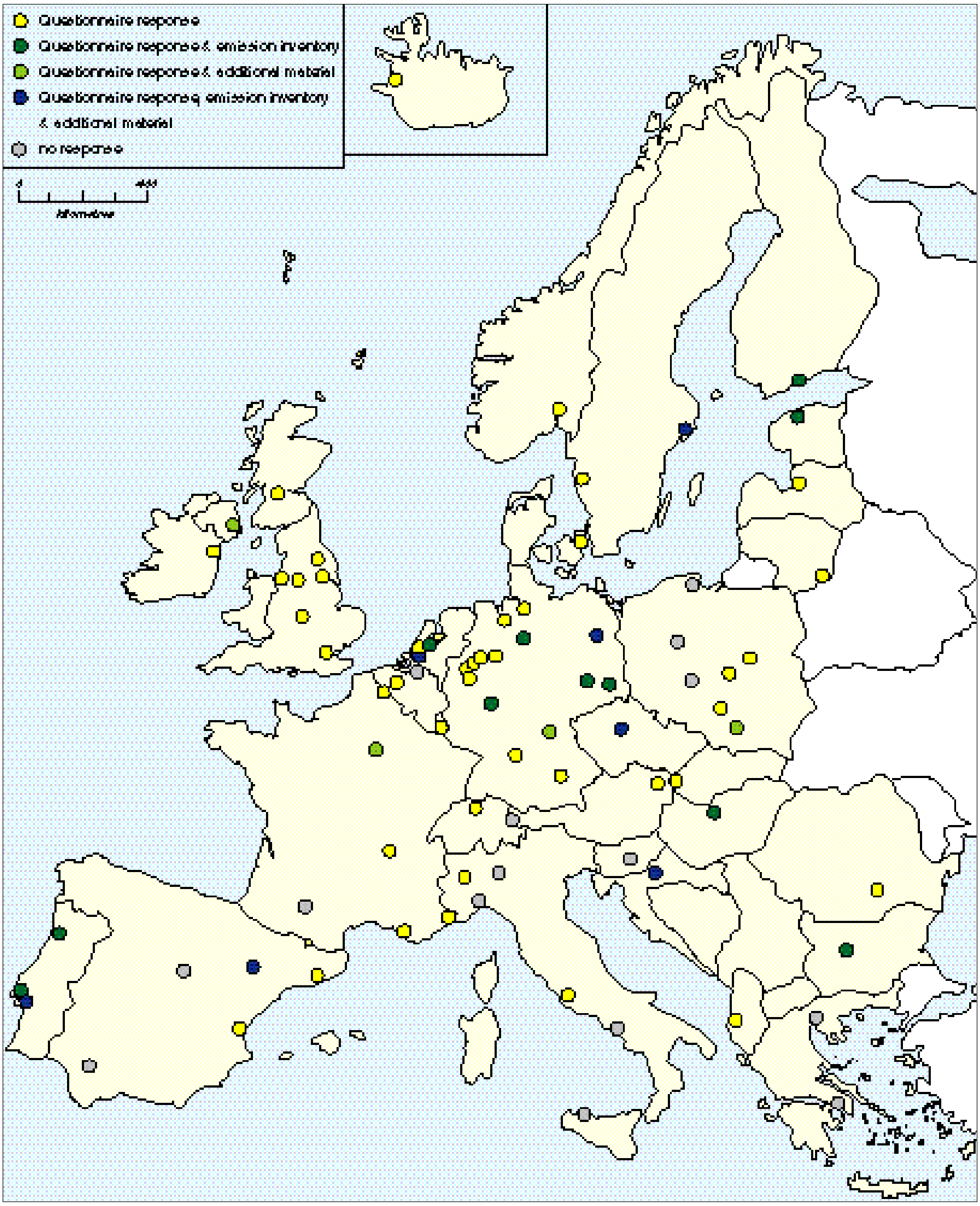
- **Air quality measurement capacity index:** Assessment of spatial and temporal variation of pollutant concentrations in ambient background and hot-spot air and the reliability and representatives of this monitored data.
- **Data assessment and availability index:** Assessment of statistical procedures, dissemination and usage of the air quality data in epidemiological studies, the prediction of episodes with unacceptable air quality and for smog warnings issued to authorities and the public.
- **Emissions estimates index:** Assessment of the conducting of source and pollutant-specific emission inventories, including method of inventory construction, frequency of updates and data validation.
- **Management enabling capabilities index:** Assessment of the legislative framework which allows the establishment and enforcement of air quality management strategies to assure human and environmental well-being and health.

Evaluation of the Management and Assessment Capabilities Survey

This chapter contains the results of the questionnaire survey which was conducted in Europe's major urban areas with the aim of facilitating the assessment of air quality monitoring and management capabilities. Of the 79 investigated cities, 64 answered and returned the questionnaires. The reply rate from each of the four European regions in combination with the average overall score is shown in *Figure 9.3*. Additional information material concerning local air quality or emission inventories was supplied by 21 cities *(Map 9.1)*. The four individual indicator components will be discussed separately below, before the overall management and assessment capabilities index is derived and finally evaluated.

Air Quality Measurement Capacity Index

The importance of air quality monitoring for the production of representative and dependable data has been pointed out before, and the fundamental role that the measurement of pollutant concentrations has in the different steps of the air quality management cycle is depicted in *Figure 9.1*. Thus a series of questions assessing the quantity and quality of measurements formed the first section of the questionnaire. Information about traditional air pollutants, location and distribution of monitoring stations, as well as data quality assurance and control, was also sought. An important aspect investigated in this section was the reliability and representativeness of data, assessed in questions



Map 9.1
Response of investigated cities to the questionnaire on Air Quality Assessment and Management Capability

about data validation, instrument calibration procedures and whether guidelines for monitoring network density and station position had been formulated. This meta-information is essential for the comparison of data from different networks in a pan-European assessment.

More than half the cities who took part in the survey achieved good results *(Figure 9.4)*; only for Lodz and Tallinn were the monitoring capacities rated as limited. In many cities monitoring networks have been greatly extended and renewed over the last few years. Thus sometimes, for example in Leeds and Monaco, the time series of data are shorter than five years and the assessment of trends is not yet possible, but the necessary capacities are clearly in place and will soon permit the appraisal of longer term developments in air quality.

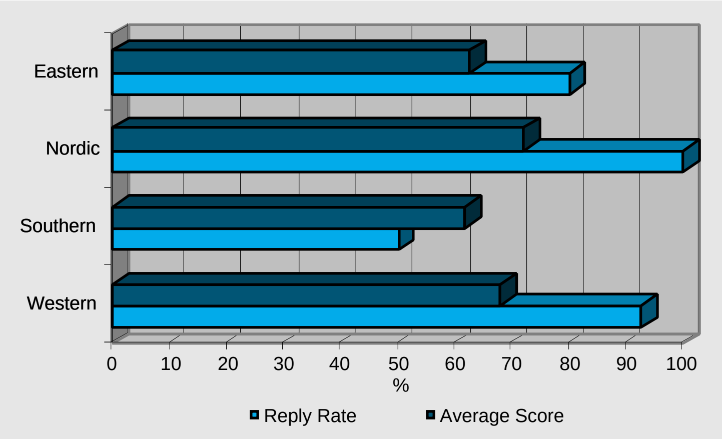


Figure 9.3 Questionnaire reply rate and average score by region

From *Map 9.2* it can be seen that excellent and good results dominate in central Europe, whereas moderate and limited ratings are more frequent further east and south. The introduction of new automatic monitoring equipment, in combination with comprehensive quality control and assurance programmes in many cities, resulted in an average of good ratings (17.8 points) for Europe as a whole. In a previous study of 20 major cities across the world, 6 cities, mainly in developing countries, had limited or minimal scores for this index (UNEP/WHO, 1996). Europe, as a whole, therefore has a comparatively well developed air quality measurement capacity.

A more detailed analysis of the questionnaire responses allows the conclusion that those cities whose excellent monitoring networks are in place also conduct frequent and reliable calibrations of the equipment. The most frequently monitored compound is sulphur dioxide (SO_2), whilst lead (Pb) and carbon monoxide (CO) are measured much less often, the first because it is often assumed that the introduction of unleaded petrol reduced concentrations in ambient air sufficiently, the latter probably because it is not yet included in the EC Directives. The questions referring to spatial distribution of monitoring sites, inquiring whether stations are located in central, industrial or suburban areas, as well as at the roadside, achieved lower scores than those referring to urban background stations. Guidelines for monitoring network design, regarding the density of stations and their location with respect to their specific purpose, had been adopted by almost two thirds of the responding cities.

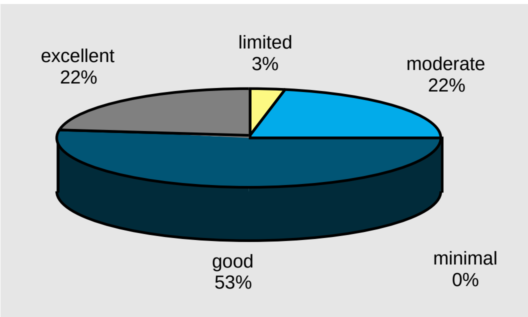


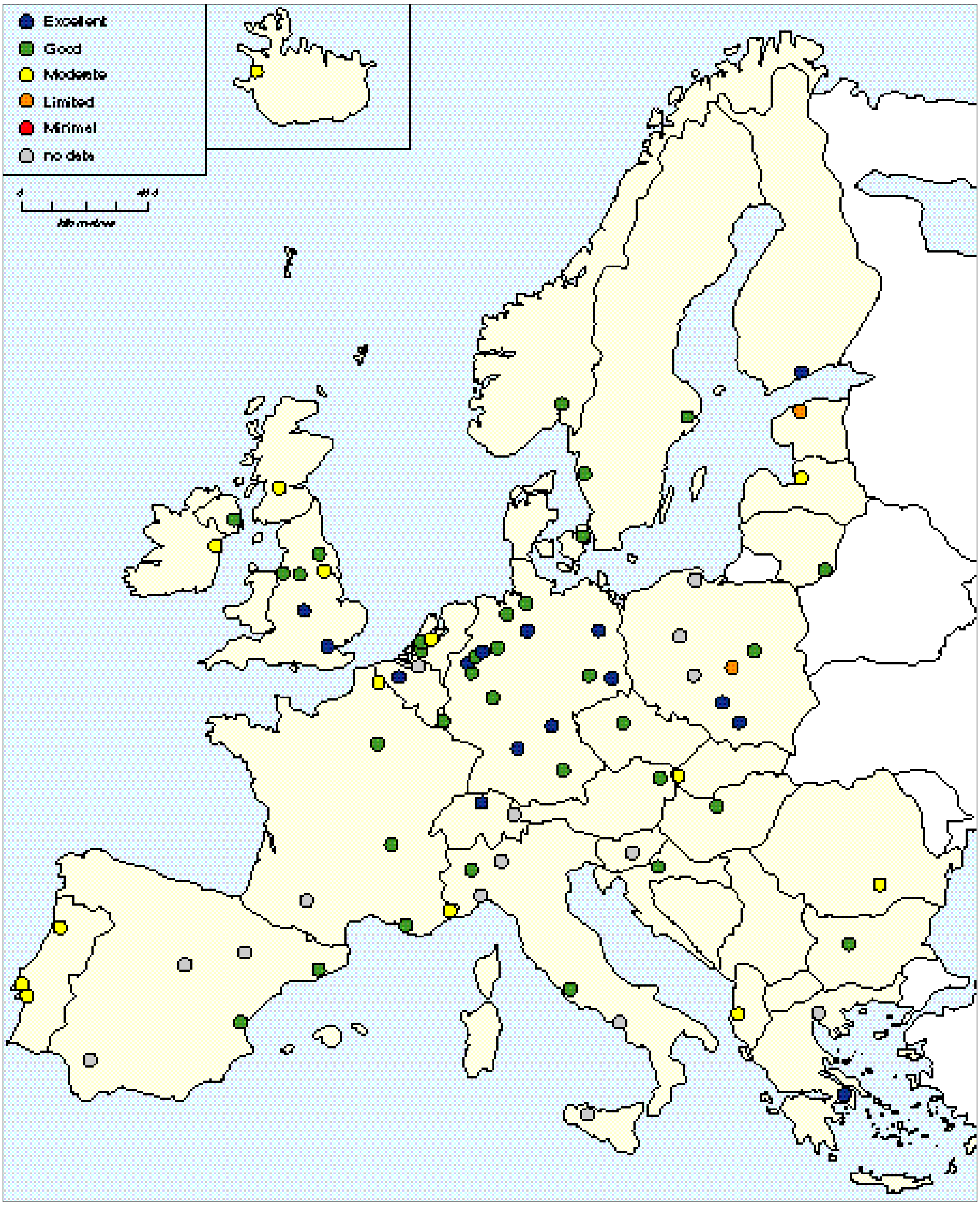
Figure 9.4 Apportion of index bandings for measurement capacity

Data Assessment and Availability Index

This component index investigates the extent to which collected monitoring data are analysed and how they are made available to the public. Numerous excellent and good scores were achieved by the cities for this index *(Figure 9.5)* and it contributed as much of the measurement capacity index to the overall index *(Figure 9.9)*. This shows that, for the majority of cities, the important step from data generation to its evaluation and interpretation is being made. The transformation of raw measurement results into decision-relevant information is essential for successful air quality management. The application of data analysis techniques, such as the calculation of means or the recognition of maxima and various more sophisticated procedures, is standard Europe-wide. Analytical methods and investigations applied to assess the impact of air quality on human health are summarised in *Figure 8.1*.

Dissemination of the monitoring results is another significant aspect of successful air quality management, because only an informed public can reach an opinion and then act to help prevent air pollution. Data are generally made available to the public through more than one route, such as newspapers, television or information boards. Furthermore, many municipalities publish brochures which explain and describe air quality. Examples of these were provided by several cities, and they gave a good insight into local as well as general air quality problems.

In several cities where guideline exceedances have not been observed recently and air quality generally is so good that breaches are not expected, smog warning procedures and pollution abatement strategies have not been developed because they were considered unnecessary. This is the case, for instance, in Reykjavik, where prevailing strong winds usually disperse emissions, but on wind-still winter days the formation of a yellow-brownish pollution haze has been observed with increasing frequency over the last couple of years (Gustafsson and Steinecke, 1995). These pollutant concentrations might still not be harmful to the population, but will have an adverse impact on the sensitive sub-Arctic environment around the city. Thus, introduction of appropriate measures



Map 9.2
Measurement Capacity Index for investigated cities

to reduce emissions – originating from mainly road traffic, since part of the electricity and all of the energy for domestic heating is generated by a large geothermal plant – has to be considered.

Map 9.3 shows that good and excellent results were achieved by cities in all geographic regions, although in northern and western Europe these high scores were more frequent. The replies to the specific questions regarding air quality modelling

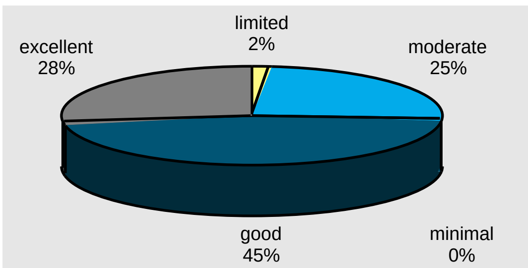
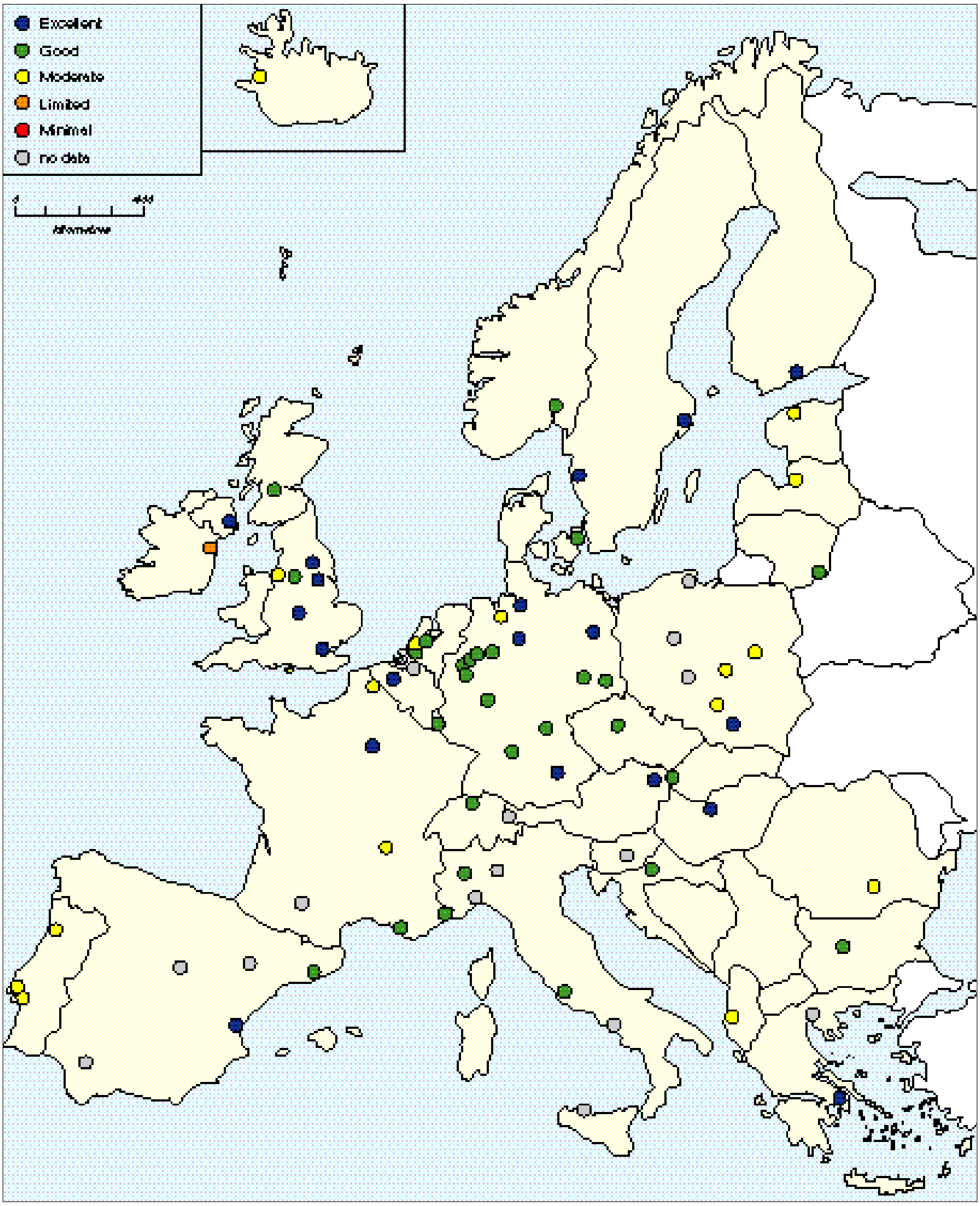


Figure 9.5
Apportion of index bandings for assessment and availability

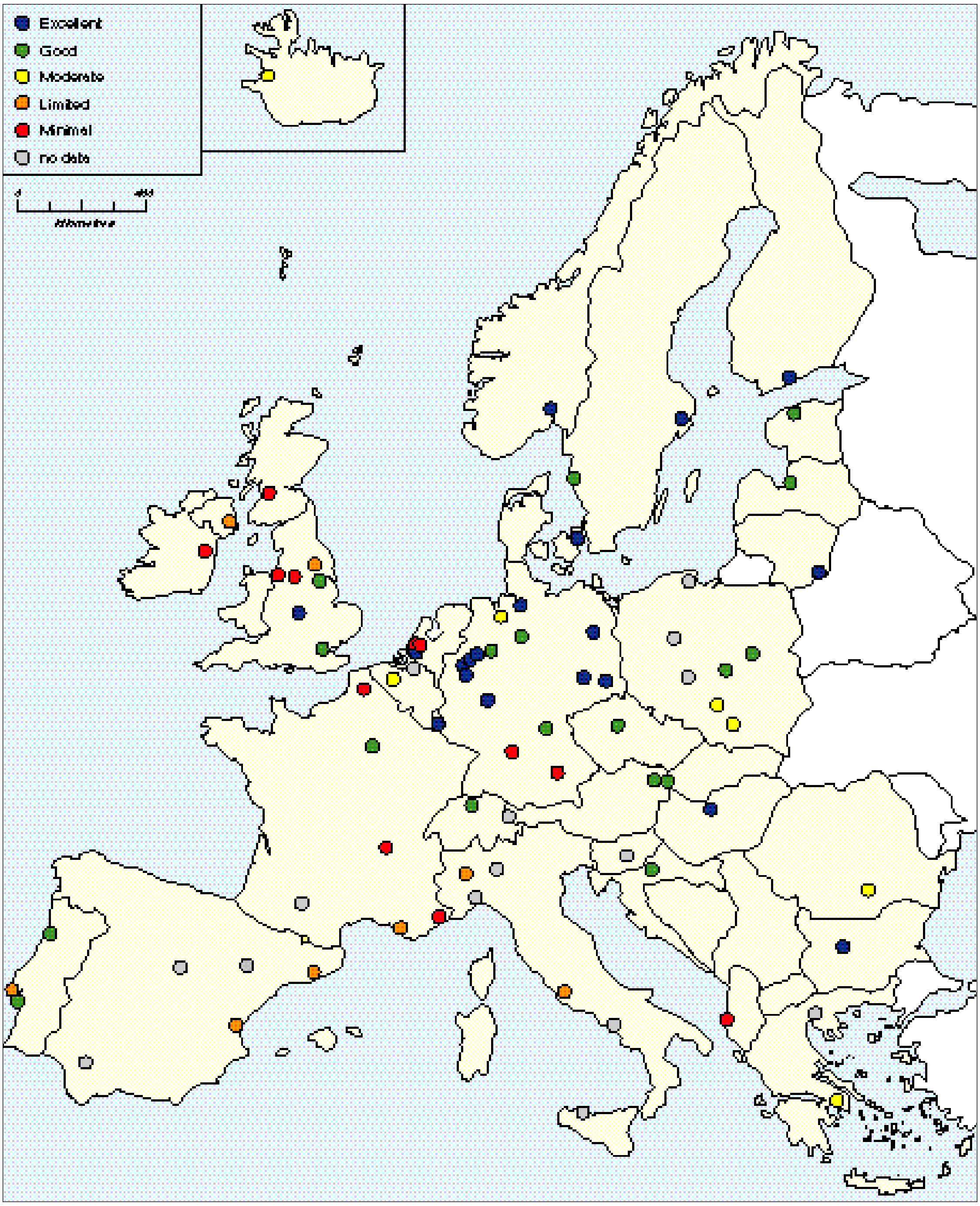


Map 9.3
Data Assessment and Availability Index for investigated cities

and issuing of smog warnings are summarised in *Figures 9.13* and *6.3* respectively. The adoption of the EC decision on the reciprocal exchange of information and data from networks and individual stations measuring ambient air pollution (C30, 1996) will certainly harmonise data assessment and increase its availability, particularly once the air quality database AIRBASE is in full operation (Sluyter et al., 1996).

Emissions Estimates Index

The results for indicators of emission estimates show the greatest diversity, with scores ranging from 0 to 24 points, for example, in Glasgow and Leipzig respectively. In comparison to the other three components, the ratings achieved were the poorest, since many of the investigated cities had not produced emission inventories or these were restricted to few pollutants or emission source



Map 9.4
Emissions Estimates Index for investigated cities

categories; thus 33% had minimal or limited ratings *(Figure 9.6)*. On the other hand, about one-third of the cities achieved excellent results, balancing the low marks in the calculation of indicator contribution to the overall index *(Figure 9.10)*. The average rating of all cities is moderate (14.2 points), but this does not give a good guide to the actual situation. Cities either conduct fairly complete emission inventories, very limited ones or none at all. At this point, it has to be noted that in several countries, for example France, the organisation responsible for air quality monitoring does not conduct the emission inventories, thus full information may not have been available to the persons contacted.

The performance of each city is shown in *Map 9.4*; it can be clearly seen that cities in central, eastern and northern Europe achieved the highest scores, whereas those in the southern and western

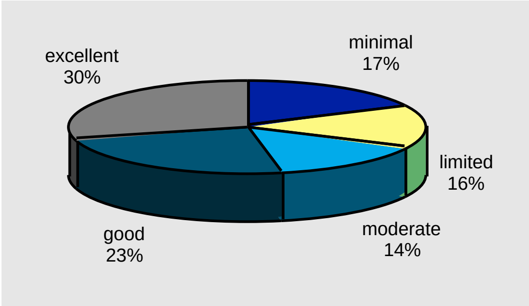


Figure 9.6
Apportion of index bandings for emission estimates

parts scored lower. The lack of comprehensive emission inventories in many cities, which were found to otherwise possess good air quality management capabilities, is remarkable and a problem which has to be tackled. National inventories are produced for all countries under the CORINAIR concept, thus it can be assumed that the necessary expertise is available.

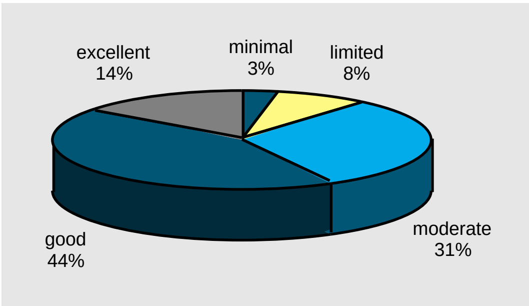
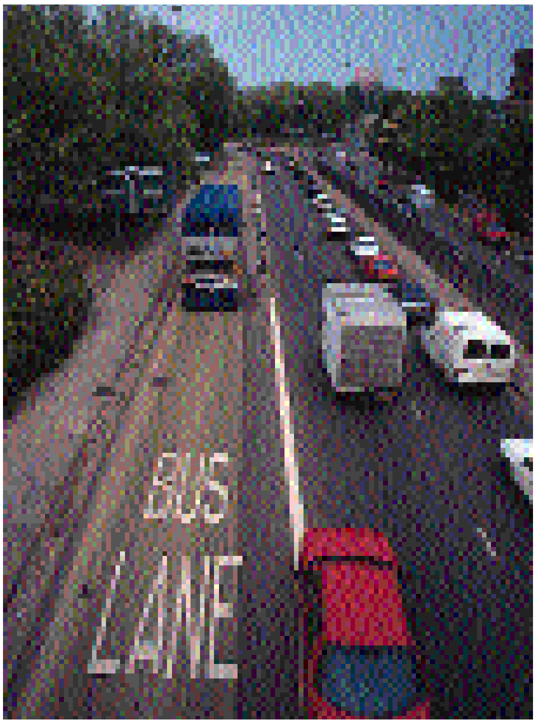


Figure 9.7
Apportion of index bandings for management capability



Bus lanes provide one means of reducing pollution from vehicles

Several cities, for instance Sheffield and Manchester, noted on the questionnaires that emission inventories were currently under development and were expected to be available by the end of 1996. This information could not be taken into account in the calculation of the index score, but will obviously be an important improvement of those cities' air quality management capability.

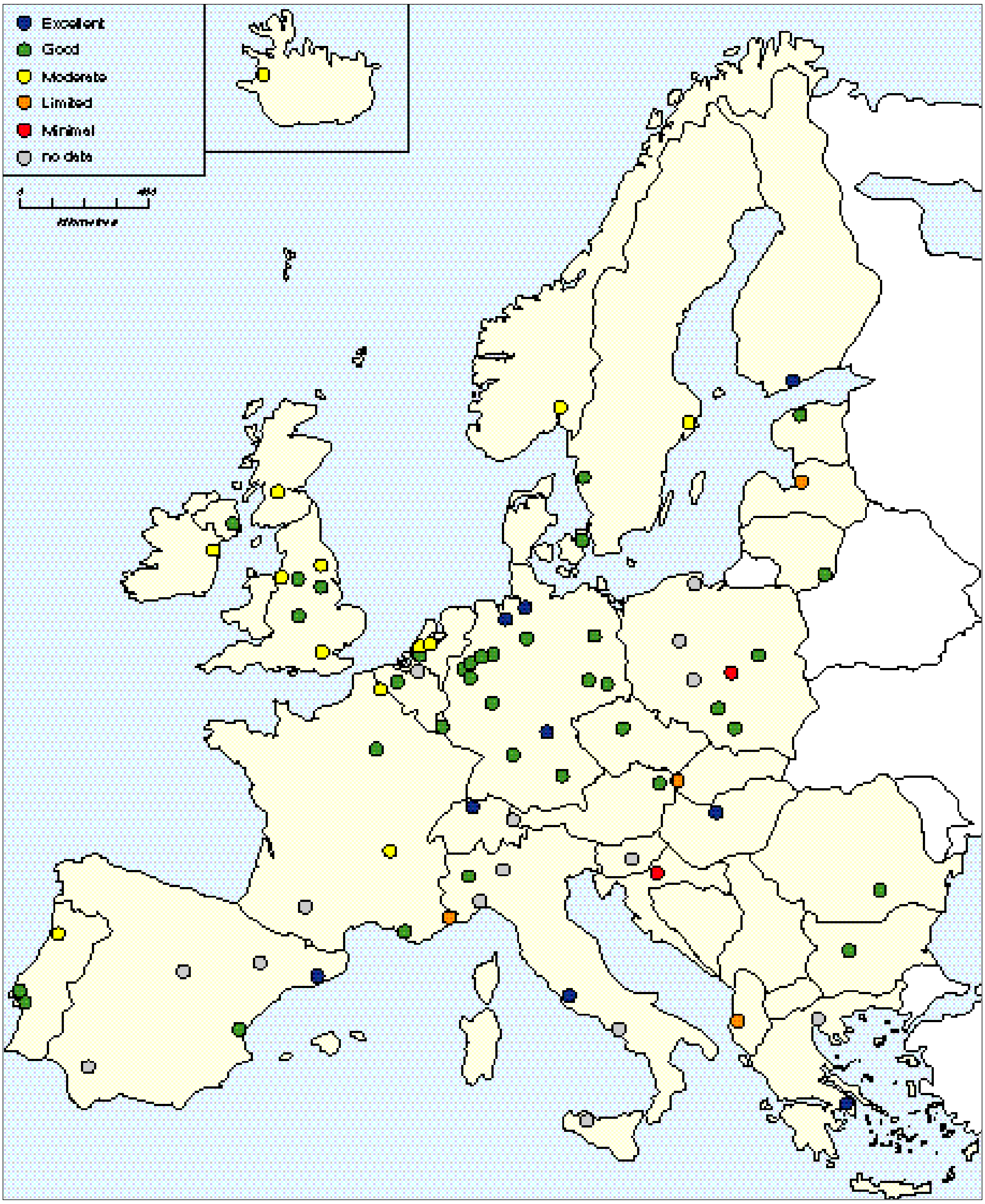
Particularly poor results were found for emission inventory availability; even if comprehensive inventories were produced, they were generally not published in full or made available to the public. This is emphasised further by the limited response to the request for a copy of emission inventories from each city, required for future EEA projects. Only 17 out of the 79 cities supplied local emission data which varied considerably in detail and format, ranging from one table with valuable information to brochures with detailed analysis of each local point source (Lisbon) and full assessment of emission source categories and pollutants (Hannover).

Management Enabling Capabilities Index

Although in most cases a legislative framework to facilitate effective air quality management is in place on national or local level, the capabilities to enforce the limits and standards set in this legislation are often restricted. This leads to relatively few cities reaching excellent results *(Figure 9.7)*. Air quality standards, which are primarily aimed at protecting the population from adverse acute and chronic health effects, were adopted in almost all countries. Monaco and Croatia were exceptions, although the latter is currently preparing a law on the protection and improvement of air quality, with regulations and limit values based on European standards (Mücke and Turowski, 1995). In Latvia, guidelines so far concentrate on acute heath effects and several EU Member States have not adopted national standards for CO.

Answers regarding the use of short- and long-term methods of pollution abatement, such as restriction of traffic and industrial production, were less frequently positive than those dealing with long-term strategies, such as the intention to conduct environmental impact assessments for major building projects. Although unleaded petrol should be available all over Europe, several cities did not answer the relevant question affirmatively. On the other hand, many cities had already terminated their monitoring programmes for airborne lead, since it was no longer considered a health threat.

In *Map 9.5*, the distribution of management capabilities over Europe shows that all cities in EU member states reached at least moderate results,



Map 9.5
Air Quality Management Capacity Index for investigated cities

due to the harmonised legislation. Additional legislative and administrative tools were adopted in several countries.

The variety of results achieved in Poland, ranging from minimal to good ratings, is partially due to the fact that no national emission limits have been set. However, the local authorities of the heavily industrialised areas of Katowice and Krakow have taken measures to deal with emissions. Enterprises within the Katowice region are charged for their emissions, which have to remain within certain limits. Emissions are commonly determined by the enterprises themselves, but random inspections are conducted, and additional fines can be applied if those limits are exceeded. Problems occur since a large number of smaller enterprises are not yet included in this system and even large emitters might, for social and political considerations, not be charged the full rate (UNEP/WHO, 1996).

Coal-fired power station, Dublin

Air Quality Management and Assessment Capabilities Index

In order to achieve the ultimate aim of this study, of expressing each city's capability to monitor, assess and manage their air quality in an easily understandable and comparable manner, the results of the individual index components were added to form the overall index score *(Figure 9.10)*. The capabilities generally ranged between moderate to excellent, and for only four of the investigated cities was the total score 40 points or less, indicating limited capacities.

Although the average contributions of the index components to the overall score are relatively evenly distributed *(Figure 9.9)*, great variation exists between the cities, particularly for the emissions estimates index. *Figure 9.10* clearly shows that the cities' performances were generally poorest for the emissions estimates index; several cities with fair measurement, assessment and management capabilities have not yet produced any emission inventories.

Figures 9.4 to *9.8* and *Figure 9.10* (overleaf) show that good results were predominant for the single components, with the exception of emission estimates, as well as for the overall index, reflected in an average total score of 67.1 points. *Map 9.6* shows the spatial distribution of score results in the bandings from limited to excellent. In accordance with those results for the individual indicator components, highest overall scores occurred in the Nordic countries and central Europe.

Dublin, Lille, Monaco and Tirana are the four cities with limited overall score for air quality management and assessment capabilities. None of these cities had produced emission inventories, and monitoring capabilities showed considerable gaps, leading to moderate results in all four cases. Low scores for data assessment and availability in Dublin and Lille came from the restricted use made of the collected data and the particularly poor information dissemination. The situation in Monaco and Tirana is different; here, low scores for management enabling capabilities influenced the overall results. In Monaco, emission limits for mobile sources have been set and are enforced, but limits for stationary sources and air quality guidelines are lacking. Albania has air quality guidelines but no emission limits. Improvements in the overall air quality management and assessment capabilities of each city can thus be achieved by addressing these problems.

Figure 9.11 shows the distribution of index score by region. For every region there is a wide range of city performance. Many of the highest scores were obtained by cities in western countries, but this is by no means entirely true, with several cities in the lower bands. Cities in southern countries tend to be in the moderate range. Scores for Nordic and eastern countries show no obvious pattern and results range widely.

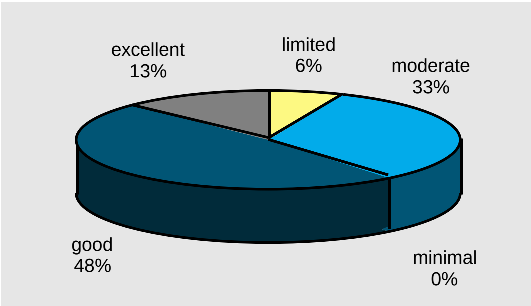


Figure 9.8 Apportion of index bandings to overall index score

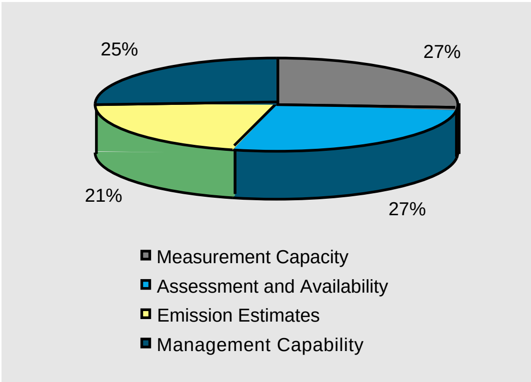


Figure 9.9 Average contribution of each indicator to overall score

The ratings achieved by Europe's major cities are generally higher than those calculated for 20 urban agglomerations world wide (UNEP/WHO, 1996). In the latter study, one-third of the investigated cities only reached minimal and limited results, but again half the participants were rated as good. Birmingham and Katowice took part in both studies, the air quality management capabilities of Katowice were once again ranked as good, whereas Birmingham's rating improved from good to excellent. The production in 1996 of a detailed emission inventory for the Birmingham area raised the result for emission estimates from limited to excellent and thus gave the higher overall score. Similar improvements could be achieved in other cities, for example, in Munich and Stuttgart.

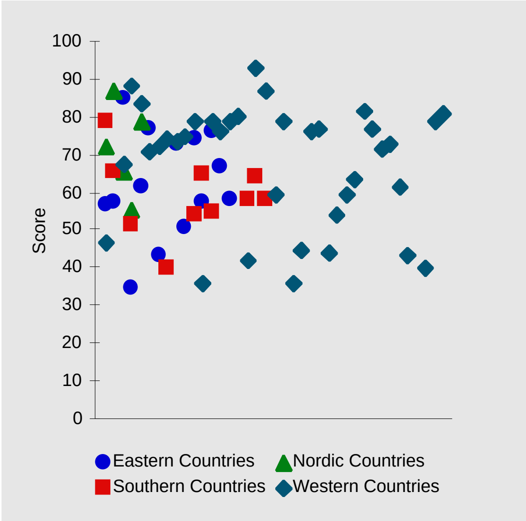


Figure 9.11
Distribution of overall index score by region

Case Studies

A more detailed analysis has been conducted on the questionnaire returns of the 10 cities outlined in *Chapter 5*, since each had provided good data on air quality and monitoring networks, and responded to the air quality management and assessment capability questionnaire. The purpose of this in-depth analysis was to highlight the individual city variation that occurs and the specific management strategies that have been adopted. The analysis also reveals that most cities could substantially raise their scores by prioritising improvement where there are gaps in management and assessment capability. The responses provided by a yes/no questionnaire cannot provide a complete source of information on management capacity, but they do provide a useful indication of where problems may lie. Additional information supplied by the cities has been used wherever possible to supplement the responses to the questionnaire.

Barcelona

Barcelona obtained an overall air quality management and assessment capability score of 65.5, which is at the lower end of the good category. This indicates that there are substantial achievements in the development of the capability to manage air quality but that there is still work to be done in some areas.

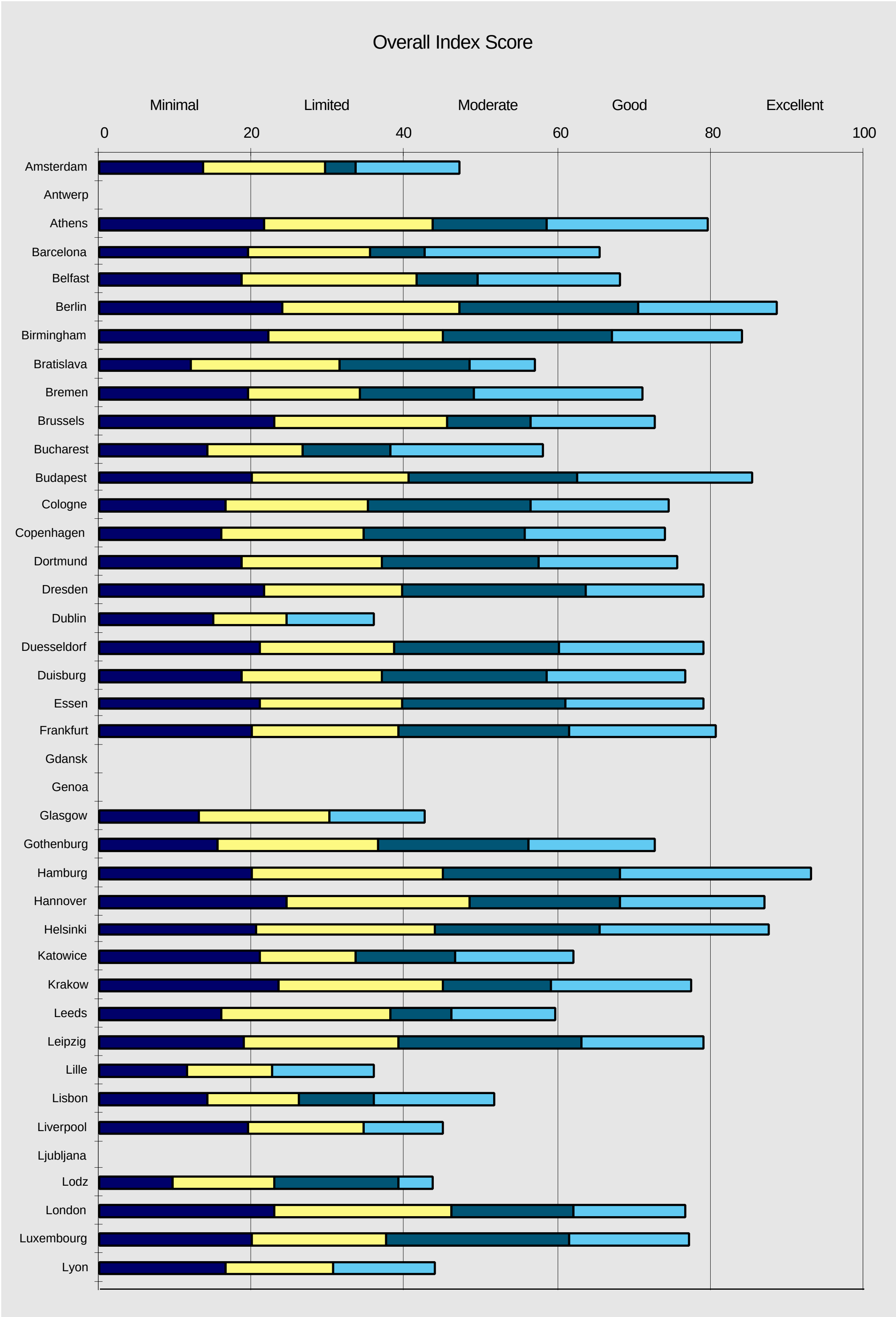
The city has a monitoring network of: 8 manual stations for SO_2; 3 automatic stations for particulates, SO_2, oxides of nitrogen (NO_x), CO, O_3 and hydrocarbons; 2 stations for measuring total suspended particulates (TSP), lead (Pb), cadmium (Cd), mercury (Hg) and one for pollen and spores.

Closer examination of the distribution of scores shows that Barcelona has a very good rating for measurement capacity. The only significant shortfall is the absence of roadside monitoring to enable an assessment of the importance of vehicle emissions. Some improvement in quality control could be made by using an independent audit to compare measurements from different instruments in the network and to introduce checks on the inter-comparability of measurements and techniques with other networks.

The assessment and dissemination of the collected data were rated as good, with raw data and aggregated data assessed in relation to air quality guidelines and predictions made and released for air pollution episodes. Modelling, health studies and population exposure assessments could be introduced to make fuller use of the collected air quality data. Information is widely disseminated in newspapers, television and radio but there are no city-centre bulletin boards.

The lowest scoring section for Barcelona occurred in the indicator of emission estimates category where the city only had limited capability in place. In particular, there have been no estimates of emissions from point sources, and those for traffic emissions do not contain a breakdown into vehicle type. Estimates have been made of

Smog and smoke over Barcelona


Overall Index Score
Minimal
Limited
Moderate
Good
Excellent
0
20
40
60
80
100
Amsterdam
Antwerp
Athens
Barcelona
Belfast
Berlin
Birmingham
Bratislava
Bremen
Brussels
Bucharest
Budapest
Cologne
Copenhagen
Dortmund
Dresden
Dublin
Duesseldorf
Duisburg
Essen
Frankfurt
Gdansk
Genoa
Glasgow
Gothenburg
Hamburg
Hannover
Helsinki
Katowice
Krakow
Leeds
Leipzig
Lille
Lisbon
Liverpool
Ljubljana
Lodz
London
Luxembourg
Lyon

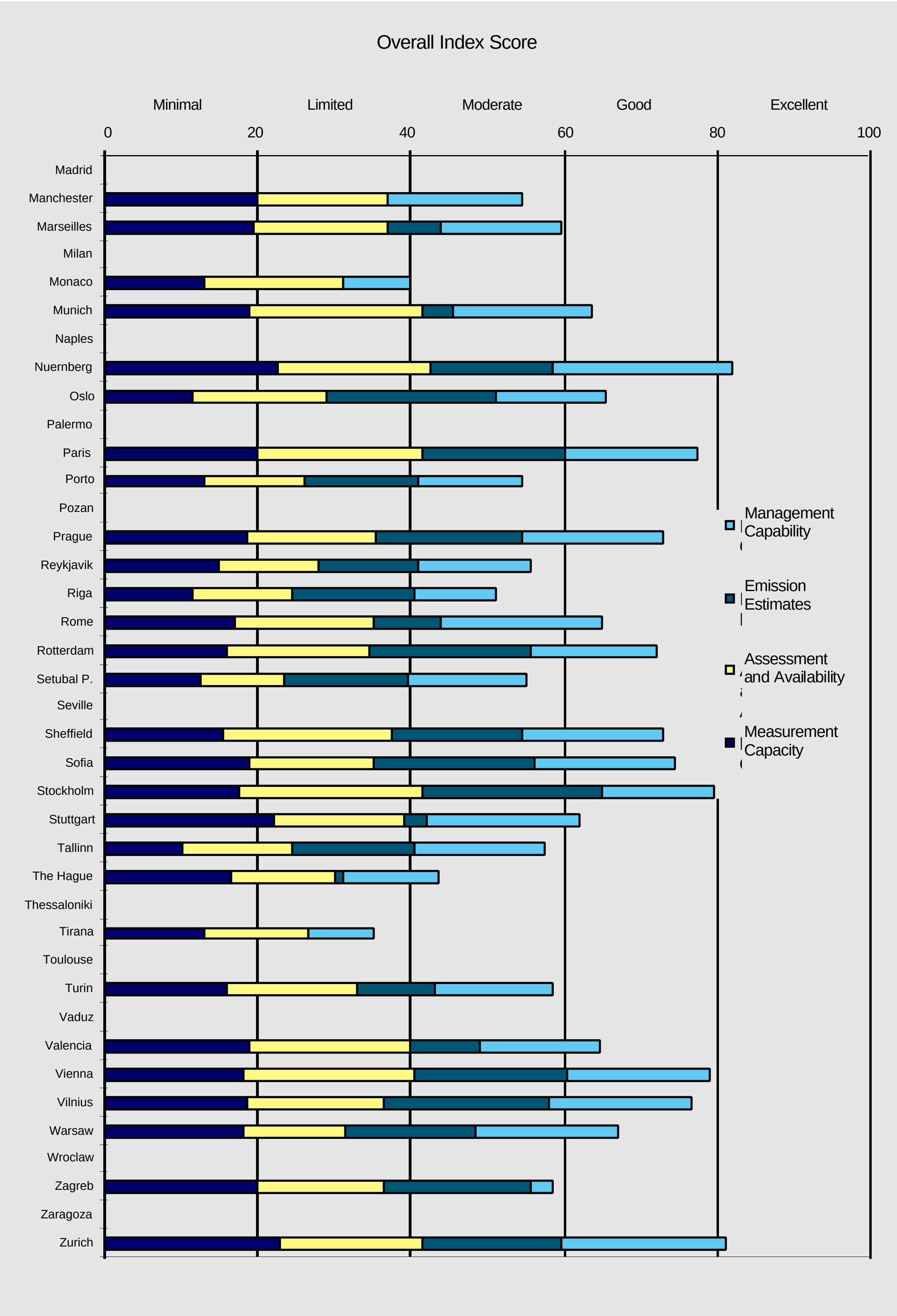
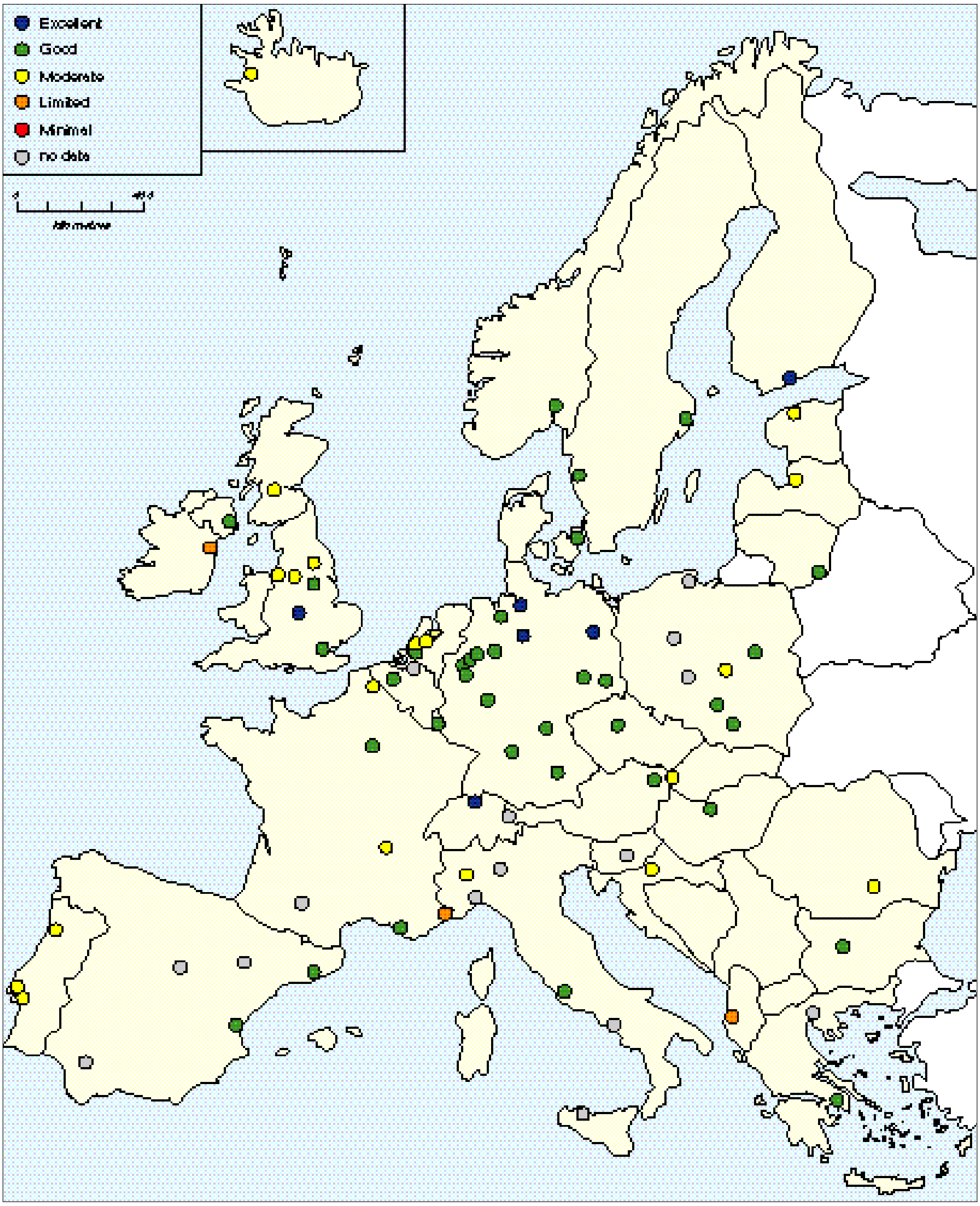


Figure 9.10
Scores for investigated cities for Index components and overall capability



Map 9.6
Overall Air Quality Assessment and Management Capability Index for investigated cities

total generation of most major pollutants, although Pb emission and O_3 generation has not been estimated. The latter would be particularly useful in relation to the summer smog episodes. Future inventories are planned and it is proposed that they will include information on the spatial distribution of stationary emission sources.

The highest scoring section for Barcelona is the air quality management capability, where the city rating is excellent. Emission limits have been set and are enforced for the whole range of investigated emission source types. Air quality standards relating to acute and chronic health effects have been set as appropriate for the major pollutants, and a range of other measures have been adopted to ensure compliance to standards and restrict emissions during periods of particularly poor air quality.

Belfast

The overall capability index score for Belfast was 68.0, which lies in the mid-range of the good category. This indicates that the city has taken serious steps to develop its air quality management capability, but a closer look at the scores for different components of the index reveals shortcomings that could be overcome in the future.

Belfast has a monitoring network of 6 stations measuring smoke and SO_2, 4 sites for nitrogen dioxide (NO_2) (1 kerbside, 1 intermediate and 2 urban background sites), plus 1 station which is part of the UK automatic urban network (AUN) and measures NO_x, SO_2, CO, O_3 and particulates continuously (BCC, 1996).

Examining the response to the questionnaire on measurement capacity, Belfast was found to score in the good category. The shortfalls in this section are namely that the pollutants NO_2, CO, Pb and O_3 have not been monitored for at least five years and so trend evaluation is not yet possible. Longer records are available for SO_2 and particulates. This is perhaps to be expected as the major air pollution concern in Belfast in the past has related to the widespread use of coal as a main domestic fuel.

The score for data assessment and availability is excellent, with a wide range of data analysis procedures conducted, using the results as input data for computer models and in epidemiological studies. However, exposure assessment for different population groups has not been carried out. The data are widely available as aggregated data, and dissemination through the media is complemented by the use of information boards in the city. Warnings are issued to the public prior to and during episodes of poor air quality.

In common with many of the cities scoring an overall moderate-good capability score, Belfast has only a limited rating for emission indicators. Emissions estimates are available for domestic output, power generation, industry and total traffic, but there is no breakdown for the different types of vehicle. Furthermore, the figures are restricted to SO_2 and particulates/smoke. The emission estimates were based on fuel consumption alone, rather than by being supported and validated by emission monitoring. Future inventories are planned and it would be beneficial if these were extended to all relevant pollutant and source types. The inventories are not published in full but are partially available to the public.

The score for the air quality management capability index is good and borders on excellent. Limits are set for emissions of all types and there are enforced penalties for any exceedance. In accordance with EU legislation, air quality standards relating to acute and chronic exposure have been set for all major pollutants except for CO. Further measures include the use of environmental impact assessment (EIA) for major new developments; unleaded petrol is also available. There are no additional restrictions adopted during periods of particularly poor air quality.

Bucharest

With a total of 58.0 points for the overall index of air quality management and assessment capability, Bucharest falls into the moderate category. This generally indicates that the air quality monitoring network is somewhat limited and that there are several areas where improvements could be made.

Air quality is monitored at 14 stations in Bucharest. Of these stations, 5 belong to the Bucharest Environmental Protection Agency, 5 to the Ministry of Environment and 4 to the Preventive Health Centre. Sulphur dioxide, NO_2, dust, heavy metals and ammonia (NH_3) are sampled on a 24-hour basis (RIVM, 1995b).

The city scores 14.0 on the measurement capacity index, which is lower than average for responding cities. The primary reason for this is the fact that data are only collected for NO_2, SO_2 and particulates. Lead, CO and O_3 are not routinely monitored. However, for those parameters that are measured, the records are good and provide data for urban, suburban and industrial areas of the city. The quality control procedures within the network are partially in place, calibration procedures are sound, but there is no audit procedure for comparing measurements using different instruments. However, the locations of sites are reviewed periodically to ensure they meet the objectives of the network and guidelines for site selection are given.

Bucharest scores only 12.5 on the index of data assessment and availability, which is one of the five lowest scores of cities taking part in the questionnaire survey. The data assessment is good, although the data are not used to give a spatial distribution of pollution conditions and there are no exposure assessments of different population groups. The collected data are normally not released to the public but can be made available on request. A considerable improvement to this index could be achieved by formal reporting and dissemination of information to the public. Smog warnings are, however, issued to the public during episodes of poor air quality.

The index score for emissions estimates for Bucharest is in the moderate category, in the lower quartile of responding cities. However, the city scores well on the basic component of this index, namely the fact that emissions from all major urban source types, apart from motorcycles, have been estimated in the past five years. Actual estimates of emission generation are limited to the compounds SO_2, NO_2, particulates and CO, and are based on fuel consumption statistics alone, rather than being supported by direct measurements. Inventories are not conducted regularly and none are planned in the short term. It should be noted that, as with the air quality data, the results are not available to the general public.

One very strong feature of the indices for Bucharest is the air quality management enabling capability index, with a very good score of 20.0 points. Limits have been set for emissions from a wide range of sources and these are enforced with penalties. In addition to those air quality standards relating to long- and short-term exposure of the population, local guidelines, which take sensitive environments into account, have been set. Other measures in place include the requirement to carry out EIA on major new developments and the provision of unleaded petrol. There are no special restrictions during episodes of poor air quality.

Gothenburg

The overall air quality management and assessment capability score for Gothenburg is 72.5, which is in the upper half of the good range. In fact, three indices are in the good or excellent category and the fourth is at the top of the moderate; this indicates a broad achievement of fundamental capabilities.

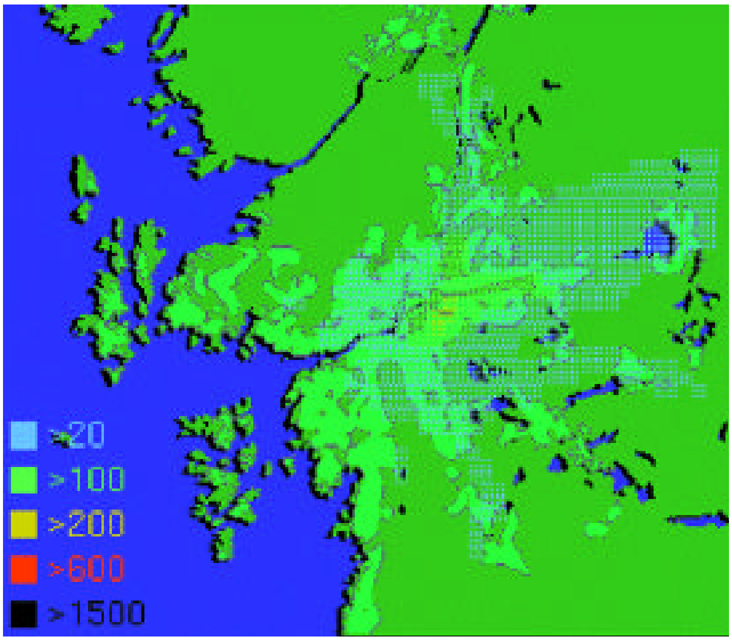


Figure 9.12
An example of a NO_x forecast for Gothenburg

Gothenburg has 6 monitoring stations which report hourly to a central computer system. Five stations monitor SO_2, 1 station monitors particulates, 3 stations measure NO_2, 5 stations monitor O_3 and 1 station monitors CO.

The measurement capacity index score for Gothenburg is 15.5, just in the good category. The regular monitoring of all major pollutants other than Pb has occurred routinely over the past five years and so trend analysis is possible, although the sampling was restricted to the winter half-year. The use of a roadside site has enabled the importance of vehicle emissions to be evaluated. The primary shortfall is that not all parameters are measured at each site, and only for SO_2 is there suburban, urban and industrial site data, which allow spatial distribution to be evaluated. Quality control is well developed, although there are no site audits to compare measurements from different instruments in the network. There are currently no guidelines on network design in relation to the distribution and number of monitoring sites.

The data assessment and availability index score for Gothenburg is an excellent 21.0. However, there is a lack of spatial distribution data and the lack of exposure assessments for vulnerable population groups within the city; this reduces the total score. The dissemination of aggregated data to the public is excellent, although there are no city centre information boards. This may be due to the perceived low risk of exceedance of WHO AQG in the city which generally exhibits very good air quality *(Chapter 7)*. An additional medium used for data dissemination is the internet. The netsite, called Luftnet, has been produced by the Gothenburg Environmental Protection office and contains information on the weather and NO_x concentrations for the day, and forecasts for the following day *(Figure 9.12)*. In addition, it contains the latest monthly reports on air quality trend information and the annual report for 1996 (Luftnet, 1996).

The emissions estimates index score for Gothenburg is very good at 19.5. Emissions estimates have been made for all source categories including a breakdown into traffic categories other than motorcycles. Emission inventories have been made for NO_2, SO_2, CO and hydrocarbons, but not for O_3, Pb or particulates. The inventories are made at least every two years and this will continue in future inventories; this will enable the effectiveness of any emission control strategies to be tested. The emission inventories are published in full and are available to the general public.

Gothenburg scores a good 16.5 in the Air Quality Management Capability Index. Emission limits are set for most source types other than domestic dwellings. Penalties exist for limits exceedance by industry, power generation, heavy goods vehicles (HGV) and buses, but are not enforced for cars and light goods vehicles.

Further measures to control air quality include the adoption of EIA and the availability of unleaded petrol. New standards are expected in the future. As there are no periods of poor air quality in Gothenburg, there are no special regulations to deal with such an eventuality. Overall, it should be noted that cities with good air quality may not need to adopt the most complete and stringent programmes or air pollution monitoring and management, but the indices highlight where strengthening could take place were it deemed necessary by the city authorities.

Hannover

Hannover scored a total of 87.0 points for the air quality monitoring capabilities index. This is an excellent rating and represents one the five highest scores achieved. It indicates a very complete approach to air quality management in the city with few deficiencies in any section of the index. Hannover collects all appropriate air quality data and applies strict quality control measures. A range of sites allows a comparison of spatial distribution of pollutants, and there are good data on all major pollutant compounds going back at least five years, allowing trends to be evaluated. Lead is not currently on the list, probably because the emissions of this metal are no longer seen as a threat due to emission reduction measures taken previously. The measurement capacity index gained an outstanding score of 24.5.

The full data set has allowed the production of a wide range of assessments, including predictions of air pollution episodes and exposure assessments for different population groups. Air quality data reports are published and readily available to the public. The score for the index of data assessment and availability was also outstanding at 24.0. The emission estimates for different source categories are also very complete apart from the breakdown of total traffic emissions into vehicle types. Emission generation estimates are available for all the major air pollutants except lead. The spatial distribution of the emission sources is not included. Although the inventories are not conducted every two years, future inventories to update the figures are planned. The score for the emissions index was 19.5, just below the excellent category.

Hannover scored 19.0 points for the air quality management capability index. Limits have been set for all sources of emissions but it would appear that no penalties or enforcement for exceedance of these limits exist, apart from that for cars. In accordance with EU legislation, air quality standards relating to acute and chronic exposure have been set for all major air pollutants as appropriate. Other management measures adopted include EIA, further emission restrictions during pollution episodes, and the availability of unleaded petrol.

Hannover provides an example of the difficulty in relying solely on questionnaire responses, since two somewhat different returns were received which needed to further investigation. In the case of German cities, the questionnaire was sent to the contact person in the city and a second set of questionnaires was sent to the Federal Environmental Agency who forwarded them to the cities. In some cases different contact persons filled in the two questionnaires, leading to some discrepancies, but these were generally of a minor nature and were resolved by further enquiry. Regardless of this, the overall high standard of the air quality management programme in Hannover is certainly not in doubt.

Lisbon

Lisbon scored a total of 51.5 points on the combined capabilities index. This is a rather low value, mid-way in the moderate category. Cities with

Trams in Lisbon go some way to reducing vehicle pollution such scores may be good in some areas yet have no, or very limited, activity in other fields, for example, emissions estimates. For Lisbon, the indices scores range from 10.0–15.5 indicating some major shortfalls in all areas of air quality management and assessment capability.

For the measurement capacity index, Lisbon scores 14.0. The major air pollutants are monitored, apart from Pb, and have been measured in the city centre for at least five years, apart from particulates. Roadside measurements are available, again excluding Pb, while suburban, urban and industrial sites provide data for NO_2, SO_2 and CO. The quality control of data could be improved with instruments currently only being calibrated monthly and no audits being conducted. There are no guidelines on the network design but the sites are reviewed to ensure they meet the objectives of the network.

For Lisbon, the index of data assessment and availability is also only moderate, scoring 12.0. Basic assessment of the data is carried out including assessment of exceedance of air quality standards and the analysis of trends. More sophisticated procedures including prediction, spatial distribution, epidemiological studies or modelling are absent. However, a new epidemiological project is being initiated. Aggregated air quality information is published in newspapers and readily available to the general public. Smog warnings are not issued.

Detailed emission estimates have only been produced for domestic and individual industrial point sources and they have not included Pb, O_3 or hydrocarbons. Estimates are based simply on fuel consumption statistics and emission estimates, rather than actual measurements. Future inventories are planned but, to date, they are rather limited. They are, however, published and available to the general public. The score for this index was 10 and thus represents an area where major improvements could be made.

Air quality management capability in Lisbon scores 15.5. Limits have been set for all emission sources apart from domestic dwellings, but only the power generation and other industries have penalties and enforcement procedures for exceedances. In accordance with EU legislation, air quality standards relating to acute and chronic exposure have been set for all major air pollutants as appropriate. Other management measures that have been adopted include EIA and the supply of unleaded petrol.

Traffic congestion in Paris

Paris

The overall capabilities index score for Paris is 77.5, which is at the top end of the good category. Individual indices range from 17.5–21.5 and are therefore all in the good or excellent categories. These scores indicate a highly effective air quality management programme with few, if any, major shortfalls.

Paris has a very extensive monitoring network of 59 background stations, classified as highly populated and less populated urban sites, plus 3 rural sites. Forty-eight urban sites monitor SO_2, 35 NO_2, 13 O_3, 8 particulates and 2 CO (Airparif, 1996). Traffic stations include 9 measuring NO_2, 2 measuring particulates, 9 for CO, 6 for Pb and 1 for benzo[a]pyrene.

Examining each index in detail, Paris scores 20 points on the measurement capacity index. The range of data available from the extensive monitoring network is very complete and includes roadside, urban background, suburban and industrial sites. Quality control is also very good, although there appears to be no accreditation of laboratories for audit control and there is a need for guidelines on monitoring network design.

The excellent database allows for a full range of assessment; the only noticeable shortfalls appear to be that aggregated data alone, rather than raw data, are made available to the public, and that warnings are not given to the public prior to forecasted periods of poor air quality. The score for the data assessment and availability index was an excellent 21.5.

Emissions estimates for different sources are complete, including a breakdown of traffic emissions from different types of vehicle. Most pollutant emissions have been estimated in the past five years except for Pb and O_3 generation. The estimates included actual measurements of emissions.

Inventories are not conducted every two years and there are no definite plans to carry out a future inventory. The inventories are not published in full but are partially available. The score for this index was 18.5.

The air quality management capability score for Paris was 17.5. Limits are set and enforced for all emission sources other than domestic dwellings. In accordance with EU legislation air quality standards relating to acute and chronic exposure have been set for all major air pollutants as appropriate, apart from CO. Of the other management measures suggested in the questionnaire, Paris has EIA and unleaded petrol, but does not impose special regulations during episodes of poor air quality and there are no special air quality standards for sensitive areas.

An interesting feature of the air quality management system in Paris is the separation of responsibilities for air quality and emissions control. This can lead to a lack of communication on respective roles and the questionnaire responses for the city indicated that this was occurring. This separation of functions may also account, in part, for the major differences that exist between French cities, with total scores ranging from 36.0 to 77.5 and one nil response.

Rome

Rome achieved an overall air quality management and assessment score of 65.0, which is at the lower end of the good category. This indicates that many aspects of air quality management capability are in place but that steps could be taken to refine or expand the system. Examination of the scores in detail indicate that Rome has high scores (17.0–21.0) for three indices but that the emissions estimation index scores only 9.0. The same problem has been noted earlier for several other cities.

The index of measurement capacity scores 17.0 with all pollutants currently monitored at one or more central urban background location, although the records do not extend back for five years. There is a range of monitoring sites and thus an evaluation of spatial distribution is possible, although there is no roadside station for the specific evaluation of traffic emissions. Quality control of data is very good, but the site audits are not carried out by an independent agency.

The score for the index of data assessment and availability is also in the good category (18.0). The collected data are subjected to a range of analyses, which have been used to conduct trend analysis, epidemiological studies and population exposure assessments. Prediction of pollution episodes and other modelling exercises have not been adopted.

Rush hour traffic comes to a standstill in Rome

Information dissemination is good and there are warnings issued to the public during periods of poor air quality, but there are no central city bulletin boards displaying current pollutant concentrations to the public. Data are generally available to the public on request only, rather than through published and widely available documents.

Rome, like several other cities with generally good air quality monitoring and management capability, scores poorly on emission inventories (9.0). However, some estimates of traffic-related emissions, including actual measurements, have been made and future inventories are planned.

With respect to the index of air quality management capability, Rome scores very highly (21.0), indicating that air quality management has been given a relatively high priority in the city. Limits are set and enforced for major emission sources other than domestic dwellings, and a full range of air quality standards relating to acute and chronic exposure have been set for all major air pollutants as appropriate. Other management measures include the availability of unleaded petrol, the imposition of additional restrictions during periods of poor air quality, and EIA is now adopted for new developments.

Vienna

With a total of 79.0 points, Vienna's air quality management and assessment capabilities are in the upper range of the class described as good. This shows that a large number of fundamental capabilities for successful air quality management are in place and only few areas need substantial improvement.

The urban monitoring network consists of 18 stations in different areas of the city determining concentrations of most traditional air pollutants (Mücke and Turowski, 1995). For the measurement capacity, Vienna scored 18.0. Deduction of points from the maximum achievable score had to be made since levels of airborne lead are not monitored and so far no guidelines for monitoring network design and station location have been adopted.

Comprehensive data assessment and dissemination of data were conducted and the score for this index was 22.5. However, no forecasts of air quality are produced, and therefore smog warnings can only be issued during pollution episodes. Information given to the public in advance, when deterioration of the air quality can be anticipated, could help to reduce and avoid peak pollution events. However, all monitored data are available to the public through a variety of media.

Very detailed emission inventories for most important pollutants and all significant urban emission source types are produced, including emissions from non-combustion processes, and include actual emission monitoring. Data are published and fully available to the public, but emission inventories are not conducted at least every two years and do not include the spatial distribution of emission sources. This information would be very valuable for assessing the success of emission abatement measures. The score for this index was a very good 20.0.

The management capability index score for Vienna was 18.5. With the exception of domestic sources, emission limits have been set and are enforced; furthermore, air quality guidelines relating to acute and chronic health effects have been adopted. During summer smog episodes, additional emission restrictions may be imposed on road traffic and/or industry if alarm levels are reached. The high frequency of O_3 threshold exceedances reported in 1994 shows the necessity for these measures, but they are not yet sufficient to permanently reduce O_3 concentrations to acceptable levels *(Chapters 5 and 6)*.

The overall very good air quality management and assessment capabilities of Vienna, in combination with the external impacts on air quality, result in generally good air quality. The major difficulties relate to elevated O_3 concentrations during hot and sunny periods. To tackle this complex problem, an evaluation of impacts on a scale larger than the city limits is necessary. Long-range transboundary transport of O_3 precursor substances might significantly exacerbate the problem.

Warsaw

Warsaw scores a total of 67.0 on the overall monitoring and management capability index and thus, like Barcelona, Rome and Belfast, falls into the lower half of the good range. However, unlike the other three, which all score poorly on the emissions estimate index but have at least one index in the excellent range, Warsaw has a more even distribution of scores (13.5–18.5), indicating a general overall capability but with some shortfall in all areas.

Examining the indices in more detail, Warsaw has a good pollutant monitoring network which has been operating for at least five years. There is information on the spatial distribution of NO_2, SO_2 and particulate matter, but not on CO, Pb and O_3. Vehicle emissions of all the major pollutants are monitored at a roadside site/s. Quality assurance of the data could be improved in terms of instrument calibration, and through independent audits of instruments. However, inter-comparison exercises are conducted and guidelines for site selection and network design are available. The index score for measurement capacity for Warsaw was 18.0.

The index score for data assessment and availability in Warsaw was a relatively poor 13.5. This was because, although good data were collected, these do not seem to have been used to best effect as no trend analysis, prediction, epidemiological studies or exposure analyses are performed. The data are also neither widely available nor distributed in the media, although information boards are present in the city.

The indicator of emissions estimates shows a substantial employment of this tool in Warsaw (17.0). Emission estimates are restricted to domestic, power generation and industry and do not include mobile sources, which is a major shortfall. Pollutants investigated do not include O_3 or Pb. However, it is clear that the emission estimates that are conducted are very thorough and based on actual measurements. The inventories are not published, nor are they available in full, but the public does have some access to the information.

Warsaw also scores in the good category for management capability (18.5). Limits are set and at least partially enforced for all major emission sources other than domestic dwellings. There are also nationally adopted acute and chronic health standards for all the pollutants as appropriate. Other useful measures include the availability of unleaded petrol and extra restrictions can be enforced if an area exceeds air quality standards. EIA has also been adopted.

Air Quality Modelling

In addition to the collection of air quality observations and the assessment of this monitored data, modelling of air pollution is employed with rapidly increasing frequency. Numerous different models for application in the most diverse situations have been developed. A review of requirements for models and their applications has recently been conducted by the ETC-AQ within the project 'Harmonisation in the Use of Models for Ambient Air Quality and Pollution Dispersion/Transport'. This project also included a survey on the extent to which existing models fulfil potential demands and data prerequisites to assure successful modelling (Moussiopoulos, 1996). A model documentation system has been built to provide guidance to any model user on the selection of an appropriate model for a specific application, and a pilot version is available on the internet (http://www.etcaq.rivm.nl).

The potential capabilities of air quality modelling as an important tool in air quality assessment and management has been acknowledged by the European Union, which is considering the possibility of replacing monitoring with modelling in situations which meet certain specifications. This has been incorporated into the Framework Council Directive on Ambient Air Quality (EC Directive 96/62/EC, 1996). Models are an indispensable tool for the prediction of the impact that various management strategies could have on future air quality, since they make the investigation of alternative scenarios possible. Thus, they assist in identifying the most efficient strategy and support decision-making processes and policy development.

A classification of models by the spatial and temporal scale they cover, and accordingly the air pollution problem they address, was developed and is summarised in *Table 9.2* (Moussiopoulos, 1996). Further aspects, which would allow a distinction of model groups and determination of application areas, could be for instance:

- qualitative and quantitative capacities, which kind of statements can be made and what accuracies can be expected;
- input data requirements and the types of processes included, such as transport, chemical reaction and deposition of pollutants, or
- mathematical approach employed to describe the dispersion process, for instance Gaussian, Eularian or Lagrangian.

Application areas for the various model types include regulatory purposes, policy support, public information and scientific research. The complexity of the models and the modules covered depends on the scale of the investigated problem. Chemical reactions in the atmosphere, as well as pollutant sinks through scavenging and deposition, and modelling in one to three dimensions, can all be performed. Following the model development or selection, a calibration has to be performed, generally done by modelling an event for which sufficient monitoring data exist to allow a comparison of observations and model results. The accuracy of model results has to be evaluated and quality assurance procedures have to be developed and applied, otherwise the model output cannot be considered reliable.

In addition to approaches which start with emissions and analyse their dispersion, it is possible to use the observed impact on a receptor as a starting point and determine the impact of separate emission sources and other key factors.

Scale of dispersion phenomenon Characteristic time	Local <few minutes	Local-to-regional several hours	Regional-to-continental several days	Global > weeks
Policy issue				
Climate change				X
Ozone depletion			X	X
Tropospheric ozone			X	X
Tropospheric change			X	X
Acidification			X	
Eutrophication			X	
Summer smog		X	X	
Winter smog		X	X	
Air toxics	X	X	X	
Urban Air Quality	X	X		
Industrial pollutants	X	X		
Nuclear emergencies	X	X	X	
Chemical emergencies	X	X	X	

Table 9.2
Atmospheric models (Moussiopoulos, 1996)

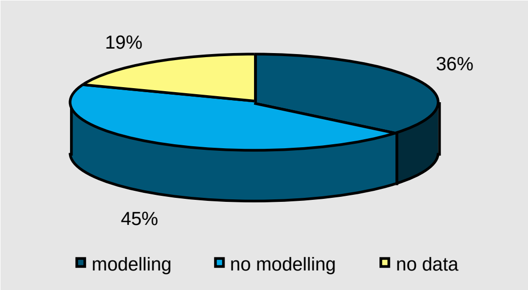


Figure 9.13
Application of air quality models with emission and/or meteorological data

Several questions referring to modelling capabilities were asked in the questionnaire survey, but it was not specified whether these models were supplied on a regular basis or had been used in rather isolated studies. *Figure 9.13* shows the number of cities using meteorological measurements and/or emission data as model inputs. It can be seen that almost half of those who replied use modelling as an air quality assessment tool. This shows that so far the capabilities of air quality modelling as a management tool are not yet regularly applied, but rapid improvement is to be expected.

Overall, the investigation of air quality management and assessment capabilities in Europe and the status and application of air quality modelling has shown that, although measurements of pollutant concentrations and the analysis of these observed data still play a fundamental role in the assessment of air quality, various other aspects have gained importance.

Chapter 10

The Way Forward

Air Quality Management in an Overall European Pollution Control Context

In the preceding chapters a review has been made of urban air quality in Europe. This topic has been addressed in the widest sense by not only examining the data that have been collected in 79 major European cities, but also by using various indicators to predict the occurrence of poor air quality and to test these predictions against the observed data. In addition, 64 cities have responded to a questionnaire survey, which provides a guide to the capacity of cities to monitor, assess and manage air quality.

This report is opportune since it appears at a time of transition in the concepts and designs of monitoring and assessment programmes. For example, the EU Framework Directive on Air Quality Assessment and Management was adopted in September 1996 (EC, 1996). A recurrent difficulty in the past has been that the monitoring data collected have not always addressed management needs, and the variety of methods and approaches in use make inter-comparisons and decision-making difficult. The challenge for the future is to provide a monitoring and assessment system, which can provide aggregated information that is suited to management requirements. There is also the need to develop management infrastructures, which are capable of using the information to not only effectively manage air quality in the cities, but also relate city management requirements to national, regional and global needs.

Another recent trend is towards the development of integrated pollution control, which brings together previously separate approaches to air, water, soil, and food quality. The overview that can be provided by an integrated approach is the only way in which management can obtain the information to set and enforce environmentally acceptable levels of toxic chemicals in different media, in order to safeguard human and ecosystem health. Furthermore, it is the only way in which priorities can be set and a real step forward be made towards sustainable development. However, for such a goal to be realized, this prioritisation will need significant development of the various instruments available for management over and above those currently used. This would necessarily include fines and incentives for compliance to mandatory standards and emission reduction, as well as the application of cost-benefit analysis in relation to the management options for pollution control scenarios.

Management Objectives

One of the problems encountered in this study has been the difficulty in comparing cities in different parts of Europe which have, for reasons of location, economic, social and environmental issues, given different priorities to air quality management, and thus to air quality monitoring and assessment. Some cities have placed emphasis on monitoring capacity but conducted no emission inventories. Other cities have monitored only a narrow range of pollutants, and some monitor different pollutants only on a seasonal basis. It is not always possible, or sufficient, to judge cities entirely on an index score, as this can sometimes be simplistic. Why, for example, should Gothenburg, which has good air quality and so far few, if any, occasions on which current air quality guidelines have been exceeded, maintain a city centre bulletin board to warn of non-events. On the other hand, why should not all cities publish their air quality and related emissions data in full and disseminate such information to the media.

Air Quality Management – Questions and Data Requirements

Air quality managers working at city, regional and national levels will wish to address one or more (or perhaps all) the following questions, and will thus need to carry out the associated monitoring and assessment to provide the answers:

Is there a problem, will the problem occur, and, if present, is it currently getting better or worse?

- measurement of current levels of key pollutants,
- determination of trends.

Where is the problem originating and are existing standards and limits being effectively enforced?

- determination of sources and estimation of the spatial distribution of emissions of primary pollutants and precursor substances for secondary pollutants,
- ensuring compliance to standards and limits.

Is the public at risk now or in the future, and are appropriate measures in place to safeguard the public?

- monitoring to measure exceedance of limits,
- predicting exceedance of standards,
- warning the public,
- assessing exposure of the population to poor air quality.

Are materials and ecosystems being affected by poor air quality?

- ambient air quality monitoring in remote, rural and sensitive area locations,
- determination of ambient air quality impact on materials and structures,
- biomonitoring – effects on flora, fauna, ecosystems, agriculture and livestock.

How do urban air quality problems rate with respect to local and global pollution control priorities?

- assessing pollution control priorities,
- assessing contribution of urban air emissions to national, transboundary and global problems,
- the use of economic instruments and cost-benefit analysis.

Do the current air pollution control monitoring, assessment and management infrastructure and policies meet the agreed objectives and thus provide answers to the appropriate questions?

- quality control of the whole monitoring and assessment process,
- feedback on the effectiveness or otherwise of current policies.

In Europe as a whole all these questions are topical and relevant issues, and they are addressed in *Chapters 4 to 9* of this report. It is, however, debatable as to whether they are all explicitly accepted as relevant by all air quality managers in cities. In particular, it is quite probable that city priorities have been developed in response to strictly local urban demands, for example, in order to protect city inhabitants and artefacts. Little priority has been given by cities generally to some of the pressing national, regional and global issues which lie outside their constituency remit. If these broader issues are to be addressed effectively, then the mechanism for hierarchical management priority setting needs close integration. There are, of course, national and international monitoring and assessment networks, for example, EMEP, BaP-MON and GEMS/Air, but how far individual cities are aware of these programmes, or see how their problems and efforts at resolution impact on the wider environment, is by no means certain. The evidence from the questionnaire responses indicates that city awareness of even EU directives and guidelines is patchy.

Urban Air Quality Problems – Present and Future

The survey of existing data described in this report confirms that air quality problems are widespread across Europe and that much work still has to be done to achieve the goal of healthy urban air for all. Two previous published studies on urban air quality, 'Urban Air Pollution in Megacities of the World' (WHO/UNEP, 1992) and 'Air Quality Management and Assessment Capabilities in 20 Major Cities' (WHO/UNEP, 1997) have concentrated on highly populated cities, with populations over 10 million and 3 million respectively. On a global scale, this is appropriate as the number of cities which will grow to these sizes in the developing world in the next century is increasing exponentially. For Europe, the scenario is rather different, since population growth is no longer seen as a major driving force and thus city growth is unlikely to be as great. For many cities, such as London and Paris, the trend over the past few years has been for a level of decentralisation, with decreasing population numbers resident in the city centres leading to suburban sprawl. In other regions, city boundaries have coalesced, leading to agglomerations of cities, such as in the industrial belt of the Ruhr. Similarly, coastal cities in tourist areas may spread along coastlines, producing laterally extended agglomerations, such as in Monaco and the French/Italian Riviera.

In this report, the population limit for city inclusion was 500,000 and some 68 cities satisfied this criterion. Eleven smaller cities were included to ensure that at least one city from each country in the area investigated was included. It is evident in this review that all the cities for which data are available had air quality problems of one sort or another and at varying levels of severity. All the larger cities, such as Rome, Paris, Berlin, London and Warsaw, had a very wide range of air quality problems whilst a few of the smaller cities with low population densities, such as Gothenburg, had air pollution problems well under control, so that exceedance of air quality standards was unlikely. However, some of the smaller cities, for example those with high population density (Katowice) and/or other unfavourable conditions (Belfast), had quite extensive air pollution problems. WHO has suggested that cities with over 50,000 inhabitants are likely to encounter air pollution problems *(Chapter 5)*. Air quality is therefore an issue shared by all European countries, and one which potentially affects all city residents; by the year 2000, these will number about 350 million in the area covered by this report.

In addition to the great variety of city size, population density and topography, the geographic spread of the cities investigated presents a wide regional diversity. There is some evidence presented in this report that climate and economic conditions can be influential in affecting air quality problems at a regional level. Air quality management capability has been shown to be correlated with the wealth of the nation (Purchasing Power Parity) of the city involved (WHO/UNEP, 1997).

It could be expected that the larger the city the more likely people are to be at risk; but the proportion of the population exposed during pollution episodes is a reflection of a mixture of factors, including levels of exceedance, population density and pollution source distribution. However, much of the data show a patchwork of pollution problems that are not strictly regionally stratified or classified readily on any one particular criterion; for example, Belfast is an outlier in *Map 7.8* on winter smog occurrences. Although this may appear disappointing or discouraging for developing regional and national strategies, it does highlight the conclusion that each individual city has to be regarded as a management entity with specifically identified problems and goals.

This conclusion perhaps explains how urban air quality monitoring and management has developed in a very ‘bottom-up’ way for each city; inevitably, this is leading to difficulties in applying the ‘top-down’ national, EU and international guidelines and directives in a consistent manner. One of the needs to be addressed in the future, therefore, is the satisfactory incorporation of national and regional air quality needs into city air quality management strategies.

One of the specific needs in international and regional policy development is the provision of internationally comparable data sets of known quality. A new EU Decision on Exchange of Air Quality Information is likely to be agreed in 1997. AIRBASE and EIONET are under development by the EEA with the intention of building and using the data supplied under this and other decisions as well as the EU Air Quality Directives. An EEA workshop in Copenhagen (ETC-AQ, 1996b) has proposed a number of recommendations including the development of a European monitoring network, EURO-AIRNET, based on current national monitoring networks.

There is a confusing diversity of reporting periods for many pollutants, ranging from annual means to 24 hours, 8 hours and 10 minutes. It would be very beneficial for comparisons if guidelines could be issued to all cities suggesting a fixed set of reporting modes for each pollutant in accordance with the needs to address different issues. However, for data continuity, it would be desirable to overlap any changes that cities incorporate (see *Chapter 4* on monitoring methods for black smoke, TSP and PM_{10} and $PM_{2.5}$).

All cities have at least some level of quality assessment and quality control (QA/QC) which they apply to their air quality monitoring networks, but it is not known how many reach the highest international standards in this respect. The recent EEA workshop recommended a four-phase development of QA/QC. If city data are to be used for regional and international strategic planning, or to enforce compliance to international agreements on pollution discharges, then there is a real need to encourage a commonality of quality control measures across Europe.

Overall, there are changes taking place in the relative importance of different pollutants. In many areas lead (Pb) levels have fallen to well below set standards. For sulphur dioxide (SO_2), the problems within cities are now frequently under control, but the transboundary movement is still an issue in several areas. The growth of road transport is probably the most uniform development, taking place right across Europe, but even here the rate of increase varies enormously and the measures in place to control the resultant pollutants are still incomplete.

Cities traditionally monitor pollutants that they regard as significant in their city. Is it desirable for a city to measure oxides of nitrogen (NO_x,), ozone (O_3) and volatile organic compounds (VOCs) if the risk of summer smog is non-existent? Should SO_2 be measured if power plants are nuclear, industries are fitted with flue gas desulphurization, domestic burning of coal is banned, and if concentrations have fallen to less than 20% of levels in the 1980s and no longer exceed recommended guideline limits? Should Pb still be measured if unleaded petrol is now the predominantly used fuel? For the sake of international comparability and trend analysis, the simple answer to these questions is probably 'yes' and the data collection should be continued albeit at a reduced level. However, for a city with other pollution and economic priorities the cost may not be deemed worthwhile. To optimise the use of the limited resources, these issues need to be resolved in the future.

Less frequently monitored substances, such as VOCs and hazardous air pollutants, need to be given a higher priority to allow an assessment of the current situation. Harmonisation efforts are particularly important in this area due to the wide variety of compounds and parameters involved. For some reported measurements it is not clear whether VOC concentrations include methane, the most abundant species, or which compounds were selected as representatives. Concentrations of individual pollutants, such as benzene, as well as specified relevant mixtures, need to be determined and subsequently used for assessment.

Air Quality Monitoring and Assessment Capability

One of the special features of this report is the analysis which is provided of air quality management and assessment capability. Ultimately, it is on the capacity to achieve management targets and goals that a city's air quality management capability will be judged, rather than on adherence to particular policies. Nevertheless, the aggregated index and its four component parts can be used to help a city prioritise development of its programme. The regional distribution of returns of the questionnaire leads to some cause for concern, as cities in the southern region gave a 55% response compared with a 100% return for the five cities in the Nordic region. This may indicate that cities in the southern region are less integrated into the information exchange processes within Europe. Perhaps this is due to language difficulties (the questionnaire was only made available in English) and/or that air pollution is not seen as a problem, or that air quality management is not given a high priority. It is recommended that the reasons for this discrepancy should be addressed, and that cities which have failed to respond from all regions should be targeted in the future. In the scheme presented, all four indices are given equal weighting whilst the answers to particular questions may vary from 0.5–3.0. The weights chosen may be argued against but they represent an attempted rationality in relation to the perceived importance of the various factors and indices.

In many ways the first index, the measurement capacity, is the most fundamental in that without good data, air quality management cannot be effective. City scores for this index average 17.8, which is near the median of the good range, indicating that most cities have given priority to collecting sound data. Cities that fail to reach the good category have most frequently not adopted a variety of monitoring stations to measure industrial, suburban, urban background and roadside levels, or have limited quality control measures in place. Some only measure a limited range of pollutants – Bucharest, for example, does not measure ozone – or only measure levels for part of the year, as in the Swedish cities. Bearing in mind local conditions, cities should be encouraged to achieve at least a good standard for this index and this could be a future target for Europe as a whole.

The data assessment and dissemination index clearly builds on the measurement capacity index; a poor score in measurement capacity will obviously limit the range of assessments that can be made. A similar percentage of countries, 74% for measurement capacity and 73% for data assessment and availability, achieved an excellent or good score for these two indices. In 60% of cities, the rating for the two indices was in the same class and in only two cases was the variance in scores more than one class. One relatively easy area for improvement, which down-rated a number of cities, was the failure of some cities to make data freely available through the media to the general public. Communication of air quality information to the public should be encouraged.

The scores for the emissions estimate index were more patchy; 53% of cities received a good or excellent rating but 33% were in either minimal or limited categories. Emissions estimates are undoubtedly valuable management tools for cities since they enable prioritisation of different pollution control measures to be judged, polluter-pays principles to be introduced and feedback to be provided on the effectiveness of any control measures. In a pan-European regulatory framework, they are essential to expose problems of transboundary pollution and compliance with nationally agreed emission limits. City management has failed in many cases to give this area priority, mainly because the uniform application of control measures can achieve pollution abatement targets measured in terms of reducing ambient air pollution levels without the absolute need for emission inventories. If future regulations require detailed emission inventories from cities, improvements may be achieved by providing incentives for cities to either carry them out or organise a national inventories programme, linked to the CORINAIR project, on top of the city monitoring programmes.

For the fourth index, air quality management capability, the distribution of scores reflects more closely the first two indices in that the minimal and limited categories account for only 11% of responding cities. The average score for this index may be expected to be somewhat lower than for the first two indices as it depends on them to a certain extent. One or two anomalies do arise, for example Barcelona achieves an excellent rating for management capability whilst scoring lower for all the other indices.

It is worth noting, and not only in this context, that the availability and reliability of data for this report was not as good and as up-to-date as one would have wished. The EU Framework Directive on Ambient Air Quality Assessment and Management (EC, 1996) requires all cities with over 250,000 inhabitants to provide data in the future and this will present a real challenge in achieving data consistency and QA/QC.

Relatively few cities have sufficient data to estimate the percentage of inhabitants exposed to exceedances of different pollutants in ambient air. There has been some debate as to whether ambient air monitoring is a totally adequate indicator of the risk of human exposure to poor air quality. Individual exposure to pollutants is a complex relationship between ambient, workplace and home concentrations and activity patterns. In northern regions, most individuals will spend the majority of their time indoors in winter whilst in the southern areas, during working hours, individuals will be increasingly exposed to an air-conditioned environment during the summer months. Further city epidemiological studies to evaluate regional differences and relative risks of exposure would add significantly to our understanding of the impacts of poor air quality on Europe's population.

The attitude of national government or local authority to freight and public transport in cities varies considerably. In the long term, traffic restriction may be necessary in many cities. Emergency restrictions are not the whole answer, and national and EU encouragement of cleaner technology and energy-efficient public transport systems is an increasingly vital tool for vehicle emission control.

City management infrastructure has often been developed *ad hoc* to deal with particular air quality issues. For example, in some countries there is no single authorised body for air quality management. In France, for example, emission inventories and air quality status are dealt with by separate agencies, whilst the Bucharest monitoring network exists under the control of three separate government bodies. A unification of such responsibilities would certainly make the work of pan-European air pollution information exchange and pollution control much easier.

Recommendations for the Future

1. It is recommended that cities from all regions which have failed to respond to this and other Europe-wide surveys with air quality data or air quality management data, should be encouraged to respond in the future *(Chapter 10)*.

2. Explicit statements are required of management objectives for air quality at city level but linked with national, regional and global objectives. An EEA workshop (ETC-AQ, 1996b) agreed that the ETC-AQ should help carry out the Assessment of Air Quality which should:

   a. present and map air quality in Europe at relevant spatial and temporal scales,
   b. provide quantitative relationships between air quality and the source emissions responsible, and
   c. provide quantitative information on the exposure of people, ecosystems and materials to air pollution, in order to allow risk assessment and effect evaluations to be carried out.
   d. Priority issues were identified as:
      - urban and local air quality,
      - ozone and photochemical air pollution, and
      - fine particulates.

3. Harmonisation of air quality measurement methods and quality control of the data collection and dissemination processes (QA/QC) should be encouraged across Europe. If city data are to be used for regional and international strategic planning, or to enforce compliance with international agreements on pollution discharges, then there is a real need to encourage a commonality of quality control measures across Europe (*Chapter 9* and EEA Workshop Report (ETC-AQ, 1996b)).

4. The procedures for reporting city pollutant levels and exceedances should be harmonised by the publication of pan-European guidelines (EEA Workshop Report (ETC-AQ, 1996b)).

5. The continuity of selected data sets should be encouraged if there is an international and national need for trend data, even if the local issues appear to have been solved *(Chapter 5)*.

6. Monitoring data should be available to assess the spatial distribution of pollutants within a city and allow an assessment of exposure of sensitive groups of people and areas (EEA Workshop Report (ETC-AQ, 1996b)).

7. Epidemiological studies should be encouraged and some of these should aim to provide a relative risk assessment of exposure from different exposure routes, including those from ambient air, occupational and indoor sources *(Chapter 8)*.

8. The further development of cost-benefit analysis and economic instruments in the context of prioritisation of actions to promote sustainable development should be considered *(Chapter 2)*.

9. Cities should be encouraged to disseminate air quality information to the public and to adopt a proactive role with the population to enhance public awareness *(Chapter 9)*.

10. Cities should be encouraged to develop a unified management infrastructure to deal with all aspects of air pollution measurement and provide management to integrate strategies, avoid duplication of effort, and ensure compatibility of data sets *(Chapter 9)*.

11. Cities should also be encouraged to develop management infrastructures which are capable not only of using the information to effectively manage air quality locally, but are equally able to tailor city management requirements to national and international sustainable development *(Chapter 9)*.

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Appendix 1

The questionnaire for the Air Quality Assessment and Management Capability Survey

Air Quality Monitoring Capability Index

As part of an earlier study on air quality monitoring and assessment capabilities of 20 major cities around the world carried out by MARC, conducted for the GEMS/AIR programme, an index score was developed (WHO/UNEP, 1996). The application of this index intends to assess the capabilities of different cities and identify the extent to which the components required for the application of effective air quality management are utilised. The purpose of this exercise is to identify the extent and means by which key information generated through air quality monitoring and the production of emissions inventories is collected and applied to develop effective air quality management strategies. Through determining the capabilities of cities in the different components of an integrated air pollution control strategy it is easier to identify those areas in which resources could be most effectively used.

The index will be calculated from questionnaire responses, which use specific indicators intended to identify the air quality management capabilities of the cities. The greater the number of the indicators a city is able to meet, the greater the air quality management capacity of the city. There are four sets of indicators assessing the different components of air quality management:

1. **Indicators of measurement capacity** – the ability to measure the levels of air pollution in the city.
2. **Indicators of data assessment and availability** – the extent to which data are used, the confidence with which these can be considered, and accessibility of the data in the public domain.
3. **Indicators of emissions estimates** – the extent of emissions knowledge about the city.
4. **Indicators of air quality management** – the ways in which the different components of air quality monitoring are applied to develop management strategies.

These sets of indicators can then be combined to give an overall appraisal of the air quality monitoring capability of the city in a manner which is objective and therefore more free of bias and less likely to misrepresent the capabilities of the city. In this assessment, each of the four components of air quality monitoring capability has been given equal weight toward the overall assessment.

This innovative method to assess the air quality monitoring capability of a large number of cities has been successfully tested and will provide decision-relevant information for policy makers, to help target resources most efficiently to help improve capacities.

The following pages contain the indicator questions, which have been developed for the air quality monitoring capabilities index. All the questions require a simple yes/no response.

Indicators of Measurement Capacity

The following questions are indicators of the extent to which objectives of air quality monitoring networks are met for different pollutants. Only monitoring which is **currently taking place regularly** (at least once a week) should be included:

1. For which of the following pollutants does your city have at least **one site monitoring central urban background concentrations, which has been operating for at least one year** (and therefore provides data from which evaluation of possible chronic health effects is possible)?

NO_2	Yes / No
SO_2	Yes / No
Particulate matter	Yes / No
Pb	Yes / No

2. For which of the following pollutants does your city have at least one site monitoring central urban background concentrations, which has been operating for at least one year and provides daily or hourly mean values (and therefore provides data from which evaluation of possible acute health effects is possible)?

NO_2	Yes / No
SO_2	Yes / No
Particulate matter	Yes / No
CO	Yes / No
O_3	Yes / No

3. For which of the following pollutants does your city have at least one site monitoring central urban background concentrations, which has been operating for at least five years (and therefore provides data from which evaluation of trends is possible)?

NO_2	Yes / No
SO_2	Yes / No
Particulate matter	Yes / No
CO	Yes / No
Pb	Yes / No
O_3	Yes / No

4. For which of the following pollutants does your city have at least one site each monitoring suburban and central urban background concentrations and those in industrial areas of the city which has been operating for at least one year (and therefore provides data from which evaluation of spatial distribution is possible)?

NO_2	Yes / No
SO_2	Yes / No
Particulate matter	Yes / No
CO	Yes / No
Pb	Yes / No
O_3	Yes / No

5. For which of the following pollutants does your city have at least one site monitoring at the roadside or kerb (and therefore provides data from which evaluation of the importance of vehicle emissions is possible)?

NO_2	Yes / No
SO_2	Yes / No
Particulate matter	Yes / No
CO	Yes / No
Pb	Yes / No

The following questions are indicators of the quality control and assurance procedures operated by the air quality monitoring network in your city:

6. Are the instruments calibrated at least every two weeks? **(Yes / No).**

7. Are calibrations/analysis conducted using certified solutions or gases and gas flow meters? **(Yes / No).**

8. Are site audits conducted to compare measurements from different instruments in the network, (inter-comparisons)? **(Yes / No).**

9. Are audits conducted by an independent body? **(Yes / No)**.

10. Are analysis and audits performed by a laboratory with an accreditation certificate? **(Yes / No)**.

11. Are the sites reviewed at least every five years to ensure they still meet the objectives of the network and hence are appropriate? **(Yes / No)**.

12. Is a quality control procedure applied to the data before it is finally released? **(Yes / No)**.

13. Are inter-comparison exercises conducted between different measurement techniques and/or instruments from other networks? **(Yes / No)**.

14. Are there guidelines on monitoring network design regarding the amount and distribution of monitoring sites? **(Yes / No)**.

15. Are there guidelines regarding the location of each monitoring site according to its purpose (background/hot spot site)? **(Yes / No)**.

Indicators of Data assessment and Availability

The following questions are indicators of the procedures used, and extent to which, data assessment and dissemination is conducted:

16. Are computers used in data assessment? **(Yes / No)**.

17. Which of the following data assessments are conducted? Determination of:

Means (daily, monthly, annual, etc.)	Yes / No
Maximum values (Daily, monthly, annual, etc.)	Yes / No
Daily variations	Yes / No
Percentiles	Yes / No
Exceedences of national or WHO air quality standards	Yes / No
Trends	Yes / No
Spatial distribution (mapping)	Yes / No
Predictions of air pollution episodes	Yes / No
Epidemiological (health) studies	Yes / No
Modelling with meteorological measurements	Yes / No
Modelling with emissions	Yes / No
Exposure assessments (determining the exposure of different population groups to air pollution)	Yes / No

18. Is air quality information available?

As raw data	Yes / No
As aggregated data	Yes / No
In newspapers	Yes / No
On television and radio	Yes / No
On information boards in the city centre	Yes / No

19. In what forms are the data released *(select one)? Please underline correct response*:

    Published and readily available to the general public

    Produced in internal reports/bulletins and not readily available to the general public

    Data available only when requested - no formal documents available

20. Are warnings to the public issued during or before forecasted periods of poor air quality? **(Yes / No)**. *(Either/Or - please underline correct response)*.

Indicators of Emissions Estimates

21. For which of the following emissions sources have estimates of emissions been made in your city in the past five years?

Domestic emissions	Yes / No
Power generating facilities emissions	Yes / No
Industrial emissions	Yes / No
Total traffic only	Yes / No
Cars	Yes / No
Motorcycles	Yes / No
LGV (light goods vehicles)	Yes / No
HGV (heavy goods vehicles) / buses	Yes / No
Others, e.g., ships, aircraft	Yes / No

22. For which of the following primary/secondary pollutants have estimates of emissions/ generation been made in your city in the past five years?

Nitrogen oxides	Yes / No
Sulphur dioxide	Yes / No
Particulate matter / smoke	Yes / No
Carbon monoxide	Yes / No
Lead	Yes / No
Ozone	Yes / No
Hydrocarbons	Yes / No

23. The following questions refer to how the inventory was produced:

Estimates including some actual measurements of emissions?	Yes / No
Estimates based upon fuel consumption statistics and emissions estimates only?	Yes / No
Are emissions from non-combustion processes included?	Yes / No
Is the inventory cross-checked (validated)?	Yes / No
Are inventories conducted at least every 2 years?	Yes / No
Are future inventories planned?	Yes / No
Spatial distribution of emission sources included?	Yes / No

24. How are details of the inventory available?

Published in full and available to the general public. **(Yes / No)**.

Partially available. **(Yes / No)**.

Indicators of Air Quality Management Capability

25. Which of the following sources of emissions have emissions limits been set, and for which are these enforced and penalties imposed for exceeding this limit:

Emission source	Limit set	Penalty for exceedence exists and enforced
Cars	Yes / No	Yes / No
LGV	Yes / No	Yes / No
HGV / buses	Yes / No	Yes / No
Domestic dwellings	Yes / No	Yes / No
Power generation	Yes / No	Yes / No
Industry	Yes / No	Yes / No

26. Are environmental impact assessments conducted before the construction of major new projects such as roads or industrial facilities? **(Yes / No)**. *(Either/Or - please underline correct response)*.

27. Is unleaded petrol available? **(Yes / No)**.

28. Are additional emission controls imposed on industry, or vehicle use restricted during episodes of particularly poor air quality? **(Yes / No)**. *(Either/Or - please underline correct response)*.

29. Are there enforced regulations to ensure compliance with air quality standards (if an area exceeds an air quality standard are additional measures enforced to control emissions and ensure this is not repeated)? **(Yes / No)**.

30. Are there local air quality standards to take account of sensitive environments, such as nature parks, residential areas, etc.? **(Yes / No)**.

31. Are new air quality standards/amendments being introduced in the future? **(Yes / No)**.

32. For which of the following pollutants have acute and chronic effect ambient air quality standards (such as limit values or health guidelines) been set? (Acute is taken for averaging times shorter than 24 hours; chronic is taken to mean an averaging time longer than 24 h running mean, such as monthly or annual).

Pollutant	Acute standard	Chronic standard
NO_2	Yes / No	Yes / No
SO_2	Yes / No	Yes / No
Particulate matter	Yes / No	Yes / No
O_3	Yes / No	Not applicable
CO	Yes / No	Not applicable
Pb	Not applicable	Yes / No

Thank you very much for correcting and completing this questionnaire.

Appendix 2

Population Location, Area and Population Density for the investigated cities

City	Location co-ordinates (latitude/longitude)	City/Conurbation Population (*1000)	Area (km²) Total	Area (km²) Built-up	Population density (Inh/km²)	Density class
Amsterdam	52.21/4.52	**1,077**	**583**		1,847	1
Antwerp	51.13/4.25	**785**		**299**[92]	2,625	1
Athens	38.00/23.44	**3,100**		**350**	8,857	3
Barcelona	41.25/2.10	**3,097**	**457**		6,777	3
Belfast	54.40/-5.50	**295**	**106**		2,783	2
Berlin	52.32/13.25	3,454[92]	**880**		3,925	2
Birmingham	52.30/-1.50	3,020[90]		**150**[#]	20,133	5
Bratislava	48.10/17.10	**475**		**132**	3,598	2
Bremen	53.05/8.48	**553**[92]		**100**	5,530	2
Brussels	50.50/4.21	**1,349**[90]		**402**[90]	3,356	2
Bucharest	44.28/26.07	**2,388**[90]		**182**[90]	13,121	4
Budapest	47.25/19.13	**4,434**[91]	**525**[92]		8,446	3
Cologne	50.56/6.57	**954**[92]	**120**		7,950	3
Copenhagen	55.47/12.34	**1,700**[90]		**670**	2,537	1
Dortmund	51.32/7.27	601[92]		**280**	2,146	1
Dresden	51.03/13.45	483[92]		**226**	2,137	1
Dublin	53.20/-6.05	**547**		**115**[#]	4,757	2
Duisburg	51.26/6.48	538[92]	**140**		3,843	2
Düsseldorf	51.13/6.47	**577**[92]		**95**	6,074	3
Essen	51.27/6.57	661[92]	**300**		2,203	1
Frankfurt	50.06/8.41	**645**[92]		**50**[#]	12,900	4
Gdansk	54.22/18.41	**467**[92]	**50**[#]		9,340	3
Genoa	44.24/8.56	**696**[92]		**240**	2,900	2
Glasgow	55.53/-4.18	688		**150**[#]	4,587	2
Gothenburg	57.43/11.58	**734**[92]		**132**	5,561	2
Hamburg	53.33/10.00	**1,626**[93]	**755**		2,154	1
Hannover	52.33/9.44	**514**[92]		**204**	2,520	1
Helsinki	60.08/25.00	**929**[92]		**242**	3,839	2
Katowice	50.13/19.02	**360**[90]		**46**	7,826	3
Krakow	50.03/19.55	**800**[92]	**220**		3,636	2

City	Location co-ordinates (latitude/longitude)	City/Conurbation			Population density (Inh/km^2)	Density class
		Population (*1000)	Area (km^2) Total	Built-up		
Leeds	53.50/-1.35	**712**^{91}		**180**$^{\#}$	3,956	2
Leipzig	51.20/12.25	500^{92}		**140**$^{\#}$	3,571	2
Lille	50.39/3.05	**950**^{92}		**198**	,798	2
Lisbon	38.44/-9.08	**2,000**^{91}		**100**$^{\#}$	20,000	5
Liverpool	53.25/-2.55	474^{91}		**150**$^{\#}$	3,160	2
Ljubljana	46.03/14.30	**273**^{90}		**43**	6,349	3
Lodz	51.49/19.28	846^{91}		**120**	7,050	3
London	51.30/-0.10	**10,570**^{90}	**1,580**^{91}		6,690	3
Luxembourg	49.37/6.08	**78**^{92}		**22**^{92}	3,545	2
Lyon	45.46/4.50	**1,262**^{92}		**150**$^{\#}$	8,413	3
Madrid	40.25/-3.43	**3,120**		**100**$^{\#}$	31,200	5
Manchester	53.30/-2.15	**2,578**		**280**$^{\#}$	9,207	3
Marseille	43.18/5.22	**810**^{92}		**75**$^{\#}$	10,800	4
Milan	45.28/9.12	**1,432**^{92}		**160**$^{\#}$	8,950	3
Monaco	43.44/7.24	27		1$^{\#}$	27,000	5
Munich	48.08/11.35	1,241^{92}	**200**		6,205	3
Naples	40.50/14.15	**1,054**^{91}		**93**	11,333	4
Nurnberg	49.27/11.05	**500**^{92}		**95**^{93}	5,263	2
Oslo	59.56/10.45	**616**^{90}		**400**	1,540	1
Palermo	38.08/13.23	697^{91}		**50**$^{\#}$	13,940	5
Paris	48.52/2.20	**8,510**^{90}	**1,200**^{90}		7,092	3
Porto	41.09/-8.37	**1,315**		**100**$^{\#}$	13,150	4
Poznan	52.25/16.53	590^{91}		**125**	4,720	2
Prague	50.06/14.26	**1,216**^{92}		**210**^{91}	5,790	2
Reykjavik	64.09/-21.58	**112**^{92}		**4**	28,000	5
Riga	56.53/24.08	**897**^{92}		**307**^{92}	2,922	2
Rome	41.53/12.30	**2,693**^{91}		**125**^{90}	21,544	5
Rotterdam	51.55/4.29	**1,089**^{91}		**183**	5,951	2
Setubal P.	38.31/-8.54	650		50$^{\#}$	13,000	4
Sevilla	37.24/-5.59	**780**	**210**		3,714	2
Sheffield	53.23/-1.30	**520**^{91}		**100**$^{\#}$	5,200	2
Sofia	42.40/23.18	**1,300**^{90}		**200**	6,500	3
Stockholm	59.20/18.05	684^{92}	**188**		3,638	2
Stuttgart	48.47/9.12	596^{92}	**200**		2,980	2
Tallinn	59.22/24.48	**500**	183		2,732	1
The Hague	52.50/4.16	**654**	**151**		4,331	2
Thessaloniki	40.38/22.58	**969**		70$^{\#}$	13,843	5
Tirana	41.20/19.49	**450**^{92}		**25**^{92}	18,000	5
Toulouse	43.37/1.27	**608**^{92}		**250**^{92}	2,432	1
Turin	45.04/7.40	**1,784**^{92}		**100**^{92}	17,840	5
Vaduz	47.86/9.22	5		1.6$^{\#}$	3,125	2
Valencia	39.29/-0.29	**753**		**44**	17,114	5
Vienna	48.12/16.22	**1,564**^{90}		**190**	8,232	3
Vilnius	54.40/25.19	584^{93}	287		2,035	1
Warsaw	52.13/21.01	**1,653**^{92}	495		3,339	2
Wroclaw	51.05/17.00	643^{91}		**75**	8,573	3
Zagreb	45.48/15.58	**954**^{92}		**80**^{92}	11,925	4
Zaragoza	41.39/-0.54	598^{91}		**25**$^{\#}$	23,920	5
Zurich	47.23/8.33	356^{91}		24^{91}	14,833	5

Figures printed superscript refer to year of reference — # (built-up area): Area estimated from topographical maps

Plain characters changed according to demographic yearbook 1993; bold characters (RIVM, 1995a)

Appendix 3

The Vehicle Emission Index calculated for the investigated cities

City	Vehicle Smog Emission Index		
	Emission class for NO_x	Emission class for CO	Vehicle smog emission class, total
Amsterdam	2.0	1.0	2
Antwerp		5.0	5
Athens	3.0	5.0	4
Barcelona	1.0	2.0	1
Belfast			
Berlin	2.0	2.0	2
Birmingham			
Bratislava	2.0	1.0	2
Bremen			
Brussels			
Bucharest	3.0	2.0	3
Budapest	2.0	3.0	2
Cologne			
Copenhagen			
Dortmund			
Dresden	2.0	1.0	2
Dublin			
Duisburg			
Düsseldorf			
Essen			
Frankfurt	5.0	5.0	5
Gdansk			
Genoa			
Glasgow			
Gothenburg	2.0	2.0	2
Hamburg	2.0		2
Hannover	3.0	2.0	3
Helsinki	3.0	2.0	3
Katowice			
Krakow	4.0	4.0	4
Leeds			

City	Vehicle Smog Emission Index		
	Emission class for NO_x	Emission class for CO	Vehicle smog emission class, total
Leipzig	2.0		2
Lille			
Lisbon	5.0	5.0	5
Liverpool			
Ljubljana	5.0		5
Lodz			
London	2.0	3.0	2
Luxembourg	3.0		3
Lyon			
Madrid			
Manchester	4.0	3.0	4
Marseille			
Milan	3.0	4.0	3
Monaco			
Munich			
Naples	2.0	5.0	3
Nurnberg	3.0		3
Oslo	2.0	2.0	2
Palermo			
Paris	3.0		3
Porto	4.0	5.0	4
Poznan			
Prague	2.0	2.0	2
Reykjavik	2.0		2
Riga			
Rome			
Rotterdam	5.0	1.0	3
Setubal P.	5.0	5.0	5
Sevilla			
Sheffield			
Sofia	2.0	3.0	2
Stockholm	3.0	3.0	3
Stuttgart			
Tallinn	1.0	1.0	1
The Hague			
Thessaloniki			
Tirana			
Toulouse			
Turin			
Vaduz			
Valencia	2.0		2
Vienna	3.0	2.0	3
Vilnius			
Warsaw	2.0		2
Wroclaw			
Zagreb	3.0	2.0	3
Zaragoza	1.0	1.0	1
Zurich	5.0		5

The management of air quality is a complex task consisting of assessing the situation including monotoring and the appropriate usage of data, existence of a legislative framwork allowing the control of emissions and, enforcement of such legislation in situations where air quality standards or objectives are not being achived. The aim of the monograph is to give a comprehensive overview of the situation in European cities. A short introduction into general air pollution problems is followed by a summary of air quality guidelines and monitoring and data assessment techniques frequently employed. The air quality monitoring and management capability of 72 major urban agglomerations within 32 countries is assessed on a city by city basis. A further analysis of 10 detailed case studies into the relative importance of key factors such as climate, economic, topographic and demographic viewpoints is conducted and recommendations on how to improve air quality conditions most efficiently are suggested.

European Environment Agency