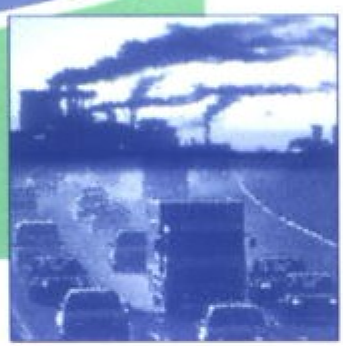
Issues in Environmental Science and Technology 8

EDITORS: R.E.HESTER AND R.M.HARRISON

Air Quality Management



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Air Quality Management

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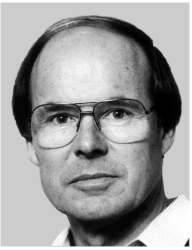

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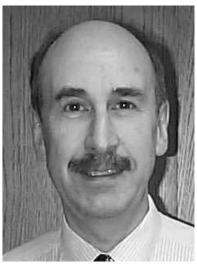
Ronald E. Hester is now Emeritus Professor of Chemistry in the University of York. He was for short periods a research fellow in Cambridge and an assistant professor at Cornell before being appointed to a lectureship in chemistry in York in 1965. He was a full professor in York from 1983 to 2001. His more than 300 publications are mainly in the area of vibrational spectroscopy, latterly focusing on time-resolved studies of photoreaction intermediates and on biomolecular systems in solution. He is active in environmental chemistry and is a founder member and former chairman of the Environment Group of the Royal Society of Chemistry and editor of 'Industry and the Environment in Perspective' (RSC, 1983) and 'Understanding Our Environment' (RSC, 1986). As a member of the Council of the UK Science and Engineering Research Council and several of its sub-committees, panels and boards, he has been heavily involved in national science policy and administration. He was, from 1991 to 93, a member of the UK Department of the Environment Advisory Committee on Hazardous Substances and from 1995 to 2000 was a member of the Publications and Information Board of the Royal Society of Chemistry.



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Roy M. Harrison is Queen Elizabeth II Birmingham Centenary Professor of Environmental Health in the University of Birmingham. He was previously Lecturer in Environmental Sciences at the University of Lancaster and Reader and Director of the Institute of Aerosol Science at the University of Essex. His more than 300 publications are mainly in the field of environmental chemistry, although his current work includes studies of human health impacts of atmospheric pollutants as well as research into the chemistry of pollution phenomena. He is a past Chairman of the Environment Group of the Royal Society of Chemistry for whom he has edited 'Pollution: Causes, Effects and Control' (RSC, 1983; Fourth Edition, 2001) and 'Understanding our Environment: An Introduction to Environmental Chemistry and Pollution' (RSC, Third Edition, 1999). He has a close interest in scientific and policy aspects of air pollution, having been Chairman of the Department of Environment Quality of Urban Air Review Group and the DETR Atmospheric Particles Expert Group as well as currently being a member of the DEFRA Expert Panel on Air Quality Standards, the DEFRA Advisory Committee on Hazardous Substances and the Department of Health Committee on the Medical Effects of Air Pollutants.

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Contents

Preface

Concern over air quality has never been higher in the public mind in both developed and less developed countries. This concern is reflected in ever tightening legislation, and the vigorous activity of regulatory authorities. The easily won gains in air quality have already been made throughout the developed world by the implementation of inexpensive but effective control measures. Air quality management is therefore addressing an ever steepening part of the cost/benefit curve, whereby each incremental improvement in air quality becomes increasingly expensive as the atmosphere becomes cleaner. Thus, methods to quantify the improvements required, to predict the source controls most appropriately applied, and to provide cost/benefit analyses of the reductions are becoming increasingly sophisticated. This volume deals with the scientific aspects of such air quality management procedures.

The first article, by D. R. Middleton, sets the scene by describing from a UK perspective the developments currently in hand to provide a scientific basis for air quality management. Subsequent articles deal with specific components of the air quality management process. Effective control of primary air pollution depends critically upon good knowledge of the sources of emissions and their geographic locations. This is encompassed by emissions inventories, and the article by D. Hutchinson deals with the now rather sophisticated subject of compilation of source emissions inventory data; it is illustrated by reference to the recently compiled emissions inventory for the UK West Midlands. A second crucial aspect of air quality management is the monitoring of air pollution. This provides information on the temporal trends in air quality and gives a direct measure of the compliance or otherwise of air pollutant concentrations with ambient air quality standards designed to protect human health, ecosystem function or the integrity of inert materials. The design and operation of air monitoring networks is described in the third article by J. Bower. Both source emissions data and monitoring information are central to the activity described in the fourth article by A. Skouloudis, who gives a comprehensive overview of the scientific considerations in the European Auto-Oil study, which was sponsored by the European Commission in order to determine the most cost-effective means of meeting air quality targets. It was therefore central to the setting of vehicle emission and fuel quality standards for implementation in the years 2000 and 2005.

Secondary air pollutants are those formed within the atmosphere and these present considerable difficulties in evaluating the effectiveness of controls of precursor emissions upon concentrations of the secondary pollutant. Often the relationship between emission of the precursor and concentration of the pollutant are strongly non-linear. The fifth article by P. Hopke on source–receptor modelling of air pollution addresses the very difficult technical issue of how, starting from ambient air quality data, it is possible to identify the source areas contributing to secondary pollutants to the atmosphere. The sixth article by M. Hornung and colleagues deals with the use of geochemical or biological tolerances (critical loads) to determine the maximum allowable inputs of acidic pollutants to the terrestrial environment. This approach is now heavily embodied in air pollution control policy development within Europe. The final article by A. C. Lloyd gives a fascinating perspective of the successes and problems of air pollution control in California, the US state which has for many years led the way in promoting vigorous air pollution control measures, but still has massive problems to overcome.

We are very fortunate in having attracted articles from leading workers in this field representing the best of scientific endeavour from both Europe and North America. We are most grateful to them for providing readers with a comprehensive perspective of the current state of the art of air quality management.

Roy M. Harrison
Ronald E. Hester

Improving Air Quality in the United Kingdom

DOUGLAS R. MIDDLETON*

1 Introduction

The concentration of pollutants in urban areas from sources near the ground has become of increasing concern in the UK, particularly since the London pollution episode of December 1991. During this episode from 11 to 15 December 1991, NO_2 was unusually high, with values from 350 to 400 ppb recorded at several sites and reaching 423 ppb at Bridge Place.[1,2] These values were well above the standard[3] which recommended a maximum hourly average concentration for NO_2 of 150 ppb. A study[4] by South East Institute of Public Health mapped contours of air pollution measurements in the form of annual average concentrations of nitrogen dioxide (NO_2). During 1995, these contours in much of London were above the NO_2 Standard that appears in the UK National Air Quality Strategy.[1] This Standard is 21 ppb for an annual mean. Since in London some 76% of the emissions of oxides of nitrogen are associated with road transport,[5] measures for improving air quality will have to address transport planning. Looking forward, the report[2] shows a projection of NO_2 contours in London for the year 2000. It suggests that by that date in central London, NO_2 will still be likely to exceed $40\,\mu g\,m^{-3}$ (*i.e.* 21 ppb).

The Environment Act 1995 has increased the powers for local authorities to manage air quality and to consult with a wide range of bodies. The decisions to be taken in managing air quality will cross traditional boundaries. It will be necessary, for example, for Environmental Health Officers and environmental scientists in local government to liaise quite closely with traffic planners and

*Any views expressed are those of the author.

1 DoE, *The United Kingdom National Air Quality Strategy*, Department of the Environment CM 3587, HMSO, London, 1997.
2 QUARG, *Urban Air Quality in the United Kingdom*, first report of the Quality of Urban Air Review Group, Department of the Environment, London, 1993.
3 EPAQS, *Expert Panel on Air Quality Standards* (*Nitrogen Dioxide*, *Ozone*, *Carbon Monoxide*, *Sulphur Dioxide*, *Benzene*, *1,3-Butadiene*), Department of the Environment, HMSO, London, 1996.
4 SEIPH, *Air Quality in London 1995*, third report of the London Air Quality Network, South East Institute of Public Health, Tunbridge Wells, Kent, 1996.
5 M. Chell and D. Hutchinson, *London Energy Study*, London Research Centre, London, 1993.

highway engineers, as well as with managers of local industry and the Environment Agency inspectors, in order to assemble the emissions databases upon which the modelling of air quality for reviews and assessments will rely. The National Strategy for Air Quality[1] sets out Government policy with regard to improving ambient air quality in the UK. It looks to the year 2005 and is relevant to both statutory requirements and to further voluntary action.

The Environment Act 1995 requires Local Authorities to review past and assess future air quality within their areas of jurisdiction. It also requires them to identify areas where levels of pollutants are high and, if necessary, designate them to be local air quality management areas. Such areas will be defined using the Standards and Objectives which appear in Table 3.1 of the Strategy.[1] Management areas might be based upon administrative or other boundaries, but will need to contain locales where air quality will be high to the year 2005. Computer models provide not only a means of forecasting air pollution events, but also ways to investigate the contribution of actual or planned pollution sources. Similarly, monitoring data can be used as a means of projecting forward in order to assess the extent of control that is needed. Monitoring data are costly to acquire, and do not easily lend themselves to consideration of future controls on individual sources. There will therefore be more use of emissions inventories and modelling to complement the monitoring of pollutants.

We have here an example of how the new moves to improve air quality through local management are providing a stimulus to scientific research. As well as encouraging the development of simple assessment techniques, it has led to the need to develop simple monitoring methods for pollutants such as buta-1,3-diene, along the lines of the diffusion tubes for benzene. There is also work now in progress by a number of local authority groupings funded by the Department of the Environment (DoE) to validate dispersion models against each other and against measurements. Finally, we shall see below that the UK National Air Quality Strategy[1] presents Standards and Objectives that will serve as a yardstick against which to judge air quality improvements.

2 Pollution in Street Canyons

Much monitoring has focused on the background level of airborne substances such as Pb, NO_x, CO, O_3, particles and organic compounds.[2,6–8] However, it is at kerbside locations where the general public may suffer exposures to the highest concentrations of pollutants. This is particularly true in a street canyon,[9] a

[6] QUARG, *Vehicle Emissions and Urban Air Quality*, second report of the Quality of Urban Air Review Group, Institute of Public and Environmental Health, University of Birmingham, Birmingham, 1993.

[7] QUARG, *Airborne Particulate Matter in the United Kingdom*, third report of the Quality of Urban Air Review Group, Institute of Public and Environmental Health, University of Birmingham, Birmingham, 1996.

[8] V. Bertorelli and R. G. Derwent, *Air Quality A to Z: A Directory of Air Quality Data for the United Kingdom in the 1990s*, Meteorological Office, Bracknell, Berks, 1995.

[9] A. T. Buckland, *Validation of a Street Canyon Model in Two Cities*, draft paper: IOP conference on 'Urban Air Quality—Monitoring and Modelling', Hatfield, 11–12 July 1996, *Environ. Monitoring Assessment*, 1997, submitted.

relatively narrow street between buildings that line up continuously along both sides. The combination of large vehicle emissions and reduced dispersion in these circumstances can lead to high levels of pollution. A well-trafficked street canyon therefore represents an important facet of air quality management.[9]

Recognizing that some authorities may not have the resources to run elaborate models, but will need a quantitative method, Buckland and Middleton[10] have produced a simple method. The result is AEOLIUS, a selection of nomograms and charts that has been devised along similar lines to volume 11 of the Design Manual for Roads and Bridges.[11] AEOLIUS is designed with one purpose in mind: to estimate the likely maximum concentrations from traffic in urban street canyons. It does not include the additional background concentrations from sources outside the street; they should be added by the user as necessary. AEOLIUS and other models are being tested by some local authorities during the trials cited earlier.

Only a brief outline of canyon dispersion principles is made here. A fuller description of canyon models appears in Buckland[9] and the papers cited therein. When the wind blows across a street canyon a vortex is typically generated, with the wind flow at street level opposite to that above roof level. A consequence is lower concentrations of pollutants on the windward side of the street compared with those of the leeward. The windward side is here defined as the side the roof wind blows to whilst the leeward side is the side the roof wind blows from. The quantity of pollutant that a monitor directly receives from vehicle emissions is calculated using a simple Gaussian model. The contribution from air recirculated by the vortex is calculated using a simple box model. The principle is that the inflow rate of pollutant into the volume of recirculated air is equal to the outflow rate and that the pollutants are well mixed inside this volume.

The canyon concentration[9] is proportional to the total emission rate Q from all vehicles, which will reflect changes in the vehicle fleet emission factors. For N vehicles an hour (with all vehicle types combined) and a combined emission factor of q grams km^{-1} vehicle^{-1}, the total emision rate Q μg m^{-1} s^{-1} is given by the equation: $Q = Nq/3.6$, which converts grams to micrograms, km^{-1} to m^{-1} and vehicles hr^{-1} to vehicles s^{-1}. This equation means that in order to improve air quality by reducing motor vehicle emissions Q, it is necessary to reduce the number of vehicles N and their average mass emission factor q. When Q is used in a dispersion model to calculate air pollutant concentration, it is multiplied by road length or distance travelled S; to improve air quality this also indicates reductions in the distance S. Traffic management and public transport can be regarded as managing q, N and the distance travelled S, whilst changes in technology such as catalysts or particle traps on new vehicles, and the maintenance of existing vehicles, seek to reduce q. Other developments such as cleaner diesel or unleaded petrol also serve to reduce q (for particulates or lead, respectively). Similar principles apply to fast moving traffic on open roads, and to idling engines in congestion. When vehicles are first started, and the catalyst is

[10] A. T. Buckland and D. R. Middleton, *Nomograms for Street Canyons*, 1997, submitted to *Atmos. Environ.*

[11] TRL, *Design Manual for Roads and Bridges*, vol. 11, sect. 3, part 1—Air Quality, Transport Research Laboratory, Department of Transport, amended 1994, HMSO, London, 1995.

Table 1 Road transport emission factors[12] q for urban traffic flow with fleet averages[10]

Vehicle type	*Number of vehicles per hour*	$NO_x/g\,km^{-1}$	$CO/g\,km^{-1}$
Cars*	830	2.11	19.36
LGV*	80	1.49	11.20
Medium HGV	40	12.60	6.00
Large HGV	10	16.95	7.30
Bus	10	14.40	6.60
Motorcycle	30	0.30	20.00
All types	1000	2.70	17.94

*When calculating the factors for an average car or light goods vehicle, the assumed percentages of petrol and diesel were: cars 90%P, 10%D; light goods vehicles 50%P, 50%D.

cold, the value of q may be much larger than for normal driving. Some published values[12] for q are shown in Table 1; a busy traffic flow N might be 2000 vehicles per hour. Finally, it can be seen from the Strategy[1] that even as average q is reduced in coming years, growths in N and S beyond the year 2010 are projected to outweigh the benefits of catalysts. The Strategy,[1] p. 46, therefore lists the principles for improving air quality, which we summarize here:

- improved technology
- tighter fleet management
- environmentally responsible use of vehicles
- policies and planning to reduce reliance on cars.

3 Motor Vehicle Contribution

The importance of motor vehicles to the urban air quality debate is manifest in figures published by the newly completed West Midlands Emissions Inventory study. This survey of all major sources of air pollutants in the seven local authorities was funded by the DoE to provide the first inventory in the UK at a very detailed local scale. Hutchinson and Clewley[13] collected data on transport (road, rail, air), domestic and industrial, Part B (*i.e.* those under local authority control), and Part A (*i.e.* under Environment Agency control), processes. Emissions of sulfur dioxide, oxides of nitrogen, carbon monoxide, carbon dioxide, non-methane volatile organic compounds, benzene, buta-1,3-diene and particles were mapped on 1 km squares. The database contains approximately 9000 road links (derived from the data used to run the traffic model for the West Midlands) with their start and end co-ordinates, peak hour traffic flows and vehicle speeds. They[13] concluded that:

> 'The single most significant source of atmospheric pollutants in the West Midlands is road traffic. In the case of carbon monoxide, benzene and

[12] C. A. Gillham, P. K. Leech and H. S. Eggleston, *UK Emissions of Air Pollutants 1970–1990*, DoE Document LR 887 (AP), Department of the Environment, London, 1992.

[13] D. Hutchinson and L. Clewley, *West Midlands Atmospheric Emissions Inventory*, London Research Centre, London, 1996.

Table 2 Road transport emission factors representing the national vehicle fleet for the year 1996

Vehicle type	*Number of vehicles per hour*	NO_x/ g km^{-1}	CO/ g km^{-1}	PM_{10}/ g km^{-1}	SO_2/ g km^{-1}	*Benzene*/ g km^{-1}	*Buta-1,3-diene*/ g km^{-1}
Cars P	747	1.57	14.86	0.028	0.051	0.0917	0.0267
Cars D	83	0.57	0.19	0.156	0.059	0.0042	0.0068
LGV P	40	1.51	18.37	0.044	0.168	0.1499	0.0349
LGV D	40	1.41	1.00	0.259	0.059	0.0065	0.0104
Medium HGV	40	6.87	4.99	1.187	0.229	0.0106	0.0136
Large HGV	10	13.17	5.99	0.996	0.387	0.0106	0.0220
Bus	10	14.75	18.73	1.347	0.352	0.0108	0.0198
Motorcycle	30	0.20	16.53	0.087	0.023	0.0404	0.0148
All types	1000	1.897	12.83	0.1195	0.0693	0.07695	0.02373

Source: T. Murrells, NETCEN AEA Technology (personal communication, see Buckland and Middleton[10]).

Table 3 Some scaling factors to reflect changing emissions 1996–2005*

Year	NO_x	CO	PM_{10}	C_6H_6	C_4H_6
1996†	1.0	1.0	1.0	1.0	1.0
1997	0.905	0.889	0.827	0.895	0.874
1998	0.824	0.813	0.717	0.800	0.763
1999	0.752	0.763	0.626	0.715	0.668
2000	0.688	0.698	0.539	0.636	0.574
2001	0.626	0.636	0.484	0.560	0.489
2002	0.570	0.580	0.433	0.491	0.411
2003	0.517	0.527	0.402	0.427	0.335
2004	0.489	0.491	0.381	0.382	0.287
2005	0.455	0.461	0.358	0.344	0.243

*Values were based on national vehicle fleet estimates of emission factors (kindly supplied by NETCEN AEA Technology) for each vehicle type, and weighted here by the traffic pattern of Table 1 as discussed in the text (see also Buckland and Middleton[10]).
†Values in each year are normalized by the last row of Table 2, the 1996 revised emission factors for an average vehicle.

> buta-1,3-diene, road traffic accounts for over 96% of emissions. . . . Road traffic also accounts for 85% of emissions of oxides of nitrogen and 75% of black smoke, but only 16% of sulfur dioxide.'

It is therefore clear that improvements in air quality will be dependent upon measures to reduce the total rate of emissions (SNq) from the motor vehicle fleet.

The composition of the vehicle fleet in terms of catalysts and type of fuel will change. To reflect this, revised emission factors (Table 2) provided by NETCEN AEA Technology for the expected national fleet in future years were also used[10] to estimate the likely fractional changes in q (Table 3). The decrease in revised emission factor for each pollutant from 1996 to 2005 is in Table 3 where the values shown are normalized to the 1996 estimates of revised emissions, *e.g.* for a CO calculation in the year 2001, the emissions must be multiplied by 0.636. In the absence of detailed local traffic analyses in different towns, Table 3 should provide reasonable estimates of future trends in vehicle emissions. Similar information on emission factors and their future trends appears in the Design Manual for Roads and Bridges,[11] and in the Strategy.[1] Finally, whilst on the subject of models, Middleton[14] reviewed physically based models for use in air quality management, for local or distant plumes.

4 Future Air Quality Objectives

In order to improve air quality, the targets at which to aim must be made visible. The Strategy[1] gives Standards for priority pollutants and possible Objectives for achieving them. Table 4 is derived from the Strategy and EPAQS[3] reports. Compliance or otherwise with the proposed values will be assessed for the year 2005. Breaching of these may point to a detailed assessment being necessary and

[14] D. R. Middleton, *Physical Models of Air Pollution for Air Quality Reviews*, Clean Air 26 (2), National Society for Clean Air and Environmental Protection, Brighton, 1996, pp. 28–36.

Table 4 Air quality quantities

Benzene	Strategy 5 ppb running annual mean; EPAQS[3] also recommended reduction to 1 ppb; timescale not specified
Buta-1,3-diene	Strategy 1 ppb running annual mean; EPAQS[3] recommended review in five years
Carbon monoxide	Strategy 10 ppm running 8 hour mean; as EPAQS[3]
Lead	Strategy 0.5 $\mu g\,m^{-3}$ annual mean; EPAQS (pending) lower?
Nitrogen dioxide	Strategy 150 ppb 1-hour mean; as EPAQS[3] Strategy also 21 ppb annual mean
Ozone*	Strategy 50 ppb running 8 hour mean; as in EPAQS[3] Objective 97th percentile of running 8 hourly means not to exceed standard value above of 50 ppb
Fine particles PM_{10}	Strategy 50 $\mu g\,m^{-3}$ running 24 hour mean; as in EPAQS[3] Objective 99th percentile of running 24 hourly means not to exceed standard value above of 50 $\mu g\,m^{-3}$
Sulfur dioxide	Strategy 100 ppb as 15 minute mean; as in EPAQS[3] Objective 99.9th percentile of 15 minute means not to exceed standard value above of 100 ppb

Source: the National Strategy[1] and others.[3]
*Ozone is a pollutant formed by chemical reactions in the atmosphere taking place over large distances; national and international measures are seen as the likely approach.[1]

the likely declaration of an Air Quality Management Area. This will in turn invoke the need for a formal statement or Action Plan; in this the local authority will set out its programme of local action, including the pollution controls as needed to achieve compliance with the Objectives. Such plans may estimate the amount of future emission control that is indicated, and imply constraints on planning.

To identify pollution ‘hot spots’, air quality management areas, calculations are likely to be required at many receptors so that mapping can be carried out. Table 3.1 of the Strategy[1] has 15 minute mean, 1 hour mean, running 8 hour mean, running 24 hour mean, annual mean and running annual mean. The list also uses percentiles of some of these quantities.

Some quantities are to be used as their means for testing likely compliance by 2005 AD, *i.e.* for benzene, buta-1,3-diene, carbon monoxide, lead and nitrogen dioxide. Others involve their percentiles (on percentiles, see Spiegel[15]; on log-normal and Weibull distributions to describe air quality data, see Seinfeld[16]). It is then their concentrations at the various percentiles that are tested for compliance. They include 97th, 99th and 99.9th percentiles, which need additional processing of model results to generate the cumulative frequency distribution and derive the relevant percentile, *i.e.* ozone (not a local authority modelling task, *cf.* the DoE[1]), particles as PM_{10} and SO_2. After the calculations, running means and percentiles can be evaluated (using spreadsheets, or routines within some models). Surrogate

[15] M. R. Spiegel, *Probability and Statistics*, McGraw-Hill, Maidenhead, 1980.
[16] J. H. Seinfeld, *Atmospheric Chemistry and Physics of Air Pollution*, Wiley, Chichester, 1986.

statistics might also be considered, such as appear in the EPAQS standard for the maximum 15 minute means of SO_2 *versus* the hourly means. In general, the modelling will need to calculate hourly averages as sequential means and then apply the relevant running means. For mapping air quality and the publication of results, annual averages are often convenient, such as in SEIPH.[4] They give a clear overview of the variations in air quality across an area. Maps of the Standards and Objectives in the Strategy may need special treatment, as outlined below.

5 Mapping an Air Quality Management Area

The Environment Act 1995 seeks to establish improvements in air quality through the identification of air quality management areas. At the time of writing, the manner in which such areas will be defined has yet to be announced; it is likely to be part of the regulations or guidance. Nevertheless, it is important to analyse ways in which such areas might be mapped. Future planning by local authorities may be strongly influenced by the projected extent of such areas, and public decision making in this area will need to be transparent and accountable. The following suggestions give an idea of the special nature of this mapping of regions that might exceed air quality Standards or Objectives.

Mapping Principles

In pollution modelling the phrase 'long term' is often used to convey the notion that the average concentration is to be obtained for some very long time period, such as one year or even 10 years. Annual average concentration is a typical quantity of this sort and would average some 8760 hourly values in a year. For reliable statistics, a 10 year run which requires 87 600 iterations might model the plumes from all sources, and generate a time series of results that would then be averaged. To map the likely pollution 'hot spots' using the annual average concentration, each hourly run would have to be repeated at each receptor position over the area to be mapped. Where the criterion for compliance to identify a problem area is based upon a concentration at some percentile, then instead of the average being found at each receptor, the results must be used to obtain the percentile at each receptor. The mapped 'hot spot' is the area enclosed within a contour that follows the positions where the percentile either exceeds or is less than the standard. For NO_2 a mapped area may enclose receptor points with maximum values greater than the standard 150 ppb (Table 4) and mark these as exceeding the Objective. Receptors with maximum values less than 150 ppb would be judged as complying with the Objective. Alternatively, there is scope in the Strategy[1] to map an area where annual average concentration of NO_2 may exceed 21 ppb.

On a map to show exceedance of the Objective for Fine Particles as PM_{10}, the exceedance area would be the region where the receptors have 99th percentile $c_p > 50\,\mu g\,m^{-3}$. In the case of Particles, the concentrations must be expressed in the form of running 24 hour means before the percentiles of the distribution are evaluated at each receptor.

Modelling

The input data must be formatted to suit the chosen model. Although broadly the same emissions inventory information are needed to model a given stack or line source, each computer code is likely to have its own sequence of data entry and slight variations on the parameters that are needed. For example, effluents from a chimney require stack height, stack diameter, exit momentum, exit buoyancy flux and emission rate of pollutant. Some models may require details of nearby buildings, whilst others will not.

The next step will be to prepare the meteorological data file. Either a series of short-term hourly observations of meteorology will be needed, or a frequency table sorted into joint categories by wind direction, stability class and wind speed. This choice of sequential *versus* statistical data can be decided using Table 4 for each pollutant in turn.

When the emissions data file and the meteorological data file are ready, the receptor layout must be decided upon. This can range from a short list of locations, to a line or grid of receptors. If aiming to map the quantities from the UK National Air Quality Strategy as listed below, then a large number of receptors may be indicated. If so, particular care is needed in identifying the region to be mapped, as a large grid of closely spaced receptors means a large number of dispersion calculations. Near to ground level sources such as roads, it can be necessary for hourly averages to have receptors as close together as every 10 metres in order to obtain meaningful contours when near the source. For annual averages a coarser spacing may suffice. The user of the model should obtain some sensitivity studies (*cf.* Royal Meteorological Society Guidelines cited below), to check that any contouring is robust and not adversely affected by an inappropriate receptor layout. Finally, we note for running means (*cf.* Table 4) that results in time and date order will be averaged in overlapping groups. Frequency data are not appropriate when running means are required. It is expected that guidance will advise local authorities on appropriate methods to map air quality management areas.

6 Quality Control

Meteorological data should be observed (where practicable) to the recognized World Meteorological Organization standards, and quality assured after recording and before use. There is also a need to ensure that meteorological data are from a relevant site. For urban pollution studies, it may be necessary to use measurements taken within the urban area and this poses particular problems of instrument siting and exposure; some measurements may be unduly influenced by some upwind building or structure. However, models such as street canyon models require (in principle at least) a roof-top wind; this will rarely be available so the models will rely on a 10 metre wind speed recorded at an observing station outside the town. AEOLIUS, for example, was designed[10] to use a 10 m wind when used for screening, although the detailed calculations within the model then extrapolate this wind to roof height. Other models such as the Indic model can accept meteorological data directly from a data logger that records the signals from instruments mounted on a mast in the urban area, whereas the ADMS model was designed for flexibility in its data requirements.

When calculating percentiles and running means, adequate data capture is required. For running means it is recommended that 75% data capture (*e.g.* 6 hours out of every group of 8 consecutive hours, or 16 out of every 24) be required; if less than this is available, then the running mean is not acceptable. Running means should be stored by the time/date at the end of the period.

The Royal Meteorological Society has issued a Policy Statement[17] for the use and choice of models. Dispersion modelling may be part of a public decision making process, with the results being entered into the public record. We may expect air quality reviews and assessments to be public documents, so any dispersion modelling runs may be subject to public scrutiny. Therefore in seeking to make plans to improve air quality, just as in the regulating of industrial processes, full documentation to establish an audit trail should be prepared. The Guidelines[17] establish principles for a technically valid and properly communicated modelling exercise.

7 Other Approaches

Surrogate Statistics

In the event that some but not necessarily all of the quantities in Table 4 may not be easily calculable, such as percentiles of running means, alternative quantities that are simpler to calculate may be useful. In their paper on the CAR model, Eerens and colleagues[18] gave some important insights from the work of Den Tonkelaar and van den Hout, who analysed measured concentrations in streets:

1. Whilst short-term concentrations are strongly affected by street geometry, the long-term annual concentration pattern is much less sensitive to the presence of buildings.
2. The ratio between the annual average values and the high percentiles of the frequency distribution of concentrations did not vary very much from street to street.

These points suggest that the use of surrogate statistics is proving to be a reasonably convenient way of deriving the high percentiles; by analogy we may expect a similar approach to the high percentiles of the running means. There is also the hope that such surrogates might be reasonably independent of particular towns or localities. They would then be useful in towns with no long-term monitoring records. However, Laxen[19] has suggested at a meeting of dispersion modellers that high percentiles may not have consistent relationships with the annual means. Clearly much more research in this area is indicated.

[17] RMS, *Atmospheric Dispersion Modelling: Guidelines on the Justification of Choice and Use of Models, and the Communication and Reporting of Results*, The Royal Meteorological Society/Department of the Environment, London, 1995.

[18] H.C. Eerens, C.J. Sliggers and K.D. Van Den Holt, *Atmos. Environ.*, 1993, **27B**, 389.

[19] D. Laxen, *Air Quality Standards in the UK National Strategy*, presented at the NSCA workshop, London, 26 November 1996, Techniques for Dispersion Modelling and Development of Good Practices, UK Dispersion Model Users Group Fourth Meeting, NSCA, Brighton, 1996.

Roll-back of Means

There are occasions where the magnitude of emission reductions needs to be quickly estimated. The 'roll-back' equation can be used[16] to estimate a factor R which is by how much emissions should be reduced to achieve a given reduction in the annual mean concentration (it assumes the background concentration is constant, *i.e.* independent of the source being evaluated):

$$R = \frac{\text{mean} - \text{standard}}{\text{mean} - \text{background}}$$

This approach may find application in assessing the control needed for sources influencing an air quality management area. It assumes that the standard is expressed as an annual mean. The equation means that a measure of the reduction can be obtained without dispersion modelling.

Reduced Percentiles

Air quality data are very often better described by a log-normal distribution than by a normal one. Seinfeld[16] considers the fitting of log-normal distributions to air pollution data, and describes an extension of the above 'roll-back' idea to the controls needed to manage the high percentiles seen in the monitoring. Assuming that meteorological conditions are unchanged, background concentrations are negligible and all sources would be given the same amount of emission reduction, the standard geometric deviation of the distribution is unchanged when the emissions are varied, *i.e.* the slope of the line is unchanged by emissions control. Therefore reduction in emissions would move the plotted line of the log-normal distribution downwards to lower concentrations (plotted vertically, *cf.* page 691 of Seinfeld[16]) with the same slope. This translation on the graph is the same for all percentile concentrations; the expected shift in, say, a 98th percentile is the same as that expected for the 50th percentile (or median). Therefore as emission controls are applied, the lowering of the frequency at which a standard concentration is likely to be exceeded can be read from the graph (or calculated from the two parameters of the log-normal distribution that fits the data).

8 Role of Air Quality Modelling

Under the Environment Act 1995, as local authorities seek to review and manage air quality, there is likely to be increased use of air pollution modelling. The importance of modelling as a tool for air quality managers is manifest in European as well as DoE papers. Control of emissions in order to manage air quality relative to the standards is the *raison d'être* for dispersion modelling.