

Chapter 1

Introduction

1. The Air Quality Expert Group (AQEG) was established to help the Government and Devolved Administrations tackle air pollution by examining sources and concentrations of pollutants in the UK. It was set up following publication of the *Air Quality Strategy for England, Scotland, Wales and Northern Ireland* with the following functions:
 - to advise the Government on levels, sources and characteristics of air pollutants in the United Kingdom (UK);
 - to assess the extent of exceedences of existing and proposed Air Quality Strategy objectives and European Union (EU) limit values, where monitoring data are not available;
 - to analyse trends in pollutant concentrations;
 - to assess current and future ambient concentrations of air pollutants in the UK; and
 - to suggest potential priority areas for research aimed at providing a better understanding of the issues that need to be addressed in setting air quality objectives.
2. The aim of this report, the second by the group, is to address these issues with respect to particulate matter (PM). The amenity effects of dust are not addressed in full here, but a study of the full database of visibility measurements at meteorological stations in the UK has been conducted previously (Doyle and Dorling, 2002; Doyle, 2004). Care has to be taken to account for natural visibility variability, but there is evidence at some sites of trends that can be ascribed to reductions in local and regional pollution. However, formulating air quality objectives for visibility, or predicting future trends, as part of an air quality management system would not be possible at the present time and hence has not formed part of this report.

1.1 Particulate matter

3. Atmospheric PM consists of a wide range of materials arising from a variety of sources. These may be solid or liquid particles that range in size and have complex chemical compositions. PM in the UK is measured using a range of metrics. The most frequently used is PM_{10} : this measure describes the mass of particles that pass a sampler entry with a 50% efficiency at 10 micrometres (μm). Thus as a good approximation, PM_{10} describes the mass of particles in the atmosphere with a diameter less than 10 μm . This is also the fraction of particles that is most likely to be deposited in the lung. The less commonly measured determinant $PM_{2.5}$ is defined similarly, but applies to particles with a diameter less than 2.5 μm . For many years atmospheric PM in the UK was measured in terms of its blackness, using a measure known as black smoke. Black smoke data still have value and this report also addresses particle data measured in this way.

1.2 Health effects of particulate matter

4. The Air Quality Strategy objectives¹ for PM are primarily based on health effects. The Department of Health's Committee on the Medical Effects of Air Pollutants (COMEAP) estimated that in Great Britain in 1996 PM₁₀ pollution was associated with around 8,100 deaths brought forward and 10,500 hospital admissions that were either brought forward or would not otherwise have happened (COMEAP, 1998).

This was due to short-term (acute) exposure. It is likely that the health impacts of long-term (chronic) exposure on the population were even greater. COMEAP have estimated that over the lifetime of the current population of England and Wales, the health gain that would result from a reduction of 1 µg m⁻³ of PM_{2.5} could lead to a gain of 0.2–0.5 million life years. Estimates derived using the same COMEAP coefficients, but more recent exposure data, are lower.

5. PM causes inflammation of the airways that may worsen existing lung disease and enhance the sensitivity to allergens of people with hay fever and asthma. It may also alter the ability of blood to clot and the circulation of red blood cells and platelets, a mechanism that could explain the adverse influence of inhaled particles on cardiovascular morbidity (illness) and mortality (death).
6. There have been a limited number of health studies on a range of PM parameters, including PM_{2.5}, PM_{1.0}, PM_{0.1}, particle numbers and surface area and there is much debate about the effects of the various size fractions. This report covers all the particle parameters for which UK measurements are available.
7. PM₁₀ standards are generally based on available epidemiological studies relating to the relevant geographical area. For example, the PM₁₀ standard recommended by the Expert Panel on Air Quality Standards (EPAQS) was derived from studies done in London and Birmingham and was later confirmed by a larger study done in the West Midlands once further PM₁₀ and PM_{2.5} monitoring data were available.
8. The health effects of PM will be addressed in brief in Chapter 3.

1.3 Emissions

9. PM may be either primary or secondary. Primary particles such as carbon particles from combustion, salt from the sea and mineral particles derived from stone abrasion are released directly into the air, whereas secondary particles are formed in the atmosphere by chemical reactions that lead to the formation of low volatility compounds that condense into particles.
10. The main sources of primary PM are road transport (combustion by-products, brake and tyre wear and re-entrainment of dust from road surfaces); stationary combustion (mainly domestic coal burning); and industrial processes (production of metals, cement, lime, coke and chemicals, bulk handling of dusty materials, construction, mining and quarrying). In 2001, road transport accounted for about

¹ Objectives are policy targets, which outline what the Government intends should be achieved in the light of air quality standards.

16% (combustion only) of total UK emissions of PM_{10} , with further major contributions from the electricity supply industry (10%) and the industrial (13%) and domestic (18%) sectors. In London, road transport accounted for 68% of PM_{10} emissions. It is worth noting that this 68% value does not include the long-range PM component originating outside the London area or coarse PM_{10} sources because these are difficult to quantify. UK PM_{10} emissions have declined substantially over the last 30 years, with an overall reduction of 67% between 1970 and 2001. The decline is mainly due to reductions in coal use. Domestic emissions have fallen by 85% between 1970 and 2001 and road transport emissions have declined by 12.5% over the same timescale.

11. Emissions are likely to decline further over the coming years as new technology and emissions standards continue to be introduced. Estimates of current and future emissions are provided via emissions inventories, which allocate emissions to categories – for example, road transport and power generation – and also provide spatial maps. The National Atmospheric Emissions Inventory (NAEI) covers the whole of the UK, mapping emissions on a 1 km x 1 km spatial grid. There are, in addition, several local inventories, for example, the London Atmospheric Emissions Inventory (LAEI).
12. Secondary particles are less easy to ascribe to their original sources. They are comprised mainly of ammonium sulphate and nitrate. These originate from the oxidation of sulphur and nitrogen oxides in the atmosphere to acids, which are then neutralised by atmospheric ammonia derived mainly from agricultural sources. The chemical processes involved in their formation are relatively slow and their persistence in the atmosphere is prolonged. Thus, while road traffic may be the main source of the original oxides of nitrogen and coal and oil burning the main source of sulphur oxides, the secondary particles are distributed more evenly throughout the air with fewer differences between urban and rural areas. They can also travel large distances, resulting in the transport of particles across national boundaries.

1.4 Measurements of particulate matter

13. The UK has an extensive national network of 64 automatic monitoring sites and an additional seven gravimetric analysers that measure PM. These comprise the Automatic Urban and Rural Network (AURN) and some affiliated sites from the London Air Quality Network (LAQN). The AURN sites include both those operated for the Department for Environment, Food and Rural Affairs (Defra) and the Devolved Administrations and those owned and operated by other organisations, mainly local authorities. These sites use a Tapered Element Oscillating Microbalance (TEOM), sequential gravimetric analyser (Partisol) or β -attenuation monitor (one site only) to measure PM_{10} . The automated instruments (TEOM and β -attenuation monitor) were chosen mainly for their reliability in the field and their ability to provide near real-time data for public information. In addition, several regional networks are operated, for example by the Highways Agency and power generators. Collective measurements, some extending over 10 years, provide an invaluable resource with which to assess the temporal and spatial variations in PM_{10} , including exceedences of the air quality objectives. These data have been used extensively in this report.

14. In addition, national monitoring of a number of other metrics and components, including PM_{2.5}, particulate nitrate, particulate sulphate, elemental and organic carbon, polycyclic aromatic hydrocarbons (PAHs), black smoke, heavy metals and particle numbers, also takes place.

1.5 Modelling

15. Although the monitoring sites have a wide spatial coverage, they can provide only a representation of pollutant concentrations at a relatively small number of points throughout the UK. When gradients of concentration are relatively small, as occurs in rural areas, measurements can be interpolated to give the spatial variation in concentration, which is broadly consistent with regional models. At the urban and local scales as well as close to significant sources, measurements give a limited indication of the spatial variation in concentration, and models are required to determine the complete picture. In addition, measured data cannot be used in a simple way to project future concentrations and to assess future exceedences because of the complex nature of the likely future emissions of primary PM and of the processes involved in the formation of secondary PM. As a result, modelling is essential for assessing the links between estimates of emissions and of atmospheric concentrations, to provide maps of particle concentration and to estimate future concentrations and exceedences.
16. A robust fundamental approach – in which meteorology and chemistry are modelled on a range of scales, from metres to many kilometres, using mathematical formulations – is not yet available for assessment purposes. A semi-empirical approach, utilising statistical analysis of large amounts of monitoring data – coupled in some circumstances with dispersion modelling – has been widely used in the UK for policy development. It forms a central component of the analysis and projections presented in this report and is coupled with surface concentration modelling to generate maps of PM₁₀ concentrations across the UK. Urban scale and local models that can take account of local features such as street canyons and smaller averaging times are also used to produce maps for urban areas; these maps are then used to test the assumptions implicit in the national mapping approach and for air quality review and assessment. In this report numerical models for regional scales up to the European scale have been used mainly to assess and project the contribution of secondary particulates.

1.6 Policy background

17. PM emissions and concentrations in the UK are subject to a number of national and international agreements and initiatives. These are outlined below and are described in more detail in individual chapters where appropriate.

1.6.1 International legislation and agreements

18. There are four EU directives that relate directly to emissions and concentrations of PM:
- i. The First Air Quality Daughter Directive (1999/30/EC) sets limit values for 24-h and annual average PM₁₀ that must be achieved throughout the European Community (EC) by 1 January 2005. The Directive also contains Stage II indicative limit values for both 24-h and annual average PM₁₀ to be achieved by 1 January 2010 (Table 1.1). These Stage II limit values are only indicative

and will be reviewed by the EC in light of further information on health and environmental effects, technical feasibility and experience gained in the application of Stage I limit values by Member States. They have no legal standing. Monitoring of PM_{2.5} is also included in this directive, although no limit values have been set.

- ii. The Auto-Oil Programme introduced tighter European vehicle emission and fuel quality standards by regulating particulates, carbon monoxide, hydrocarbons and nitrogen oxides. In 1998, three Auto-Oil proposals for the introduction of further standards from 2000 were agreed. The key elements to this agreement – now consolidated into two directives – are:
 - a stringent series of emission standards (known as the Euro III standard) to apply to all new cars and light vans sold from January 2001 and to all new heavy duty vehicles sold from October 2001;
 - more stringent standards (Euro IV standards) to apply from 1 January 2006 for new cars and light vans and from October 2006 to new heavy-duty vehicles;
 - tighter quality specifications to apply to all new petrol and diesel fuel sold from 1 January 2000 and 1 January 2005; and
 - a ban on the general marketing of leaded petrol from 1 January 2000.
- iii. For industrial plants, two additional directives provided (both directly and indirectly) controls on emissions of both particles and the secondary particle precursors sulphur dioxide and nitrogen oxides: the Large Combustion Plant Directive (2001/80/EC) established controls on emissions from large combustion plants, which include power stations, oil refineries and large energy producers within industry, particularly the metals sector.
- iv. The Integrated Pollution Prevention and Control (IPPC) Directive (96/61/EC) requires site-specific permits, that take account of the characteristics of each installation, its location and the state of the local environment. A wide range of installations and environmental impacts are taken into account by the regulator in considering a permit application. Conditions must be included that address any transboundary pollution caused by the installation. The Directive requires individual industrial plants to take any measures necessary to comply with any relevant EC legislation.

19. The National Emission Ceilings Directive (2001/81/EC) does not regulate PM directly but affects particle precursors such as ammonia (NH₃), sulphur dioxide (SO₂) and nitrogen oxides (NO_x). It establishes for each Member State a national limit for emissions of certain atmospheric pollutants including NO_x, sulphur (as SO₂), NH₃ and non-methane volatile organic compounds (NMVOCs). The National Emission Ceilings Directive incorporates (and in some cases goes beyond) ceilings established previously under the UNECE Convention on Long-Range Transboundary Air Pollution Gothenburg Protocol. Under the Directive, the UK is committed to reducing its national annual emissions of NO_x to below 1167 kt, SO₂ to below 585 kt, NH₃ to below 297 kt and NMVOCs to below 1200 kt, all by 2010.

- 20.** The EC's ongoing Clean Air for Europe (CAFE) programme, culminating in the publication of a Thematic Strategy on air quality in summer 2005, will lead to a number of revisions to existing Directives, including the first, second and third Daughter Directives as well as the National Emission Ceilings Directive. Revisions to the first Daughter Directive may include the introduction of controls on PM_{2.5}. The CAFE Technical Working Group on Particulate Matter has suggested a range of ambient PM_{2.5} concentrations for consideration in CAFE's integrated assessment of possible future PM targets. This range encompasses PM_{2.5} concentrations that are equivalent to or more stringent than the comparable Stage II indicative annual average limit value for PM₁₀. This is the range of possible limit values discussed in Chapter 9.

1.6.2 National framework

- 21.** Part IV of the Environment Act 1995 required the Government to produce a National Air Quality Strategy containing standards and objectives and also measures for achieving the objectives (Table 1.1). The first edition of the Strategy, published in 1997, fulfilled that requirement. It contained objectives for annual mean and 24-h exposure to PM₁₀. The Strategy was reviewed in 1999 and the Air Quality Strategy for England, Scotland, Wales and Northern Ireland was published in January 2000. This contained revisions to the PM₁₀ objectives. The PM₁₀ objectives were reviewed again in September 2001 and revised in an Addendum to the Strategy published in February 2003. The Act also laid the foundations for the system of Local Air Quality Management (LAQM). The Air Quality Strategy is undergoing a further review during 2004/5, this time focusing on a more measures-based approach.
- 22.** Local Air Quality Management forms an important part of the Government's Strategy for meeting both the UK air quality objectives and EU limit values. The Strategy recognises that national measures, for example, controls on emissions from new motor vehicles, will not always be the most appropriate way to deal with localised hotspots. LAQM requires all local authorities to carry out regular reviews and assessments of air quality in their area, with a view to identifying all those locations at which one or more of the objectives is unlikely to be met by the relevant date, taking account of relevant exposure (Defra, 2003). Such locations have to be formally designated as Air Quality Management Areas (AQMAs) and an Action Plan prepared for moving towards meeting the objectives. Now in its sixth year, the LAQM process has identified the need for 132 of 407 local authorities in England, Scotland and Wales to declare AQMAs. (Northern Ireland is working to a different timetable.) Of these, 92% are for nitrogen dioxide (NO₂), 45% for PM₁₀ (mostly in combination with NO₂) and 4% for SO₂ exceedences. The PM₁₀ declarations are mainly for road traffic, although in some cases exceedences are due to combined contributory emissions from industry. These local studies of PM₁₀ have generated information that supplements the findings of the national studies, and both are drawn upon in this report. For instance, although the national studies were inevitably focused on London and other major conurbations, as well as on the most heavily trafficked roads, the LAQM studies have shown that exceedences can also occur in smaller towns, where narrow streets coincide with congested traffic.

Table 1.1 EU limit values and Air Quality Strategy (AQS) objectives for PM₁₀.

Legislation	24-hourly values	Annual values (µg m ⁻³)	Achieved by
EU First Daughter Directive (99/30/EC) Stage I limit value	50 µg m ⁻³ with up to 35 exceedences per year	40	1 January 2005
EU First Daughter Directive (99/30/EC) Stage II indicative limit value	50 µg m ⁻³ with up to 7 exceedences per year	20	1 January 2010
AQS (2000) statutory objectives	50 µg m ⁻³ with up to 35 exceedences per year	40	31 December 2004
AQS Addendum (2003) – all parts of UK except London and Scotland provisional objectives	50 µg m ⁻³ with up to 7 exceedences per year	20	31 December 2010
AQS Addendum (2003) – Scotland provisional objectives	50 µg m ⁻³ with up to 7 exceedences per year	18	31 December 2010
AQS Addendum (2003) – London provisional objectives	50 µg m ⁻³ with up to 10 exceedences per year	23	31 December 2010

- 23.** The Greater London Authority Act received Royal Assent in November 1999. It provides for the Mayor of London to prepare and publish a Mayor's Air Quality Strategy (MAQS) for Greater London. London local authorities must take the MAQS into account when exercising their functions under Part IV of the Environment Act 1995.
- 24.** The MAQS, published in September 2002, sets out how the Mayor intends to implement the National Strategy in Greater London and achieve the objectives in the relevant regulations. It also contains:
- information about current and likely future air quality in Greater London;
 - the measures that are to be taken by the Greater London Authority, Transport for London and the London Development Agency to implement the Strategy;
 - information about measures the Mayor will encourage other people and organisations to take; and
 - any other proposals and policies the Mayor considers appropriate.

25. Part I of the Environmental Protection Act 1990 has been the main mechanism for minimising air pollution from industrial sources for a number of years. This Act established two pollution control regimes: the Local Air Pollution Control (LAPC) regime and the Integrated Pollution Control (IPC) regime, which not only takes account of releases to air, but also to land and water.
26. The IPC and LAPC are being succeeded by the new pollution prevention and control (PPC) regime, implementing the IPPC Directive 96/61/EC. There are separate regulations in Scotland and it will be for the new Executive to determine the arrangements for Northern Ireland. Although the terminology used differs slightly, the principles underpinning both IPC and PPC are similar. Regulators are required to ensure that pollution from industry is minimised through the use of the best available techniques (BAT), which take into account the balance between the costs and environmental benefits. Both systems also require regulators to take account of the characteristics of each installation, its geographical location and local environmental conditions. In England and Wales, PPC is regulated by the Environment Agency and local authorities, in Scotland, by the Scottish Environment Protection Agency (SEPA). In Northern Ireland, PPC is the responsibility of the Industrial Pollution and Radiochemical Inspectorate of the Environment and Heritage Service and district councils.

1.7 Structure of the report

27. This report aims, for the specific case of PM, to fulfil the tasks placed on AQEG and outlined in paragraph 1. It draws on several previous reports including *Airborne Particulate Matter in the UK* (QUARG, 1996), *Source Apportionment of Airborne Particulate Matter in the UK* (APEG, 1999), *Health Aspects of Air Pollution with Particulate Matter, Ozone and Nitrogen Dioxide* (WHO, 2003) and the *Second Position Paper on Particulate Matter* (CAFE, 2004).
28. Chapter 2 provides essential background material, including the physical characteristics and chemical composition of airborne PM, mass closure issues, receptor modelling and source apportionment. Chapter 3 briefly discusses the health effects of particles. Chapters 4 and 5 review the main issues relating to the construction of emissions inventories and the measurement and monitoring of PM. Where possible and appropriate, the Group has included a discussion of fundamental as well as practical issues, although much less detail is provided than for the AQEG report *Nitrogen Dioxide in the United Kingdom* (AQEG, 2004) because of the availability of previous reports on PM.
29. Chapters 6 and 7 provide a detailed analysis of data and an examination of historic trends in PM₁₀. Chapter 6 considers the data and asks what they imply about the sources, properties and spatial distributions of PM. Chapter 7 considers what are the main past and present trends in PM in the UK.
30. Chapter 8 provides some essential background information on the modelling of PM and considers the data from current models, including current and predicted future PM concentrations.

- 31.** The Discussion (Chapter 9) summarises the answers to the questions set for AQEG by Defra and the Devolved Administrations.
- Are the current assessment methods (emissions inventories, measurements and modelling) fit for purpose? How could they be improved?
 - Are there sources missing from (a) the UK emissions inventories and (b) other European inventories?
 - Is the UK likely to achieve, with current abatement measures and technologies, (a) the Stage I and indicative Stage II annual and daily mean PM_{10} limit values in the First Air Quality Directive and (b) the Air Quality Strategy objectives for PM_{10} ? If not, why not? What levels of PM_{10} are likely to be achieved by current measures and policies?
 - Will the UK be able to meet the range of targets for $PM_{2.5}$ as proposed in the draft CAFE Position Paper on Particulate Matter? If not, why not? What levels of $PM_{2.5}$ are likely to be achieved by current measures and policies?
 - What are the practical maximum feasible reductions of PM_{10} and $PM_{2.5}$ concentrations at (a) hotspots and (b) urban background, for example, central London locations?
 - Where and what are the main source contributors to current and future concentrations of PM_{10} and $PM_{2.5}$? What are the contributions of different sources to forecast exceedences of the EU limit values and UK objectives?
 - What are the potential sources of abatement and types of measures to reduce particle concentrations at (a) hotspots, such as near busy roads, (b) at urban background, central London and (c) across the whole country? What role can local/national/EU-wide measures play in meeting targets? These measures should be defined as technical (for example, vehicle standards); non-technical (for example, traffic management systems); and international (for example, controlling European/hemispheric emissions). Are there alternatives to emissions reduction?
 - A number of recent studies (including the WHO report) have highlighted the health effects of certain components of particulate matter (that is, fines, ultrafines, particle number, metals and elemental/organic carbon). Where further abatement techniques are known, how might they specifically affect reduction of the different PM metrics (for example, PM_{10} , $PM_{2.5}$, PM_1 and particle numbers) and chemical components?
 - Ultrafines – What have we learned from the measured data, including source apportionment? Are the observed trends real? What fraction of ultrafine particles volatilise?
 - Source apportionment – How does the UK source apportionment for PM_{10} , $PM_{2.5}$ and other metrics compare with other modelling in Europe? Is road traffic more important than current models show? How is the coarser fraction between 2.5 and 10 μm accounted for?

- Can we explain the trends in measured PM₁₀, sulphur and black smoke since 1992?
- What are the differences between strategies that address hotspots of exceedence and those that aim to reduce population exposure? Should policy evaluation consider impacts on population exposure, as well as concentrations at specific locations?

32. Chapter 10 draws conclusions and makes recommendations.