Review of the UK Air Quality Index

A report by the Committee on the Medical Effects of Air Pollutants

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Foreword

This is the first report prepared by the Standards Advisory Subgroup (CSAS) of the Committee on the Medical Effects of Air Pollutants. The subgroup was formed in June 2009 when the Expert Panel on Air Quality Standards (EPAQS) was merged with COMEAP. The work of the subgroup is supported by a joint Secretariat from both the Department for Environment, Food and Rural Affairs (Defra) and the Health Protection Agency.

In 2009, the subgroup was asked by Defra to review the current UK air quality index. Since the air quality index was last revised in 1998, there have been a number of developments in the regulation of air pollution and in the presentation of air quality information, which are reflected in these proposals.

COMEAP is very keen to enhance the way we communicate facts about air pollution to the public and the findings from the public insight study, which was commissioned by Defra, have been invaluable for developing the health advice and the presentation of the index. I am grateful to Stephen Holgate, the Chairman of the Standards Advisory Subgroup, who has ensured that the needs of the public for clear information were central to the development of these proposals. I am also grateful to the Secretariat and Members of the subgroup who developed the report and, indeed, to all Members of COMEAP. This is a real advance in helping the public deal with the impact of polluted air. I look forward to seeing how these proposals are received by Defra.

Professor Jon Ayres

Chairman of the Committee on the Medical Effects of Air Pollutants

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Executive Summary

The Committee on the Medical Effects of Air Pollutants (COMEAP) Standards Advisory Subgroup was asked by the Department for Environment, Food and Rural Affairs (Defra) to review the UK air quality index (AQI) to ensure that it is fit for purpose. The current UK air quality index has now been in operation essentially unchanged for a period of around 12 years. Therefore, it is timely to review the index to determine its suitability, given the developments in the field of air quality.

The air quality index is used to communicate information about real-time and forecast levels of outdoor air pollution in the short term. Forecasted air quality information is reported in terms of the air quality index and provides advanced warning of potentially health-damaging air pollution events. With advanced warning of poor air quality, individuals who are sensitive to the effects of air pollution can have the opportunity to modify their behaviour to reduce the severity of their symptoms. The air quality index does not provide guidance on the effects of long-term exposure to air pollution.

The pollutants included in the current index are particulate matter (PM_{10}), ozone (O_3), sulphur dioxide (SO_2), carbon monoxide (CO) and nitrogen dioxide (NO_2). The index has four bands indicating 'Low', 'Moderate', 'High' and 'Very High' levels of air pollution. These bands are further divided into a ten-point scale to provide greater gradation of air pollution levels.

The current air quality index was developed by COMEAP and is based on health evidence. The 'Low' bands indicate air pollution levels where it is unlikely that anyone will suffer any adverse effects of short-term exposure, including people with lung or heart conditions who may be more susceptible to the effects of air pollution. The 'Moderate' band represents levels of air pollutants at which there are likely to be small effects for susceptible people only. Values for the 'High' bands are associated with significant effects in susceptible people. At 'Very High' levels of air pollution even healthy individuals may experience adverse effects of short-term exposure.

Approach to the review of the bandings

COMEAP sought to review the health evidence relating to the index pollutants to assess whether the levels of the bands were appropriate. COMEAP looked at the coverage of the index and whether additional pollutants should be included. The review also took into account the current levels of pollutants, developments in European legislation and UK Air Quality Objectives.

COMEAP was keen to ensure that the review was centred on the requirements of the users of the index, namely the general public – particularly those more at risk of the adverse health effects of air pollution. In order to inform the review, dedicated research was commissioned to investigate the general public's current awareness and comprehension of air quality information, and to assess the challenges that exist to understanding and interpreting such material.

COMEAP considered several possible approaches to assessing and evaluating pollutant-specific evidence on health impacts that could be used in the revision of an index. We also took other evaluations and additional information into account in our deliberations. An Expert Group of the World Health Organization (WHO) undertook a thorough evaluation of the evidence concerning air pollution and health effects, with the resulting revised WHO Air Quality Guidelines published in 2006. In most cases, COMEAP proposes the adoption of the WHO values as proposed breakpoints between the bands. However, in some cases, our proposals do not adopt the WHO recommendations directly, for reasons which we explain.

The implications of the proposed changes to the bands, summarised below, will be an increase in the number of Moderate and High pollution days, and a decrease in the number of Low days reported across the year.

Summary of key recommendations

COMEAP recommends breakpoints between the bands of Low, Moderate, High and Very High for each of the index pollutants. We recommend that the air quality index be presented as a ten-point scale with colour coding to aid the interpretation of the index, as detailed in the table below. With respect to the current air quality index, the proposed bandings remain unchanged for sulphur dioxide (SO_2). The breakpoints for a change in band for ozone (O_3), nitrogen dioxide (NO_2) and particulate matter (of less than 10 μm in diameter, PM_{10}) are more stringent. Particulate matter of less than 2.5 μm in diameter ($PM_{2.5}$) has been added to the index, and carbon monoxide has been removed in view of the considerable reductions in outdoor levels of this pollutant.

		Ozone	Nitrogen dioxide	Sulphur dioxide	$PM_{2.5}$ particles	PM_{10} particles
Band	Index	Running 8-hour mean (μg m^{-3})	1-hour mean (μg m^{-3})	15-minute mean (μg m^{-3})	24-hour mean (μg m^{-3})	24-hour mean (μg m^{-3})
Low	1	0–26	0–66	0–88	0–11	0–16
	2	27–53	67–133	89–176	12–23	17–33
	3	54–80	134–200	177–265	24–35	34–50
Moderate	4	81–107	201–267	266–354	36–41	51–58
	5	108–134	268–334	355–442	42–46	59–66
	6	135–160	335–400	443–531	47–53	67–75
High	7	161–187	401–467	532–708	54–58	76–83
	8	188–213	468–534	709–886	59–64	84–91
	9	214–240	535–600	887–1063	65–70	92–100
Very High	10	241 or more	601 or more	1064 or more	71 or more	101 or more

We recommend that the information to accompany the new air quality index comes in three parts and includes additional advice for susceptible individuals, together with advice for the general population:

A Instructions on how the air quality index should be used

B Short-term health effects of air pollution and action that can be taken to reduce impacts

C Health advice linked to each band to accompany the air quality index

These are detailed below.

We also recommend the use of 'trigger' values to complement the proposed new air quality index and allow for the prediction of episodes of elevated air pollution in real time as they emerge. With the averaging times* of 24 hours for particulate matter and 8 hours for ozone it is not possible to provide public information about an unexpected pollution episode until it is well established. Triggers have been derived to provide information to the public to warn of exposure as it is taking place at Moderate, High or Very High levels. These triggers can be used by organisations that operate real-time public information services.

Finally, we recommend that links to information on the long-term health effects of air pollution are provided together with the index, such as the 2009 COMEAP report entitled *Long-Term Exposure to Air Pollution: Effect on Mortality* (http://www.comeap.org.uk).

A How to use the Air Quality Index (AQI)

Step 1 Determine whether you (or your children) are likely to be at risk from air pollution. Information on groups who may be affected is given in the section on 'Additional information on the short-term effects of air pollution'. Your doctor may also be able to give you advice

Step 2 If you may be at risk, and are planning strenuous activity outdoors, check the air pollution forecast

Step 3 Use the health messages corresponding to the highest forecast level of pollution as a guide

* The averaging time is the period of time that is used to smooth short-term variations in pollutant concentrations. These differ from pollutant to pollutant reflecting two aspects of the evidence on health effects: firstly, the timescale of exposure over which adverse health effects might be caused and, secondly, the averaging times used in the studies on which the assessment is based.

B Additional Information on the Short-term Effects of Air Pollution

The air quality index has been developed to provide advice on expected levels of air pollution. In addition, information on the short-term effects on health that might be expected to occur at the different bands of the index (Low, Moderate, High and Very High) is provided here

Short-term effects of air pollution on health

Air pollution has a range of effects on health. However, air pollution in the UK does not rise to levels at which people need to make major changes to their habits to avoid exposure; nobody need fear going outdoors

Adults and children with lung or heart conditions It is known that, when levels of air pollutants rise, adults suffering from heart conditions, and adults and children with lung conditions, are at increased risk of becoming ill and needing treatment. Only a minority of those who suffer from these conditions are likely to be affected and it is not possible to predict in advance who will be affected. Some people are aware that air pollution affects their health: adults and children with asthma may notice that they need to increase their use of inhaled reliever medication on days when levels of air pollution are higher than average

Older people are more likely to suffer from heart and lung conditions than young people and so it makes good sense for them to be aware of current air pollution conditions

General population At Very High levels of air pollution, some people may experience a sore or dry throat, sore eyes or, in some cases, a tickly cough – even healthy individuals

Children need not be kept from school or prevented from taking part in games. Children with asthma may notice that they need to increase their use of reliever medication on days when levels of air pollution are higher than average

Action that can be taken

When levels of air pollution increase it would be sensible for those who have noticed that they are affected to limit their exposure to air pollutants. This does not mean staying indoors, but reducing levels of exercise outdoors would be reasonable

Older people and those with heart and lung conditions might avoid exertion on High pollution days

Adults and children with asthma should check that they are taking their medication as advised by their health practitioner and may notice that they need to increase their use of inhaled reliever medication

Adults with heart and circulatory conditions should ***not*** modify their treatment schedules on the basis of advice provided by the air quality index: such modification should only be made on a health practitioner's advice

Some athletes, even if they are not asthmatic, may find their performance is less good than expected when levels of a certain air pollutant (ground-level ozone) are High, and they may notice that deep breathing causes some discomfort in the chest. This might be expected in summer on days when ground-level ozone levels are raised. This does not mean that they are in danger but it may be sensible for them to limit their activities on such days

C Health Advice to Accompany the Air Quality Index

Air pollution banding	Value	Accompanying health messages for at-risk groups and the general population	
		At-risk individuals*	General population
Low	1–3	***Enjoy*** your usual outdoor activities	***Enjoy*** your usual outdoor activities
Moderate	4–6	Adults and children with lung problems, and adults with heart problems, ***who experience symptoms***, should ***consider reducing*** strenuous physical activity, particularly outdoors	***Enjoy*** your usual outdoor activities
High	7–9	Adults and children with lung problems, and adults with heart problems, should ***reduce*** strenuous physical exertion, particularly outdoors, and particularly if they experience symptoms. People with asthma may find they need to use their reliever inhaler more often. Older people should also ***reduce*** physical exertion	Anyone experiencing discomfort such as sore eyes, cough or sore throat should ***consider reducing*** activity, particularly outdoors
Very High	10	Adults and children with lung problems, adults with heart problems, and older people, should ***avoid*** strenuous physical activity. People with asthma may find they need to use their reliever inhaler more often	***Reduce*** physical exertion, particularly outdoors, especially if you experience symptoms such as cough or sore throat

* Adults and children with heart or lung problems are at greater risk of symptoms. Follow your doctor's usual advice about exercising and managing your condition

Chapter 1
Introduction

The air quality index (AQI) is used to communicate information about real-time and forecast levels of outdoor air pollution. The pollutants included in the current index are particulate matter (PM)[1], ozone (O_3), sulphur dioxide (SO_2), carbon monoxide (CO) and nitrogen dioxide (NO_2). The index evolved through a series of iterations to become a ten-point scale divided into four bands indicating 'Low', 'Moderate', 'High' and 'Very High' levels of air pollution. The current UK index with related health information is presented in Annex 1.

The main objective behind the AQI is the prevention of adverse health effects from short-term elevations in air pollution. Forecasted air quality information is reported in terms of the AQI and provides forewarning of potentially health-damaging air pollution events. With advanced warning of impending poor air quality, sensitive individuals can, in principle, modify their behaviour to reduce their individual exposure to the pollution or reduce the severity of their symptoms. The AQI can also be used to draw attention to the day-by-day, month-by-month variations in air pollutant concentrations and so contribute to education and awareness of air quality issues amongst the public and policy-makers.

Another use of an AQI is to monitor the success of air quality management policies in reducing the frequency and severity of air pollution episodes. However, it is less suitable for monitoring progress towards air quality strategy objectives in general as not all pollutants are monitored continuously, and many objectives are not set for short-term averaging periods upon which the AQI is based.

1.1 Why is a review needed?

The air quality situation in the UK has changed dramatically over several decades for a number of pollutants. For example, traffic emissions of CO and SO_2 have been reduced to such an extent due to the introduction of Euro Standards[2] for vehicles that roadside levels are no longer of concern. On the other hand, there is now an increased recognition of the public health significance of particulate matter from road traffic. Further information on trends in levels of air pollutants in the UK is given in Annex 2.

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1 Suspended particulate matter is any non-gaseous material (liquid or solid) that, owing to its small gravitational settling rate, remains suspended in the atmosphere for appreciable time periods. PM_{10} refers to the mass concentration (expressed in $\mu g\ m^{-3}$) of particulate matter that is generally less than 10 millionths of a metre (10 μm) in diameter. $PM_{2.5}$ refers to the mass concentration of particles less than 2.5 μm in diameter. This is the mass per cubic metre of particles passing through the inlet of a size selective sampler with a transmission efficiency of 50% at an aerodynamic diameter of 10 μm for PM_{10} or 2.5 μm for $PM_{2.5}$.

2 Information on European regulation of pollutant emissions from road vehicles is available at http://ec.europa.eu/environment/air/transport/road.htm

European legislation and UK Air Quality Objectives have also changed within that period of time, including the introduction of EU Limit Values and Air Quality Objectives for $PM_{2.5}$. In addition, the impact of air pollution on health has continued to be an active area of epidemiological and toxicological research and a considerable amount of new information has become available since the AQI was developed around 12 years ago.

The current UK AQI has now been in operation essentially unchanged for over a decade. Therefore, based on new knowledge it is timely to review the index to determine its suitability, given the developments in the field of air quality.

1.2 Public perception issues

Although air pollution can have a significant impact on human health, research suggests that there is both a lack of awareness amongst the public regarding the links between air pollution and ill-health, and a lack of understanding concerning existing air quality information. Such information is often inaccessible and incomprehensible for the layperson.

The development of an AQI that will be useful constitutes a careful balance between condensing scientific evidence into an easily understandable format, and without losing valuable information. An AQI should be easily understandable by the non-scientist, have sufficient gradations to indicate variation in concentrations, contain information that is clear and focused, and provide relevant information on the level of air quality, the short-term effects of pollution on health, and suggestions for controlling symptoms. Our review of the index therefore included a public insight study to evaluate how well the current index meets the needs of users and how it can be improved. See Annex 3 for further information.

Chapter 2
Air Pollution – An Introduction

2.1 Sources and effects of air pollutants

In this section we describe the main air pollutants of concern, the source of these pollutants, and their health effects. Whilst we also briefly make reference to indoor air pollution here, the air quality index (AQI) is concerned only with outdoor air pollution. Further information on the health evidence for each pollutant can be found in Annex 4.

2.1.1 Particulate matter, PM_{10} and $PM_{2.5}$

Particulate matter (PM) is a complex mixture of organic and inorganic substances. Particles found in ambient air range in size from a few nanometres (nm) to several hundred micrometres (µm) in diameter. PM_{10} refers to the mass concentration (expressed in $\mu g\ m^{-3}$) of particulate matter that is generally less than 10 millionths of a metre (10 µm) in diameter. $PM_{2.5}$ refers to the mass concentration of particles less than 2.5 µm in diameter.

Particles can be primary (emitted directly to the atmosphere) or secondary (formed by the chemical reaction of other pollutants in the air such as SO_2 or NO_2). Particles may arise from a wide variety of sources, man-made or natural. The main source of particles is combustion, i.e. from traffic and power stations. Other man-made sources include quarrying and mining activities, industrial processes, dust from construction work, and particles from tyre and brake wear. Natural sources include wind-blown dust, sea salt, pollens, fungal spores and soil particles.

Most of our knowledge of the effects of particles on health comes from studies that relate either short-term or long-term levels of PM_{10} and $PM_{2.5}$ (such as those gathered by the UK monitoring network – see Section 2.2.1) to population-level indications of effects on health, such as mortality (death), increased admissions to hospital of people suffering from cardiovascular (heart) disease (attacks and strokes) and pulmonary (lung) disease, e.g. chronic obstructive pulmonary disease (COPD), bronchitis, and those with asthma [see Dominici et al (2006), Liang et al (2009), Rosenlund et al (2006), Stieb (2009) and Strickland et al (2010)]. It appears that for these susceptible people, elevations in particulate air pollution can worsen their illnesses.

2.1.2 Sulphur dioxide, SO_2

Sulphur dioxide exists as a gas but can dissolve in water to form an acidic solution which is readily oxidised to produce sulphuric acid droplets in the atmosphere. Chemical reactions of SO_2 can also produce sulphates which remain in the air as secondary particles contributing to particulate matter.

SO_2 is produced when sulphur-containing fuels, such as coal, are burned. Coal was once widely used for domestic heating and cooking, creating high concentrations of SO_2 and smoke in our towns and cities but, with the increased use of gas and electricity, this is now relatively uncommon and levels of SO_2 have steadily declined over the last 50 years. Most SO_2 in the UK now comes from industrial sources such as power stations burning fossil fuels, as well as domestic sources such as boilers and gas stoves. The introduction of low sulphur fuels has reduced the emissions of SO_2 from motor vehicles. SO_2 is also produced naturally by active volcanoes and forest fires.

SO_2 has an irritant effect on the lining of the nose, throat and lungs and can cause coughing, tightness in the chest and narrowing of the airways of the lung, reducing the flow of air to the lungs. People with asthma are much more sensitive to SO_2 than non-asthmatics. When SO_2 levels are high, people with asthma may therefore find breathing more difficult and, during pollution episodes, levels of SO_2 may trigger asthma attacks.

2.1.3 Nitrogen dioxide, NO_2

Nitrogen dioxide is a gas produced by the oxidation of nitric oxide (NO) by oxygen or ozone in the air, and is also directly emitted from vehicle exhausts. Once formed, NO_2 takes part in chemical reactions in the air, producing nitric acid and nitrates. Nitrates may remain in the air as secondary particles contributing to PM_{10} and $PM_{2.5}$. The term 'oxides of nitrogen' (NO_X) refers to the combination of NO and NO_2.

Domestic emissions of NO_2 form a small part of the total outdoor emissions. Nonetheless, as most people in the UK spend more time indoors than outdoors, indoor levels are the more important exposure source. The main indoor source of NO_2 is cooking with gas. Cigarette smoking is also a source of exposure. In outdoor air, the main source of NO (and therefore NO_2) is traffic, but it is also produced by the burning of fossil fuels in power stations and by industry. Outdoor NO_2 levels tend to be higher in the winter months and in urban areas.

NO is not considered to be of much concern with respect to health. At high concentrations, NO_2 acts as an irritant, causing inflammation of the airways. By affecting the immune cells in the lungs, it can also increase susceptibility to respiratory infections and to allergens.

It has been difficult to investigate the direct health effects of NO_2 at ambient concentrations because it is emitted from the same sources (notably traffic) as other pollutants such as particulate matter. NO_2 is often regarded as a marker for the presence of other traffic-related pollutants.

2.1.4 Ozone, O_3

Ozone is a secondary pollutant gas, formed by photochemical reactions – chemical reactions driven by sunlight in the lower atmosphere (the troposphere). In the higher layers of the atmosphere (the stratosphere) O_3 is formed by the action of ultraviolet light on oxygen molecules. This produces the ozone layer and at this level the gas has a beneficial effect by acting as an ultraviolet light filter.

In the lower atmosphere O_3 is produced by the photochemical effect of sunlight on oxides of nitrogen and volatile organic compounds produced by motor vehicles and industry. These reactions take place over periods of several hours or even days. Once formed, O_3 can travel long distances, accumulate and reach high concentrations often far away from the sources of the original pollutants. O_3 episodes normally follow a clear diurnal pattern, with the greatest concentrations being measured during the mid-afternoon (as shown in Figure A9-1 of Annex 9). NO_X emitted in cities reduces local O_3 concentrations as NO reacts with O_3 to form NO_2. This means that O_3 precursors generated in countries with large traffic and industrial emissions may affect less polluted countries, and that levels of O_3 in the air are often higher in rural areas than in urban areas. For example, it is often the case that when O_3 levels are elevated in Southeast England, much of the O_3 has originated in continental Europe. O_3 concentrations are greatest in the summer (usually on hot, sunny, windless days) and lowest in the winter months.

O_3 is an oxidising agent and acts as an irritant, producing inflammation of the respiratory tract. At high concentrations O_3 irritates the eyes, nose and throat, causing coughing and chest discomfort whilst breathing. Exposure over several hours can lead to damage of the lining of the airways. This is followed by inflammation and narrowing of the airways and increased sensitivity to stimuli such as cold air and exercise. This is called 'airway hyper-responsiveness' (twitchy airways). There is a wide variation in individuals' sensitivity to the effects of O_3. During High pollution episodes, high levels of O_3 may exacerbate asthma or trigger asthma attacks. Some non-asthmatic individuals might also experience discomfort when breathing, particularly if they are exercising vigorously outdoors.

2.1.5 Carbon monoxide, CO

Carbon monoxide is a colourless, odourless and tasteless gas produced when fossil fuels (such as gas, oil, coke and coal), wood and charcoal are burned without an adequate supply of oxygen. Petrol engines used to emit significant amounts of CO but concentrations are now very low due to the introduction of catalytic converters on car exhausts. People are more likely to be exposed to CO indoors. The main indoor sources are incorrectly installed, poorly maintained or poorly ventilated cooking and heating appliances such as gas fires, gas boilers and wood burning stoves. Cigarette smoke is also a major source of exposure.

CO is toxic to humans and exposure to high levels in indoor air can be fatal. CO prevents the normal transport of oxygen by the blood and its delivery to the body's tissues. Inhalation of CO at lower levels can result in symptoms which resemble influenza, viral infections or food poisoning, such as headaches, nausea, tiredness and difficulty in thinking clearly.

2.2 Air quality data and information

The UK has an obligation under European legislation to report monitored and modelled air quality data to the European Commission (see Table A5-2 in Annex 5). Monitoring and modelling play a key role in identifying emerging issues with air quality, and in guiding future policies which will be needed to address them.

2.2.1 Monitoring air quality

The Department for Environment, Food and Rural Affairs (Defra) has several monitoring networks across the UK to measure the levels of a number of different pollutants in the air. There are currently over 400 air quality monitoring sites in the national networks, and many more at local authority level. The 130 sites in the Automatic Urban and Rural Network (AURN) make continuous measurements of PM_{10}, $PM_{2.5}$, NO_2, NO_X, SO_2, O_3 and CO, delivered in near real-time[3]. The air quality index is set for use with data generated from European reference methods and data collected by other methods may need to be scaled for comparison. Further details of air quality monitoring in the UK are provided in Annex 5.

2.2.2 Modelling air quality

To support the management of air quality across the UK, Defra commissions air pollution modelling. This allows the assessment of air quality across a far wider geographical area than would be possible by monitoring alone. Defra relies upon models to provide air quality assessment across many rural areas of the UK, but they can also be extremely valuable in urban areas: local authorities often use a combination of monitoring and modelling to assess air quality in heavily trafficked areas. Modelling also helps policy-makers determine how air quality will change in the future and what action will be required to meet UK Air Quality Objectives and EU Limit Values. Further details of air quality modelling in the UK are provided in Annex 5.

2.2.3 Forecasting air pollution

The daily UK air pollution forecasting service predicts levels of the index pollutants for the forthcoming 24–48 hours. If conditions are changing rapidly, a new or revised forecast may be issued. The forecasts are based on information from a number of sources, including monitoring and meteorological data. Forecasting air pollution allows individuals and organisations to plan actions to reduce air pollution and respond to any likely health impacts of predicted air pollution. Further information on the air quality forecasting system, including the models used to create the forecasts, is provided in Annex 6.

2.2.4 Pollution 'episodes'

Prolonged periods of abnormally elevated outdoor air pollution are often referred to as 'episodes'. Pollution episodes vary depending on the source of the pollution and the atmospheric processes that also determine pollution concentrations. It should be noted that not all health-damaging pollution episodes are driven by poor atmospheric dispersion conditions created by still air. Some may result from unusually large emissions, perhaps following traffic accidents, forest and urban fires, or building works, meaning that they cannot be forecast. Examples of the types of episodes that can affect the UK are given in Annex 7.

2.2.5 Provision of information and alerts

Information on measurements and forecasts of air pollution levels, reported in terms of the four air pollution bands and the ten-point index, are presented through a range of media, including the UK Air Information Resource website (UK-AIR, http://uk-air.defra.gov.uk). There are separate forecasts for rural areas and for towns and for each region and large urban area. In addition, many local authorities make air quality data available on their websites. Air quality information is also available to the public on a freephone service (0800 556677).

[3] Data from the AURN can be found at http://uk-air.defra.gov.uk. Please note that not all these pollutants are measured at all sites.

A number of other methods for disseminating measurements and forecasts of air quality are used, such as text message alerts or smart phone applications. Some of these are targeted specifically at those most likely to be susceptible to the effects of short-term elevations in air pollutants.

2.3 Health basis for the current air quality index

The air quality index (AQI) was developed by the Committee on the Medical Effects of Air Pollutants (COMEAP) and is based on health evidence. The following text is a brief summary from the COMEAP statement on banding of air quality describing the health effects that occur at increasing levels of the pollutants (COMEAP, 1998a).

COMEAP assigned the Air Quality Standards set by the Expert Panel on Air Quality Standards (EPAQS) as the values for the Low bands of CO, SO_2, PM_{10} and NO_2 (EPAQS, 1994a, 1995a,b, 1996). For O_3, the Low band was based on the UK Air Quality Standard (EPAQS, 1994b). At these values it is unlikely that anyone, including susceptible people, will suffer any adverse effects of short-term exposure. These values include a margin of safety below the lowest levels at which significant effects on health have been described. The Moderate band represents concentrations of the pollutant at which there are likely to be small effects for susceptible people only. Values for the High bands are associated with significant effects in sensitive people. In the High band O_3 exposure may affect some individuals, causing eye irritation, coughing and discomfort on breathing deeply, particularly if exercising. With High SO_2 exposure people with asthma may suffer significant narrowing of the airways and may need to increase their inhaled reliever medication. After High NO_2 exposure those suffering from diseases of the heart and lungs may suffer a worsening of their symptoms.

For PM_{10} exposure, epidemiological studies have revealed that increased daily deaths, increased hospital admissions of patients suffering with heart and lung disorders, and worsening of asthma may occur. Health effects may occur even at low concentrations of particles and therefore an arbitrary index was devised. In the Very High band for PM_{10}, susceptible people, i.e. those suffering from diseases of the heart and lungs, may suffer a worsening of their symptoms.

Carbon monoxide is different from the other air pollutants in that concentrations of CO in the blood are related to concentrations in the air. Exposure to concentrations of CO in the Moderate and High bands may particularly affect those with angina and other heart diseases who may experience a more rapid onset of chest pain on exercise. The levels of CO in indoor air can sometimes greatly exceed outdoor levels when there is an indoor source such as a malfunctioning gas heating boiler. The consequent high CO levels can lead to serious health implications for those exposed.

Chapter 3
Review of the Air Quality Index: Considerations and Approaches Taken

In making our recommendations for a revised air quality index (AQI), we have considered new research and a number of relevant developments both in the regulation of air pollution (such as new EU Limit Values) and in the presentation of air quality information (for example, new air quality indices in different countries). We have also considered the scientific challenges in developing an AQI suitable for use in a public information dissemination system designed to convey information on short-term variations in air pollution.

3.1 Different approaches in developing air quality indices

Considerable work on the comparison of air pollution indices has already been carried out through a number of research projects funded by the European Union, in particular the CITEAIR project which produced the report *Comparing Urban Air Quality Across Borders* in June 2007 (van der Elshout and Leger, 2007). The CITEAIR report shows that there are significant differences between the various systems adopted in different countries. The authors note that the indices used in the USA and UK cover a wide range of concentrations and use high concentrations as the band breakpoints, as these are based on perceivable health effects. Most other indices reviewed by the project seem inspired by EU Limit Values and 'alert thresholds' (see Section 3.4).

Our view, now also supported by the public insight research undertaken to inform the review of the AQI (see Annex 3), is that **the AQI should reflect short-term variations in air quality in a way that can be meaningfully interpreted by individuals in terms of potential health effects**. Our review therefore focused on selecting an appropriate basis for a health-based index and consideration of the detailed evidence of short-term health effects caused by different air pollutants.

3.2 Pollutants for inclusion

The current AQI covers PM_{10}, O_3, SO_2, CO and NO_2. As part of the review, we considered which pollutants should be included in a revised index. In view of the dramatic reductions in outdoor concentrations of CO and SO_2 since the current index was introduced, we concluded that an index for CO in ambient air was no longer necessary. We decided to retain an index for SO_2 as levels exceeding the current Low pollution band are occasionally experienced at certain locations.

We also noted that European Directive 2008/50/EC makes provisions for the regulation of fine particulate matter ($PM_{2.5}$) which is responsible for significant negative impacts on human health (European Union, 2008; see also Table A5-2 in Annex 5). There is as yet no identifiable threshold below which $PM_{2.5}$ would not pose a risk. Therefore, we recommend the addition of $PM_{2.5}$ to the index.

3.3 Relationship with EU Limit Values

The current UK index is based on short-term health effects of various pollutants. The EU Limit Values (detailed in Annex 8) are also often health based, being largely derived from a World Health Organization evaluation published in 2006 (WHO, 2006). In some cases, the current index does not reflect the EU Limit Values. For example, the Limit Value for NO_2 is 200 $\mu g\ m^{-3}$ as an hourly average, whilst the Low banding for NO_2 is 0–286 $\mu g\ m^{-3}$. This means that the AQI could report Low NO_2 pollution even though the concentration exceeds the Limit Value.

Our view was that no revised Low air pollution band should exceed an Air Quality Objective or EU Limit Value. However, we could envisage a situation where our health-based recommendations for the breakpoints between the Low and Moderate pollution bands were lower (i.e. more stringent) than the regulatory limits.

3.4 Links to EU information/alert thresholds

European Directive 2008/50/EC specifies alert thresholds for SO_2 and NO_2 and both information and alert thresholds for O_3. An 'alert threshold' is defined in the Directive as a 'level beyond which there is a risk to human health from brief exposure for the population as a whole' (European Union, 2008). The alert thresholds (500 $\mu g\ m^{-3}$ for SO_2 and 400 $\mu g\ m^{-3}$ for NO_2, measured over three consecutive hours, and 240 $\mu g\ m^{-3}$ for O_3 based on a 1-hour average) are rarely breached in the UK. The 'information threshold' for O_3 (180 $\mu g\ m^{-3}$ as a 1-hour average) is defined as a 'level beyond which there is a risk to human health from brief exposure for particularly sensitive sections of the population'. When the information or alert thresholds are reached, information must be disseminated to the public by radio, television, newspapers or the internet.

The current UK AQI for O_3 is based on the higher of the 1-hour or running 8-hour average. The breakpoint between the Moderate and High bands (index levels 6 and 7) for O_3 is 180 $\mu g\ m^{-3}$, which is the same as the EU information threshold when the 1-hour average reaches the High band. The boundary between index levels 7 and 8, at 240 $\mu g\ m^{-3}$, is the same as the EU alert threshold. Thus, the provision of information as required by the European Directive can be linked to the reporting of air quality using the index. Although we noted the potential communication benefits of adopting these thresholds as divisions of the revised index, we considered it more important that the index should be reflective of risks to health.

The EU alert thresholds for SO_2 and NO_2 are not reflected in the current index. Monitoring data suggest that it is highly unlikely that the alert threshold for SO_2 would be reached in the UK, and that exceedance of the alert threshold for NO_2 over three consecutive hours is also likely to be a rare event. Therefore, we did not consider these alert thresholds to be important factors in the review of the AQI.

3.5 Averaging times and triggers

The averaging times specified in the current index (as for those incorporated in recommendations by EPAQS and WHO) differ from pollutant to pollutant. This reflects two aspects of the evidence on health effects: firstly, the timescale of exposure over which adverse health effects might be caused and, secondly, the averaging times used in the studies on which the assessment is based. Our review of the current health evidence did not suggest that the averaging times for the pollutants included in the index needed revision. The averaging times are summarised in Table 3-1.

Table 3-1: Averaging times for index pollutants as recommended by the Expert Panel on Air Quality Standards (EPAQS, 1994a,b, 1995a,b, 1996)

Pollutant	Averaging period	Rationale
Particulate matter, PM_{10}	24-hour mean	Evidence indicates that acute health effects occur after pollution episodes lasting at least 24 hours, therefore the averaging period should be 24 hours
Sulphur dioxide, SO_2	15-minute mean	Since the effects of sulphur dioxide may occur very rapidly, a short averaging period is desirable. Very short periods of 1 minute are impracticable, therefore a 15-minute averaging period is a sensible compromise between desirability and practicability
Ozone, O_3	Running 8-hour mean	A running 8-hour average most closely represents the exposures likely to be harmful to human health, as effects occur from exposure over several hours
Nitrogen dioxide, NO_2	1-hour mean	Since the effects on health in experimental studies on people with asthma were detectable within an hour of exposure commencing, an hourly averaging period is appropriate
Carbon monoxide, CO	Running 8-hour mean	An 8-hour standard provides the tightest control to keep blood carboxyhaemoglobin levels below 2.5% where health effects (including a safety margin) can be observed

For some pollutants, the averaging times are relatively long: 24 hours for particulate matter, and 8 hours for O_3. This can have implications for predicting elevated concentrations in an appropriate timescale. We considered two aspects of this in some detail: whether to specify particulate pollution levels in terms of a running or daily average, and whether 'triggers' could be used to give an early indication of a developing air pollution episode.

The use of a running, rather than daily, average allows fuller use of the available data and is more responsive to changes in pollution levels in identifying periods of elevated pollution. However, a running average might not identify a pollution episode sufficiently early to allow information to be communicated in a timely fashion, and so appropriate precautions to be taken. For example, if there was a peak in PM_{10} at 8 p.m. – feasible on Bonfire Night – the change in pollution band may not be reflected in a running 24-hour mean for several hours, by which time the highest levels (and the highest consequent risks to health) will have passed. Our view was that the approach to averaging times used in the index should be consistent with those for the Air Quality Objectives (i.e. a running 8-hour mean for O_3 and a daily 24-hour mean for particulate matter). This approach is also consistent with the reporting and forecasting of air pollution levels, which are usually on a day-by-day basis.

While PM_{10}, $PM_{2.5}$ and O_3 are measured hourly, the bandings relate to 24-hour (PM_{10} and $PM_{2.5}$) and 8-hour (O_3) averaging times, which implies a long delay between the onset of a pollution episode and the time that a banding can be assigned. Real-time measurement can provide detailed information on the magnitude and spatial extent of air pollution episodes, and can detect pollution episodes that have not been correctly forecast. With these averaging times, for O_3 it is not possible to give public information about an unexpected pollution episode until it is well established. Similarly, with the use of a 24-hour mean exposure for $PM_{2.5}$ and PM_{10}, an episode cannot be determined by measurement until the end of the day when a 24-hour mean can be calculated.

To maximise the utility of near real-time air pollution measurements a series of 'triggers' has been derived to provide information to the public as exposure is taking place. **'Trigger' concentrations are hourly pollution measurements that indicate a period of Moderate, High or Very High air pollution may be taking place or is likely to happen soon.** These triggers can be used by organisations that operate real-time public information services.

Following analysis of air pollution measurements the suggested trigger thresholds are shown in Table 3-2. The triggers are based on two consecutive hourly mean concentrations. The first hourly mean has to be greater than or equal to a threshold. To avoid false triggers from short-term measurement spikes, the trigger has to be confirmed by a second hourly mean. It is clearly desirable to be able to predict pollution exposure before the accumulated 8-hour or daily mean concentration indicates that Moderate, High or Very High air pollution has taken place. For this reason the triggers are biased towards increasing concentrations, i.e. the second hourly mean concentration is greater than or equal to the first. More details on triggers can be found in Annex 9.

Table 3-2: Suggested trigger thresholds based on two consecutive hourly mean concentrations, with the second one being greater than or equal to the first

Pollutant	Band	Trigger (μg m^{-3})
Particulate matter, PM_{10}	Moderate or above	67
	High or above	107
	Very High or above	176
Particulate matter, $PM_{2.5}$	Moderate or above	48
	High or above	74
	Very High or above	101
Ozone, O_3	Moderate or above	82
	High or above	168
	Very High or above	Not determined

3.6 Thresholds for effect

Recent research has shown that, at a population level, no thresholds of effect can be identified for the common air pollutants (Laden et al, 2006; Pope et al, 2002). This is likely to be due to variability between individuals of sensitivity to the pollutants studied. The implications of this finding for an AQI are that effects can be expected to occur in some individuals even at low concentrations and that, as concentrations rise from band to band, effects will increase. Setting the breakpoints between bands is therefore, to a large extent, an arbitrary process. This was appreciated by COMEAP when the original banding for PM_{10} was devised (COMEAP, 1998a).

At that time, it seemed possible that levels for O_3, NO_2, SO_2 and CO concentrations unlikely to be associated with effects on health could be identified, and these were used to identify the breakpoint between Low and Moderate concentrations. Epidemiological data suggest that this is no longer the case, at least for O_3, NO_2 and SO_2. For these pollutants, it is likely that each individual in the population might be characterised by an individual threshold. Furthermore, a wide range of individual thresholds can be identified in studies of human volunteers exposed to O_3 or SO_2. Some people – for example those with asthma – fall into a sensitive sub-population with regard to the effects of SO_2 on the airways.

Ambient concentrations of common air pollutants seldom approach zero and, therefore, statistical confidence in associations between exposure to very low concentrations and effects on health is limited. In statistical terms, the confidence limits of the regression lines widen at low (and at high) concentrations because the number of data points available in these regions tends to be low. This adds to the uncertainty about whether or not a threshold actually exists.

While we recognise the possibility that there is no threshold for the health effects of air pollutants, nonetheless we consider that an AQI can be developed that provides useful information on the possible effects on health at different pollution levels in the short term, and identifies individuals likely to be most susceptible.

3.7 Variations in response to air pollution

The health response to increases in outdoor air pollution varies between individuals and subgroups of the population. There are a number of terms to describe this variation; we shall use the term 'susceptibility' but the terms sensitivity and vulnerability and individuals at risk are also widely used to express the same concept. Individual susceptibility may affect the level at which health effects are noticed and the rate of increase in symptoms as air pollution concentrations increase. Some individuals appear to be more susceptible because of a genetic predisposition. In others, it is due to the presence of chronic respiratory or cardiovascular disease which is exacerbated by increases in air pollution. The response to air pollution may be modified by the presence of metabolic diseases, such as diabetes, and by the level of antioxidants in the diet. Certain subgroups of the population may be more susceptible for human biological reasons. It is generally accepted that in children the developing lung may be more susceptible to air pollution. Most evidence suggests that this is more likely in situations when concentrations are higher over the longer term. There is no evidence that short-term increases in air pollution have permanent effects on the developing lung. Another potentially susceptible group is at the other extreme of life. With increasing age, a combination of accumulating chronic disease – possibly unrecognised – and ageing of body systems, such as the lung, leads to the elderly having less capacity to deal with increases in air pollution that would not trouble younger people. Another reason for increased susceptibility is increased exposure to air pollution through activities associated with increased ventilation of the lungs, such as active work or sport outdoors; while this may be associated with health effects in susceptible individuals during episodes, it is unlikely that these would cause long-term health impairments. There is some evidence that more deprived social groups may show greater susceptibility; this is probably due to a combination of the factors above – higher levels of chronic disease, poorer diet and greater exposure.

In response to this we propose to amend the health advice relating to the bands of the index to include additional advice for susceptible individuals, together with advice for the general population.

3.8 Spatial and temporal variations in air pollution

Public advice on air quality is necessarily based on monitoring stations that best describe the average concentrations relating to a given population. Some pollutants have a regional distribution, while others are more influenced by local sources. Typically urban background monitors describe concentrations not affected directly by local sources such as busy roads. Clearly, while the air pollution concentrations informing air quality advice may be reasonably accurate overall, they are unlikely to be precisely those occurring at an individual address. The situation is further complicated by movement of people around their neighbourhood and city, spending time in areas with different levels of air pollution. Not all pollutants follow the same spatial distribution at ground level. Primary pollutants from traffic will be highest near busy roads, whereas ozone will tend to be lowest near roads and highest in rural areas. Some components of the particulate mixture are fairly uniformly spread over large regions. Similar variations occur over time. Pollution concentrations will vary over hours and days depending on the temporal pattern of sources (such as traffic) as well as meteorological factors that influence the dispersion of pollutants and atmospheric chemistry. Taken together, this temporal and spatial variation implies that the actual concentration experienced by individuals is likely to be more or less than that indicated by the air quality band.

We recognise that the index will provide only a general guide to the levels of air pollution that an individual will experience. Real-time and local air pollution monitoring information is available to the public from a range of sources through which individuals can remain informed of changes to air pollution in their environment[4].

3.9 Long-term and cumulative effects of air pollution

The AQI provides information that is intended for immediate use. It deals with the effects likely to be experienced on the day described by the index or, perhaps, on days soon afterwards. The index is not intended to provide information on the effects of long-term exposure to air pollutants; such information would be better provided by looking at long-term average concentrations.

Research has shown that variations in day-to-day concentrations of air pollutants can have delayed effects. Thus, a high concentration on a specific day could produce effects not only on

[4] Air quality information is available at http://uk-air.defra.gov.uk, on freephone 0800 556677, and other local information sources.

that day or in the following few days but also for a month or more afterwards (Zanobetti et al, 2003). It is also possible that exposure to peaks of concentrations would contribute to chance disease processes that might not become obvious as regards their effects for some years. Taking these delayed effects into account in an AQI designed to provide advice on effects 'today or tomorrow' is very difficult.

A further difficulty is posed by the cumulative effect of a run of days of higher-than-usual concentrations. It is possible, or perhaps likely, that exposure that accumulates over a series of days has a larger effect than similar exposure on days which include intervals of lower concentrations. This is also difficult to take into account in developing an AQI. In the index, days are treated as discrete events and not as a cumulative series. It would be confusing, for example, if the index ascribed to a day when the PM_{10} value was (or was predicted to be) between 50 and 100 µg m^{-3} varied depending on the concentration on the previous day or previous few days. It would also be fair to say that our knowledge of how to make the appropriate adjustments to the index to account or allow for preceding days is limited.

We recognise these difficulties, but consider that there are no methods at present that can be used to address long-term and cumulative effects in developing an AQI. In addition, it seems that to do so would be an over-complication of what is intended to be a straightforward and easily understood system.

3.10 Mixtures of pollutants

The current method for assigning an overall air quality index is to take the highest pollutant index. For example, if the forecast or measurement for O_3 is Moderate and for particulate matter it is Low, the overall index assigned will be Moderate. There is no provision within the index to take into account the possible effects of a mixture of pollutants. Thus, for example, if O_3 is Moderate (level 4) and particulate matter is Moderate (4), then the overall index assigned is Moderate (4) – the index is not increased to allow for the potential additive or interactive effects of pollutants.

Concerns about the interactive effects of pollutants are often expressed. The phrase 'toxic cocktail effect' is sometimes used, the implication being that exposure to a number of pollutants has a greater effect than would be expected if the responses to the individual pollutants were simply summed. Whilst possible, there is little evidence for such synergistic effects of air pollutants. The Advisory Group on the Medical Aspects of Air Pollution Episodes, in its report *Health Effects of Exposures to Mixtures of Air Pollutants* (MAAPE, 1995), noted that synergy had been seen in some studies of mixtures of air pollutants administered at high doses to experimental animals, but did not regard these studies as helpful in interpreting likely effects in humans at ambient concentrations. The Group also noted that, in chamber studies involving sequential exposure to air pollutants, any observed increased response to the second pollutant was small and that there was no clear evidence of synergism. In addition, there was no evidence from studies of concurrent exposures to mixtures for effects greater than that expected from summation of the responses to individual gases.

It might be thought that epidemiological studies of the effects of the mixtures of air pollutants that occur in ambient air would shed light on this problem. However, the analytical methods used tend to focus on one pollutant (single pollutant models) and, when several pollutants are included in the analysis (multi-pollutant models), interactions have proved difficult to disentangle. This is because pollutants are often closely correlated, including during episodes of elevated pollution. During winter, pollution episodes in urban areas, elevated NO_2 and particulate matter levels may become closely correlated, with the depletion of O_3 by reaction with NO. During summer, particulate matter and O_3 may become positively correlated during pollution episodes because of long-range transport from continental Europe and elsewhere. Such correlations may confound epidemiological studies relating human health impacts to daily levels of NO_2, O_3 or particulate matter, and make the results of multi-pollutant models difficult to interpret. Nonetheless, there is a small amount of evidence for effect modification of PM_{10} by city levels of O_3.

The correlation between pollutants during episodes makes the question of how the health effects from more than one pollutant should be represented within the index very relevant. Nonetheless, it is our view that multi-pollutant models are not sufficiently informative to enable a weighting of pollutants in an index using multiple pollutants. **Since there have been no major developments in the understanding of the effects of mixtures of air pollutants we propose that the current methodology for assigning an overall AQI is retained.**

3.11 Information requirements from the public

In order to inform the review of the AQI, research was undertaken by the University of Brighton, on behalf of Defra, to investigate the general public's current awareness and comprehension of air quality information, and to assess the challenges that exist to understanding and interpreting such material. Key themes investigated included people's current environmental and air quality awareness, perceived indicators of air quality and health effects, their current understanding and awareness of air quality indicators, and their needs and requirements for the provision of air quality information. The public insight research is detailed in Annex 3.

We found the public insight research very helpful in steering our discussion on some aspects of the revised index. In particular, the stated requirements relating to the health advice and preferences relating to the presentation of the information were central to some of our decisions.

The public insight survey did not identify a clear preference for the number of 'bands' or 'points on a scale' within an AQI. However, data obtained from the focus groups indicated that there was a need for a scale that allowed greater gradation in the AQI than provided by the bands alone, as the variation in the level of air quality was felt to be lost by compressing the data into a smaller (one to four) scale. Therefore we decided to retain a ten-point index incorporated within four pollution bands. Further detail of how we included the recommendations of this work in the review can be found in Chapter 6 on presentation of the index.

3.12 Approaches to deriving health-based pollution bands

We considered several possible approaches to assessing and evaluating the pollutant-specific evidence on health impacts that could be used in a revision of the AQI. These included an approach based on effects (e.g. mortality) reported in time-series studies, and an alternative approach based on effects seen in chamber studies of human volunteers.

Time-series studies are epidemiological studies which relate observed health effects at the population level to daily changes in levels of air pollutants. A large number of such studies has been published [e.g. Dominici et al (2006), Liang et al (2009), Rosenlund et al (2006), Stieb (2009) and Strickland et al (2010)]. Expert groups (e.g. COMEAP, 1998b) have used time-series studies as the basis for recommendations for coefficients that can be used to calculate the short-term health impacts likely to result from different levels of air pollutants. One possible approach would be to base the index on the increases in serious effects (hospital admissions or deaths) which time-series studies investigate. Pollution bands could be defined in terms of a percentage change on health endpoints (e.g. 2.5% or 5%) and the concentrations of each pollutant associated with those levels of effect calculated using published coefficients. This approach is based on the assumption that there is no threshold for an effect and that there is a linear relationship between concentrations and effects. In implementing such a scheme, the choice of percentage change in outcome used as the basis of the band breakpoints would be essentially arbitrary, or based on socioeconomic considerations of 'acceptable' or 'tolerable' risk at the population level.

An alternative approach might be to base the index on the effects observed in studies of human volunteers exposed to single pollutants in chamber studies. Some aspects of these studies make them seem to provide a more suitable evidence base than time-series studies for an AQI reporting short-term variations in air pollution: chamber study work relates to more minor effects that are more common in the population; the effects observed can be more confidently linked to individual pollutants; and the smaller sample sizes involved mean that the effects identified are those with a higher level of risk (even if the effects themselves are less serious). In contrast to an index based on the results of time-series studies, which could be characterised as being based on catastrophic events (death) with a low risk, this approach would be based on less serious effects (which are nonetheless undesirable) that are more likely to be reversible with individual actions and carry a higher probability of occurrence.

We considered that both approaches have some merits but also present difficulties. For example, coefficients for different health endpoints are available for different pollutants, making comparison difficult, and COMEAP (1998b) did not consider the time-series evidence for the health effects of some pollutants sufficiently convincing to suggest that they should be included in central estimates of health impacts of short-term exposures. On the other hand, an approach which took no account of the time-series evidence would not be making the best use of all the available data.

Instead, our view was that the review of the health-based AQI requires a comprehensive evaluation of the various lines of evidence, experimental and epidemiological, concerning air pollution and health effects. Fortunately, such a review was undertaken by a WHO Expert Group as a basis for setting air quality guidelines (AQG) to assist national authorities in formulating their national air quality strategies, air quality standards and health advice (WHO, 2006). The WHO review overlapped considerably with the Clean Air for Europe (CAFE) Directive review for the European Union's air quality strategy (WHO, 2004). The WHO review was carried out by a Working Group comprising, together with external reviewers, nearly 90 experts from all over the world. Background reviews were prepared observing best current practice for systematic reviews. Draft chapters prepared by the Working Group were reviewed by the external experts.

The drafting of the WHO Air Quality Guidelines confronted two important issues. One was that current evidence indicated that there was no clear threshold for health effects in the ambient range, while the demand from potential users of the AQG was for a stated concentration. The other was that those regions with very high concentrations required a guideline level that was attainable in the shorter term. This led to the concept of 'interim targets' – values which were proposed as incremental steps in a progressive reduction of air pollution. The process of setting the AQG and interim targets required each to be justified in health risk terms but could not be formulaic because each pollutant has a different pattern of scientific evidence to be interpreted. In some cases, the human experimental evidence (chamber studies) was pivotal, whereas in others epidemiological studies provided the information base. As well as long-term (often annual) AQG and interim targets, recommendations were made for AQG and interim targets as short-term averages. It was not intended that the interim targets would form a basis for a banding scheme but, since these targets were based on health considerations, our opinion was that they were an appropriate and solid basis for developing bandings for a UK air quality index.

Thus, **when reviewing the pollutant-specific bandings, we used the WHO Air Quality Guidelines and interim targets as our starting point.** However, we also took other evaluations and additional data and considerations into account in our deliberations. In most cases, we adopted the WHO values as proposed breakpoints between the bands. In some, our proposals do not adopt the WHO recommendations directly, for reasons we explain in Chapter 4.

Chapter 4
Recommendations for a Revised Air Quality Index

4.1 Pollutant-specific recommendations for revised bands

This chapter presents our detailed recommendations for revised air pollution bands[5] for particulate matter, sulphur dioxide, nitrogen dioxide and ozone. As explained above, our starting points for these recommendations were the thorough reviews of the evidence of the health effects of air pollutants by WHO (2006), although we also took other evaluations, and additional data and considerations, into account.

4.1.1 Proposed bandings for particulate matter, PM_{10} and $PM_{2.5}$

Derivation of WHO short-term guidelines and interim targets

Studies of the effects of particulate matter (PM) on health have used a variety of different metrics including PM_{10}, $PM_{2.5}$, black smoke (BS) and total suspended particulates (TSP). Much of the epidemiological evidence on the effects of particulate matter comes from studies in which PM_{10} was measured. However, the key studies of the effects of long-term exposure to particulates report concentrations in terms of $PM_{2.5}$ and these were used by WHO as the basis for the derivation of air quality guidelines (AQG).

The long-term (annual average) guideline of 10 $\mu g\ m^{-3}$ $PM_{2.5}$ was set at a concentration considered to be below the most likely effects levels. Data from the American Cancer Society (ACS) cohort study (Pope et al, 2002) and the Harvard Six Cities study (Laden et al, 2006) were important in this derivation. The guideline represents the lower end of the range at which significant (more than 95% confidence) effects on survival (total, cardiopulmonary and lung cancer mortality) were observed in the ACS study. It was supported by data from the Six Cities study suggesting that effects were likely in the range 11–15 $\mu g\ m^{-3}$. Nonetheless, WHO noted that there is little evidence for a threshold of effect and that adverse effects on health cannot be ruled out even below this level.

Annual average interim targets were derived based on concentrations at which effects were seen in studies of long-term exposure. The increased risk of mortality at these concentrations, compared with the risks at the guideline concentration, was calculated. The mortality risk at the interim target 3 (IT-3) level (15 $\mu g\ m^{-3}$ $PM_{2.5}$) was estimated as being 3% higher than at the guideline value. Guidelines and interim targets for PM_{10} were derived using the relationship between $PM_{2.5}$ and PM_{10} (approximated as a ratio of 0.5, typical of urban areas in developing countries) to give an annual average guideline of 20 $\mu g\ m^{-3}$ PM_{10} and an IT-3 of 30 $\mu g\ m^{-3}$ PM_{10}.

[5] Reference material for each pollutant is given in the bibliography (Chapter 9).

The primary goal underpinning the derivation of the WHO short-term guidelines was the control of long-term averages to ensure that the annual average guidelines would be met. The relationship between annual and 24-hour average concentrations of particulate matter was used to extrapolate the annual guidelines to short-term (24-hour mean) guidelines of 50 μg m^{-3} PM_{10} and 25 μg m^{-3} $PM_{2.5}$. WHO noted that, where these short-term guidelines are met, peaks of pollution that would lead to substantial excess illness or deaths are unlikely to occur.

As for the short-term guideline, the short-term IT-3 (75 μg m^{-3} PM_{10}, 37.5 μg m^{-3} $PM_{2.5}$ as a 24-hour mean) was primarily designed to manage long-term average concentrations and was derived from the long-term IT-3 value. An effects coefficient of 0.5% per 10 μg m^{-3} PM_{10} (based on relative risks seen in multi-city time-series studies in the USA and Europe, and meta-analyses[6] of studies from cities elsewhere) was used to calculate the increased risk of short-term mortality associated with the 24-hour mean IT values, compared with the risk at the guideline. The increased short-term mortality risk at the IT-3 level was estimated to be about 1.2% (WHO, 2006). The interim target 1 (IT-1) of 150 μg m^{-3} PM_{10} as a 24-hour mean was set at a concentration estimated to cause about a 5% increase in short-term mortality compared with the AQG. The IT-2 (100 μg m^{-3} PM_{10}) represents an approximately 2.5% increased risk. The 24-hour average IT-1 (75 μg m^{-3}) and IT-2 (50 μg m^{-3}) for $PM_{2.5}$ were derived using the $PM_{2.5}$: PM_{10} relationship of 0.5.

WHO air quality guidelines and interim targets for particulate matter: 24-hour mean (taken from WHO, 2006)

	24-hour mean (μg m^{-3}) *		
	PM_{10}	**$PM_{2.5}$**	**Basis for the selected level**
WHO IT-1	150	75	Published risk coefficients from multicentre studies and meta-analyses (about 5% increase in short-term mortality over the WHO AQG)
WHO IT-2	100	50	Published risk coefficients from multicentre studies and meta-analyses (about 2.5% increase in short-term mortality over the AQG)
WHO IT-3 †	75	37.5	About 1.2% increase in short-term mortality over the AQG
WHO AQG	50	25	Relationship between 24-hour and annual particulate matter levels

* 99th percentile (three days per year)

† For management purposes, based on annual average guideline values, the precise number to be determined on the basis of local frequency distribution of daily means

Recommendations for UK pollution bandings

We regard the effects of particulate matter following short-term exposures to be the most relevant to the proposed use of the air pollution banding system and, therefore, consider the effects of PM_{10} examined in daily time-series studies as the most appropriate evidence base for the bands. We note that the 24-hour mean AQG recommended by WHO for PM_{10} (50 μg m^{-3}) is the same as the Air Quality Standard recommended by the predecessor of

[6] Meta-analysis is a statistical technique for combining the findings from independent studies.

the COMEAP Standards Advisory Subgroup, the Expert Panel on Air Quality Standards (EPAQS, 1995a)[7]. EPAQS considered that this was a concentration at which effects on individuals following short-term exposures are likely to be small (a rise from 20 µg m^{-3} – an approximate annual average in the UK – to 50 µg m^{-3} was calculated as likely to result in one extra patient per day in a population of one million being admitted to hospital with respiratory effects).

We therefore recommend 50 µg m^{-3} as the boundary between the Low and Moderate air pollution bands. We propose 75 µg m^{-3} and 100 µg m^{-3} (the same as the WHO 24-hour mean IT-3 and IT-2 levels) as the boundaries between the Moderate and High, and High and Very High, bands. While these boundaries are, to a certain extent, arbitrary, using current estimates, they are approximately equivalent to 1.25% and 2.5% increases, respectively, in short-term mortality compared with 50 µg m^{-3}.

WHO noted that, although it is believed that much of the health impact of particulate matter is due to fine particulates ($PM_{2.5}$), coarse particulates ($PM_{2.5\text{-}10}$) cannot be considered as harmless and that this indicates a need for guidelines and targets for both $PM_{2.5}$ and PM_{10}. For the same reason, we consider that the AQI should include both $PM_{2.5}$ and PM_{10}. Like WHO, we recognise that it is possible to use the proportion of PM_{10} that is typically present as $PM_{2.5}$ (i.e. the ratio of $PM_{2.5}$: PM_{10}) to extrapolate guidelines/targets from one particulate matter metric to the other. However, the mean $PM_{2.5}$: PM_{10} ratio in the UK is close to 0.7 [8], which is somewhat different from the 0.5 'global' figure used by WHO. As WHO suggested that it may be appropriate to change the ratio used based on local data, breakpoints between bands of 35 µg m^{-3}, 52.5 µg m^{-3} (rounded to 53 µg m^{-3}) and 70 µg m^{-3} $PM_{2.5}$ are recommended, derived from the PM_{10} values using a factor of 0.7.

In considering the suitability of a ratio of 0.7 for this extrapolation in the context of an AQI reflecting risk during short-term elevations, we examined data from episodes of elevated particulate matter in London. The $PM_{2.5}$: PM_{10} ratio varied considerably, depending upon whether the episode was primarily due to $PM_{2.5}$ (episodes driven either by long-range transport or by poor dispersion of locally generated particulate matter) or PM_{10} (coarse particle episodes). These data confirmed the need for a PM_{10} index to ensure an appropriate indication of the level of risk during coarse particle episodes. They also indicated that the derived $PM_{2.5}$ breakpoints would be precautionary during episodes driven by $PM_{2.5}$.

Recommended bandings for particulate matter: 24-hour mean

Pollutant	Averaging period	Units	Low	Moderate	High	Very High
PM_{10}	24-hour mean	µg m^{-3}	0–50	51–75	76–100	101 or more
$PM_{2.5}$	24-hour mean	µg m^{-3}	0–35	36–53	54–70	71 or more

[7] Compliance with the standard recommended by the EPAQS was measured using a slightly different approach from that proposed for the particulate matter bands: different monitoring equipment was used and the standard was a rolling 24-hour mean rather than the fixed 24-hour mean of the proposed bands. Nonetheless, we considered the EPAQS recommendation offers support for adoption of the WHO AQG as the boundary between the Low and Moderate bands in the proposed banding system. Overall, the proposed boundary between the Low and Moderate bands is slightly more stringent than the EPAQS standard.

[8] Figures calculated using 2009 data available from $PM_{2.5}$ and PM_{10} measurements within the AURN with at least 75% data capture for both pollutants.

Comparison with UK Air Quality Objectives and EU Limit Values

There are no short-term EU Limit Values or UK Air Quality Objectives for $PM_{2.5}$. The short-term EU Limit Value and UK Air Quality Objective for PM_{10} are the same: a 24-hour mean of 50 µg m^{-3}, not to be exceeded more than 35 times a year.

4.1.2 Proposed bandings for sulphur dioxide, SO_2

Derivation of WHO short-term guidelines and interim targets

WHO based the derivation of its short-term air quality guideline for SO_2 on controlled studies of individuals with asthma exercising. These suggested that some individuals experienced symptoms after exposure times as short as 10 minutes and WHO therefore proposed the short-term AQG as a 10-minute average. A value of 500 µg m^{-3} was proposed, being lower than the concentration (572 µg m^{-3}) at which small changes in lung function, not regarded as being of clinical significance, were observed after exposure for 15 minutes in a key study. Nonetheless, WHO noted that two sensitive subjects had experienced changes in airway resistance at 286 µg m^{-3} in an early study (WHO, 2006).

Effects following longer-term exposures (24-hour and chronic) were also considered. WHO noted that evidence from time-series studies suggests an association between daily concentrations of SO_2, and both hospital admissions and daily mortality. Associations have also been found between long-term concentrations and mortality. Nonetheless, WHO considered there to be considerable uncertainty as to whether SO_2 is directly responsible for the observed effects, or a surrogate for an active component of the pollution mixture. WHO chose to adopt what was described as a prudent, precautionary approach in recommending a 24-hour average AQG of 20 µg m^{-3}. This balanced the uncertainty of SO_2 as the causal agent in the epidemiological studies against a perceived need to provide greater levels of protection than that provided by the previous WHO guideline (WHO, 2000). As it was recognised that some countries may find the guideline difficult to achieve in the short term, WHO suggested a stepped approach to compliance using interim targets of 50 µg m^{-3} (IT-2) and 125 µg m^{-3} (IT-1, the same concentrations as the previous guideline value).

WHO considered that an annual guideline was not needed, since compliance with the 24-hour guideline would assure low annual average concentrations.

WHO air quality guidelines and interim targets for SO_2: 10-minute and 24-hour means (taken from WHO, 2006)

	SO_2 (µg m^{-3})		
	10-minute mean	**24-hour mean**	
WHO IT-1	–	125	–
WHO IT-2	–	50	Intermediate goal based on controlling either: (a) motor vehicles, (b) industrial emissions, and/or (c) power production; this would be a reasonable and feasible goal to be achieved within a few years for some developing countries and lead to significant health improvements that would justify further improvements (such as aiming for the guideline)
WHO AQG	500	20	–

Recommendations for revised UK pollution bandings

As well as the recommendations of WHO, we considered an evaluation of the effects of SO_2 by the predecessor of the COMEAP Standards Advisory Subgroup, the Expert Panel on Air Quality Standards (EPAQS, 1995b). Like WHO, EPAQS took the view that the majority of people with asthma would not suffer clinically significant effects at ambient concentrations of SO_2 below 200 ppb (parts per billion) (equivalent to 532 $\mu g\ m^{-3}$). Nonetheless, EPAQS recommended a lower standard of 100 ppb (266 $\mu g\ m^{-3}$) averaged over 15 minutes. This recommendation took into account the fact that measurements averaged over 15 minutes would include brief periods of higher concentrations, perhaps as high as double the average. Thus, if the 15-minute average was 200 ppb, there may be periods of higher exposure within those 15 minutes which might affect susceptible individuals. EPAQS also noted the need to ensure an adequate margin of safety for individuals with more severe asthma.

We considered the standard recommended by EPAQS as more appropriate for adoption as the breakpoint between the Low and Moderate bands than the WHO AQG.

We also considered whether an index based on 24-hour average concentrations of SO_2 was desirable. Our deliberations included a review of historical SO_2 concentrations (averaged over both 15 minutes and 24 hours) from the AURN. Our attention focused on exceedances of the current Low to Moderate band breakpoint (15-minute averages) or of a concentration which would equate to the same mortality risk as that posed by particulate matter at the breakpoint between the Low and Moderate bands for particulate matter (24-hour averages). Our conclusion was that an AQI based on 15-minute averages was appropriate and sufficient. Thus, we saw no need to recommend changes to the existing bandings for SO_2.

Recommended bandings for SO_2: 15-minute mean

Pollutant	Averaging period	Units	Low	Moderate	High	Very High
SO_2	15-minute mean	$\mu g\ m^{-3}$	0–265	266–531	532–1063	1064 or more

Comparison with UK Air Quality Objectives and EU Limit Values

The EU Limit Values for SO_2 are 350 $\mu g\ m^{-3}$ as a 1-hour mean, not to be exceeded more than 24 times a year and 125 $\mu g\ m^{-3}$ as a 24-hour mean, not to be exceeded more than three times a year. As well as these two values, the UK has an Air Quality Objective of 266 $\mu g\ m^{-3}$ as a 15-minute mean, not to be exceeded more than 35 times a year. Thus, our recommendation for the breakpoint between the revised Low and Moderate pollution bands is the same as the UK Air Quality Objective.

EU member states are required to provide information to the public if the alert threshold of 500 $\mu g\ m^{-3}$ is exceeded for three consecutive hours. The EU alert threshold for SO_2 is not reflected in the current index or in our recommendations for a revised index. The alert threshold for SO_2 relates to the concentration averaged over a different time period (three consecutive hourly averages) to the index for SO_2 (15 minutes), making it difficult to compare with the index. Monitoring data from the AURN show that measured hourly averages of SO_2 in the UK did not approach 500 $\mu g\ m^{-3}$ between 2005 and 2008 – in fact, none exceeded the Air Quality Objective of 350 $\mu g\ m^{-3}$ as a 1-hour mean. Thus, it is extremely unlikely that the alert threshold for SO_2 will be reached and we did not consider it relevant to the review of the AQI.

4.1.3 Proposed bandings for nitrogen dioxide, NO_2

Derivation of WHO short-term guidelines

In 2000, WHO recommended a short-term guideline for NO_2 of 200 μg m^{-3} as an hourly average (WHO, 2000). This was based on experimental studies of people with asthma and patients with chronic obstructive pulmonary disease (COPD), who are more susceptible than healthy individuals to the acute effects of NO_2 on the lungs. WHO considered 200–300 ppb (375–565 μg m^{-3}) to be a lowest observed level for effects in such studies. In deriving a guideline, a 50% margin of safety on this value was proposed in the light of a meta-analysis suggesting changes in airway responsiveness (an increase in response to bronchoconstrictors in the presence of NO_2) at concentrations below 365 μg m^{-3} and one study showing increased airway responsiveness at 100 ppb (190 μg m^{-3}), although the statistical significance of the response at this concentration was questioned.

The WHO Working Group that reconsidered the guidelines for NO_2 (WHO, 2006) concluded that the scientific literature had not accumulated sufficient evidence that necessitated a change from the 2000 guidelines. It reiterated the summary that short-term experimental human toxicology studies show acute health effects at levels higher than 500 μg m^{-3} and that one meta-analysis has indicated effects at levels exceeding 200 μg m^{-3}.

WHO also noted associations of NO_2 with hospital admissions for respiratory and cardiovascular symptoms in time-series studies, but did not attempt to use these to recommend a guideline based on 24-hour concentrations. When developing an annual average guideline, WHO observed that epidemiological evidence had emerged that increased the concern about the health effects of outdoor air pollution mixtures that include NO_2. It also noted that NO_2 is a marker for complex mixtures of traffic-related pollutants. However, whilst commenting that NO_2 might have direct toxic effects at low concentrations, WHO recognised that it was difficult to disaggregate the effects of NO_2 from those of other, coincidentally occurring, pollutants in epidemiological studies.

WHO air quality guideline for NO_2: 1-hour mean (taken from WHO, 2006)

	NO_2 (μg m^{-3}) 1-hour mean
WHO AQG	200

Recommendations for revised UK pollution bandings

We recommend the adoption of the WHO AQG of 200 μg m^{-3} as the basis for the boundary between the revised Low and Moderate bands for NO_2. Levels below this value are considered unlikely to elicit significant short-term health effects. Boundaries between the other bands of 400 and 600 μg m^{-3} are recommended.

Recommended revised bandings for NO_2: 1-hour mean

Pollutant	Averaging period	Units	Low	Moderate	High	Very High
NO_2	1-hour mean	μg m^{-3}	0–200	201–400	401–600	601 or more

Comparison with UK Air Quality Objectives and EU Limit Values

The short-term EU Limit Value, and UK Air Quality Objective, for NO_2 is 200 µg m^{-3} as a 1-hour mean, not to be exceeded more than 18 times a year. This is the same as our recommendation for the breakpoint between the Low and Moderate air pollution bands.

EU member states are required to provide information to the public if the alert threshold of 400 µg m^{-3} is exceeded. Monitoring data from the AURN suggest that an occurrence of concentrations exceeding the alert threshold over three consecutive hours is likely to be a rare event. Therefore, we did not consider that consistency with the alert threshold should be a major factor in developing our proposals for an index for NO_2. Nonetheless, the breakpoint between the Moderate and High bands in our proposed index for NO_2 is 400 µg m^{-3} as a 1-hour average; this will facilitate the identification of any occurrence of concentrations exceeding the alert threshold for three consecutive hours.

4.1.4 Proposed bandings for ozone, O_3

Derivation of WHO short-term guidelines and interim targets

In its 2000 review, WHO recommended an air quality guideline (AQG) for O_3 of 120 µg m^{-3} as an 8-hour average (WHO, 2000). This was described as a level at which acute effects on public health were likely to be small, although WHO noted that some effects would be expected in some members of the population at this level.

By the time of the next WHO review (WHO, 2006) there was a substantial amount of new epidemiological evidence from time-series studies. This revealed small, but significant associations between health effects (mortality) and daily O_3 levels at concentrations lower than the previous guideline value. WHO considered that these data, together with evidence from chamber and field studies indicating that there is considerable variation between individuals in their response to O_3, suggested a need to reduce the guideline from 120 µg m^{-3}. A guideline of 100 µg m^{-3} for a daily maximum 8-hour mean was recommended, although WHO noted that it was possible that health effects would occur below this level in some sensitive individuals.

WHO used extrapolation from chamber and field studies (taking into account that real-life exposure tends to be repetitive, and that chamber studies tend not to study highly sensitive or clinically compromised people or children) when deriving the guideline, and bore in mind the likelihood that O_3 is a marker for related oxidants. WHO estimated a 1–2% increase in daily mortality at this concentration, based on findings of daily time-series studies. This estimate was calculated as deaths attributable to O_3 concentrations above an estimated baseline of 70 µg m^{-3}, using a coefficient of 0.3–0.5% increase in daily mortality per 10 µg m^{-3} 8-hour O_3.

WHO recommended an interim target 1 (IT-1) level of 160 µg m^{-3}. This was based on measurable, but transient, effects on the lung in healthy young adults during intermittent, vigorous exercise in controlled chamber studies. WHO noted that, although these responses might not necessarily be adverse and occurred only during vigorous exercise, there may be substantial numbers of people in the general population who might be more susceptible to the effects of O_3 than the subjects of these studies. An increase of 3–5% in deaths brought forward daily, attributable to exposure to concentration of 160 µg m^{-3}, was calculated for daily exposures above the estimated background of 70 µg m^{-3}.

Important health effects were considered likely at concentrations exceeding 240 μg m^{-3}, which WHO regarded as a high level. Daily exposures to 240 μg m^{-3} were estimated to be associated with a 5–9% increase in attributable deaths brought forward above the estimated background. Both people with asthma and healthy adults would be expected to suffer symptoms at these concentrations. WHO had additional concerns about increased morbidity in children.

WHO air quality guidelines and interim targets for O_3: daily maximum 8-hour mean (taken from WHO, 2006)

	O_3 (μg m^{-3}) daily maximum 8-hour mean	**Effects of O_3 at the selected level**
High level	240	Significant health effects; substantial proportion of the vulnerable population affected
WHO IT-1	160	Important health effects; an intermediate target for populations with O_3 concentrations above this level. Does not provide adequate protection of public health *Rationale* • Lower level of 6.6-hour chamber exposures of healthy exercising young adults, which show physiological and inflammatory lung effects • Ambient level at various summer camp studies showing effects on health of children • Estimated 3–5% increase in daily mortality* (based on findings of daily time-series studies)
WHO AQG	100	This concentration will provide adequate protection of public health, although some health effects may occur below this level *Rationale* • Estimated 1–2% increase in daily mortality* (based on findings of daily time-series studies) • Extrapolation from chamber studies and field studies based on the likelihood that real-life exposure tends to be repetitive and chamber studies do not study highly sensitive or clinically compromised people or children • Likelihood that ambient O_3 is a marker for related oxidants

* Deaths attributable to O_3 concentrations above an estimated baseline of 70 μg m^{-3} (based on an 0.3–0.5% increase in daily mortality for 10 μg m^{-3} 8-hour O_3)

Recommendations for revised UK pollution bandings

WHO noted that small, but significant effects may be expected in sensitive individuals within the population at its recommended guideline of 100 μg m^{-3}. Because of this, we consider that the boundary between the Low and Moderate bands should be set at a lower level. A value of 80 μg m^{-3} is proposed. We recognise that this value is close to the hemispheric background level, meaning that concentrations within the Moderate band may occur due to O_3 reaching the UK after having been formed elsewhere.

We recommend the adoption of the WHO IT-1 level of 160 μg m^{-3} (at which important health effects may occur) as the boundary between the Moderate and High bands and the

WHO 'high level' of 240 µg m^{-3} (at which a substantial proportion of the vulnerable population may be affected) as the boundary between the High and Very High bands.

Recommended revised bandings for O_3: 8-hour running mean

Pollutant	Averaging period	Units	Low	Moderate	High	Very High
O_3	8-hour mean	µg m^{-3}	0–80	81–160	161–240	241 or more

Comparison with UK Air Quality Objectives and EU target values

The EU requires its member states to aim to reach a target value of 120 µg m^{-3} O_3 as an 8-hour maximum daily mean, not to be exceeded more than 25 times a year averaged over three years. The UK Air Quality Objective is an 8-hour running mean of 100 µg m^{-3}, not to be exceeded more than ten times a year. The revised breakpoint between the Low and Moderate bands is lower than both of these.

EU member states are required to provide information to the public if either the information threshold (180 µg m^{-3} averaged over an hour) or the alert threshold (240 µg m^{-3} averaged over an hour) for O_3 is exceeded. Because of the different averaging times, this is not directly comparable to any of the values in the revised air quality index.

4.1.5 Summary of recommendations

In summary, we recommend the following bandings for the air quality index.

Pollutant	Averaging period	Unit	Low	Moderate	High	Very High
Particulate matter, PM_{10}	24-hour mean	µg m^{-3}	0–50	51–75	76–100	101 or more
Particulate matter, $PM_{2.5}$	24-hour mean	µg m^{-3}	0–35	36–53	54–70	71 or more
Sulphur dioxide, SO_2	15-minute mean	µg m^{-3}	0–265	266–531	532–1063	1064 or more
Ozone, O_3	Running 8-hour mean	µg m^{-3}	0–80	81–160	161–240	241 or more
Nitrogen dioxide, NO_2	1-hour mean	µg m^{-3}	0–200	201–400	401–600	601 or more
Carbon monoxide, CO	Recommend removal from the index					

We also recommend that these bands be further subdivided into a ten-point air pollution index. These recommendations are included in Table 4-1 and are compared with the current index in Annex 10.

Table 4-1: Proposed air quality index

Band	Index	Ozone Running 8-hour mean ($\mu g\ m^{-3}$)	Nitrogen dioxide 1-hour mean ($\mu g\ m^{-3}$)	Sulphur dioxide 15-minute mean ($\mu g\ m^{-3}$)	$PM_{2.5}$ particles 24-hour mean ($\mu g\ m^{-3}$)	PM_{10} particles 24-hour mean ($\mu g\ m^{-3}$)
Low	1	0–26	0–66	0–88	0–11	0–16
	2	27–53	67–133	89–176	12–23	17–33
	3	54–80	134–200	177–265	24–35	34–50
Moderate	4	81–107	201–267	266–354	36–41	51–58
	5	108–134	268–334	355–442	42–46	59–66
	6	135–160	335–400	443–531	47–53	67–75
High	7	161–187	401–467	532–708	54–58	76–83
	8	188–213	468–534	709–886	59–64	84–91
	9	214–240	535–600	887–1063	65–70	92–100
Very High	10	241 or more	601 or more	1064 or more	71 or more	101 or more

4.2 Implications of changes

The implications of the proposed new bandings for the presentation of air quality information in the UK have been investigated by examining how many days would have been assigned to each band if the proposed bandings had been in place during 2008. Measurements from automated monitoring sites were examined at a range of roadside, urban background and rural locations. The proportion of days in each index category for the proposed new bandings is shown in Figure 4-1 for selected monitoring sites and discussed below. The sites have been chosen to illustrate the contrast between the values of the index at monitoring sites with higher and lower concentrations for different pollutants.

4.2.1 Particulate matter, PM_{10}

Using the proposed revised index, Moderate pollution is likely to be reported on more days at roadside and some industrial sites than at urban background or rural sites. There are also likely to be infrequent days where pollution is reported as Very High at some sites. There are likely to be more days reported when air pollution is reported as Moderate, rather than Low, with the current index.

4.2.2 Particulate matter, $PM_{2.5}$

The number of days within each band for $PM_{2.5}$ is likely to be similar to the number of days for PM_{10}. This is to be expected because the breakpoints for $PM_{2.5}$ have been derived from those set for PM_{10}. There is, however, likely to be some variation because the proportion of PM_{10} that is $PM_{2.5}$ varies from place to place and over time, depending on the composition of the particulate matter.

4.2.3 Sulphur dioxide, SO_2

There is no proposed change to the bandings for SO_2. Days with concentrations in the Moderate or higher bands are likely to remain infrequent. These infrequent events are most likely to be associated with either industrial or domestic heating emissions.

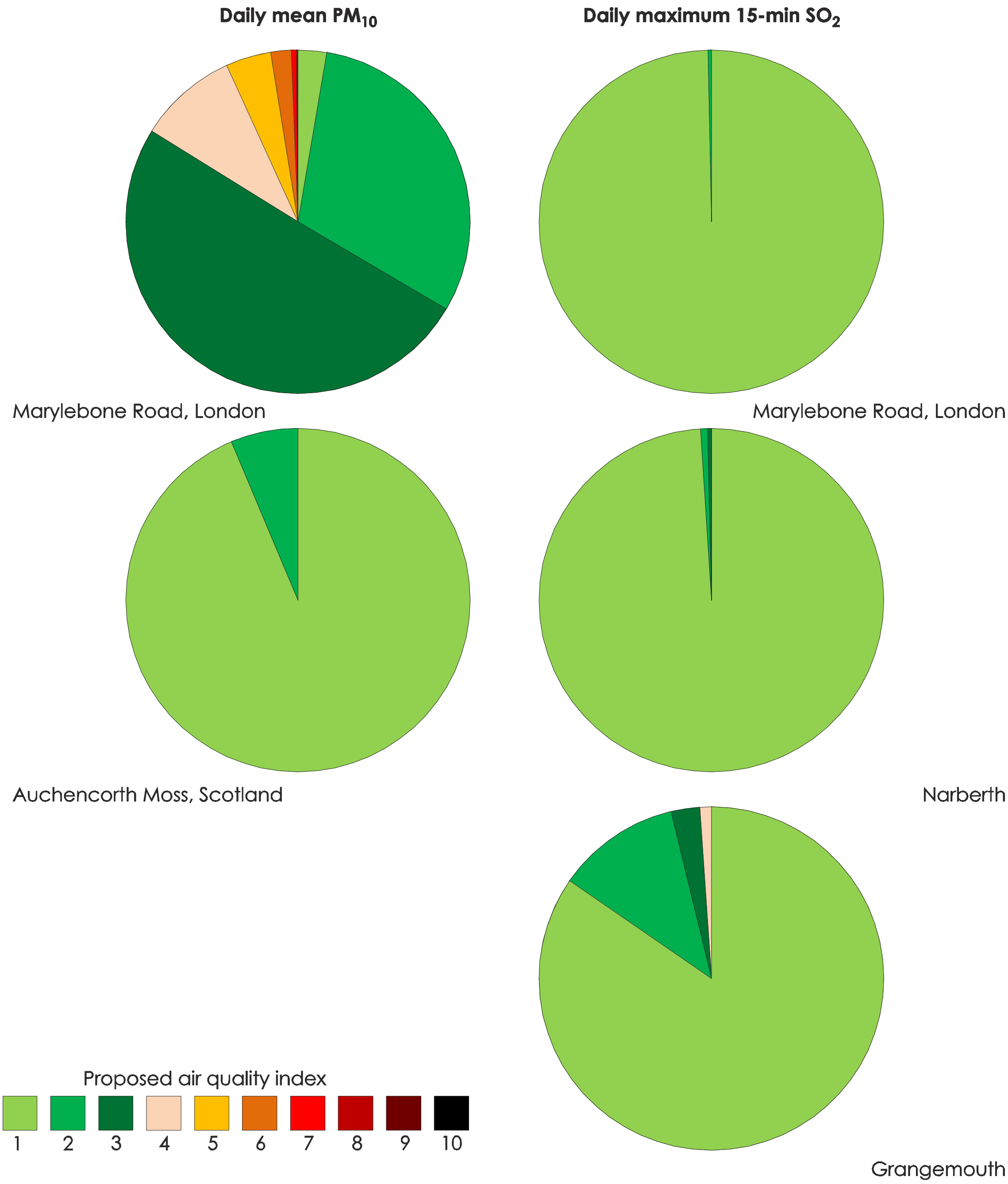

Figure 4-1: Proportion of days in each category in the proposed air quality index for PM_{10}, SO_2, NO_2 and O_3 using data for 2008 from a range of monitoring stations

4.2.4 Nitrogen dioxide, NO_2

Using the proposed revised index, days of Moderate pollution are likely to be more frequent at some roadside sites than using the current bandings, because the breakpoint concentration between the Low and Moderate bands is lower. These elevated roadside concentrations are thought to be associated with direct emissions of NO_2 from vehicles equipped with some modern exhaust after-treatment technologies. Days with Moderate NO_2 pollution are more likely to occur at roadside sites than at urban background and rural sites. High or Very High pollution levels are likely to be very infrequent at all sites.

Figure 4-1 *continued*

4.2.5 Ozone, O_3

Days reported as Moderate due to O_3 are expected to be more frequent using the proposed revised bandings, because the breakpoint concentration between the Low and Moderate bands is lower than for the current bandings. In contrast to many of the other air pollutants, the number of Moderate or higher days due to O_3 is likely to be lowest at roadside sites and greatest at rural sites. The breakpoint concentration between the Low and Moderate bands is close to current hemispheric baseline O_3 concentrations. This is likely to lead to the frequent reporting of days as having Moderate pollution, which are associated with baseline concentrations, rather than European regional photochemical O_3 episodes, at some sites.

4.2.6 All index pollutants

Further analysis was conducted on data from the London network indicating the impact that the change in banding will have on the overall index[9] with seasonal variations of the different pollutants (see Annex 11 for further details). This indicates that there will be an increase in the number of Moderate and High air pollution days, and a decrease in the number of Low days reported across the year. At background sites in London, the overall proportion of days of Low air pollution would fall from 82% in the current system to 67% in the proposed system. The proportion of Low days at kerb/roadside sites in London would also reduce, changing from 42% to 15%. This is illustrated in Figure 4-2.

[9] The index number issued each day with the daily forecast is for the highest pollutant level which varies depending upon the time of year, as indicated in Figures A11-1 to A11-5 of Annex 11.

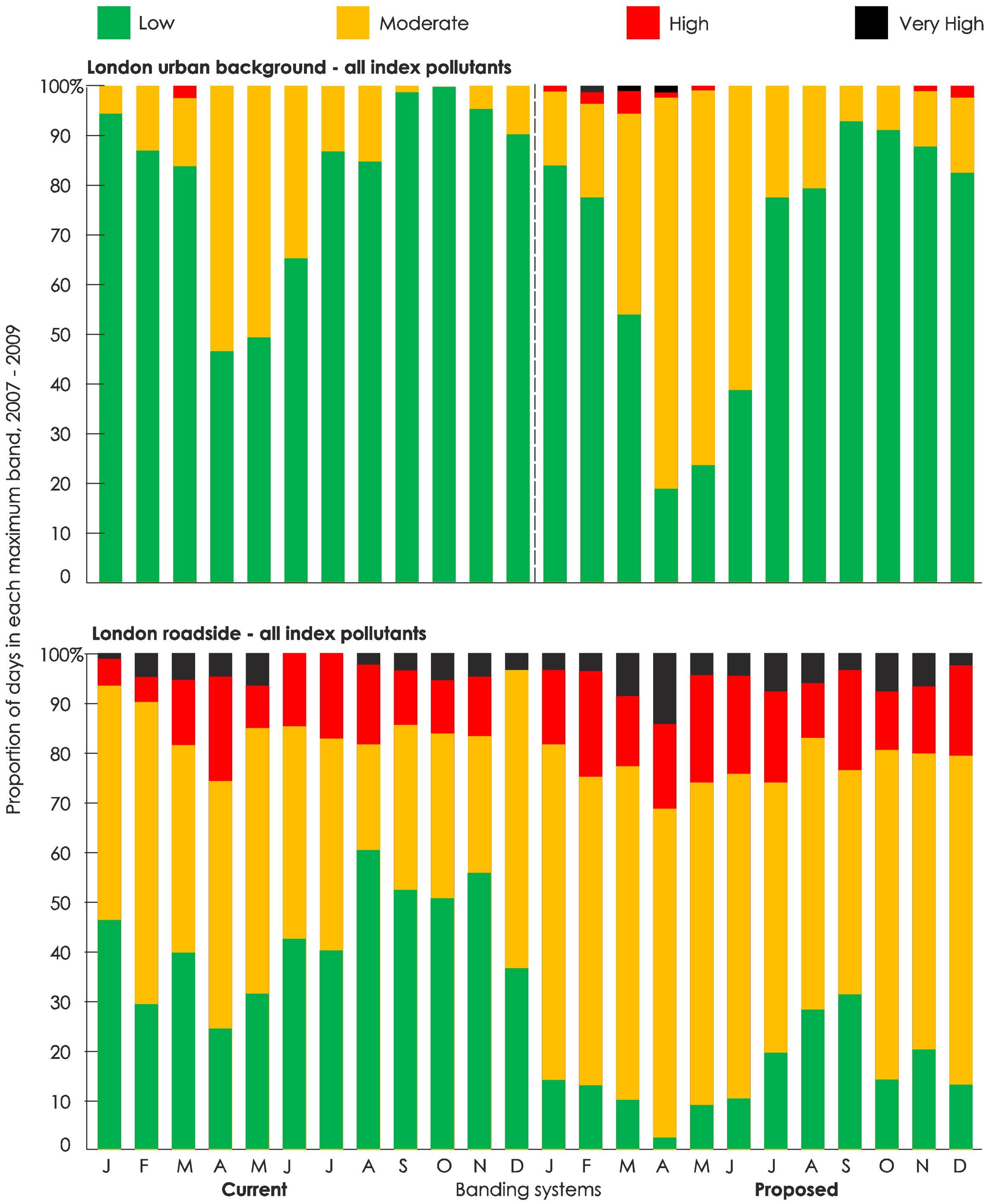

Figure 4-2: Comparison between the current and proposed banding systems for overall pollution

The upper panel shows background air pollution from 32 sites and the lower panel shows air pollution from 40 kerb/roadside sites in London

Chapter 5
Health Advice

5.1 Requirements from the public insight survey

The public insight study provided valuable information on the public's preference for how the index and associated health advice should be presented. Key points relating to preferences for the health advice were:

a information which is clear, concise and easy to understand

b focused, jargon-free, activity (health) advice

c provision for separate health advice for susceptible and non-susceptible groups

d clear identification of groups at greater risk than the general population

e avoidance of information that might be alarming or fear-inducing

Also relevant is that most participants wanted to know the level of air pollution in general, but not information about the levels of individual pollutants.

5.2 Developing the revised health advice

We reviewed health advice associated with air pollution indices provided (on websites) by public bodies in several different English-speaking countries, and examined the extent to which it met the requirements indicated by the public insight survey. Further details of health advice from other indices are given in Annex 12. We particularly noted several useful features of an example from Canada, which included accompanying advice to the public on how to use the index and how to identify whether they were particularly at risk of the adverse health effects of air pollution. We decided to draft our advice using a similar structure, but to base the content on our understanding of the medical effects of air pollution, and to draw on advice from COMEAP members. In developing the health advice our discussion included consideration of:

a the need not to overemphasise the proportion of the population that is likely to be noticeably susceptible to the effects of air pollution

b the need to avoid an exaggerated level of worry and concern

c variation in the sensitivity of individuals with asthma to air pollution

d our view that children with no known respiratory disease were unlikely to be particularly susceptible to the effects of air pollution, and should not be discouraged from taking exercise outdoors e the extent to which we could be specific about the types of activities that we might suggest susceptible (and other) people should avoid at times of high air pollution

f the fact that there might be benefit in giving advice in such a way that the public is aware of times when rural areas are as likely to be polluted as urban areas (i.e. when O_3 is elevated) and making it clear that the people who are susceptible to O_3 might be different from those susceptible to other pollutants

g the need to be clear and consistent in the use of terms such as sensitive, susceptible and at risk

h whether advice to reduce strenuous activity should also extend to activity indoors as some pollutants (e.g. $PM_{2.5}$) penetrate indoors significantly

i the extent to which we could or should be precise as to the age groups considered to be particularly at risk (e.g. more precise than 'the elderly')

5.3 Proposed advice

We recommend that the information to accompany the air quality index comes in three parts:

A Instructions on how the air quality index should be used

B Short-term health effects of air pollution and action that can be taken to reduce impacts

C Health advice linked to each band to accompany the air quality index

These are detailed below.

A How to use the Air Quality Index (AQI)

Step 1 Determine whether you (or your children) are likely to be at risk from air pollution. Information on groups who may be affected is given in the section on 'Additional information on the short-term effects of air pollution'. Your doctor may also be able to give you advice

Step 2 If you may be at risk, and are planning strenuous activity outdoors, check the air pollution forecast

Step 3 Use the health messages corresponding to the highest forecast level of pollution as a guide

B Additional Information on the Short-term Effects of Air Pollution

The air quality index has been developed to provide advice on expected levels of air pollution. In addition, information on the short-term effects on health that might be expected to occur at the different bands of the index (Low, Moderate, High and Very High) is provided here

Short-term effects of air pollution on health

Air pollution has a range of effects on health. However, air pollution in the UK does not rise to levels at which people need to make major changes to their habits to avoid exposure; nobody need fear going outdoors

Adults and children with lung or heart conditions It is known that, when levels of air pollutants rise, adults suffering from heart conditions, and adults and children with lung conditions, are at increased risk of becoming ill and needing treatment. Only a minority of those who suffer from these conditions are likely to be affected and it is not possible to predict in advance who will be affected. Some people are aware that air pollution affects their health: adults and children with asthma may notice that they need to increase their use of inhaled reliever medication on days when levels of air pollution are higher than average

Older people are more likely to suffer from heart and lung conditions than young people and so it makes good sense for them to be aware of current air pollution conditions

General population At Very High levels of air pollution, some people may experience a sore or dry throat, sore eyes or, in some cases, a tickly cough – even healthy individuals

Children need not be kept from school or prevented from taking part in games. Children with asthma may notice that they need to increase their use of reliever medication on days when levels of air pollution are higher than average

Action that can be taken

When levels of air pollution increase it would be sensible for those who have noticed that they are affected to limit their exposure to air pollutants. This does not mean staying indoors, but reducing levels of exercise outdoors would be reasonable

Older people and those with heart and lung conditions might avoid exertion on High pollution days

Adults and children with asthma should check that they are taking their medication as advised by their health practitioner and may notice that they need to increase their use of inhaled reliever medication

Adults with heart and circulatory conditions should ***not*** modify their treatment schedules on the basis of advice provided by the air quality index: such modification should only be made on a health practitioner's advice

Some athletes, even if they are not asthmatic, may find their performance is less good than expected when levels of a certain air pollutant (ground-level ozone) are High, and they may notice that deep breathing causes some discomfort in the chest. This might be expected in summer on days when ground-level ozone levels are raised. This does not mean that they are in danger but it may be sensible for them to limit their activities on such days

C Health Advice to Accompany the Air Quality Index

Air pollution banding	Value	Accompanying health messages for at-risk groups and the general population	
		At-risk individuals*	**General population**
Low	1–3	***Enjoy*** your usual outdoor activities	***Enjoy*** your usual outdoor activities
Moderate	4–6	Adults and children with lung problems, and adults with heart problems, ***who experience symptoms***, should ***consider reducing*** strenuous physical activity, particularly outdoors	***Enjoy*** your usual outdoor activities
High	7–9	Adults and children with lung problems, and adults with heart problems, should ***reduce*** strenuous physical exertion, particularly outdoors, and particularly if they experience symptoms. People with asthma may find they need to use their reliever inhaler more often. Older people should also ***reduce*** physical exertion	Anyone experiencing discomfort such as sore eyes, cough or sore throat should ***consider reducing*** activity, particularly outdoors
Very High	10	Adults and children with lung problems, adults with heart problems, and older people, should ***avoid*** strenuous physical activity. People with asthma may find they need to use their reliever inhaler more often	***Reduce*** physical exertion, particularly outdoors, especially if you experience symptoms such as cough or sore throat

* Adults and children with heart or lung problems are at greater risk of symptoms. Follow your doctor's usual advice about exercising and managing your condition

Chapter 6

Presentation of the Air Quality Index

6.1 Descriptors of the ten points and four bands

The current UK air quality index is a ten-point index, with 1 representing 'Low' and 10 representing 'Very High' pollution levels. These ten points are organised into four bands: 'Low' (1–3), 'Moderate' (4–6), 'High' (7–9) and 'Very High' (10). In the light of the findings from the public insight research, we decided to retain the approach of a ten-point scale organised into four bands.

We considered different ways that the four bands could be described, drawing upon examples used in other countries. Although there might be benefits in using descriptors that avoided ambiguity (e.g. 'high' could be interpreted to mean 'high quality' as well as 'high pollution') we were not convinced that the other possibilities considered would be improvements. For example, we felt that a set of descriptors based on health effects (e.g. 'healthy' or unhealthy') would probably overemphasise the proportion of the population likely to experience adverse effects. Nonetheless, we proposed three possible alternative sets of descriptors which could be subject to further public insight work:

a air pollution based bands (as at present): Low, Moderate, High and Very High

b air quality based bands: Good, Fair, Poor and Very Poor

c descriptors based on health risk: Low Health Risk, Moderate Health Risk, High Health Risk and Very High Health Risk

Participants in the public insight work indicated that they disliked the descriptors based on health risk but found both the air pollution and air quality based descriptors to be acceptable. Therefore we recommend retaining the current descriptors based on air pollution: Low, Moderate, High and Very High.

We also note the need identified by the public insight survey for visual clues (i.e. colour coding) to aid the interpretation of the index, and the preferences indicated:

a green and blue were considered best for good air quality

b red was preferred for poor air quality

The preference for the index to be represented as a simple block scale, rather than images or a graduated scale, is also noted. Therefore we recommend the index be presented similarly to that indicated in Figure 6-1.

1	2	3	4	5	6	7	8	9	10
Low			Moderate			High			Very High

Figure 6-1: Visual presentation of the air quality index

6.2 The need to use the ten-point scale in presenting information

During the public insight research, it was noted that local council and air quality websites often only report a band (e.g. Low, Moderate, High or Very High) rather than using the ten-point scale. The data obtained from the focus groups clearly indicated that there was a need to use a scale that allowed greater gradation in the AQI, as the variation in the level of air quality was felt to be lost by compressing the data into a smaller (four-point) scale. The gradation was considered particularly important by those with pre-existing conditions that might make them more susceptible to the effects of air pollution; it would allow them to calibrate their own sensitivity against the scale and to interpret more accurately how likely they might be to experience adverse effects on a given day.

Therefore, we strongly recommend that any presentation of air quality information using the revised UK AQI and bands should include information on pollution levels using the ten-point scale, and not rely upon the bands alone. We also recommend that the numbers should always be displayed with their colour code.

6.3 Triggers

The public insight research found that use of 'triggers' to provide additional 'real-time' health advice was considered helpful. A level of confidence in the occurrence of a pollution event, similar to that used in weather forecasting, was considered acceptable. We recommend the use of 'trigger' values to complement the proposed new air quality index and allow for the prediction of episodes of elevated air pollution in real time as they emerge.

6.4 Information on long-term health effects of air pollution

We recommend that links to information on the long-term health effects of air pollution are provided together with the index, such as the 2009 COMEAP report entitled *Long-Term Exposure to Air Pollution: Effect on Mortality* (http://www.comeap.org.uk).

Chapter 7
Summary of Recommendations

We recommend the following breakpoints between bands in the air quality index.

Pollutant	Averaging period	Unit	Low	Moderate	High	Very High
Particulate matter, PM_{10}	24-hour mean	µg m^{-3}	0–50	51–75	76–100	101 or more
Particulate matter, $PM_{2.5}$	24-hour mean	µg m^{-3}	0–35	36–53	54–70	71 or more
Sulphur dioxide, SO_2	15-minute mean	µg m^{-3}	0–265	266–531	532–1063	1064 or more
Ozone, O_3	Running 8-hour mean	µg m^{-3}	0–80	81–160	161–240	241 or more
Nitrogen dioxide, NO_2	1-hour mean	µg m^{-3}	0–200	201–400	401–600	601 or more
Carbon monoxide, CO	Recommend removal from the index					

With respect to the current air quality index, the bandings remain unchanged for SO_2. The breakpoints for a change in band for O_3, NO_2 and PM_{10} are more stringent. $PM_{2.5}$ has been added to the index, and CO has been removed in view of the dramatic reductions in outdoor levels of this pollutant. The implications of these changes are more Moderate and High air pollution days forecast.

We recommend that the information to accompany the air quality index comes in three parts and includes additional advice for susceptible individuals, together with advice for the general population:

A Instructions on how the air quality index should be used

B Short-term health effects of air pollution and action that can be taken to reduce impacts

C Health advice linked to each band to accompany the air quality index

We recommend that the air quality index be presented as a ten-point scale with colour to indicate gradations.

We recommend the incorporation of 'trigger' values to allow the prediction of episodes of elevated air pollution in real time as they emerge.

Finally, we recommend that links to information on the long-term health effects of air pollution are provided together with the index, such as the 2009 COMEAP report entitled *Long-Term Exposure to Air Pollution: Effect on Mortality* (http://www.comeap.org.uk).

Chapter 8
References

COMEAP (1998a). Statement on Banding of Air Quality. Available at http://www.comeap.org.uk

COMEAP (1998b). The Quantification of the Effects of Air Pollution on Health in the United Kingdom. Department of Health. HMSO, London. Available at http://www.comeap.org.uk/documents/reports.html

Dominici F, Peng RD, Bell ML, Pham L, McDermott A, Zeger SL and Sarnet JM (2006). Fine particulate air pollution and hospital admission for cardiovascular and respiratory disease. *JAMA,* **295**, 1127–34.

EPAQS (Expert Panel on Air Quality Standards) (1994a). A Recommendation for a United Kingdom Air Quality Standard for Carbon Monoxide. Department of the Environment. HMSO, London.

EPAQS (Expert Panel on Air Quality Standards) (1994b). A Recommendation for a United Kingdom Air Quality Standard for Ozone. Department of the Environment. HMSO, London.

EPAQS (Expert Panel on Air Quality Standards) (1995a). A Recommendation for a United Kingdom Air Quality Standard for Particles. Department of the Environment. HMSO, London.

EPAQS (Expert Panel on Air Quality Standards) (1995b). A Recommendation for a United Kingdom Air Quality Standard for Sulphur Dioxide. Department of the Environment. HMSO, London.

EPAQS (Expert Panel on Air Quality Standards) (1996). A Recommendation for a United Kingdom Air Quality Standard for Nitrogen Dioxide. Department of the Environment. HMSO, London.

European Union (2008). EU Directive 2008/50/EC of the European Parliament and of the Council of May 2008 on ambient air quality and cleaner air for Europe. *Off J Eur Union,* 11.6.2008, L152/1.

Laden F, Schwartz J, Speizer FE and Dockery DW (2006). Reduction in fine particulate air pollution and mortality: extended follow-up of the Harvard Six Cities study. *Am J Respir Crit Care Med,* **173**, 667–72.

Liang W, Wei H and Kuo H (2009). Association between daily mortality from respiratory and cardiovascular diseases and air pollution in Taiwan. *Environ Res,* **109**, 51–8.

MAAPE (1995). Advisory Group on the Medical Aspects of Air Pollution Episodes. Health Effects of Exposures to Mixtures of Air Pollutants. Department of Health. HMSO, London.

Pope CA III, Burnett RT, Thun MJ, Krewski D, Ito K and Thurston GD (2002). Lung cancer, cardiopulmonary mortality, and long-term exposure to fine particulate air pollution. *JAMA,* **287**, 1132–41.

Rosenlund M, Berglind N, Pershagen G, Hallqvist J, Jonson T and Bellander T (2006). Long-term exposure to urban air pollution and myocardial infarction. *Epidemiology,* **17**, 383–90.

Stieb DM (2009). Air pollution and emergency department visits for cardiac and respiratory conditions: a multi-city time-series analysis. *Environ Health,* **8**, 25.

Strickland MJ, Darrow LA, Klein M, Flanders WD, Sarnat JA, Waller LA, Sarnat SE, Mulholland JA and Tolbert PE (2010). Short-term associations between ambient air pollutants and pediatric asthma emergency department visits. *Am J Respir Crit Care Med,* **182**(3), 307–16.

van der Elshout S and Leger K (2007). Comparing Urban Air Quality Across Borders. DCMR, Environmental Protection Agency, Rijnmond. Available at http://www.airqualitynow.eu/download/CITEAIR-Comparing_Urban_Air_Quality_across_Borders.pdf

WHO (2000). Air Quality Guidelines for Europe. 2nd edition. WHO Regional Publications. European Series, No. 91. World Health Organization, Copenhagen.

WHO (2004). Health Aspects of Air Pollution – Answers to Follow-Up Questions from CAFE. Report on a Working Group Meeting, Bonn, Germany, 15–16 January, 2004. World Health Organization, Copenhagen.

WHO (2006). Air Quality Guidelines. Global Update 2005. Particulate Matter, Ozone, Nitrogen Dioxide and Sulfur Dioxide. World Health Organization, Copenhagen.

Zanobetti A, Schwartz J, Samoli E, Gryparis A, Touloumi G, Peacock J, Anderson RH, Le Tertre A, Bobros J, Celko M, Goren A, Forsberg B, Michelozzi P, Rabczenko D, Hoyos SP, Wichmann HE and Katsouyanni K (2003). The temporal pattern of respiratory and heart disease mortality in response to air pollution. *Environ Health Perspect,* **111**(9), 1188–93.

Chapter 9
Bibliography

9.1 Particulate matter

Airborne Particles Expert Group (1999). Source Apportionment of Airborne Particulate Matter in the United Kingdom. HMSO, London.

Birmili W, Schepanski KA, Ansmann A, Spindler G, Tegen I, Wehner B, Nowak A, Reimer E, Mattis I, Muller K, Bruggemann KE, Gnauk T, Herrmann H, Wiedensohler A, Althausen D, Schladitz A, Tuch T and Loschau G (2008). A case of extreme particulate matter concentrations over Central Europe caused by dust emitted over the southern Ukraine. *Atmos Chem Phys,* **8**, 997–1016.

Clancy L, Goodman P, Sinclair H and Dockery DW (2002). Effect of air-pollution control on death rates in Dublin, Ireland: an intervention study. *Lancet,* **360**, 1210–14.

Dockery DW, Pope CA, Xu X, Spengler JD, Ware JH, Fay ME, Ferris BG Jr and Speizer FE (1993). An association between air pollution and mortality in six US cities. *NEJM*, **329**, 1753–9.

Dominici F, Peng RD, Bell ML, Pham L, McDermott A, Zeger SL and Sarnet JM (2006). Fine particulate air pollution and hospital admission for cardiovascular and respiratory disease. *JAMA,* **295**, 1127–34.

Donaldson K, Stone V, Borm PJA, Jimenez LA, Gilmour PS, Schins RPF, Knappen Ad M, Rahman I, Faux SP, Brown DM and MacNee W (2003). Oxidative stress and calcium signaling in the adverse effects of environmental particles (PM_{10}). *Free Radic Biol Med,* **34**, 1369–82.

Fuller GW and Green D (2006). Evidence for increasing primary PM_{10} in London. *Atmos Environ,* **40**, 6134–45.

Fuller GW, Carslaw DC and Lodge HW (2002). An empirical approach for the prediction of daily mean PM_{10} concentrations. *Atmos Environ,* **36**, 1431–41.

Green D, Fuller GW and Baker T (2009). Development and validation of the volatile correction model for PM_{10} – an empirical method for adjusting TEOM measurements for their loss of volatile particulate matter. *Atmos Environ,* **43**, 2132–41.

Harrison RM, Stedman JR and Derwent RG (2008). Why are PM_{10} concentrations in Europe not falling? *Atmos Environ,* **42**, 603–6.

Hayman G, Yardley R, Quincey P, Butterfield D, Green D, Alexander J, Johnson P and Tremper A (2008). CPEA 28: Airborne Particulate Concentrations and Numbers in the United Kingdom (Phase 2). Annual Report – 2007. National Physical Laboratory, Teddington.

Katsouyanni K, Touloumi G, Samoli E, Gryparis A, Le Tertre A, Monopolis Y, Rossi G, Zmirou D, Ballester F, Boumghar A, Anderson HR, Wojtyniak B, Paldy A, Braunstein R, Pekkanen J, Schindler C and Schwartz J (2001). Confounding and effect modification in the short-term effects of ambient particles on total mortality: results from 29 European cities within the APHEA2 project. *Epidemiology,* **12**, 521–31.

Kelly FJ (2003). Oxidative stress: its role in air pollution and adverse health effects. *Occup Environ Med,* **60**, 612–16.

Laden F, Schwartz J, Speizer FE and Dockery DW (2006). Reduction in fine particulate air pollution and mortality: extended follow-up of the Harvard Six Cities study. *Am J Respir Crit Care Med,* **173**, 667–72.

Pope CA III, Burnett RT, Thun MJ, Krewski D, Ito K and Thurston GD (2002). Lung cancer, cardiopulmonary mortality, and long-term exposure to fine particulate air pollution. *JAMA,* **287**, 1132–41.

Pope CA III and Dockery DW (2006). Health effects of fine particulate air pollution: lines and connect. *J Air Waste Manage Assoc,* **56**, 709–42.

Ryall DB, Derwent RG, Manning AJ, Redington AL, Corden J, Millington W, Simmonds PG, O'Doherty S, Carslaw N and Fuller G (2000). The origin of high particulate concentrations over the United Kingdom, March 2000. *Atmos Environ,* **36**, 1363–78.

Samoli E, Analitis A, Touloumi G, Schwartz J, Anderson HR, Sunyer J, Bisanti L, Zmirou D, Vonk JM, Pekkanen H, Goodman P, Paldy A, Schindler C and Katsouyanni K (2005). Estimating the exposure-response relationships between particulate matter and mortality within the APHEA Multicity Project. *Environ Health Perspect,* **113**, 88–95.

US Environmental Protection Agency (2008). Integrated Science Assessment for Particulate Matter. Available at http://cfpub.epa.gov/ncea/cfm/recordisplay.cfm?deid=201805

Witham C and Manning A (2007). Impacts of Russian biomass burning on UK air quality. *Atmos Environ,* **41**, 8075–90.

Yardley R, Quincey P, Butterfield D, Green D, Alexander J, Johnson P and Tremper A (2007). CPEA 28: Airborne Particulate Concentrations and Numbers in the United Kingdom (Phase 2). Annual Report – 2006. National Physical Laboratory, Teddington.

9.2 Ozone

Advisory Group on the Medical Aspects of Air Pollution Episodes (1991). First Report. Ozone. Department of Health. HMSO, London.

Bauer AK and Kleeberger SR (2010). Genetic mechanisms of susceptibility to ozone-induced lung disease. *Ann NY Acad Sci,* **1203**, 113–19.

Behndig AF, Blomberg A, Helleday R, Duggan ST, Kelly FJ and Mudway IS (2009). Antioxidant responses to acute ozone challenge in the healthy human airway. *Inhal Toxicol,* **21**(11), 933–42.

Chiu HF and Yang CY (2009). Air pollution and emergency room visits for arrhythmias: are there potentially sensitive groups? *J Toxicol Environ Health A,* **72**(13), 817–23.

Cole MP and Freeman BA (2009). Promotion of cardiovascular disease by exposure to the air pollutant ozone. *Am J Physiol Lung Cell Mol Physiol,* **297**(2), L205–8.

Eggleston PA (2009). Complex interactions of pollutant and allergen exposures and their impact on people with asthma. *Pediatrics,* **123**(Suppl 3), S160–67.

Halonen JI, Lanki T, Tiittanen P, Niemi JV, Loh M and Pekkanen J (2010). Ozone and cause-specific cardiorespiratory morbidity and mortality. *J Epidemiol Community Health,* **64**(9), 814–20.

Hazucha MJ, Folinsbee LJ and Bromberg PA (2003). Distribution and reproducibility of spirometric response to ozone by gender and age. *J Appl Physiol,* **95**(5), 1917–25.

Henrotin JB, Zeller M, Lorgis L, Cottin Y, Giroud M and Béjot Y (2010). Evidence of the role of short-term exposure to ozone on ischaemic cerebral and cardiac events: the Dijon Vascular Project (DIVA). *Heart,* **96**, 1990–96.

Hernandez ML, Lay JC, Harris B, Esther CR Jr, Brickey WJ, Bromberg PA, Diaz-Sanchez D, Devlin RB, Kleeberger SR, Alexis NE and Peden DB (2010). Atopic asthmatic subjects but not atopic subjects without asthma have enhanced inflammatory response to ozone. *J Allergy Clin Immunol,* **126**, 537–44.

Islam T, Gauderman WJ, Berhane K, McConnell R, Avol E, Peters JM and Gilliland FD (2007). Relationship between air pollution, lung function and asthma in adolescents. *Thorax,* **62**(11), 957–63.

Janke K, Propper C and Henderson J (2009). Do current levels of air pollution kill? The impact of air pollution on population mortality in England. *Health Econ,* **18**(9), 1031–55.

Peel JL, Klein M, Flanders WD, Mulholland JA and Tolbert PE (2010). Impact of improved air quality during the 1996 Summer Olympic Games in Atlanta on multiple cardiovascular and respiratory outcomes. HEI Health Review Committee. *Res Rep Health Eff Inst,* **148**, 3–23.

Stedman JR and Kent AJ (2008). An analysis of the spatial patterns of health related surface ozone metrics across the UK in 1995, 2003 and 2005. *Atmos Environ,* **42**, 1702–16.

Strickland MJ, Darrow LA, Klein M, Flanders WD, Sarnat JA, Waller LA, Sarnat SE, Mulholland JA and Tolbert PE (2010). Short-term associations between ambient air pollutants and pediatric asthma emergency department visits. *Am J Respir Crit Care Med,* **182**(3), 307–16.

The Royal Society (2008). Ground-level Ozone in the 21st Century: Future Trends, Impacts and Policy Implications. Science Policy Report 15/08 October 2008. Available at http://royalsociety.org/WorkArea/DownloadAsset.aspx?id=5484

US Environmental Protection Agency (2006). Air Quality Criteria for Ozone and Related Photochemical Oxidants. Available at http://cfpub.epa.gov/ncea/cfm/recordisplay.cfm?deid=149923

Wong CM, Yang L, Thach TQ, Chau PY, Chan KP, Thomas GN, Lam TH, Wong TW, Hedley AJ and Peiris JS (2009). Modification by influenza on health effects of air pollution in Hong Kong. *Environ Health Perspect,* **117**(2), 248–53.

Wood AM, Harrison RM, Semple S, Ayres JG and Stockley RA (2010). Outdoor air pollution is associated with rapid decline of lung function in alpha-1-antitrypsin deficiency. *Occup Environ Med,* **67**(8), 556–61.

9.3 Sulphur dioxide

Advisory Group on the Medical Aspects of Air Pollution Episodes (1992). Second Report. Sulphur Dioxide. Department of Health. HMSO, London.

Guo Y-M, Zhao A-L and Liu L-Q (2008). Association between sulfur dioxide air pollution and hospital emergency treatment for circulatory diseases: a case-crossover study. *J Environ Health,* **25**, 1035–8.

Liang W, Wei H and Kuo H (2009). Association between daily mortality from respiratory and cardiovascular diseases and air pollution in Taiwan. *Environ Res,* **109**, 51–8.

Rosenlund M, Berglind N, Pershagen G, Hallqvist J, Jonson T and Bellander T (2006). Long-term exposure to urban air pollution and myocardial infarction. *Epidemiology,* **17**, 383–90.

Routledge HC, Manney S, Harrison RM, Ayres JG and Townend JN (2006). Effect of inhaled sulphur dioxide and carbon particles on heart rate variability and markers of inflammation and coagulation in human subjects. *Heart,* **92**, 220–27.

Stieb DM (2009). Air pollution and emergency department visits for cardiac and respiratory conditions: a multi-city time-series analysis. *Environ Health,* **8**, 25.

Wang X (2008). Spatial analysis of long-term exposure to air pollution and cardiorespiratory mortality in Brisbane, Australia. Available at http://eprints.qut.edu.au/16627/

Xie J, Li R, Fan R and Meng Z (2009). Effects of sulfur dioxide on expressions of p53, bax and bcl-2 in lungs of asthmatic rats. *Inhal Toxicol,* **11**, 952–7.

9.4 Nitrogen dioxide

Advisory Group on the Medical Aspects of Air Pollution Episodes (1993). Third Report. Nitrogen Dioxide. Department of Health. HMSO, London.

Air Quality Expert Group (2007). Trends in Primary Nitrogen Dioxide in the UK. Department for Environment, Food and Rural Affairs. Available at http://www.defra.gov.uk/environment/quality/air/airquality/publications/primaryno2-trends/

Baccarelli A, Zanobetti A, Martinelli I, Grillo P, Hou L, Giacomini S, Bonzini M, Lanzani G, Mannucci PM, Bertazzi PA and Schwartz J (2007). Effects of exposure to air pollution on blood coagulation. *J Thromb Haemost,* **5**(2), 252–60.

Brauer M, Gehring U, Brunekreef B, de Jongste J, Gerritsen J, Rovers M, Wichmann HE, Wijga A and Heinrich J (2006). Traffic-related air pollution and otitis media. *Environ Health Perspect,* **114**(9), 1414–18.

Brauer M, Hoek G, Smit HA, de Jongste JC, Gerritsen J, Postma DS, Kerkhof M and Brunekreef B (2007). Air pollution and development of asthma, allergy and infections in a birth cohort. *Eur Respir J,* **29**(5), 879–88.

Goodman J, Chandalia J, Thakali S and Seeley M (2009). Meta-analysis of nitrogen dioxide exposure and airway hyperresponsiveness in asthmatics. *Crit Rev Toxicol,* **39**(9), 719–42.

US Environmental Protection Agency (2008). Integrated Science Assessment for Oxides of Nitrogen Health Criteria (Final). Available at http://cfpub.epa.gov/ncea/cfm/recordisplay.cfm?deid=194645

9.5 Carbon monoxide

US Environmental Protection Agency (2010). Integrated Science Assessment for Carbon Monoxide (Final Report). EPA/600/R-09/019F. Available at http://cfpub.epa.gov/ncea/isa/recordisplay.cfm?deid=218686

9.6 Mixtures

Advisory Group on the Medical Aspects of Air Pollution Episodes (1995). Fourth Report. Health Effects of Exposures to Mixtures of Pollutants. Department of Health HMSO, London.

Carpenter DO, Arcaro K and Spink DC (2002). Understanding the human health effects of chemical mixtures. *Environ Health Perspect,* **110**(Suppl 1), 25–42.

Committee on Toxicity of Chemicals in Foods, Consumer Products and the Environment (2002). Risk Assessments of Mixtures of Pesticides and Similar Substances. Department of Health.

Interdepartmental Group on Health Risks from Chemicals (2008). Chemical Mixtures: A Framework for Assessing Risks to Human Health. Institute for Environment and Health, Cranfield University.

9.7 Air pollution and health

Fuller G, Meston L, Green D, Westmoorland E and Kelly F (2009). Air Quality in London. London Air Quality Network Report 14, 2006–2007. Available at http://www.londonair.org.uk

Godri K, Green D, Fuller G, Kelly F, Dall'Osto M, Harrison R and Mudway I (2010). Particulate oxidative burden associated with firework activity. *Environ Sci Technol,* **44**(21), 8295–301.

Liang W, Wei H and Kuo H (2009). Association between daily mortality from respiratory and cardiovascular diseases and air pollution in Taiwan. *Environ Res,* **109**, 51–8.

Ministry of Health (1954). Reports on Public Health and Medical Subjects No. 94, Mortality and Morbidity during the London Fog of December 1952. HMSO, London.

Rosenlund M, Berglind N, Pershagen G, Hallqvist J, Jonson T and Bellander T (2006). Long-term exposure to urban air pollution and myocardial infarction. *Epidemiology,* **17**, 383–90.

Stieb DM (2009). Air pollution and emergency department visits for cardiac and respiratory conditions: a multi-city time-series analysis. *Environ Health,* **8**, 25.

Wang X (2008). Spatial analysis of long-term exposure to air pollution and cardiorespiratory mortality in Brisbane, Australia. Available at http://eprints.qut.edu.au/16627/

9.8 Committee on the Medical Effects of Air Pollutants

COMEAP (1998). Statement on Banding of Air Quality. Available at http://www.comeap.org.uk

COMEAP (1998). The Quantification of the Effects of Air Pollution on Health in the United Kingdom. Department of Health. HMSO, London. Available at http://www.comeap.org.uk/documents/reports.html

COMEAP (2006). Cardiovascular Disease and Air Pollution. Department of Health. HMSO, London. Available at http://www.comeap.org.uk/documents/reports.html

COMEAP (2009). Long-Term Exposure to Air Pollution: Effect on Mortality. Health Protection Agency. Available at http://www.comeap.org.uk/documents/reports.html

9.9 Expert Panel on Air Quality Standards

EPAQS (1994). A Recommendation for a United Kingdom Air Quality Standard for Carbon Monoxide. Department of the Environment. HMSO, London.

EPAQS (1994). A Recommendation for a United Kingdom Air Quality Standard for Ozone. Department of the Environment. HMSO, London.

EPAQS (1995). A Recommendation for a United Kingdom Air Quality Standard for Particles. Department of the Environment. HMSO, London.

EPAQS (1995). A Recommendation for a United Kingdom Air Quality Standard for Sulphur Dioxide. Department of the Environment. HMSO, London.

EPAQS (1996). A Recommendation for a United Kingdom Air Quality Standard for Nitrogen Dioxide. Department of the Environment. HMSO, London.

9.10 World Health Organization

Anderson HR, Atkinson RW, Peacock JL and Konstantinou K (2004). Meta-analysis of Time-series Studies and Panel Studies of Particulate Matter (PM) and Ozone (O_3). Report of a WHO Task Group. WHO Office for Europe, Copenhagen. Available at http://www.euro.who.int/en/what-we-do/health-topics/environmental-health/air-quality/publications/pre2009/meta-analysis-of-time-series-and-panel-studies-of-particulate-matter-and-ozone

WHO (2000). Air Quality Guidelines for Europe. 2nd edition. WHO Regional Publications. European Series, No. 91. World Health Organization, Copenhagen.

WHO (2004). Health Aspects of Air Pollution – Answers to Follow-Up Questions from CAFE. Report on a Working Group Meeting, Bonn, Germany, 15–16 January, 2004. World Health Organization, Copenhagen.

WHO (2004). Health Aspects of Air Pollution. Results from the WHO Project Systematic Review of Health Aspects of Air Pollution in Europe. World Health Organization, Copenhagen. Available at http://www.euro.who.int/document/E83080.pdf

WHO (2006). Air Quality Guidelines. Global Update 2005. Particulate Matter, Ozone, Nitrogen Dioxide and Sulfur Dioxide. World Health Organization, Copenhagen.

9.11 Other

Bowman WC and Rand MJ (1980). *Textbook of Pharmacology*. Blackwell Scientific Publications, Second Edition.

Department for Environment, Food and Rural Affairs, The Scottish Executive, Welsh Assembly Government and The Department of the Environment for Northern Ireland (2007). The Air Quality Strategy for England, Scotland, Wales and Northern Ireland: Volumes 1 and 2 (Cmnd 7169). The Stationery Office, London. Available at http://www.defra.gov.uk/environment/quality/air/airquality/strategy/

European Commission (2008). DG Environment. News Alert, Issue 30 July 2008.

European Union (2008). EU Directive 2008/50/EC of the European Parliament and of the Council of May 2008 on ambient air quality and cleaner air for Europe. *Off J Eur Union,* 11.6.2008, L152/1.

Goldstein A, Aronow L and Kalman SM (1974). *Principles of Drug Action*. Wiley International, Second Edition.

Zanobetti A, Schwartz J, Samoli E, Gryparis A, Touloumi G, Peacock J, Anderson RH, Le Tertre A, Bobros J, Celko M, Goren A, Forsberg B, Michelozzi P, Rabczenko D, Hoyos SP, Wichmann HE and Katsouyanni K (2003). The temporal pattern of respiratory and heart disease mortality in response to air pollution. *Environ Health Perspect,* **111**(9), 1188–93.

Annex 1

Current UK Air Quality Index with Related Health Information

Current UK air quality index

		Ozone		Nitrogen dioxide		Sulphur dioxide		Carbon monoxide		PM$_{10}$ particles	
		Running 8-hour or 1-hour mean*		1-hour mean		15-minute mean		Running 8-hour mean		Running 24-hour mean	
Band	Index	µg m^{-3}	ppb	µg m^{-3}	ppb	µg m^{-3}	ppb	mg m^{-3}	ppm	µg m^{-3} (Grav Equiv)	µg m^{-3} (Ref Equiv)
Low	1	0–33	0–16	0–95	0–49	0–88	0–32	0.0–3.8	0.0–3.2	0–21	0–19
	2	34–65	17–32	96–190	50–99	89–176	33–66	3.9–7.6	3.3–6.6	22–42	20–40
	3	66–99	33–49	191–286	100–149	177–265	67–99	7.7–11.5	6.7–9.9	43–64	41–62
Moderate	4	100–125	50–62	287–381	150–199	266–354	100–132	11.6–13.4	10.0–11.5	65–74	63–72
	5	126–153	63–76	382–477	200–249	355–442	133–166	13.5–15.4	11.6–13.2	75–86	73–84
	6	154–179	77–89	478–572	250–299	443–531	167–199	15.5–17.3	13.3–14.9	87–96	85–94
High	7	180–239	90–119	573–635	300–332	532–708	200–266	17.4–19.2	15.0–16.5	97–107	95–105
	8	240–299	120–149	636–700	333–366	709–886	267–332	19.3–21.2	16.6–18.2	108–118	106–116
	9	300–359	150–179	701–763	367–399	887–1063	333–399	21.3–23.1	18.3–19.9	119–129	117–127
Very High	10	360 or more	180 or more	764 or more	400 or more	1064 or more	400 or more	23.2 or more	20 or more	130 or more	128 or more

* For ozone, the maximum of the 8-hour and 1-hour mean is used to calculate the index value.

UK air pollution index health descriptors for people who are sensitive to air pollution

Banding	Index	Health descriptor
Low	1, 2 or 3	Effects are unlikely to be noticed even by individuals who know they are sensitive to air pollutants
Moderate	4, 5 or 6	Mild effects, unlikely to require action, may be noticed amongst sensitive individuals
High	7, 8 or 9	Significant effects may be noticed by sensitive individuals and action to avoid or reduce these effects may be needed (e.g. reducing exposure by spending less time in polluted areas outdoors). Asthmatics will find that their reliever inhaler is likely to reverse the effects on the lung
Very High	10	The effects on sensitive individuals described for 'High' levels of pollution may worsen

Annex 2

Recent Trends in Concentrations of UK Index Pollutants

Figure A2-1 provides a summary of the trends in the concentrations of the air pollutants included in the bandings between 1997 and 2008. These boxplots show the upper and lower quartiles of the concentrations measured at the different monitoring sites in the UK national networks. The 'whiskers' show the concentrations for the highest and lowest sites. A reference line showing the Air Quality Strategy (AQS) objective has also been included. Annual mean objectives have been set for PM_{10} and NO_2 in addition to objectives for short-term concentrations. Percentiles are shown corresponding to the permitted number of exceedances for the numerical concentration for the averaging period specified in the objective. Full details of the AQS objectives are available in the AQS for England, Wales, and Northern Ireland (Defra et al, 2007).

Concentrations of PM_{10} showed some decline in the late 1990s but there has been little change since about 2000 (Harrison et al, 2008). The weather can have a significant impact on particulate matter concentrations, which were unusually high during 2003 and 2006. The sources of ambient particulate matter include primary particulate matter, such as emissions from traffic, industry and space heating, and secondary particulate matter, formed as a result of chemical reactions of air pollutants in the atmosphere and other sources, such as wind-blown dusts and seaspray. Measurements of $PM_{2.5}$ at an extensive network of monitoring sites only commenced in 2008.

Average annual mean nitrogen dioxide (NO_2) concentrations have shown a gentle decline, while the maximum annual mean within the network increased noticeably between 2002 and 2003. High percentile 1-hour concentrations declined in the late 1990s but have shown little decline or an increase in recent years. The trends in ambient NO_2 concentrations are influenced by a combination of the trends in oxides of nitrogen (NO_X) emissions from traffic and the fraction of this emission that is emitted directly as NO_2 (AQEG, 2007).

The trends in ozone (O_3) concentrations are influenced by several factors including hemispheric background concentrations, the emissions of the precursors of photochemically generated ozone and the local urban emissions of NO_X (Stedman and Kent, 2008). Concentrations are typically highest in years with warm summers such as 2003 and 2006 but show little overall trend.

Concentrations of sulphur dioxide (SO_2) have declined as a result of reductions in coal use for space heating and both reductions in coal use and the fitting of emissions abatement measures in power stations and industry.

Carbon monoxide (CO) concentrations have declined as a result of the fitting of three-way catalysts to petrol-driven cars.

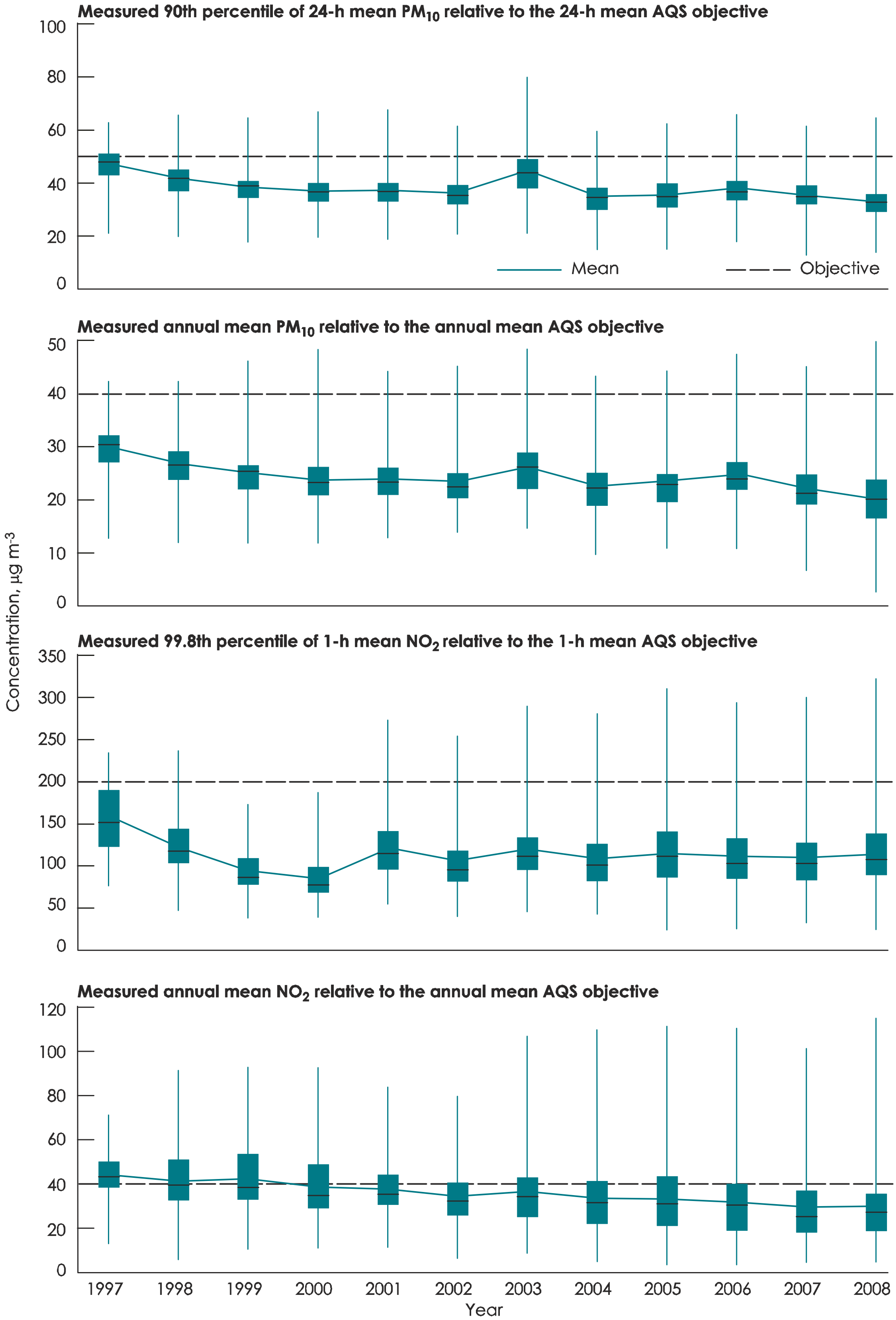

Figure A2-1: Boxplots showing the upper and lower quartiles of the concentrations of air pollutants PM_{10}, NO_2, O_3, SO_2 and CO between 1997 and 2008

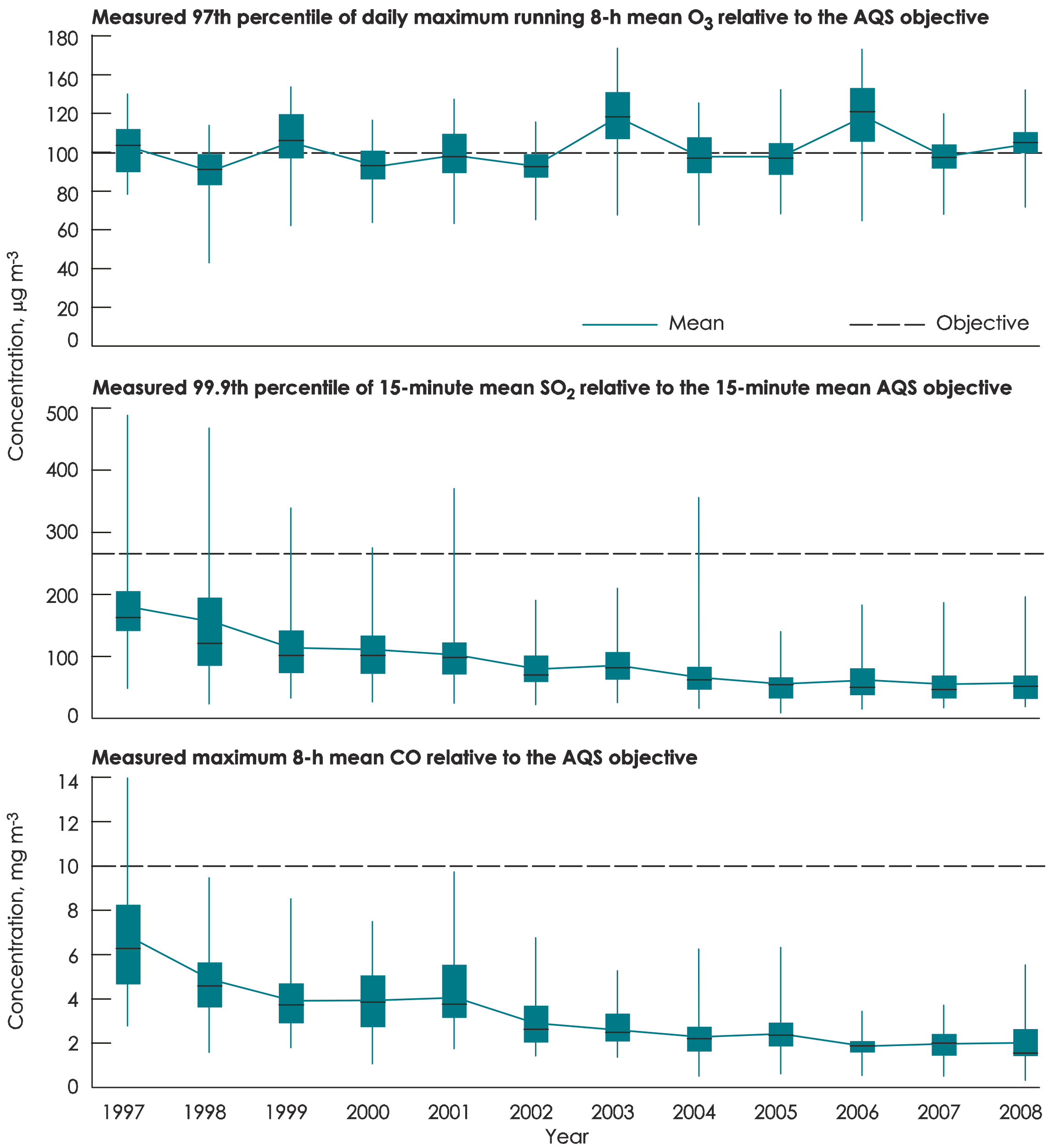

Figure A2-1 *continued*

References

AQEG (Air Quality Expert Group) (2007). Trends in Primary Nitrogen Dioxide in the UK. Department for Environment, Food and Rural Affairs. Available at http://www.defra.gov.uk/environment/airquality/panels/aqeg/publications/index.htm

Department for Environment, Food and Rural Affairs, The Scottish Executive, Welsh Assembly Government and The Department of the Environment for Northern Ireland (2007). The Air Quality Strategy for England, Scotland, Wales and Northern Ireland: Volumes 1 and 2 (Cmnd 7169). The Stationery Office, London. Available at http://www.defra.gov.uk/environment/airquality/strategy/index.htm

Harrison RM, Stedman JR and Derwent RG (2008). Why are PM_{10} concentrations in Europe not falling? *Atmos Environ,* **42**, 603–6.

Stedman JR and Kent AJ (2008). An analysis of the spatial patterns of health related surface ozone metrics across the UK in 1995, 2003 and 2005. *Atmos Environ,* **42**, 1702–16.

Annex 3

Public Insight Study

COMEAP would like to thank Dr Kirsty Smallbone at the University of Brighton for this work, which was funded by the Department for Environment, Food and Rural Affairs.

In order to inform the review of the air quality index (AQI), research was undertaken by the University of Brighton, on behalf of Defra, to investigate the general public's current awareness and comprehension of air quality information, and to assess the challenges that exist to understanding and interpreting such material. Key themes investigated included people's current environmental and air quality awareness, perceived indicators of air quality and health effects, their current understanding and awareness of air quality indicators, and their needs and requirements for the provision of air quality information.

Previous research has shown that there is a low level of awareness amongst the public regarding the link between air pollution and its effects on human health. This lack of awareness varies amongst socioeconomic groupings, with those living in less affluent and more polluted areas less aware of the risks associated with air pollution exposure. Furthermore, there is a question of whether the information currently provided is accessible and understandable to the general public.

Many people agree that air quality indices should provide clear, focused and relevant information on the level of pollution and contain advice on controlling exposure and symptom exacerbation. The current AQI uses bands of Low, Moderate, High and Very High to classify air pollution, although the last band is rarely used. Research suggests, however, that the current AQI is not easy to understand. The extract below is typical of the general public's view of the existing system:

> **"You get a message saying 'moderate air pollution' and you don't know what it means, so you just ignore it."**
>
> ***(Male, with chronic obstructive pulmonary disease, COPD)***

A3.1 Method for public insight research

A mixed-methods approach was employed using both qualitative and quantitative techniques. Qualitative techniques included small-group workshops and focus groups, both of which allowed an in-depth exploration of the key issues; while a quantitative online questionnaire was employed to gather a broad spectrum of views.

The questionnaire was piloted before being released online for a period of four weeks. Over 400 responses were received. Two small-group workshops were undertaken in Sussex and Luton. One group was held with older people with respiratory/cardiovascular illnesses and the other with children aged 9–11 years old (both with and without respiratory illnesses). The workshops were held in familiar surroundings to assist facilitation. Five focus groups were also conducted, three in the daytime and two in the evening to ensure that a cross-section of society (gender, age and socioeconomic status) could attend. The focus groups were held in London, Leicester and Nottingham. A geographical spread was employed to ensure that the data did not have a London-centric bias and that they were not affected by knowledge of direct-delivery air quality information systems such as airAlert and airTEXT, which operate in the southeast.

A3.2 Awareness

People were asked about their current knowledge of environmental awareness with specific emphasis on the sources and types of air pollution and the link to climate change. Almost all participants had a good understanding of the sources of air pollution. Road traffic was perceived as the biggest contributor to poor air quality. Specific local sources such as aeroplanes/airports, industry, shipping/ports, agriculture and waste incineration were also identified. There was some confusion as to whether pollen constituted a pollutant or not, owing to the fact that it is 'natural' in origin. In terms of identifying the types of pollutants, however, only oxides of carbon (monoxide/dioxide) and methane were mentioned (usually in connection with climate change).

There was little awareness of spatial variations in air pollution within urban areas, although rural locations were perceived as 'safe spaces', i.e. a place to escape from air pollution. In terms of temporal variation, over half of the participants felt air pollution was worse in the summer, while there were no clear views concerning diurnal pollution patterns.

Perceived indicators of air quality included odours and taste, visual clues (e.g. haze), residues (e.g. dust on washing or window sills) and health effects. The health effects that were identified included shortness of breath (reported by those with and without respiratory illnesses) and headaches, wheezing and chest tightness (reported by those with respiratory illnesses).

There was a good level of awareness of the effects of air pollution on 'at-risk' groups (e.g. children, the elderly and those with respiratory illnesses). Although knowledge of the relationship between air pollution and health was highest amongst those with a health condition, general awareness of this relationship also existed in the general public. The only exception to this was in recognising the effects of air pollution on those with heart conditions, where awareness was low.

A3.3 Needs and requirements of air quality information

There was a distinct lack of awareness amongst participants concerning the existence of air pollution indices. Awareness was higher in those with emphysema and chronic obstructive pulmonary disease (COPD) compared to those with asthma or those without a health condition. Consequently, it was necessary to explore what the participants in this research would want from a new AQI; whether the provision of such information would be necessary at all, and if so, what would be the preferred method of communication.

The key information on air quality that participants would like to know included the *level* of air pollution and the *location* of the pollution (on the local rather than regional scale), and that the information should be accompanied by specific *advice* on both actions to avoid or reduce exposure to air pollution and actions to control symptom exacerbation. Only a small number of participants were interested in knowing the *type* of air pollution triggering an AQI alert.

Previous research suggested that air quality advice is often inaccessible and difficult to understand for the general population. A review of current AQI health advice in Europe, Australia, Canada and the USA indicated that there was no standard format for either the AQI structure or the accompanying health advice. In some countries, health advice was given for sensitive and non-sensitive groups separately, while in other countries combined advice was issued. Consequently, participants in the focus groups and workshops were asked their views on the current health advice that accompanies the AQIs in the UK, Australia, Canada and the USA. Health advice from Ireland was under review and therefore not available at the time of this research. Representative comments from participants included:

> **"I didn't really understand 'effects are likely to be noticed by individuals who know they are sensitive to air pollution'. No one is going to know what that is trying to say."**
>
> ***(Male, with asthma, under 25)***

> **"I like C [Canada] because I looked at the other two and, it's like when you look at the plain English campaign, they are all garbled. This [Canada] seems to be the most straightforward and simple to me, you're in a group and then you look to see if you are affected, it's simple."**
>
> ***(Male, with asthma, 35–44)***

Comments from the focus groups, workshops and from the online survey were analysed. The findings suggested that future AQI health advice should:

a be clear and concise avoiding large blocks of text

b be easy to understand

c be focused (current advice was considered vague)

d be in-depth with sufficient detail and with links to further information

e be jargon-free (e.g. 'descriptor' and 'sensitive' were considered jargon)

f contain separate health advice for susceptible and non-susceptible groups

g contain specific health and activity advice

h avoid trivialising air quality information

i avoid panic- or fear-engendering messages

j use visual cues and colours to enable those with reading difficulties to access the information

Participants were asked which colours they felt represented the extremes of air quality. Green and blue were considered best for good air quality, whilst red was preferred for poor air quality. Participants preferred air quality to be represented as a simple scale, rather than images such as traffic lights, animals or other such devices used elsewhere.

The number of 'bands' or 'points on a scale' that participants would like to see was also explored. The existing UK AQI uses a ten-point scale with four bands. However, local council and air quality websites often only report a 'band' (e.g. Low, Moderate, High or Very High) rather than using the ten-point scale. This research found that there was no clear definitive preference from the majority of participants in terms of the number of breakpoints desired. The most popular suggestion (preferred by over a third of people) was a ten-point scale. Data obtained from the focus groups indicated that there was a need for a scale that allowed greater gradation in the AQI than provided by the bands alone, as the variation in the level of air quality was felt to be lost by compressing the data into a smaller (four-point) scale.

> **"If I could get a better idea of the air pollution, I can test myself against the condition of the day and then I know at this level I can do this, and at that level I should stay in."**
>
> ***(Male, with COPD, 65+)***

> **"[Don't like] limited level levels, what affects you might not affect me and vice versa."**
>
> ***(R155 – respondent to online questionnaire)***

These findings agree with other research that suggests the current system may cause frustration due to the perceived lack of variation in air quality; however, care must be taken to ensure that there is no 'jump' between classifications. A ten-point continuous index rather than bands alone would assist with this.

A3.4 Effective information, changing behaviours

Finally, participants were asked how they would like to receive information on air quality levels and whether such information would encourage people to change their behaviour.

By far the most popular methods of communication were by television (preferred by the over 35 age group) and via the internet (preferred by those in the 16–34 age groups). Participants requested that information on air quality be delivered only when it constituted a risk to their health, but that it should be available as a daily and five-day forecast to allow them to plan ahead.

Participants were asked if they would change their behaviour as the result of receiving an air quality warning. Over half of those with a respiratory condition said that they would change their behaviour, while the same was true for only one-fifth of those without a health condition. These findings match similar research undertaken in the USA which found that those with lifetime asthma were more likely to change their behaviour in response to an air pollution alert than those without asthma.

In this study, the most frequent change in behaviour, reported by participants without a health condition, was to reduce exposure by avoiding locations that were perceived as polluted. In addition to reducing exposure, the majority of those with a respiratory condition said that they would also increase their preparedness by ensuring that they had easy access to their reliever medications.

A3.5 Conclusions and recommendations from the public insight study

It is clear from this research that there is a good awareness of the sources of air pollution and of which 'types' of individuals are most susceptible to its effects. However, participants had their own perceived indicators of air quality, which did not always match episodes of air pollution. Rural areas where high levels of ozone (O_3) pollution may occur were not generally seen as polluted and were considered 'safe spaces' to escape from air pollution. Furthermore, the current AQI was considered vague in its advice, difficult to understand and jargon-laden. Consequently, recommendations for the review of the AQI include:

a raising awareness concerning the spatial variation of air pollution and its effects on those with heart conditions and asthma

b development of an AQI that reflects a greater gradation in air pollution, to allow individuals to 'calibrate' themselves against different levels

c provision of separate health/activity advice for 'at-risk' and 'non-at-risk' groups

d provision of air quality information on the level and location of air pollution, but not necessarily the type of pollution

e use of simple, easy to understand, jargon-free language

f in-depth, focused information without large amounts of text

g pertinent, targeted health and activity advice

h use of a coloured 'scale' to allow access to information for those with reading difficulties or where English is not the first language

Annex 4

Developments in Health Evidence for Individual Index Pollutants

A4.1 Particulate matter, PM_{10} and $PM_{2.5}$

Evidence for the impact of airborne particulate matter, PM_{10} and $PM_{2.5}$, exposure on health – update since 2000

Airborne particulate matter may be either primary or secondary. Primary particles are those emitted directly from sources such as road vehicles, power stations and quarries, while secondary particles are formed from chemical reactions within the atmosphere. Sulphates, nitrates and oxidised secondary organic compounds make up the major part of the secondary organic aerosol.

The term PM_{10} is used to describe the concentration of airborne particles, measured by mass and passing an inlet with a 50% aspiration efficiency at 10 µm. $PM_{2.5}$, also referred to as 'fine particles', is defined analogously to PM_{10}, comprising particles below 2.5 µm. Consequently the measurement of PM_{10} includes $PM_{2.5}$. In the UK, $PM_{2.5}$ is typically about 70% of PM_{10}. The fraction of particles within PM_{10} that is larger than $PM_{2.5}$ is referred to as 'coarse particles' or $PM_{2.5\text{-}10}$.

The term 'ultrafine particles' describes airborne particles smaller than one–tenth of a micrometre. Ultrafine particles are highly numerous in the atmosphere but, by virtue of their small size, contribute little mass. They are a subcomponent of both $PM_{2.5}$ and PM_{10}. While some (limited) research has attributed importance to the effects of ultrafine particle exposures, there is currently insufficient knowledge of exposure-response relationships to establish an air quality guideline or to include ultrafine particles within the banding system.

The chemical composition of $PM_{2.5}$ and PM_{10} is diverse and variable in both space and time. The $PM_{2.5}$ fraction tends to be dominated by secondary inorganic sulphates and nitrates as well as secondary organic particles and primary carbonaceous particles from combustion sources, especially road traffic. In contrast, particles in the $PM_{2.5\text{-}10}$ size range are generally dominated by sea salt, soil-derived minerals and non-exhaust (abrasion) particles from road traffic. Research has shown that both fine and coarse particle fractions contribute to effects on health, but most studies have attributed a greater health impact to the fine particle fraction which penetrates more deeply into the human respiratory system. The effect of coarse particles is less well established but may still be substantial as the methods used to quantify health impacts may be less capable of detecting effects of coarse as opposed to fine particles.

Health outcomes

Knowledge of the exposure-response relationships resulting from exposure to airborne particulate matter derives primarily from three types of population-based epidemiological studies, i.e. cohort studies, time-series studies and panel studies. By far the largest volume of information derives from cohort and time-series studies (Pope and Dockery, 2006) which elucidate effects on two different timescales:

a cohort studies reveal long-term (referred to as chronic) effects relating to exposure timescales of many years

b time-series studies reveal short-term (referred to as acute) effects related to exposure timescales from a few hours to a few days

There has been very little work conducted on timescales of less than 24 hours and most knowledge of the acute effects upon health is based on day-to-day changes in air pollutant concentrations.

The acute effects of particle exposure include increases in hospital admissions and premature death of the old and sick due to diseases of the respiratory and cardiovascular systems. The evidence is that both $PM_{2.5}$ and PM_{10} cause additional hospital admissions and deaths on high pollution days. There are also less severe effects of short-term particle exposure during pollution episodes, such as worsening of asthma symptoms and even a general feeling of being unwell leading to a lower level of activity (termed reduced activity days).

Intervention studies, such as that accompanying the ban on coal sales in Dublin (Clancy et al, 2002), have shown marked health improvements as a result of pollution abatement. A meta-analysis from single-city studies adjusted for publication bias showed a 1.2% increased relative risk of mortality for a 20 $\mu g\ m^{-3}$ increase in PM_{10} (WHO, 2006), which is the same as that found across 29 European cities in the Air Pollution and Health: A European Approach 2 (APHEA2) study. The APHEA2 study also reported a 1.5% increase in relative rise of mortality from cardiovascular causes and a 1.2% increase in respiratory mortality per 20 $\mu g\ m^{-3}$ PM_{10} (Katsouyanni et al, 2001; Samoli et al, 2005). In its 2006 report, COMEAP estimated a 1.8% increase in cardiac hospital admissions as a result of a 20 $\mu g\ m^{-3}$ exposure increment in PM_{10}.

Long-term exposure to particles causes increased levels of fatal cardiovascular and respiratory diseases, including lung cancer, which reveal themselves as increased rates of death in cities with higher concentrations of airborne particles. In its 2009 report, COMEAP expressed the view that the best estimate of chronic health impacts of particulate matter exposure was a 6% increase in death rates per 10 $\mu g\ m^{-3}$ increase in $PM_{2.5}$ concentration. As with the acute effects of particle exposure, no wholly safe level has been identified.

Mechanisms

There has been a great deal of research on the mechanisms of these effects. It is likely that an inflammatory process due to oxidative stress caused by increased levels of reactive oxygen species (ROS) is responsible for many of the effects on cardiovascular and respiratory health (Donaldson et al, 2003; Kelly, 2003). The mechanisms may include increased levels of clotting factors in the blood and alterations to the vascular system, as well as effects upon heart rate variability, or possibly a combination of a number of explicit mechanisms.

Airborne particles differ greatly from place to place in their sizes and chemical composition. Despite this, the effects of $PM_{2.5}$ and PM_{10} appear to vary to only a small degree between sites across the world. There is currently no clear understanding of which particle properties, such as their size or the presence of specific chemical substances, are most responsible for their toxic effects.

References

Clancy L, Goodman P, Sinclair H and Dockery DW (2002). Effect of air-pollution control on death rates in Dublin, Ireland: an intervention study. *Lancet,* **360**, 1210–14.

COMEAP (2006). Cardiovascular Disease and Air Pollution. Department of Health. HMSO, London. Available at http://www.comeap.org.uk/documents/reports.html

COMEAP (2009). Long-Term Exposure to Air Pollution: Effect on Mortality. Health Protection Agency. Available at http://www.comeap.org.uk/documents/reports.html

Donaldson K, Stone V, Borm PJA, Jimenez LA, Gilmour PS, Schins RPF, Knappen AdM, Rahman I, Faux SP, Brown DM and MacNee W (2003). Oxidative stress and calcium signaling in the adverse effects of environmental particles (PM_{10}). *Free Radic Biol Med,* **34**, 1369–82.

Katsouyanni K, Touloumi G, Samoli E, Gryparis A, Le Tertre A, Monopolis Y, Rossi G, Zmirou D, Ballester F, Boumghar A, Anderson HR, Wojtyniak B, Paldy A, Braunstein R, Pekkanen J, Schindler C and Schwartz J (2001). Confounding and effect modification in the short-term effects of ambient particles on total mortality: results from 29 European cities within the APHEA2 Project. *Epidemiology,* **12**, 521–31.

Kelly FJ (2003). Oxidative stress: its role in air pollution and adverse health effects. *Occup Environ Med,* **60**, 612–16.

Pope CA III and Dockery DW (2006). Health effects of fine particulate air pollution: lines and connect. *J Air Waste Manage Assoc,* **56**, 709–42.

Samoli E, Analitis A, Touloumi G, Schwartz J, Anderson HR, Sunyer J, Bisanti L, Zmirou D, Vonk JM, Pekkanen H, Goodman P, Paldy A, Schindler C and Katsouyanni K (2005). Estimating the exposure-response relationships between particulate matter and mortality within the APHEA Multicity Project. *Environ Health Perspect,* **113**, 88–95.

WHO (2006). Air Quality Guidelines. Global Update 2005. Particulate Matter, Ozone, Nitrogen Dioxide and Sulfur Dioxide. World Health Organization, Copenhagen.

A4.2 Sulphur dioxide, SO_2

Evidence for the impact of sulphur dioxide exposure on health – update since 2000

In the UK sulphur dioxide (SO_2) is largely emitted from industrial sources including power stations but there are also occasional contributions due to transport events on easterly air masses from continental Europe. The contribution from motor vehicle exhausts has been much reduced over this period of time due to the use of low sulphur fuels.

This gas is a respiratory irritant and short-term exposures can exacerbate asthma (which formed the basis for the Expert Panel on Air Quality Standards (EPAQS) Air Quality Standard in 1995), while longer-term exposures are associated with the development of chronic bronchitis/mucus hypersecretion.

Since the review by EPAQS there have been a number of epidemiological studies confirming clear associations between SO_2 and specific health endpoints, both respiratory and cardiovascular.

The 2006 COMEAP report on cardiovascular disease and air pollution summarised the epidemiological studies published up to that date, showing a clear association between short-term exposures (24 hour) and cardiovascular deaths, cardiovascular admissions and ischaemic heart disease admissions. There is no clear association between admissions for heart failure or cerebrovascular disease. The evidence is less strong for effects from long-term exposures.

These effects are seen in both the European and the American literature, although the findings are not always consistent. However, in the American Cancer Society (ACS) study there is a clear association between cardiovascular mortality and SO_2 with an odds ratio of 1.48 (95% confidence interval, CI, 1.33–1.64) in the summer months and 1.29 (95% CI 1.2–1.38) for the winter months (Pope et al, 2002).

Cardiovascular disease

The literature since 2000 on sulphur dioxide and cardiovascular disease is limited and has reinforced existing knowledge rather than added new information. For instance, studies from Taiwan (Liang et al, 2009) and China (Guo et al, 2009) show clear relationships between cardiovascular deaths, particularly in the elderly, and hospital emergency room treatment for cardiovascular disease in single pollutant models. In the Air Pollution and Health: A European Approach 2 (APHEA2) study, an effect size on hospital admissions for cardiovascular disease was 0.7% for a 10 $\mu g\ m^{-3}$ rise in SO_2 (Sunyer et al, 2003), although a study in Canada by Stieb (2009) found no association between SO_2 and emergency room visits for cardiovascular disease.

A study of long-term exposure on myocardial infarction was negative overall (Rosenlund et al, 2006), although there was a suggestion that out-of-hospital deaths were associated with SO_2 exposure, perhaps indicating an impact through arrhythmia production. A study by Wang (2008) and colleagues from Australia found a 4.7% increase in cardiopulmonary mortality for a 1 ppb annual increment in SO_2.

Respiratory disease

For respiratory disease the additional evidence is less clear. One study of asthma admissions in children (Stieb, 2009) was negative, while respiratory deaths in Taiwan were associated with SO_2 exposure, particularly in the elderly (Liang et al, 2009). Overall, the epidemiology confirms, albeit inconsistently, associations of SO_2 exposure with respiratory admissions in both the young and the elderly.

Mechanisms

There has been relatively little work on mechanisms of SO_2 over the last decade. One study (Routledge et al, 2006) of SO_2 exposure in people with coronary artery disease showed that SO_2 reduced high frequency power – a marker of heart rate variability which relates to vagal activity – in the healthy elderly, with no such impact in patients with cardiac disease. This suggests that SO_2 reduces the cardioprotective effect of vagal activity. This would cohere with the epidemiology in terms of increasing susceptibility in patients with coronary artery disease to other factors which might initiate an event.

A series of animal studies has suggested differential effects on sensitisation to ovalbumin. In a study on asthmatic rats, co-exposure to 2 ppm of SO_2 and ovalbumen produced an increase in Bcl-2 and a decrease in p53 and Bax RNA, all apoptosis-related genes (Xie et al, 2009). The same group, using the same exposure conditions, also showed significant increases in epidermal growth factor, epidermal growth factor receptor and COX-2 mRNA expression. This suggests that SO_2 may have the capability to enhance the response of allergens to which individuals might be sensitised. If this shown in humans, it would be analogous to the findings already shown for SO_2 and NO_2.

In a long-term study in rats, exposure to 20 ppm SO_2 was associated with airway remodelling and mucus hypersecretion (Wagner et al, 2006).

In summary, there is increasing evidence that SO_2 exposure is an important cause of cardiovascular death and hospital admissions and, while the evidence for influencing COPD admissions remains less strong, there is increasing mechanistic evidence to suggest that SO_2 continues to be an important source of respiratory exposure in both the short and long term.

References

COMEAP (2006). Cardiovascular Disease and Air Pollution. Department of Health. HMSO, London. Available at http://www.comeap.org.uk/documents/reports.html

EPAQS (Expert Panel on Air Quality Standards) (1995). A Recommendation for a United Kingdom Air Quality Standard for Sulphur Dioxide. Department of the Environment. HMSO, London.

Guo Y-M, Zhao A-L and Liu L-Q (2008). Association between sulfur dioxide air pollution and hospital emergency treatment for circulatory diseases: a case-crossover study. *J Environ Health,* **25**, 1035–8.

Liang W, Wei H and Kuo H (2009). Association between daily mortality from respiratory and cardiovascular diseases and air pollution in Taiwan. *Environ Res,* **109**, 51–8.

Pope CA III, Burnett RT, Thun MJ, Krewski D, Ito K and Thurston GD (2002). Lung cancer, cardiopulmonary mortality, and long-term exposure to fine particulate air pollution. *JAMA,* **287**, 1132–41.

Rosenlund M, Berglind N, Pershagen G, Hallqvist J, Jonson T and Bellander T (2006). Long-term exposure to urban air pollution and myocardial infarction. *Epidemiology,* **17**, 383–90.

Routledge HC, Manney S, Harrison RM, Ayres JG and Townend JN (2006). Effect of inhaled sulphur dioxide and carbon particles on heart rate variability and markers of inflammation and coagulation in human subjects. *Heart,* **92**, 220–27.

Stieb DM (2009). Air pollution and emergency department visits for cardiac and respiratory conditions: a multi-city time-series analysis. *Environ Health,* **8**, 25.

Sunyer J, Ballester F, Tertre AL, Atkinson R, Ayres JG, Forastiere F, Forsberg B, Vonk JM, Bisanti L, Tenías JM, Medina S, Schwartz J and Katsouyanni K (2003). The association of daily sulfur dioxide air pollution levels with hospital admissions for cardiovascular diseases in Europe (The Aphea-II study). *Eur Heart J,* **24**(8), 752–60.

Wang X (2008). Spatial analysis of long-term exposure to air pollution and cardiorespiratory mortality in Brisbane, Australia. Available at http://eprints.qut.edu.au/16627/

Wagner U, Staats P, Fehmann HC, Fischer A, Welte T and Groneberg DA (2006). Analysis of airway secretions in a model of sulfur dioxide induced chronic obstructive pulmonary disease (COPD). *J Occup Med Toxicol,* **1**, 12.

Xie J, Li R, Fan R and Meng Z (2009). Effects of sulfur dioxide on expressions of p53, bax and bcl-2 in lungs of asthmatic rats. *Inhal Toxicol,* **11**, 952–7.

A4.3 Ozone, O_3

Evidence for the impact of ozone exposure on health – update since 2000

In the UK, ozone (O_3) accumulates as a secondary air pollutant following atmospheric photochemical reactions involving oxides of nitrogen (NO_X) and volatile organic chemicals (VOCs). It is therefore predominantly a summertime pollutant whose levels are greatest in the countryside outside major conurbations because of the finite time required for its generation. Indeed, in towns and cities O_3 ground-level concentrations are often low because of its chemical reaction with NO from vehicle emissions to form NO_2. Ozone may also be generated from pollutants originating in the continental air mass and be transported to the UK under certain meteorological conditions.

On account of its close link to traffic emissions and extended periods of sunshine, O_3 air pollution episodes often coincide with heat waves – as occurred in Paris in 2003 – and interactions between the adverse health effects of heat and O_3 pollution are difficult to disentangle. In general, temperature-related effects rather than O_3 exert the greatest health impacts on the older population during a heat wave.

Ozone is a respiratory irritant that formed the endpoint upon which the EPAQS Air Quality Standard was based (EPAQS, 1994). Chamber studies revealed that O_3 was an irritant gas to both healthy individuals and those with lung disease. In addition, it is a powerful oxidant that reacts to cause epithelial cell damage and inflammation, driven in large part by an influx of neutrophil leukocytes. Naturally occurring antioxidants generated by the lung offer some protection against these effects. In addition, dietary antioxidants are reported to offer some protection against O_3-induced effects (Behndig et al, 2009). There is some evidence that the bronchoconstrictor effects of inhaled O_3 decrease with age (Hazucha et al, 2003), suggesting that children and young adults may be more sensitive.

Since the EPAQS 1994 report, there has been increasing epidemiological evidence that short-term exposure to O_3 has important adverse effects on asthmatics, with evidence for increased demands on the National Health Service. Epidemiological studies have also identified O_3 as a pollutant that enhances cardiovascular disease probably through its pro-inflammatory effects on the lung (Cole and Freeman, 2009).

Respiratory disease

The literature since 2000 on O_3 is extensive. The main findings are that exacerbations of asthma can occur at lower atmospheric concentrations than previously appreciated (Strickland et al, 2010), that additive interactions occur with other pro-asthmatic stimuli, such as pollen allergen exposure (Eggleston, 2009) and other pollutants, and that there are specific genetic variations that influence the inflammatory and irritant responses to O_3 (Bauer and Kleeberger, 2010). There is also accumulating evidence that asthmatic airways respond to O_3 exposure with an enhanced inflammatory response as compared to those of allergic but non-asthmatic subjects (Hernandez et al, 2010).

A recently observed effect of O_3 on the lungs is its capacity to slow airway growth and therefore result in reduced baseline lung function in children who are repeatedly exposed to high concentrations (Islam et al, 2007). This effect is unlikely to be relevant to O_3 levels generally encountered in the UK.

In addition to asthma, O_3 episodes are associated with increased respirator morbidity in older people, especially those with co-existent chronic obstructive lung disease (Halonen et al, 2010) and the genetic variant of emphysema, alpha-1 antitrypsin deficiency (Wood et al, 2010). During the recent H1N1 influenza pandemic, O_3 also increased the risk of hospital admission for this infection (Wong et al, 2010).

Overall, O_3 exposure, along with PM_{10} exposure, is associated with higher mortality rates in studies reporting coefficients (effect sizes) which are larger than previously estimated from the primarily time-series studies for England (Janke et al, 2010). This represents a mixture of respiratory and cardiovascular events.

Cardiovascular disease

While most of the short-term adverse health effects of O_3 are attributed to asthma and allied disorders, there is mounting evidence that this pollutant is also associated with myocardial infarction (Henrotin et al, 2010; Peel et al, 2010) and cardiac arrhythmias (Chiu and Yang, 2010) in the older population.

Despite some evidence for cardiovascular effects of O_3, the majority of morbidity attributable to short-term O_3 exposure is respiratory in nature.

References

Bauer AK and Kleeberger SR (2010). Genetic mechanisms of susceptibility to ozone-induced lung disease. *Ann NY Acad Sci,* **1203**, 113–19.

Behndig AF, Blomberg A, Helleday R, Duggan ST, Kelly FJ and Mudway IS (2009). Antioxidant responses to acute ozone challenge in the healthy human airway. *Inhal Toxicol,* **21**(11), 933–42.

Chiu HF and Yang CY (2009). Air pollution and emergency room visits for arrhythmias: are there potentially sensitive groups? *J Toxicol Environ Health A,* **72**(13), 817–23.

Cole MP and Freeman BA (2009). Promotion of cardiovascular disease by exposure to the air pollutant ozone. *Am J Physiol Lung Cell Mol Physiol,* **297**(2), L205–8.

Eggleston PA (2009). Complex interactions of pollutant and allergen exposures and their impact on people with asthma. *Pediatrics,* **123**(Suppl 3), S160–67.

EPAQS (Expert Panel on Air Quality Standards) (1994). A Recommendation for a United Kingdom Air Quality Standard for Ozone. Department of the Environment. HMSO, London.

Halonen JI, Lanki T, Tiittanen P, Niemi JV, Loh M and Pekkanen J (2010). Ozone and cause-specific cardiorespiratory morbidity and mortality. *J Epidemiol Community Health,* **64**(9), 814–20.

Hazucha MJ, Folinsbee LJ and Bromberg PA (2003). Distribution and reproducibility of spirometric response to ozone by gender and age. *J Appl Physiol,* **95**(5), 1917–25.

Henrotin JB, Zeller M, Lorgis L, Cottin Y, Giroud M and Béjot Y (2010). Evidence of the role of short-term exposure to ozone on ischaemic cerebral and cardiac events: the Dijon Vascular Project (DIVA). *Heart,* **96**, 1990–1996.

Hernandez ML, Lay JC, Harris B, Esther CR Jr, Brickey WJ, Bromberg PA, Diaz-Sanchez D, Devlin RB, Kleeberger SR, Alexis NE and Peden DB (2010). Atopic asthmatic subjects but not atopic subjects without asthma have enhanced inflammatory response to ozone. *J Allergy Clin Immunol,* **126**, 537–44.

Islam T, Gauderman WJ, Berhane K, McConnell R, Avol E, Peters JM and Gilliland FD (2007). Relationship between air pollution, lung function and asthma in adolescents. *Thorax,* **62**(11), 957–63.

Janke K, Propper C and Henderson J. Do current levels of air pollution kill? The impact of air pollution on population mortality in England. *Health Econ,* **18**(9), 1031–55.

Peel JL, Klein M, Flanders WD, Mulholland JA and Tolbert PE (2010). Impact of improved air quality during the 1996 Summer Olympic Games in Atlanta on multiple cardiovascular and respiratory outcomes. HEI Health Review Committee. *Res Rep Health Eff Inst,* **148**, 3–23.

Strickland MJ, Darrow LA, Klein M, Flanders WD, Sarnat JA, Waller LA, Sarnat SE, Mulholland JA and Tolbert PE (2010). Short-term associations between ambient air pollutants and pediatric asthma emergency department visits. *Am J Respir Crit Care Med,* **182**(3), 307–16.

Wong CM, Yang L, Thach TQ, Chau PY, Chan KP, Thomas GN, Lam TH, Wong TW, Hedley AJ and Peiris JS (2009). Modification by influenza on health effects of air pollution in Hong Kong. *Environ Health Perspect,* **117**(2), 248–53.

Wood AM, Harrison RM, Semple S, Ayres JG and Stockley RA (2010). Outdoor air pollution is associated with rapid decline of lung function in alpha-1-antitrypsin deficiency. *Occup Environ Med,* **67**(8), 556–61.

A4.4 Nitrogen dioxide, NO_2

Evidence for the impact of nitrogen dioxide exposure on health – update since 2000

There are several oxides of nitrogen (NO_X) in the ambient atmosphere but the principal compound in terms of *direct* health effects is nitrogen dioxide (NO_2) The main man-made source of NO_X emissions is fossil fuel combustion, which emits primarily NO and NO_2, with NO being the predominant component in most systems, usually comprising around 90–95% of the total emission.

In the UK the transport sector emits about half of the NO emissions and industry, including electricity generation, emits the other half. In large cities such as London, road transport can account for up to two-thirds of NO emissions.

NO_2 is formed in the air by oxidation of NO. Exhaust emission technology introduced to control particulate emissions in the transport sector has led to increasing proportions of NO_X emissions being released directly as NO_2.

Exposure to elevated concentrations of NO_2 has been linked with a range of respiratory symptoms including bronchoconstriction, increased bronchial reactivity, airway inflammation, and decreases in immune defence leading to increased susceptibility to respiratory infection.

Controlled exposure studies assessing the health effects of short-term exposures to NO_2 show health effects at lower levels more consistently in asthmatics than non-asthmatics, and both chamber studies and some epidemiological studies suggest NO_2 exposure enhances response to allergen in those who are sensitised.

Some indoor studies suggest stronger associations of respiratory health with NO_2 in females compared to males, but it is not clear whether this is due to women spending more time indoors or has an underlying biological basis.

Similarly, population-based studies have shown health effects of chronic indoor NO_2 exposure in infants, children and adults, but it is unknown if this is also the case for long-term outdoor exposure to NO_2.

There is no evidence for a NO_2 threshold in epidemiological studies and the exposure-response effect of repeated, daily, peak exposures to NO_2 is unknown.

Respiratory disease

A systematic review of NO_2 health effects was published in 2009 and included 41 exposure scenarios from 28 studies (Goodman et al, 2009). Exposure to NO_2 was associated with increases in airway reactivity and this is remarkably consistent across studies. There is sufficient evidence of a causal relationship between controlled exposure to NO_2 concentrations as low as 380–560 $\mu g\ m^{-3}$ for periods of one hour or longer and a range of responses within the lung suggestive of airway inflammation and alteration in lung immune defences in asthmatics.

Other diseases

NO_2 is increasingly being implicated in a wide range of disorders. For example, increased risk of otitis media (Brauer et al, 2006), eczema (Morgenstern et al, 2008), ear/nose/throat infections and sensitisation to food allergens (Brauer et al, 2007) in children, as well as an increased blood coagulability after periods of elevated ambient exposure in adults (Baccarelli et al, 2007).

Mechanisms

It is apparent from both *in vitro* and animal toxicology studies, which toxic effects of NO_2 *might* occur in humans. However, owing to: (a) the frequent use of extremely high exposure concentrations in experimental studies, (b) the inherent differences between mammalian species, and (c) the dearth of information available on tissue response of different species to a given dose of NO_2, it is difficult to extrapolate quantitatively, with any degree of confidence, the effects that are *actually* caused by a specific inhaled dose or concentration.

In summary, evidence from animal toxicological studies indicates that long-term exposure to NO_2 at concentrations above current ambient levels has adverse effects. In population studies, NO_2 has been associated with adverse health effects even when the annual average NO_2 concentration complied with the WHO annual guideline value of 40 μg m^{-3} (WHO, 2006). However, since NO_2 is an important constituent of combustion-generated air pollution, and is highly correlated with other primary and secondary combustion products, it is still unclear to what extent the health effects observed in epidemiological studies are attributable to NO_2 itself or to other correlated pollutants.

References

Baccarelli A, Zanobetti A, Martinelli I, Grillo P, Hou L, Giacomini S, Bonzini M, Lanzani G, Mannucci PM, Bertazzi PA and Schwartz J (2007). Effects of exposure to air pollution on blood coagulation [see comment]. *J Thromb Haemost,* **5**(2), 252–60.

Brauer M, Gehring U, Brunekreef B, de Jongste J, Gerritsen J, Rovers M, Wichmann HE, Wijga A and Heinrich J (2006). Traffic-related air pollution and otitis media. *Environ Health Perspect,* **114**(9), 1414–18.

Brauer M, Hoek G, Smit HA, de Jongste JC, Gerritsen J, Postma DS, Kerkhof M and Brunekreef B (2007). Air pollution and development of asthma, allergy and infections in a birth cohort. *Eur Respir J,* **29**(5), 879–88.

Goodman J, Chandalia J, Thakali S and Seeley M (2009). Meta-analysis of nitrogen dioxide exposure and airway hyperresponsiveness in asthmatics. *Crit Rev Toxicol*, **39**(9), 719–42.

Morgenstern V, Zutavern A, Cyrys J, Brockow I, Koletzko S, Krämer U, Behrendt H, Herbarth O, von Berg A, Bauer CP, Wichmann HE and Heinrich J; GINI Study Group; LISA Study Group (2008). Atopic diseases, allergic sensitization, and exposure to traffic-related air pollution in children. *Am J Respir Crit Care Med,* **177**(12), 1331–7.

WHO (2006). Air Quality Guidelines. Global Update 2005. Particulate Matter, Ozone, Nitrogen Dioxide and Sulfur Dioxide. World Health Organization, Copenhagen.

A4.5 Carbon monoxide, CO

Evidence for the impact of carbon monoxide exposure on health – update since 2000

Carbon monoxide (CO), a toxic gas which competes very successfully with oxygen for binding sites on haemoglobin, reduces the amount of oxygen transported in the blood, and reduces the efficiency of off-loading of oxygen at the tissues.

CO kills at concentrations significantly higher than those found outdoors in the UK. Deaths due to indoor exposure continue to occur: these are often due to malfunctioning gas heating appliances.

Guidelines and standards devised to protect against the adverse effects of ambient exposure to CO are based on the view that the toxicological effects of CO are largely due to binding with haemoglobin. It has been accepted that if the carboxy-haemoglobin (COHb) concentration in blood (expressed as a percentage: COHb/Hb x 100) is kept below 2.5%, toxicological effects are unlikely (EPAQS, 1994; WHO, 1987, 2000).

Cardiovascular disease

The COMEAP report on cardiovascular disease and air pollution concluded that there was limited evidence from time-series studies of associations between peak hourly concentrations of CO and admissions to hospital for treatment of acute myocardial infarctions (COMEAP, 2006).

It is generally considered that these associations are not due to CO *per se*. It is thought that CO acts as a proxy for other motor-vehicle-generated pollutants including fine particles. However, other groups have noted that CO remains robust in co-pollutant models, which might suggest a direct effect of short-term ambient exposure to CO on cardiovascular disease morbidity (see, for example, US EPA, 2010).

Central nervous system effects

There is evidence that both short- and long-term exposure to high concentrations of CO can lead to lasting damage to the central nervous system. This may be due to processes unrelated to the binding of CO to haemoglobin (US EPA, 2010).

Mechanisms

Since 2000, research has focused on non-hypoxic mechanisms of CO action. High concentrations of CO can disrupt cellular signalling and studies have shown evidence for involvement in the inhibition of cytochrome oxidase, disruption of iron homeostasis and modulation of protein kinase pathways. Animal studies have demonstrated oxidative injury and inflammation in response to 50–100 ppm CO (US EPA, 2010).

Mechanistic studies generally involve exposure to concentrations of CO rather higher than ambient concentrations so whether these mechanisms play a part at ambient concentrations remains unknown.

In summary, evidence of health effects is associated with exposure to CO at concentrations significantly higher than those found outdoors in the UK. Outdoor concentrations of CO in the UK are now low and expected to continue to fall in urban areas of the UK.

References

COMEAP (2006). Cardiovascular Disease and Air Pollution. Department of Health. HMSO, London. Available at http://www.comeap.org.uk/documents/reports.html

EPAQS (Expert Panel on Air Quality Standards) (1994). A Recommendation for a United Kingdom Air Quality Standard for Carbon Monoxide. Department of the Environment. HMSO, London.

US EPA (2010). Integrated Science Assessment for Carbon Monoxide (Final Report). EPA/600/R-09/019F. Available at http://cfpub.epa.gov/ncea/isa/recordisplay.cfm?deid=218686

WHO (1987). Air Quality Guidelines for Europe. WHO Regional Publications. European Series, No. 23. World Health Organization, Copenhagen.

WHO (2000). Air Quality Guidelines for Europe. 2nd edition. WHO Regional Publications. European Series, No. 91. World Health Organization, Copenhagen.

Annex 5

Air Quality Monitoring and Modelling in the UK

COMEAP would like to thank Clare Bayley at the Department for Environment, Food and Rural Affairs for this work.

A5.1 Air quality monitoring

The Department for Environment, Food and Rural Affairs (Defra) undertakes a range of air quality and air pollution monitoring. Monitoring plays a key role in identifying emerging issues and guiding the future policies which will be needed to address them. There are currently over 400 national air quality monitoring sites across the UK, organised into automatic and non-automatic networks. Each of these has different objectives, scope and coverage. The automatic networks provide near real-time data, accessible to the public through the UK Air Information Resource website (http://uk-air.defra.gov.uk). The non-automatic sites measure average concentrations over a specified sampling period (typically from a day to a month), providing invaluable data for assessing levels and impacts of pollution across the country as a whole.

Defra monitors the concentration and deposition of a wide variety of air pollutants, their precursors and their components, across the UK. The monitoring programme is split into ten networks, which are listed below and described in more detail in Table A5-1.

a. Automatic Urban and Rural Network (AURN) measuring concentrations of PM_{10}, $PM_{2.5}$, NO_2 and NO_X, SO_2, O_3 and CO
b. Hydrocarbons (automatic and non-automatic)
c. Heavy metals concentrations
d. PAH monitoring
e. Particle numbers and concentrations
f. Heavy metals deposition
g. Black carbon
h. Acid waters
i. UK Eutrophying and Acidifying Pollutants (UKEAP)
j. European Monitoring and Evaluation Programme (EMEP)

The monitoring networks are complemented by air quality modelling predictions (see Section A5.2).

The Automatic Urban and Rural Network (AURN), PAH monitoring, heavy metals concentrations, and hydrocarbons networks are all structured around providing data in accordance with the requirements of the European Directives (summarised in Table A5-2). These Directives are prescriptive as to the pollutants to be measured, number of sites operated, the site type (roadside, urban background or rural) and monitoring technique.

Table A5-1: Defra air quality and air pollution monitoring networks

Network	Number of sites	Description and primary function
Automatic Urban and Rural Network (AURN)	130	**Statutory** Largest UK network consisting of automatic monitoring equipment measuring concentrations of PM_{10}, $PM_{2.5}$, NO_2 and NO_X, SO_2, O_3 and CO. Delivers near real-time air quality measurements in compliance with the Ambient Air Quality Directive (2008/50/EC)
UK ambient automatic and non-automatic hydrocarbon air quality networks	35	**Statutory** Provides information on compliance with the Ambient Air Quality Directive for benzene. Also provides information on 1,3-butadiene for comparison with the UK Air Quality Objective, information on O_3 precursors and long-term trend datasets for hydrocarbons (mainly) in urban areas. Uses both automatic and non-automatic measurement techniques
Monitoring particle numbers and concentrations	4	Research to inform possible policy developments for a new metric for ultrafine particles/nanoparticles, thought to be the main agent of health damage and a possibility for inclusion in the review of the Air Quality Directive in 2013. Forms part of the DH/HPA/MRC/NERC research programme on health effects of ultrafine particles
UK black carbon network	21	Provides a long-term dataset on combustion-derived particles going back to the early 1960s. Black carbon/black smoke is thought to provide a good metric for the particle types most likely to give rise to health effects and the measurements are used by DH and HPA in their research programme on health effects. It is being considered as a possible metric for particulate matter in the review of the Air Quality Directive in 2013
EMEP Supersites	2	Two European Monitoring and Evaluation Programme (EMEP) Supersites are used to collect concentration data for a wide range of pollutants to meet the UK EMEP measurement obligations. These sites combine measurements from existing Defra-funded monitoring networks alongside other specific measurements for particle characterisation. The EMEP observations are important elements in establishing the regional air pollution situation in Europe and its links to both the global and the urban scales Provides data to support the development and further evaluation of the international protocols on emission reductions negotiated within the Convention on Long Range Transboundary Air Pollution (CLRTAP)

Table A5-1 *continued*

Network	Number of sites	Description and primary function
UK Eutrophying and Acidifying Atmospheric Pollutants network (UKEAP)	104	Consists of four networks measuring concentrations of acidifying and eutrophying air pollutants, such as ammonia, ammonium, nitric acid and sulphate. Provides information on spatial distribution and trends of wet deposition loads of eutrophying and acidifying substances, concentrations of such species in air, and rural concentrations of particulate sulphate and nitrate Provides data for compliance checking/input to the Convention on Long Range Transboundary Air Pollution (CLRTAP) Gothenburg Protocol and coordination of the UK input to the UNECE European Monitoring and Evaluation Programme (EMEP). Linked with models to provide evidence for UK policies and European/international negotiations
UK acid waters monitoring network	18	Provides a long-term dataset on the extent of acidic deposition across the UK, and the chemical and biological quality of freshwaters and is the cornerstone of the evaluation of policies under the National Emissions Ceilings Directive and the UNECE Protocols to combat acidification and eutrophication of freshwater ecosystems Provides data to underpin future policy development within the UNECE Convention on Long Range Transboundary Air Pollution and the review of the National Emission Ceilings Directive, and also has a national environmental change monitoring role as part of the Environmental Change Network Provides data for compliance checking/input to the Convention on Long Range Transboundary Air Pollution (CLRTAP) Gothenburg Protocol and National Emissions Ceilings Directive
PAH monitoring network	31	**Statutory** Non-automatic measurement of PAH, providing information on compliance with the Ambient Air Quality Directive (2008/50/EC) and 4th Air Quality Daughter Directive (2004/107/EC). Provides data for compliance checking/input to the Convention on Long Range Transboundary Air Pollution (CLRTAP)
Heavy metals monitoring network (rural/urban/ industrial network)	24	**Statutory** Non-automatic measurement of a range of heavy metals, providing information on compliance with the Ambient Air Quality Directive (2008/50/EC) and 4th Air Quality Daughter Directive (2004/107/EC). Provides data for compliance checking/input to the Convention on Long Range Trans-boundary Air Pollution (CLRTAP) Aarhus Protocol on Heavy Metals
Heavy metals monitoring network (rural network)	15	Provides information on background metal concentrations in air and bulk deposition at rural sites across the UK Provides data for compliance checking/input to the Convention on Long Range Transboundary Air Pollution (CLRTAP) Aarhus Protocol on Heavy Metals. Provides evidence for UK policies and European/international negotiations. The 4th Air Quality Daughter Directive requires monitoring of arsenic, nickel, cadmium and mercury to be undertaken. Also provides data to meet UK commitments under the terms of the Hague Declaration and the Oslo and Paris Conventions (OSPARCOM)

The UK Eutrophying and Acidifying Pollutants (UKEAP), heavy metal deposition, and EMEP Supersite networks assess the progress in the UK against the UK commitments under the EU 6th Environmental Action Programme, UNECE Convention on Long Range Transboundary Air Pollution (CLRTAP) and the European Monitoring and Evaluation Programme (EMEP). These activities also provide data which have been, and will be, used to inform negotiations on the UK binding emission ceilings under the National Emissions Ceilings Directive*.

The black carbon and acid waters monitoring networks provide important trend data. The particle numbers and concentrations network provides information on particulate matter, and specific components of particulate matter, using metrics which are not yet part of the legislative framework. The information from these networks is important for understanding the sources and effects of particulate matter to inform more targeted policies, which are focused on the pollutant with the dominant impact on public health.

All of these data are publicly available through the internet, and the UK Air Information Resource website provides a central source of data for regulators, researchers and the public.

Local authority monitoring

Under the Environment Act 1995, local authorities are required to "review and assess the quality of air in their area" (Local Air Quality Management or LAQM). As a part of this process, most local authorities undertake air quality monitoring of the same pollutants as those covered by the AURN. For some authorities, especially those in rural areas, this consists of little more than indicative monitoring (diffusion tubes) and/or occasional 'campaign-type' monitoring where a mobile monitoring unit is placed in a location for a short time to provide data on a particular local situation. While this type of work is helpful in allowing a local authority to understand the local pollution climate, Defra cannot use these data to show compliance with the EU Limit Values as they does not meet the data requirements of the Ambient Air Quality Directive (see Table A5-2).

Many local authorities operate one or more automatic monitoring stations of the type deployed in the AURN. In some circumstances, the stations may be placed in locations which are of interest to the local authority but are inappropriate for Defra's purposes. For example, the local authority may be interested in monitoring nitrogen dioxide or particulate levels close to a busy road junction, whereas the Ambient Air Quality Directive specifically excludes such locations from its siting criteria. In addition, as a result of local budget or other constraints, the quality control and servicing arrangements for the station may not be of the standard required under the Directive. In both of these cases, the data produced by the station will not meet Defra's requirements.

However, there are a large number of stations which meet both the siting and data quality requirements of the Directive and moreover meet Directive requirements for monitoring in that area. In such cases, and where the local authority is agreeable, Defra 'affiliates' the station into the AURN. This means that the local authority retains ownership of and responsibility for

* The 6th Action Programme sets a target of achieving compliance with critical loads – a measure of ecosystem damage – across Europe. The achievement of critical loads is a strong driver for national emissions ceilings prescribed in the National Emissions Ceilings Directive and Gothenburg Protocol (under CLRTAP).

Table A5-2: European legislation requiring air quality monitoring (available at http://ec.europa.eu/environment/air/quality/legislation/existing_leg.htm)

Ambient Air Quality Directive (2008/50/EC)

Sets out assessment (monitoring) requirements and limit and target values for PM_{10}, $PM_{2.5}$, NO_2 and NO_X, SO_2, O_3, lead, benzene and CO

Article 6 and Annex III set out the basic requirements, including siting criteria for PM_{10}, $PM_{2.5}$, NO_2 and NO_X, SO_2, lead, benzene and CO

Article 6(5) requires the monitoring of chemical components of particulate matter at rural background locations and requires member states to cooperate with the EMEP monitoring strategy and measurement programme

Article 7 and Annex V set out the number of monitoring points requires in each 'zone' within a member state

Article 7(3) allows member states to reduce this number by 50% where 'supplementary assessment methods' are used (reported), providing certain criteria are met

Article 8 and Annex VI prescribe the measurement methods to be used. Annex VI also allows member states to use other measurement methods where these can be shown to be equivalent to the 'reference method'. The Commission provides guidance on the assessment of equivalence.

Article 9–11 and Annexes VII, VIII and IX repeat the same requirements for ozone

Article 10(6) and Annex X require the monitoring of ozone precursor substances (listed) of at least one site in the member state

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4th Daughter Directive (2004/107/EC)

Sets out assessment (monitoring) requirements and target values for arsenic, cadmium, mercury, nickel and polycyclic aromatic hydrocarbons (PAH). Likely to be consolidated with 2008/50/EC in about 2013

Article 4 sets out the monitoring requirements, with Annex III specifying the siting requirements for monitoring and the number of monitors required

Annex IV sets out data quality requirement and Annex V sets out the monitoring methods to be used

Article 4(8) specifies a list of PAH species which have to be monitored in addition to benzo(a)pyrene (the compound used as a marker in setting target values)

Article 4(9) requires the siting of rural background sites and requires member states to cooperate with the EMEP monitoring strategy and measurement programme

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1999 Protocol to Abate Acidification Eutrophication and Ground Level Ozone (Gothenburg Protocol

Article 8 requires parties to "encourage research, development, monitoring and cooperation related to:

> (c) the improvement of monitoring techniques and systems [for] concentrations and deposition of sulphur, nitrogen compounds and volatile organic compounds, as well as of the formation of ozone and secondary particulate matter
>
> (g) the identification of trends over time [of the effects and concentrations of acidifying and eutrophying compounds and tropospheric ozone]"

the equipment, but Defra pays for the quality assurance and quality control services to ensure data quality. Currently, 53% of sites in the AURN are affiliate sites.

There remain a significant number of local authority stations which, while they meet Directive siting and data quality requirements, are surplus to Defra's needs under the Directive. They provide the local authority with information about its area which it requires to meet both LAQM and local planning and other purposes. For example, the non-AURN sites in the London Air Quality Network fit this description. These provide Defra with an independent, high quality dataset with which Defra's modelling outputs can be compared. Such data are not collected for use on the UK Air Information Resource website, although this is being reviewed as new data collection and handling techniques are developed.

A5.2 Air quality modelling

Air quality modelling can help to explain how guidelines and targets are exceeded, and identify sources of the pollution. Modelling also helps policy-makers determine how air quality will change in the future and what action will be required to meet air quality guidelines and targets.

The European Directives on air quality allow member states to replace expensive monitoring with air quality model predictions. Defra relies upon models to provide air quality assessments across the rural areas of the UK, replacing the large number of monitoring sites that otherwise would be required. Local air quality management would be prohibitively expensive and technically difficult to manage if it were based on monitoring data alone.

However, a combination of monitoring and modelling has been found to be highly cost-effective and has allowed local authorities to develop robust air quality plans for their heavily-trafficked urban areas.

Air quality modelling has made an important contribution to Defra's policymaking through the investigation of the basic atmospheric science that drives such processes as the deposition of acidic and eutrophying substances and the formation of ground-level ozone, O_3.

New underpinning science can dramatically influence the balance between the import of pollutants through long-range transboundary transport and local UK formation, for example. Sometimes, inexplicable changes are observed by the air quality networks and air quality modelling can offer a quantitative explanation.

Models are used to tackle a wide range of policy-relevant issues:

a Dispersion models are often used in public and planning inquiries to visualise and map the likely pollution footprints from new and existing developments and processes

b Empirical models such as those in the Pollution Climate Mapping (PCM) project are used for Defra's compliance assessment reporting for the European Directives on air quality. The Master Chemical Mechanism, for example, provides an elegant and systematic means for compiling the many thousands of chemical reactions that drive ground-level O_3 formation c The Photochemical Trajectory Model (PTM) has been used to provide a first attempt at understanding the individual chemical components that make up the measured mass of particles (mass closure) for $PM_{2.5}$ and to ascertain the sources and distributions of $PM_{2.5}$ components

d The use of models as tools for the prediction of future air quality, taking into account the impacts of current and future policies within the European Union and UNECE, has been the main reason for the development of air quality models such as FRAME for acidification and eutrophication and the Ozone Source Receptor Model (OSRM) for ground-level O_3 formation

Defra also commissions daily air quality forecasts for dissemination to the general public as a contribution to public health protection.

Annex 6

Air Pollution Forecasting in the UK

AEA Technology carries out UK air quality forecasting on behalf of the Department for Environment, Food and Rural Affairs (Defra).

A6.1 Background

Defra has been providing public forecasts of air quality in the UK since 1990 in order to:

a enable groups sensitive to high levels of pollution to take actions that alleviate their symptoms or reduce their risk

b encourage the public to take personal actions during periods of poor air quality (such as using public instead of private transport)

c provide advance warning of the length and severity of pollution episodes for the purpose of providing advanced warning to the government and health service

d fulfil the public information requirements of European Directives on air quality

UK air pollution forecasts are prepared each day by a team of air quality experts. If conditions are changing rapidly, a new or revised forecast may be issued at any time.

Air pollution forecasts are based on information from a number of sources. They are prepared with reference to all available information on air pollution monitoring and forecasting for the UK.

Air quality forecasting information is available to the public on the internet at http://uk-air.defra.gov.uk, on teletext page 156, and on freephone 0800 556677. Members of the public can sign up to bulletins that detail a summary of air quality measurement data, daily updated forecasts of UK air pollution concentrations up to 24-hours ahead, and alerts in the event of an exceedance of European Directive thresholds.

The air pollution forecast covers five pollutants at present – ozone, nitrogen dioxide, sulphur dioxide, carbon monoxide and particulate matter (PM_{10}).

For each of the UK zones and agglomerations shown in Figure A6-1, air pollution levels are predicted separately for urban areas and rural areas, as well as for the roadside. The overall forecast for each area is a composite 'worst case' of all the pollutants and location types. The forecast is described in terms of the air quality index, which is based on the health effects of each of the different pollutants.

Under the current system a forecast is published at least twice daily, and is valid for 24 hours from the time of issue.

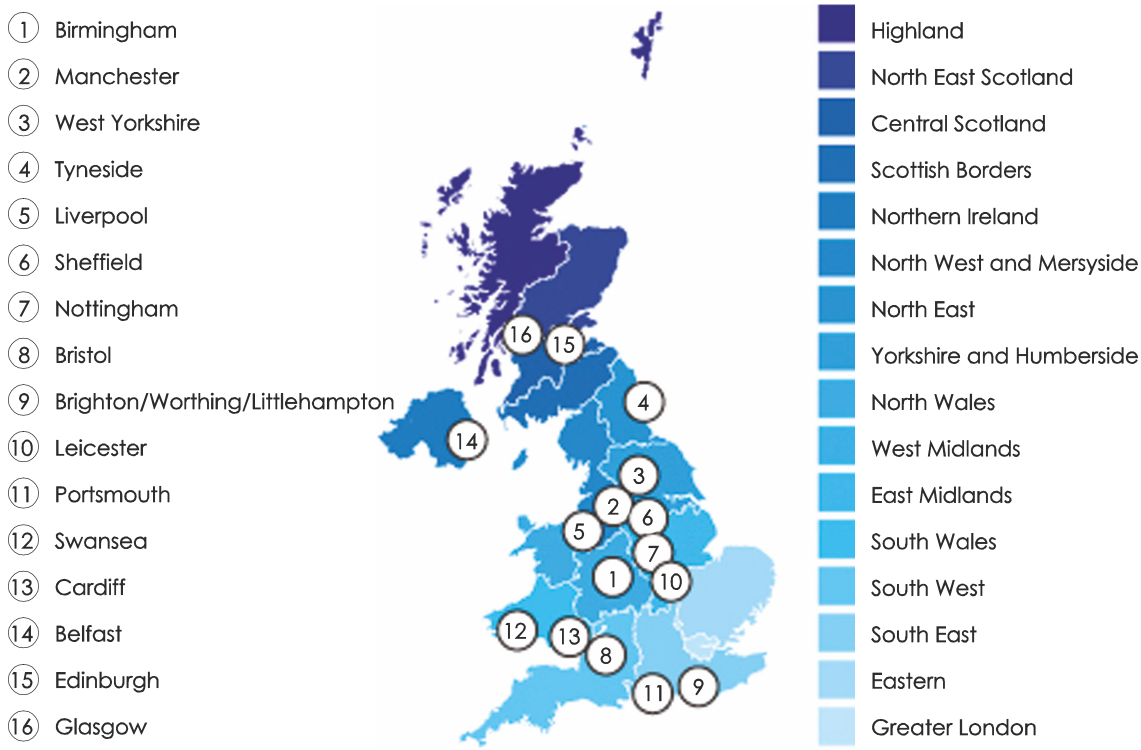

Figure A6-1: Map of UK zones and agglomerations

A6.2 Inputs to the UK air pollution forecasts

Sources of information include the following:

a weather forecasts are available from the Weather Research and Forecasting (WRF) model (detailed below), which is run each day both for the whole of Europe and in higher resolution for the UK

b WRF forecasts provide input data for the Community Multi-scale Air Quality (CMAQ) chemical transport model (detailed below), which also run daily to predict ground-level concentrations of O_3, NO_X, NO_2, CO, SO_2, PM_{10} and $PM_{2.5}$. Again, these forecasts are run both for the European domain and in higher resolution across the UK

c HYSPLIT 96-hour forecast back-trajectory data are downloaded each night for a selection of UK and cross-channel locations (details below). These trajectories are available for one, two and three days ahead to provide the forecasters with a longer-term view of the origins of the air expected to be arriving over the UK in the next few days

d other European and global air quality forecast model results are available through the PROMOTE, GEMS, SKIRON and NAAPS websites e measured concentrations are available online for all pollutants from the UK air pollution monitoring networks. Data are averaged for comparison with the relevant health effects criteria in the air quality index (i.e. for 15-minute, 1-hour, 8-hour or 24-hour averages), and are compared to the model results in near real-time for forecast validation

f near real-time measurements and predicted concentrations of selected pollutants across Europe are available through the EEA 'Eye-on-Earth' and 'Ozoneweb' websites

g satellite imagery is made available over the internet by NASA, NOAA and ESA

h other European and UK weather forecasts are made available over the internet by the BBC, The Met Office, The Weather Channel, WeatherOnline and others

WRF model

The Weather Research and Forecasting (WRF) model is a next-generation mesoscale numerical weather prediction system designed to serve both operational forecasting and atmospheric research needs. It features multiple dynamic cores, a three-dimensional variational (3DVAR) data assimilation system, and a software architecture allowing for computational parallelism and system extensibility. WRF is suitable for a broad spectrum of applications across scales ranging from metres to thousands of kilometres.

For air quality forecasts across the UK and Europe, WRF is initiated using NCEP Global Forecasting System (GFS) real-time data updated every three hours. It is then run to provide 48-hour forecasts at 50 km resolution for Europe and 10 km resolution across the UK.

The WRF model outputs are used as inputs to the CMAQ forecasting model, and also presented as a series of animated maps which the forecasting team uses to review the expected weather situation.

CMAQ model

The Community Multi-scale Air Quality (CMAQ) modelling system has been designed to approach air quality as a whole by including state-of-the-science capabilities for modelling multiple air quality issues, including tropospheric ozone, fine particles, air toxics, acid deposition, and visibility degradation. In this way, the development of CMAQ involves the scientific expertise from each of these areas and combines the capabilities to enable a community modelling best-practice. CMAQ was also designed to have multi-scale capabilities so that separate models were not needed for urban- and regional-scale air quality modelling.

The CMAQ modelling system simulates various chemical and physical processes that are thought to be important for understanding atmospheric trace gas transformations and distributions. The CMAQ modelling system contains three types of modelling components:

a a meteorological modelling system for the description of atmospheric states and motions

b emission models for man-made and natural emissions that are injected into the atmosphere c a chemical transport modelling system for simulation of the chemical transformations in the atmosphere

In addition to the meteorological inputs from WRF, CMAQ requires accurate and up-to-date emission data to run. Annual emissions inventory data for NO_X, PM, CO, NH_3, volatile organic compounds (VOC) and SO_2 are processed using standard temporal factors into hourly emissions data ready for the air quality model:

a UK National Atmospheric Emissions Inventory (NAEI), available at 1 km resolution

b EMEP emissions are used for Europe, available at 50 km resolution

c natural emissions are calculated using a Biogenic Potential Inventory

The CMAQ model is run each day to provide 48-hour air quality forecasts at 50 km resolution for Europe and 10 km resolution across the UK. The results for O_3, CO, SO_2, NO_2, PM_{10} and $PM_{2.5}$ are mapped and animated for the forecasting team to review.

The CMAQ-WRF model produces graphics such as those shown in Figure A6-2.

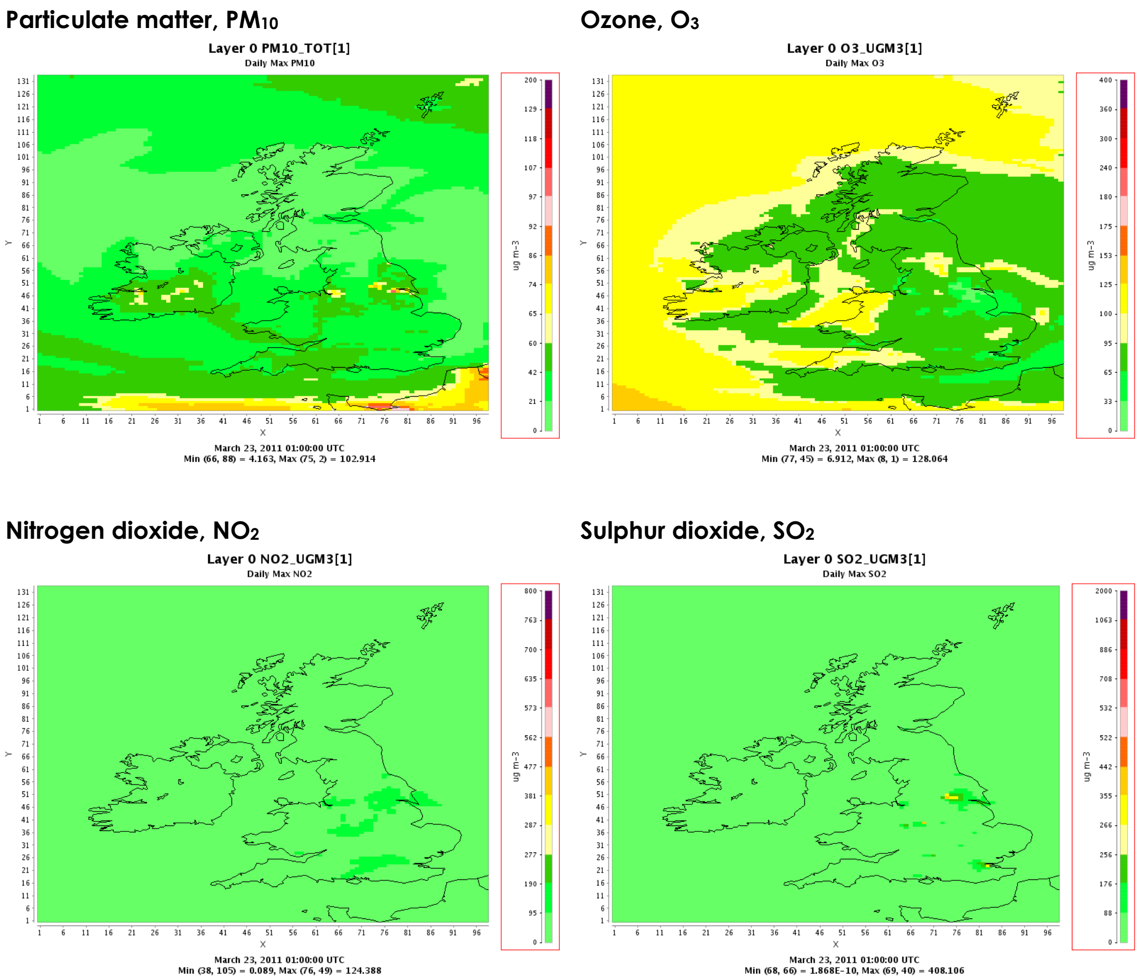

Figure A6-2: Example of index pollutants on 23 March 2011

HYSPLIT 96-hour model

The HYbrid Single-Particle Lagrangian Integrated Trajectory (HYSPLIT) model is the newest version of a complete system for computing simple air parcel trajectories to complex dispersion and deposition simulations. For the UK air quality forecasting project the model is used without the additional dispersion modules, so that HYSPLIT computes the advection of a single pollutant particle, or simply its trajectory.

Each day during the early hours of the morning HYSPLIT is automatically run in back-trajectory mode for 32 different UK and cross-channel locations. The output data are plotted and presented to the forecasters as predictions of the 96-hour paths of air masses to the UK for one, two and three days ahead. These plots are useful in combination with the CMAQ outputs for the forecasters to determine the likely source attribution of any expected increased pollution episodes.

Annex 7

Typical Air Pollution Episodes Affecting the UK

Pollution episodes can be broadly categorised according to pollution source and the atmospheric processes that also determine pollution concentrations:

a primary episodes that are caused by high concentrations of directly emitted pollutants

b secondary episodes that are caused by pollutants created by chemical processes in the atmosphere

c episodes from naturally occurring pollution sources

d local episodes where pollution arises from nearby sources

e long-range transport episodes where air pollution may be carried over several thousand kilometres

Figure A7-1 shows pollution concentrations in London during 2006 and 2007 using measurements from the London Air Quality Network (http://www.londonair.org.uk). The three panels show daily maximum NO_2 concentrations at the Ealing 2 roadside site in west London, daily mean PM_{10} concentrations at Ealing 2, and daily mean O_3 concentrations averaged across suburban sites in the London area. The PM_{10} concentrations in Figure A7-1 have been divided into PM_{10} from primary sources; using NO_X concentrations as a tracer for these emissions (Fuller et al, 2002; Fuller and Green, 2006), and the remaining non-primary PM_{10}. Five episodes (breaches of the EU Directive concentrations) are marked A to E. It can be seen from Figure A7-1 that pollution episodes are not always caused by single pollutants; instead the atmospheric processes that lead to pollution episodes can also lead to peak concentrations of multiple pollutants and that PM_{10} composition can also vary between episodes.

Episode A occurred during the 'heat wave' conditions of summer 2006 and is an example of so-called summertime smog. During this type of episode strong sunlight promotes reactions between pollutant precursors to produce elevated concentrations of secondary pollutants. During summer 2006, O_3 concentrations exceeded the EU information threshold over wide areas of the UK. During such episodes concentrations of O_3 in rural areas are often greater than those in towns and cities where local emissions of NO_X scavenge O_3. In the evening, as sunlight and convection weaken, O_3 can react with traffic emissions leading to increased concentrations of NO_2 and, as shown in Figure A7-1, breaches of the EU Limit Value concentration for NO_2 were measured at Ealing 2 and alongside busy roads in London. The EU Limit Value concentration for PM_{10} was also exceeded during the summer 2006 episodes, due to non-primary PM_{10}, specifically the formation of secondary nitrate and sulphate particles from NO_X and SO_2 emissions (Yardley et al, 2007). The chemical processes that lead to secondary pollutants during summertime smog episodes can take place over several days and consequently the precursor emissions can take place many hundreds of kilometres away – this episode is also an example of long-range transport of air pollution (APEG, 1999).

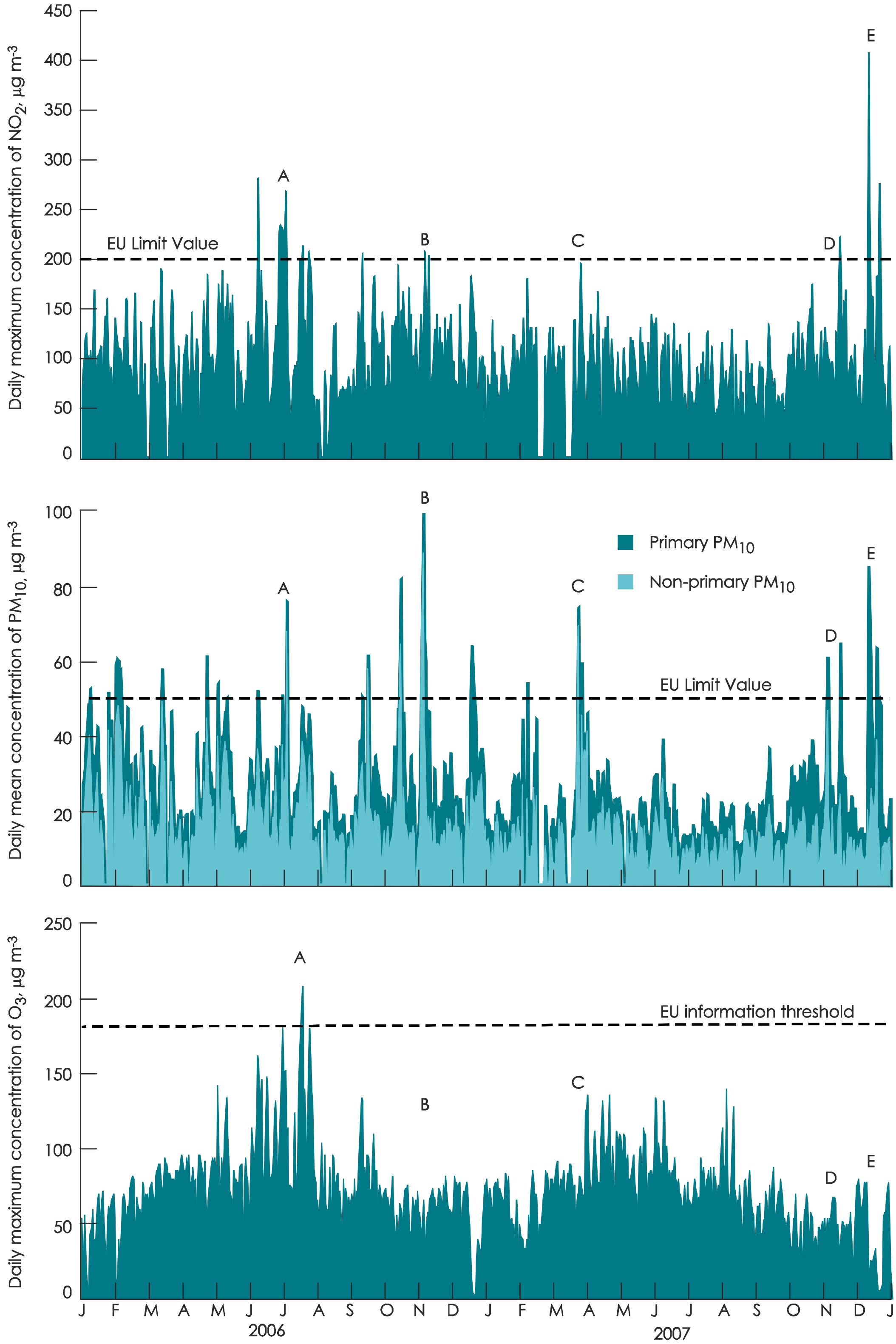

Figure A7-1: Daily concentration of NO_2 (upper panel), PM_{10} (middle panel) and O_3 (lower panel) in London during 2006 and 2007

Daily maximum NO_2 and daily mean PM_{10} were measured at the Ealing 2 roadside site in west London and daily maximum O_3 concentrations were a mean of suburban sites in the London area. PM_{10} concentrations have been apportioned between primary and non-primary sources and presented as EU reference equivalent using the volatile correction model (Green et al, 2009)

Episode B was measured on 5 November 2006 (Bonfire Night) and was a episode caused by poor dispersion of PM_{10} from bonfires and fireworks. The composition of PM_{10} during episode B was very different to that during episode A. The latter was dominated by secondary sulphate and nitrate particles, whereas episode B was caused by local emissions, in this case carbonaceous particles along with elevated concentrations of metals used in fireworks (Godri et al, 2010). Such emissions are not associated with large emissions of NO_X and were therefore apportioned as non-primary PM_{10} in Figure A7-1. The settled atmospheric conditions that led to poor dispersion of bonfire and firework particles also caused NO_2 to exceed the EU Limit Value at the Ealing 2 roadside site. PM_{10} from fireworks also caused episode D during November 2007.

Episode C, in late March 2007, was caused by long-range transport of air pollution. In fact, episode C consisted of two episodes with different causes. Breaches of the PM_{10} EU Limit Value concentration on 25 March 2007 were caused by natural sources – a dust storm in the Southern Ukraine which caused the EU Limit Value concentration to be exceeded widely across central Europe. The greatest PM_{10} concentrations during this episode were measured in Slovakia, where a peak hourly mean concentration of 1400 $\mu g\ m^{-3}$ was measured on 24 March 2007 (Brimili et al, 2008). In London, PM_{10} concentrations from the episode were around one-tenth of that measured in Eastern Europe but were sufficient to breach the EU Limit Value concentration. Whilst such episodes do not occur every year in the UK, recent natural episodes have been caused by Saharan sand in 2000 (Ryall et al, 2002) and by Russian agricultural and forest fires during 2002 and in the northern UK in 2006 (Whitman and Manning, 2007). The remainder of episode C was driven by non-primary (secondary) particles with elevated concentrations of sulphate and nitrate brought into London from distant European sources. Figure A7-1 also shows elevated O_3 concentrations were formed along with the secondary particulate matter as the episode developed.

Episode E, at the end of 2007, was a wintertime episode caused by poor pollution dispersion. Such weather conditions led to the infamous London smogs including that of 1952 (MoH, 1954). However, pollution sources have changed over the last five decades; solid fuel heating in urban areas has been replaced mainly by gas and urban pollution is now dominated by emissions from road transport. Urban winter smogs are still caused by poor dispersion of locally emitted primary pollutants but now manifest as peak concentrations of NO_2 and PM_{10} (mainly primary carbonaceous particles from vehicle exhausts). As also shown in Figure A7-1, very low O_3 concentrations are measured during such wintertime episodes due to local scavenging by NO_X. Such episodes occur during most winters in London, although in terms of background NO_2 concentrations, episode E, in 2007, was the most severe wintertime episode to affect London since 1997 (Fuller et al, 2009).

These five examples illustrate the main episode types that can affect the UK. It can be seen that most episodes are not confined to a single pollutant; the weather conditions that lead to breaches of the EU Limit Value for one pollutant can often lead to elevated concentrations of other pollutants. Although O_3 episodes are confined to springtime and summertime, the pollutant emissions and atmospheric chemical processes that lead to O_3 episodes can also lead to elevated concentrations of PM_{10} and NO_2. Wintertime episodes are characterised by peak concentrations of NO_2 and PM_{10}. Such pollutant combinations raise issues of how the health effects from more than one pollutant should be represented within the air quality index. A further issue is raised by the differences in PM_{10} composition during the different types of episode, which might reasonably be linked to differences in PM_{10} toxicity.

References

APEG (Airborne Particles Expert Group) (1999). Source Apportionment of Airborne Particulate Matter In the United Kingdom. HMSO, London.

Birmili W, Schepanski K A, Ansmann A, Spindler G, Tegen I, Wehner B, Nowak A, Reimer E, Mattis I, Muller K, Bruggemann KE, Gnauk T, Herrmann H, Wiedensohler A, Althausen D, Schladitz A, Tuch T and Loschau G (2008). A case of extreme particulate matter concentrations over Central Europe caused by dust emitted over the southern Ukraine. *Atmos Chem Phys,* **8**, 997–1016.

Fuller GW, Carslaw DC and Lodge HW (2002). An empirical approach for the prediction of daily mean PM_{10} concentrations. *Atmos Environ,* **36**, 1431–41.

Fuller GW and Green D (2006). Evidence for increasing primary PM_{10} in London. *Atmos Environ,* **40**, 6134–45.

Fuller G, Meston L, Green D, Westmoorland E and Kelly F (2009). Air Quality in London. London Air Quality Network Report 14, 2006–2007. Available at http://www.londonair.org.uk

Green D, Fuller GW and Baker T (2009). Development and validation of the volatile correction model for PM_{10} – an empirical method for adjusting TEOM measurements for their loss of volatile particulate matter. *Atmos Environ,* **43**, 2132–41.

Godri KJ, Green DC, Fuller GW, Dall'Osto M, Beddows DC, Kelly FJ, Harrison RM and Mudway IS (2010). Particulate oxidative burden associated with firework activity. *Environ Sci Technol,* **44**(21), 8295–301.

Hayman G, Yardley R, Quincey P, Butterfield D, Green D, Alexander J, Johnson P and Tremper A (2008). CPEA 28: Airborne Particulate Concentrations and Numbers in the United Kingdom (Phase 2). Annual Report – 2007. National Physical Laboratory, Teddington.

Ministry of Health (MoH) (1954). Reports on Public Health and Medical Subjects No. 94, Mortality and Morbidity during the London Fog of December 1952. HMSO, London.

Ryall DB, Derwent RG, Manning AJ, Redington AL, Corden J, Millington W, Simmonds PG, O'Doherty S, Carslaw N and Fuller G (2002). The origin of high particulate concentrations over the United Kingdom, March 2000. *Atmos Environ,* **36**, 1363–78.

Witham C and Manning A (2007). Impacts of Russian biomass burning on UK air quality. *Atmos Environ,* **41**, 8075–90.

Yardley R, Quincey P, Butterfield D, Green D, Alexander J, Johnson P and Tremper A (2007). CPEA 28: Airborne Particulate Concentrations and Numbers in the United Kingdom (Phase 2). Annual Report – 2006. National Physical Laboratory, Teddington.

Annex 8

EU Limit Values

European air quality standards
(available at http://ec.europa.eu/environment/air/quality/standards.htm)

Pollutant	Concentration	Averaging period	Legal nature	Permitted exceedances each year
Particulate matter, PM_{10}	50 µg m^{-3}	24 hours	Limit Value entered into force 1.1.2005 *	35
	40 µg m^{-3}	1 year	Limit Value entered into force 1.1.2005 *	n/a
Sulphur dioxide, SO_2	350 µg m^{-3}	1 hour	Limit Value entered into force 1.1.2005	24
	125 µg m^{-3}	24 hours	Limit Value entered into force 1.1.2005	3
Ozone, O_3	120 µg m^{-3}	Maximum daily 8 hour mean	Target value entered into force 1.1.2010	25 days averaged over 3 years
Nitrogen dioxide, NO_2	200 µg m^{-3}	1 hour	Limit Value entered into force 1.1.2010	18
	40 µg m^{-3}	1 year	Limit Value entered into force 1.1.2010 †	n/a
Carbon monoxide, CO	10 mg m^{-3}	Maximum daily 8 hour mean	Limit Value entered into force 1.1.2005	n/a

* Under the new Directive a member state can apply for an extension until three years after the date of entry into force of the new Directive (i.e. May 2011) in a specific zone. Request is subject to assessment by the Commission. In such cases within the time extension period the EU Limit Value applies at the level of the Limit Value plus the maximum margin of tolerance (e.g. 35 days at 75 µg m^{-3} for daily PM_{10} Limit Value, 48 µg m^{-3} for annual PM_{10} Limit Value)

† Under the new Directive a member state can apply for an extension of up to five years (i.e. maximum up to 2015) in a specific zone. Request is subject to assessment by the European Commission. In such cases within the time extension period the EU Limit Value applies at the level of the Limit Value plus the maximum margin of tolerance (e.g. 48 µg m^{-3} for the annual NO_2 Limit Value)

Note Under European law an EU Limit Value is legally binding from the date it enters into force subject to any exceedances permitted by the legislation. A target value is to be attained as far as possible by the attainment date and so is less strict than an EU Limit Value

Annex 9

Hourly Mean 'Triggers' for Particulate Matter, PM_{10} and $PM_{2.5}$, and Ozone, O_3

COMEAP would like to thank Gary Fuller, Timothy Baker and the team at King's College London for this work.

A9.1 Introduction

Hourly mean 'triggers' are needed to allow near real-time assessment of measured concentrations of $PM_{2.5}$, PM_{10} and O_3 against the proposed banding system that is based on daily mean concentrations for particulate matter and a rolling 8-hour mean for O_3. **'Trigger' concentrations are hourly pollution measurements that indicate a period of 'Moderate', 'High' or 'Very High' air pollution may be taking place or is likely to happen soon.**

The triggers are based on two consecutive hourly mean concentrations. The first hourly mean has to be greater than or equal to a threshold. To avoid false triggers from short-term measurement spikes, the trigger has to be confirmed by a second hourly mean. It is clearly desirable to be able to predict pollution exposure before the accumulated 8-hour or daily mean concentration indicates that Moderate, High or Very High air pollution has occurred. For this reason the triggers are biased towards increasing concentrations, i.e. the second hourly mean concentration is greater or equal to the first. This is summarised in Table A9-1.

Table A9-1: Summary of trigger operation

Time	Hourly mean concentration	Trigger action
t_0	$C_{t_0} \geq$ trigger threshold	–
t_{+1}	$C_{t_{+1}} \geq C_{t_0}$	Warn of possible Moderate, High or Very High air pollution

$PM_{2.5}$, PM_{10} and O_3 bands are based on different exposure periods. The pollutants also have different sources and atmospheric behaviour. For these reasons the triggers for O_3 operate differently to those for PM_{10} and $PM_{2.5}$.

Ozone episodes normally follow a clear diurnal pattern with the greatest concentrations being measured during the mid-afternoon, as shown in Figure A9-1. During episodes there is typically a lag of around 4 hours between a peak in hourly mean exposure and the peak value of the 8-hour mean. The triggers for O_3 have been designed to indicate that exposure to this air pollutant is taking place such that O_3 levels may reach the Moderate or High band within the next 5 hours (t_{+1} to t_{+5}). An episode is then categorically determined by the banding system based on the 8-hour mean. Once a trigger has been activated it remains valid for 5 hours. The 8-hour exposure is a definitive measure of the air quality band for Moderate or above, and this takes precedent over the trigger results.

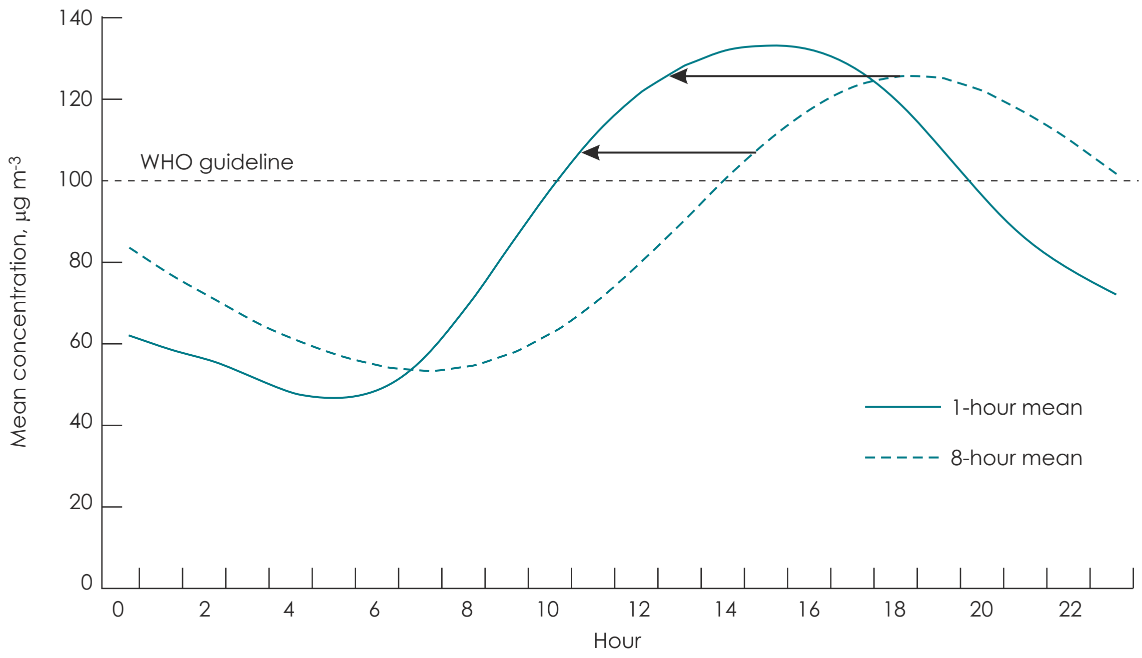

Figure A9-1: 1-hour and 8-hour mean concentrations on days when the WHO AQG was breached (data from London and Southeast England, the arrows indicate the delay between the 1- and 8-hour mean concentrations)

For PM_{10} and $PM_{2.5}$, episodes can be caused by a wide variety of sources. These include local fires or building works that may affect concentrations for an hour or two, or long-range transport of airborne particles that can affect concentrations over several days. The triggers for PM_{10} and $PM_{2.5}$ indicate that exposure to particulate matter is taking place such that the daily mean may reach the Moderate, High or Very High band when it is calculated at the end of the day. Once a trigger has been activated it remains valid for the remainder of that day.

This annex reports the determination of trigger thresholds for PM_{10}, $PM_{2.5}$ and O_3 and details the performance of the chosen triggers.

A9.2 Method

The triggers can be considered to be a categorical model; they provide a 'yes' or 'no' prediction that can be assessed against a set of yes or no observations. The performance of such models needs to be considered carefully; it is important to assess not only the times when the model correctly warns of an episode (true positives) but also the times that it misses episodes (false negative), incorrectly predicts an episode (false positives) and correctly predicts no episode (true negatives). These are normally evaluated using a 2 x 2 contingency table, as shown in Table A9-2.

Table A9-2: 2 x 2 contingency table (adapted from Stephenson, 2000)

		Event observed	
		Yes	**No**
Event modelled	**Yes**	***a*** (true positive)	***b*** (false positive)
	No	***c*** (false negative)	***d*** (true negative)

The problem being considered here is not just the usual evaluation of an existing model in the 2 x 2 matrix formulation; here we are seeking to determine optimum trigger thresholds. All possible trigger concentrations were therefore assessed in terms of their performance in predicting the proposed air quality bands for PM_{10}, $PM_{2.5}$ and O_3.

For O_3 the model was run for each possible trigger concentration and the predicted 8-hour mean concentrations was compared to the 8-hour mean O_3 concentration in the following 3 hours from t_0 (observation). The assessment was conducted on O_3 concentrations from sites in London and Southeast England from 2000 to 2008 (including AURN measurements), a total of 4.7 million hourly measurements.

For PM_{10} and $PM_{2.5}$, the model was run for each trigger concentration and the predicted daily mean time series of particulate matter concentrations in each band was compared to measured daily mean concentrations (observations). The assessment was conducted on reference equivalent PM_{10} and $PM_{2.5}$ concentrations from the AURN and from London and neighbouring networks from 2004 to 2009. Approximately 270,000 days of PM_{10} concentrations were modelled for each possible trigger for each band and approximately 27,000 days were modelled in the same way for $PM_{2.5}$.

A9.3 Results

The results for the prediction of PM_{10} concentrations in the High band or above are presented in detail and other PM_{10} and $PM_{2.5}$ triggers are summarised in tables below.

Results for PM_{10} concentrations High or above

Results for each of the contingency matrix outputs for the prediction of PM_{10} concentrations High or above are shown in Figure A9-2. By taking a vertical line from each trigger, the outputs ***a***, ***b***, ***c*** and ***d*** can be read from the graph.

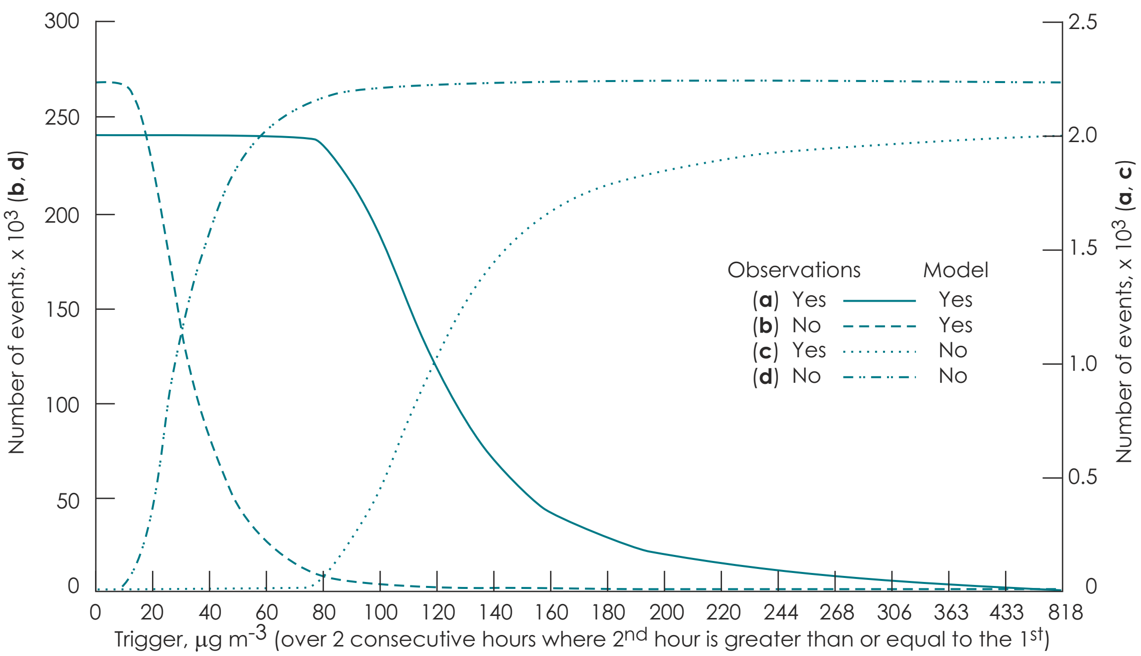

Figure A9-2: Contingency matrix outputs for PM_{10} High or above for each possible trigger

It is clear that the number of observations when PM_{10} was not High or above exceeds the number of observations of PM_{10} High or above by around two orders of magnitude. At a trigger of 0 μg m^{-3} the model will always predict pollution to be High or above. The model will correctly predict all occasions when pollution is High or above (true predictions – obs Y, model Y, ***a***), but it will not be discriminatory and produce a very high number of false positives (obs N, model Y, ***b***). As the model is tested with greater trigger values, it predicts a smaller number of events to be High or above and a smaller number of false positives. However, with greater trigger values the model also misses events when PM_{10} was High or above (obs Y, model N, ***c***) but the number of true negatives (obs N, model N, ***d***) increases.

It appears from Figure A9-2 that the numbers of true positives ***(a)*** does not diminish until trigger concentrations of around 75 μg m^{-3}. This is logical given that high PM_{10} (a daily mean concentration of 75 μg m^{-3}) will require some hourly measurements to be greater than 75 μg m^{-3}. The false positive rate ***(b)*** falls rapidly for trigger concentrations above 10 μg m^{-3}.

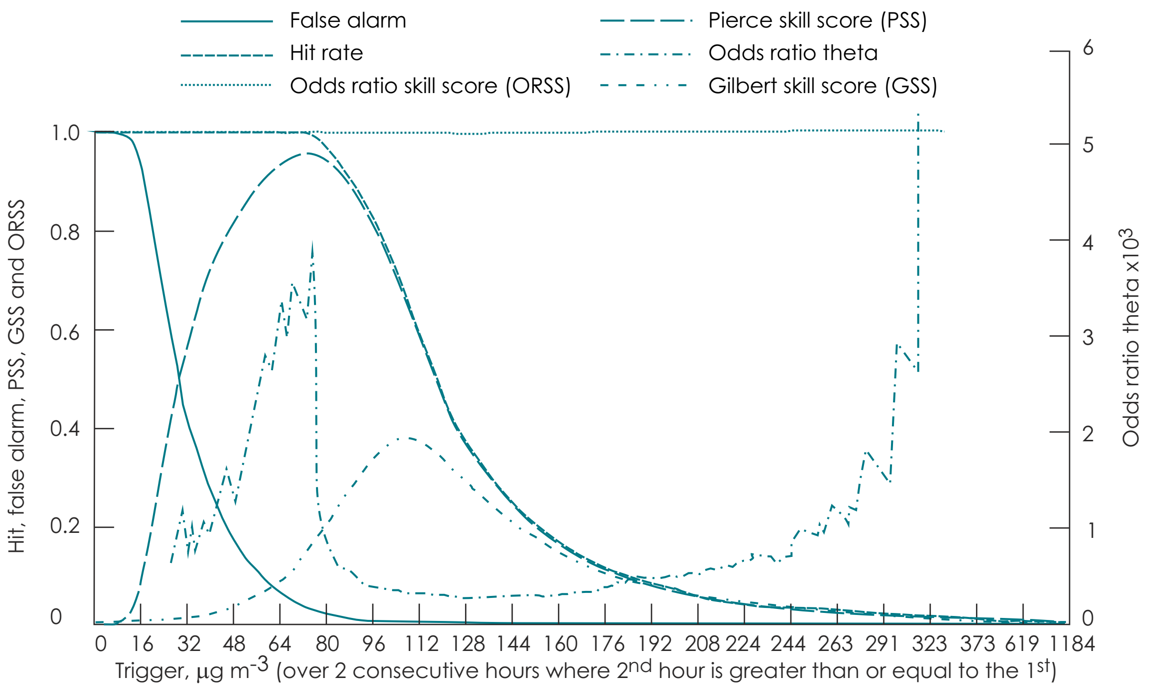

Figure A9-3: Evaluation of each possible trigger for PM_{10} High or above using metrics from Stephenson (2000)

A range of metrics for the performance of categorical models is detailed in Stephenson (2000) and also discussed in Agnew et al (2007). The performance of the model against the most appropriate metrics in Stephenson (2000) is shown in Figure A9-3. The hit rate and false alarm rate are normalised values of ***(a)*** and ***(b)*** and show the same behaviour as Figure A9-2 with a hit rate of almost one being maintained for triggers up to 75 μg m^{-3} when the false alarm rate is then approaching zero. The Pierce Skill Score (PSS) takes the difference between the hit rate and the false alarm rate. This reaches a peak of close to one at 75 μg m^{-3}, suggesting a large hit rate and a low false alarm rate at this trigger value. The odds ratio, the odds of making a correct forecast compared to the odds of making an incorrect forecast, is a metric favoured by both Stephenson (2000) and Agnew et al (2007), although care has to be taken with respect to the standard error and it cannot therefore be applied to the full range of outcomes. The odds ratio also peaks at 75 μg m^{-3}, with a secondary peak at large values of the trigger when other metrics are low.

The trigger value of 75 μg m^{-3} appears optimal from several performance metrics. The performance of the model at a trigger value of 75 μg m^{-3} to predict PM_{10} High or above is shown in the contingency matrix, Table A9-3.

Table A9-3: Contingency table for PM_{10} trigger of 75 μg m^{-3} for High or above

PM_{10} trigger High or above at 75 μg m^{-3}		**Event observed**	
		Yes	**No**
Event modelled	**Yes**	1,983	9,551
	No	15	257,878

The results in Table A9-3 show that although the model at a trigger of 75 μg m^{-3} correctly predicts almost all events, the number of false alarms is around five times greater than the number of correct predictions. The determination of this trigger as optimal in terms of model performance is affected in part by the very large number of times when air pollution was not High or above. Many metrics have this in their denominator and they therefore have little sensitivity to the ratio of true positives ***(a)*** to false positives ***(c)***. As an alternative, the Gilbert Skill Score (GSS) (Stephenson, 2000) has the advantage of not including the true negatives ***(d)*** and is instead calculated as the ratio of true positives to the total number of events when the positive outcome was either modelled or observed. The model performance at the optimum GSS is shown in Table A9-4. A trigger at 107 μg m^{-3} has only 15% of the false positives, compared with a trigger at 75 μg m^{-3} (1,423 compared to 9,551), whilst retaining 66% of the true positives (1,299 compared to 1,983). Missed events increase from 15 to 699 but this should be seen in the context of around 270,000 days analysed. On balance, it is felt that the improvement in false positives outweighs missed events, many of which may trigger at the lower threshold for Moderate or above.

Table A9-4: Contingency table for PM_{10} trigger of 107 μg m^{-3} for High or above

PM_{10} trigger High or above at 107 μg m^{-3} GSS = 0.38		**Event observed**	
		Yes	**No**
Event modelled	**Yes**	1,299	1,423
	No	699	266,006

The performance of the trigger of 107 μg m^{-3} for PM_{10} High or above is shown in terms of the Receiver Operator Characteristic (ROC) space in Figure A9-4. Here the trigger performance is above the 1 : 1 line, indicating that the hit rate is greater than the false alarm rate.

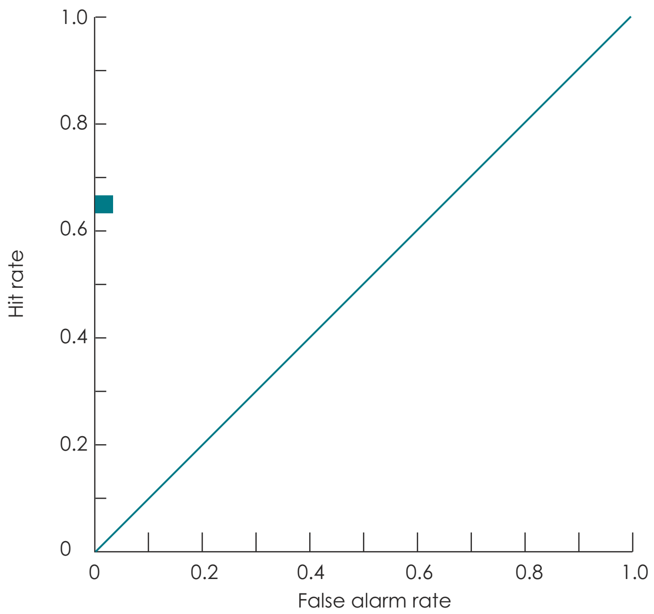

Figure A9-4: Evaluation of 107 µg m^{-3} trigger for PM_{10} High and above using a ROC curve

Results for all particulate matter metrics and bands

Similar relationships between model performance metrics and triggers to that for PM_{10} High or above can be found for predictions of Moderate or above and Very High PM_{10} and for the corresponding three bands for $PM_{2.5}$. The suggested triggers for PM_{10} and $PM_{2.5}$ are shown in Table A9-5.

Table A9-5: Suggested triggers for PM_{10} and $PM_{2.5}$ based on two consecutive hourly mean concentrations with the second one being greater than or equal to the first

Pollutant	Band	Trigger (µg m^{-3})
PM_{10}	Moderate or above	67
	High or above	107
	Very High or above	176
$PM_{2.5}$	Moderate or above	48
	High or above	74
	Very High or above	101

The detailed model performance of each trigger is shown in Table A9-6 (overleaf). Triggers for Moderate or above show the best performance for each particulate matter metric, whist triggers for Very High or above show the weakest performance with the number of false alarms exceeding the number of true positives.

An alternative trigger formulation with two consecutive hours greater than or equal to the trigger threshold was also evaluated for PM_{10} and $PM_{2.5}$. In general, this alternative trigger formulation led to a greater number of false positives when compared to the proposed trigger, with the second hourly mean being greater than or equal to the first hour.

Table A9-6: Model performance of each trigger for PM_{10} and $PM_{2.5}$, and their respective Gilbert Skill Scores (GSS)

PM_{10} trigger Moderate or above at 67 µg m^{-3} GSS = 0.55		Event observed	
		Yes	**No**
Event modelled	**Yes**	11,418	6,269
	No	3,198	248,542

PM_{10} trigger High or above at 107 µg m^{-3} GSS = 0.38		Event observed	
		Yes	**No**
Event modelled	**Yes**	1,299	1,423
	No	699	266,006

PM_{10} trigger Very High or above at 176 µg m^{-3} GSS = 0.23		Event observed	
		Yes	**No**
Event modelled	**Yes**	117	203
	No	182	268,925

$PM_{2.5}$ trigger Moderate or above at 48 µg m^{-3} GSS = 0.57		Event observed	
		Yes	**No**
Event modelled	**Yes**	904	474
	No	200	25,551

$PM_{2.5}$ trigger High or above at 74 µg m^{-3} GSS = 0.43		Event observed	
		Yes	**No**
Event modelled	**Yes**	124	113
	No	52	26,840

$PM_{2.5}$ trigger Very High or above at 101 µg m^{-3} GSS = 0.29		Event observed	
		Yes	**No**
Event modelled	**Yes**	20	46
	No	4	27,059

Results for O_3 concentrations High or above

The performance of the proposed triggers for O_3, with respect to the metrics in Stephenson (2000) and Agnew et al (2007) is broadly similar to that of PM_{10} and $PM_{2.5}$, as shown in Figure A9-5 and Figure A9-6.

However, the performance of the O_3 triggers differs from that of PM_{10} and $PM_{2.5}$ when tested at very low trigger thresholds. At very low trigger thresholds for PM_{10} and $PM_{2.5}$, the number of false positives (obs N, model Y, ***b***) becomes equal to the number of observed negatives (Figure A9-2) and the model loses all discriminatory power. However, the combination of the diurnal cycle of O_3 concentrations and the restriction that the trigger detects only rising concentrations means that the number of false positives does not attain the same value as the number of observed negatives. Owing to periods of up to six hours of declining concentrations during periods of Low air pollution, the model is still able to discriminate between Low and not Low O_3 on the basis of the concentration gradient alone.

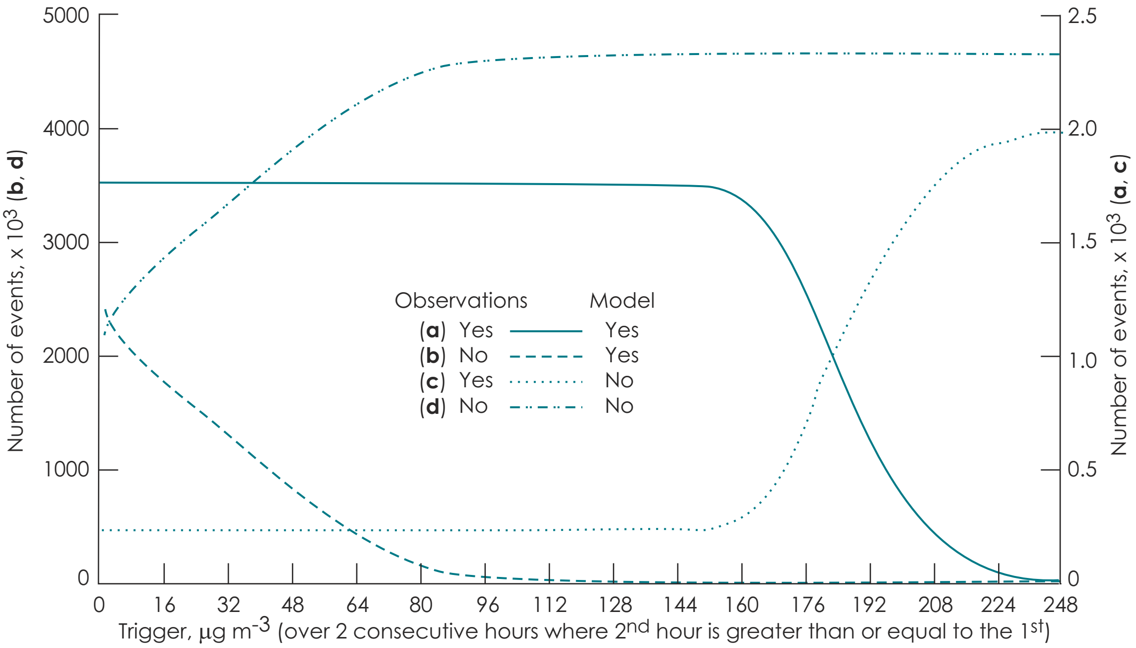

Figure A9-5: Contingency matrix outputs for O_3 High or above for each possible trigger

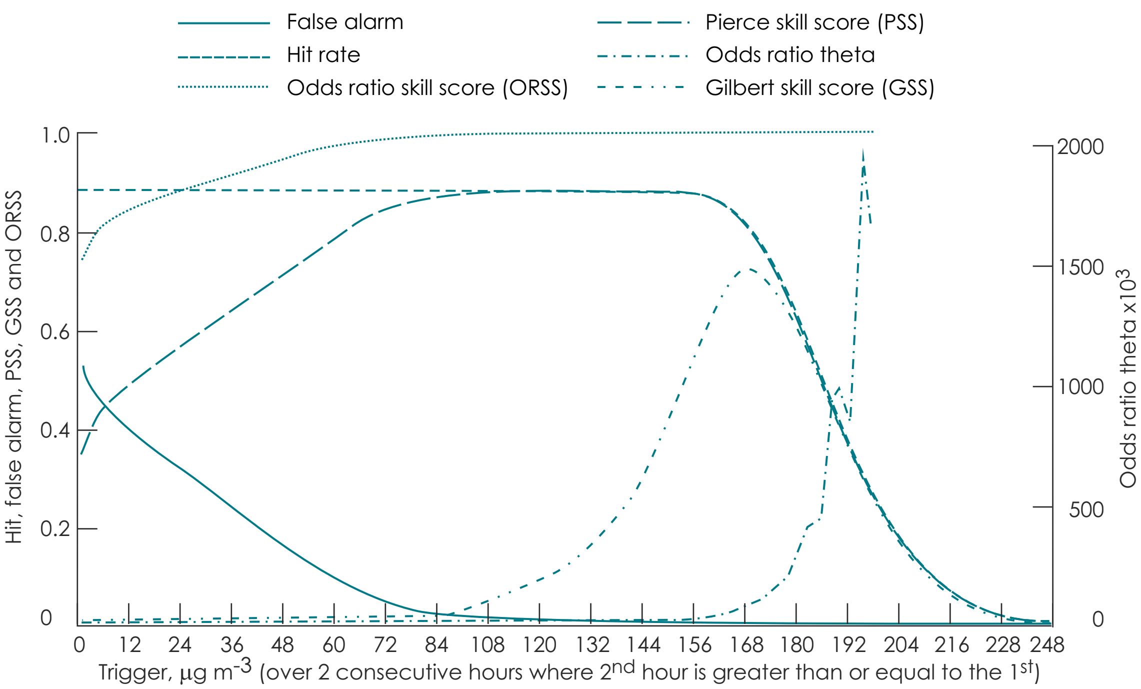

Figure A9-6: Evaluation of each possible trigger for O_3 High or above using metrics from Stephenson (2000)

Results for all O_3 bands

Similar relationships between model performance metrics and triggers for High or above were also found for predictions of Moderate or above O_3. With only one measurement of Very High O_3 in the test period, it was not possible to determine an optimal trigger for this band. The suggested triggers for O_3 are shown in Table A9-7.

Table A9-7: Suggested triggers for O_3 based on two consecutive hourly mean concentrations with the second one being greater than or equal to the first

Pollutant	Band	Trigger (µg m^{-3})
O_3	Moderate or above	82
	High or above	168
	Very High or above	Not determined

The detailed model performance of each trigger is given in Table A9-8. The trigger for Moderate or above shows better performance than the trigger for High or above.

Table A9-8: Model performance of each trigger for O_3 and their respective Gilbert Skill Scores (GSS)

O_3 trigger Moderate or above at 82 µg m^{-3} GSS = 0.79		**Event observed**	
		Yes	**No**
Event modelled	**Yes**	109,386	20,795
	No	8,742	4,208,465

O_3 trigger High or above at 168 µg m^{-3} GSS = 0.72		**Event observed**	
		Yes	**No**
Event modelled	**Yes**	1,581	203
	No	402	4,634,745

A9.4 Summary

Hourly mean trigger concentrations have been developed to provide timely information about air pollution information for $PM_{2.5}$, PM_{10} and O_3. Trigger concentrations are hourly pollution measurements that indicate a period of Moderate, High or Very High air pollution may be taking place or is likely to happen soon. Following analysis of air pollution measurements, the suggested trigger thresholds are shown in Table A9-9.

Table A9-9: Suggested triggers based on two consecutive hourly mean concentrations with the second one being greater than or equal to the first

Pollutant	Band	Trigger ($\mu g\ m^{-3}$)
Particulate matter, PM_{10}	Moderate or above	67
	High or above	107
	Very High or above	176
Particulate matter, $PM_{2.5}$	Moderate or above	48
	High or above	74
	Very High or above	101
Ozone, O_3	Moderate or above	82
	High or above	168
	Very High or above	Not determined

A9.5 References

Agnew P, Mittermaier MP, Honore C, Elbern H, Coll I, Vautard R and Peuch V-H (2007). Evaluation of GEMS regional air quality forecasts. Available at http://gems.ecmwf.int/do/get/PublicDocuments/1533/1402

Stephenson DB (2000). Use of the 'odds ratio' for diagnosing forecast skill. *Weather Forecast,* **15**(2), 221–32.

Annex 10

Comparison of Proposed and Current Air Quality Index Bands

COMEAP recommends several changes to the current UK air quality index. With respect to the current air quality index, the bandings remain unchanged for sulphur dioxide (SO_2). The breakpoints for a change in band for ozone (O_3), nitrogen dioxide (NO_2) and particulate matter (of less than 10 µm in diameter, PM_{10}) are more stringent. Particulate matter of less than 2.5 µm in diameter ($PM_{2.5}$) has been added to the index, and carbon monoxide has been removed in view of the considerable reductions in outdoor levels of this pollutant. The current and proposed bands are compared in Figures A10-1 to A10-3.

PM_{10} 24-hour mean

Current index: Index	Current index: Bands	Proposed index: Bands	Proposed index: Index
10	Very High 130+	Very High 101+	10
9	High 97–129	High 76–100	9
8	High 97–129	High 76–100	8
7	High 97–129	High 76–100	7
6	Moderate 65–96	Moderate 51–75	6
5	Moderate 65–96	Moderate 51–75	5
4	Moderate 65–96	Moderate 51–75	4
3	Low 0–64	Low 0–50	3
2	Low 0–64	Low 0–50	2
1	Low 0–64	Low 0–50	1

Scale (µg m^{-3})
150
140
130
120
110
100
90
80
70
60
50
40
30
20
10
0

Figure A10-1: Comparison of current and proposed bands for PM_{10}

O_3 8-hour mean

Current index		Scale ($\mu g\ m^{-3}$)	Proposed index	
Index	Bands		Bands	Index
		400		
10	Very High 360+	380		
		360		
		340		
9		320	Very High 241+	10
		300		
		280		
8	High 180–359	260		
		240		
		220		9
7		200	High 161–240	8
		180		
6		160		7
5	Moderate 100–179	140		6
		120	Moderate 81–160	5
4		100		
3		80		4
		60		3
2	Low 0–99	40	Low 0–80	2
1		20		
		0		1

Figure A10-2: Comparison of current and proposed bands for O_3

NO_2 1-hour mean

Current index		Scale ($\mu g\ m^{-3}$)	Proposed index	
Index	Bands		Bands	Index
		900		
10	Very High 764+	850		
		800		
		750	Very High 601+	10
9		700		
8	High 573–763	650		
7		600		
		550		9
6		500	High 401–600	8
		450		
5	Moderate 287–572	400		7
		350		6
4		300	Moderate 201–400	5
		250		
3		200		4
		150		3
2	Low 0–286	100	Low 0–200	2
1		50		
		0		1

Figure A10-3: Comparison of current and proposed bands for NO_2

Annex 11

Implications of Proposed Changes to the Air Quality Index for London

COMEAP would like to thank Gary Fuller, Ben Barratt, and the team at King's College London for this work.

A11.1 Introduction

A comparison of the current and proposed air quality index banding systems was carried out by comparing the changes in the frequency of occurrence of air pollution concentrations within each band for the period 2007 to 2009. The analysis was carried using measurements from monitoring sites in London, with separate assessments for background and kerb/roadside sites. The assessment was made retrospectively using the averaging times defined in the index and not using the real-time triggers.

Each pollutant is considered separately below. The following graphs show the number of days in each band as a percentage of the total number of site days in each month.

A11.2 Ozone, O_3

Figure A11-1 shows the frequency of occurrence of O_3 concentrations in the current and proposed bands at background and kerb/roadside sites. O_3 is mainly a spring- and summer-time pollutant and this is reflected in the monthly frequency of moderate concentrations. Compared to the so-called 'heat wave' years of 2003 and 2006, there was little photochemical activity in 2007 to 2009 and high O_3 levels were not measured using the current or proposed systems.

At background sites, the proposed system has a greater frequency of Moderate concentrations. This increase is greatest during spring and summer, rising from a peak of 25% of days in the current system to 45% of days in the proposed system. The proposed system also reports a small number of Moderate concentrations (around 1% of days) during winter due to elevated concentrations of O_3 in the tropospheric background.

Due to local-scale reactions with NO_X, O_3 concentrations at kerb/roadside sites are less than at background sites. Moderate O_3 levels can be measured at background sites, mostly at weekends, and at suburban kerb/roadsides. The frequency of moderate O_3 levels at kerb/roadside sites is greater in the proposed system when compared with the current system.

Figure A11-1: Comparison between the current and proposed banding systems for O_3
The upper panel shows measurements from 22 background sites and the lower panel shows measurements from 10 kerb/roadside sites in London

A11.3 Nitrogen dioxide, NO_2

Figure A11-2 shows the frequency of occurrence of NO_2 concentrations in the current and proposed bands at background and at kerb/roadside sites. Under the current system NO_2 was low for over 99% of days at both kerb/roadside and background sites. The proposed system more accurately reflects breaches of the short-term EU Limit Value which occurred on 1–2% of days at background sites in winter. Owing to the proximity of road traffic, NO_2 concentrations are greater at kerb/roadside sites than at background sites. At kerb/roadside sites, moderate NO_2 levels peaked in winter in the current and proposed systems, with the frequency of moderate NO_2 at kerb/roadside sites increasing from a peak of 2% of days in the current system to 7% of

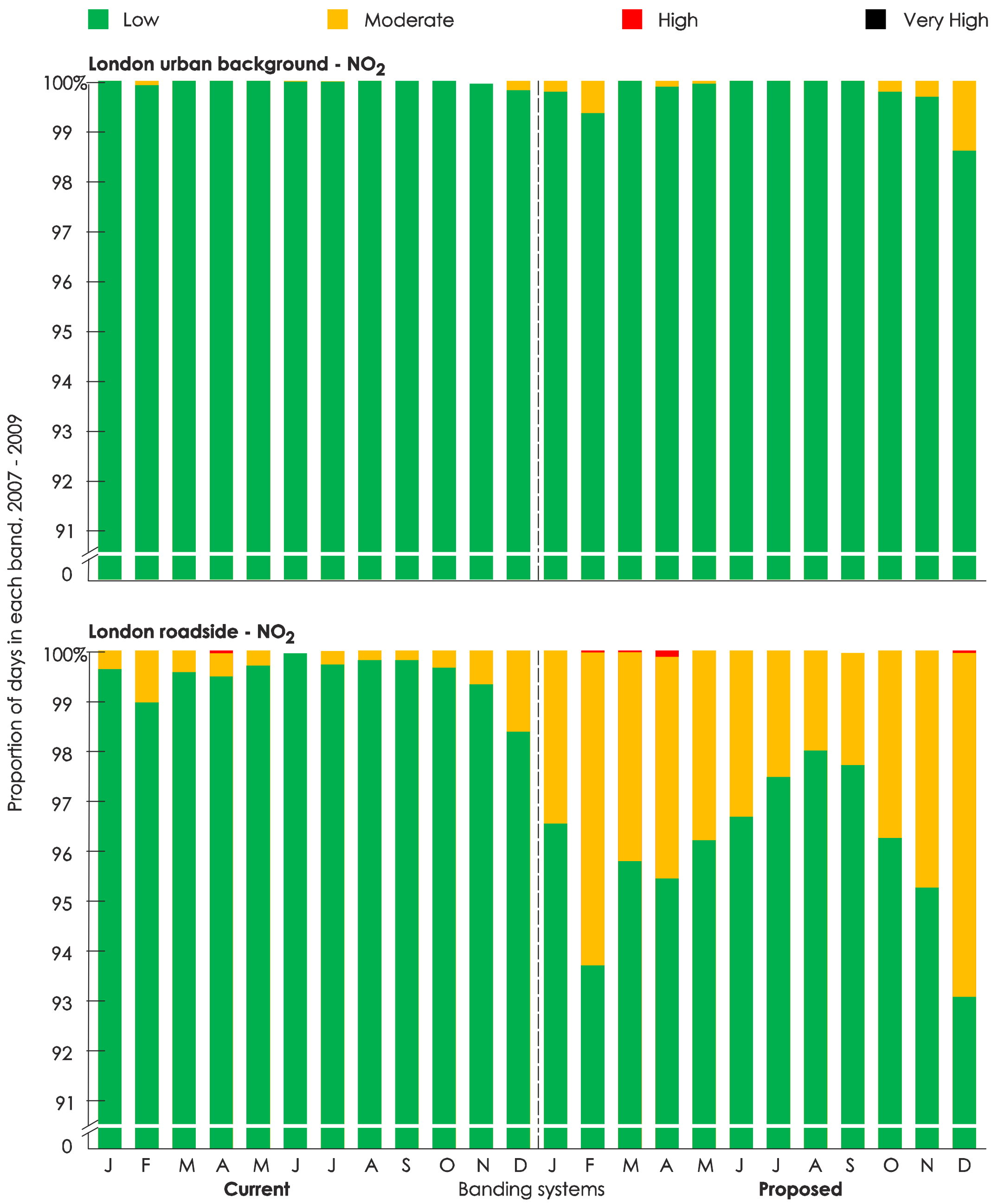

Figure A11-2: Comparison between the current and proposed banding systems for NO_2

The upper panel shows measurements from 28 background sites and the lower panel shows measurements from 34 kerb/roadside sites in London

days in the proposed system. In the new system, High NO_2 was measured in five months of the year but this was a very rare event, occurring on less than 0.2% of days overall.

A11.4 Particulate matter, PM_{10}

Figure A11-3 shows the frequency of occurrence of PM_{10} concentrations in the current and proposed bands at background and at kerb/roadside sites. Measurements have been made using EU reference equivalent methods using FDMS, VCM-corrected TEOM and BAM instruments (particulate matter monitors).

PM_{10} concentrations of Moderate or above occurred at both background and kerb/roadside sites. At background sites moderate PM_{10} occurred mainly during winter and spring in both the current and proposed systems. There is a slight increase in the frequency of days with Moderate and High PM_{10} in the proposed system. PM_{10} concentrations at kerb/roadside sites were greater than those at background sites due to additional road transport emissions superimposed on the regional background. This is clearly shown by the greater frequency of PM_{10} concentrations at Moderate or above. The proposed system has a greater frequency of days with Moderate, High and Very High air pollution at kerb/roadside sites when compared to background sites.

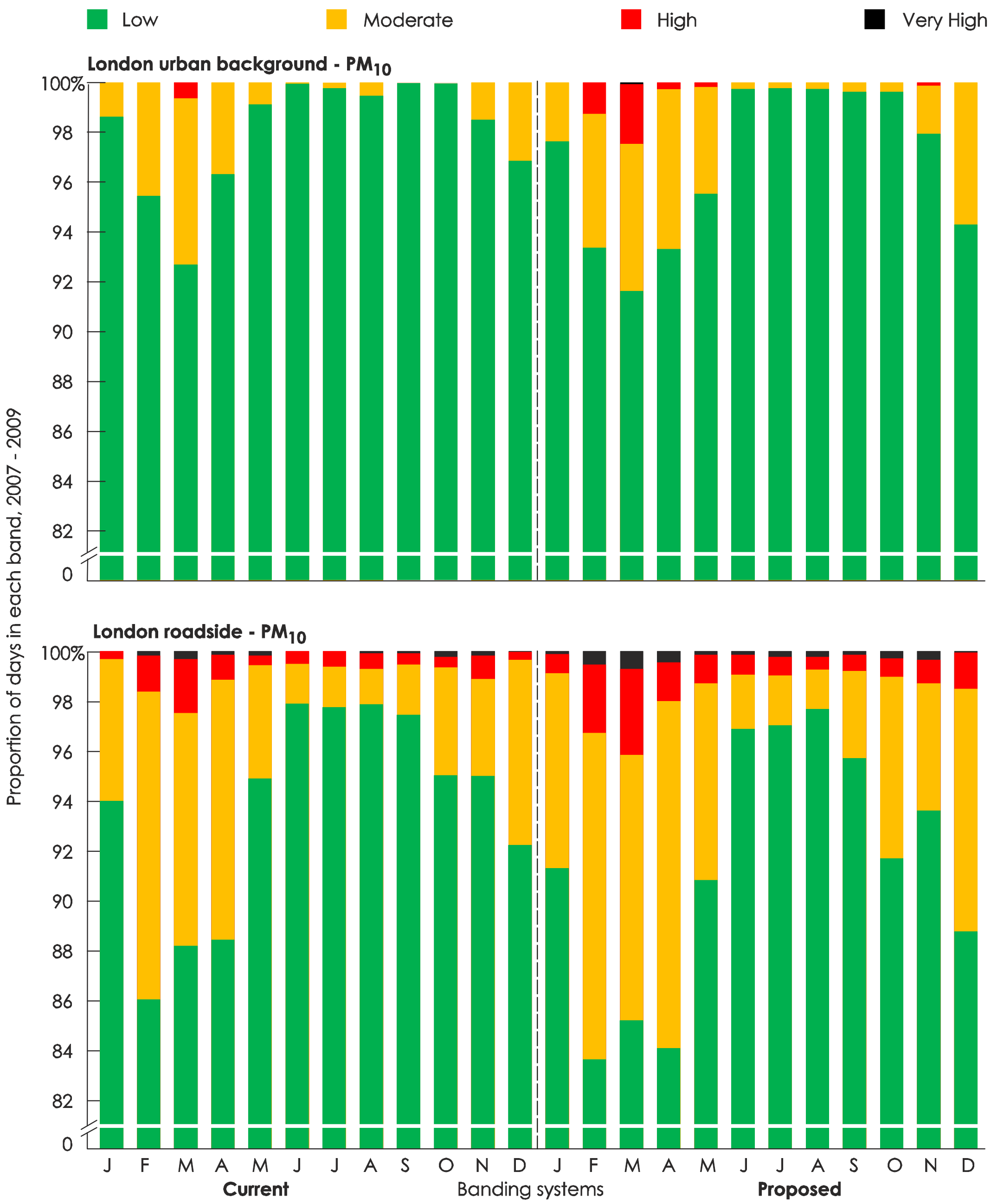

Figure A11-3: Comparison between the current and proposed banding systems for PM_{10}

The upper panel shows measurements from 17 background sites and the lower panel shows measurements from 28 kerb/roadside sites in London

A11.5 Particulate matter, $PM_{2.5}$

$PM_{2.5}$ is not included as a pollutant in the current banding system. Widespread measurement of $PM_{2.5}$ using FDMS instruments has only started in the last three years and insufficient background measurements are available for analysis. Figure A11-4 shows $PM_{2.5}$ measurements at three London kerb/roadside sites according to the proposed banding system. $PM_{2.5}$ concentrations exhibit a similar seasonal pattern to PM_{10}, with the greatest frequency of Moderate or above concentrations during winter and spring.

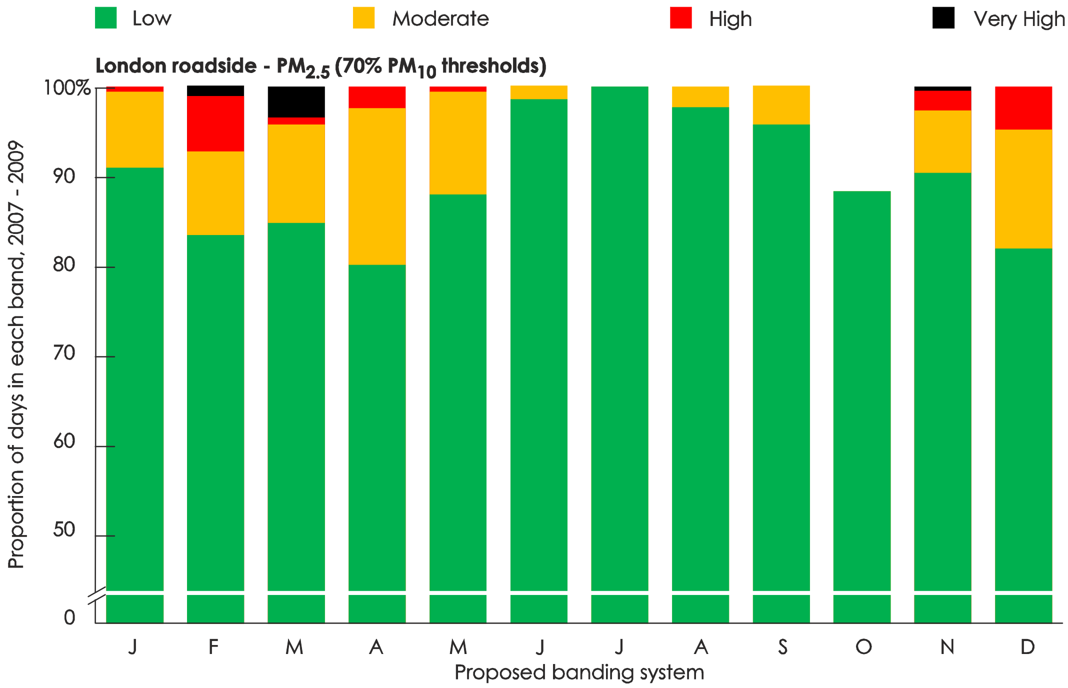

Figure A11-4: $PM_{2.5}$ at three London kerb/roadside sites using the proposed banding system ($PM_{2.5}$ thresholds are 70% of PM_{10} thresholds)

A11.6 Overall index

An overall index for air pollution, at any particular time, is given as the maximum band for any pollutant. Very few monitoring sites measure the full range of pollutants covered by the banding system. For this reason it is more representative to derive an overall band for an area, such as London, as the maximum band for any individual pollutant at any measurement site. For example, if one kerb/roadside site measures High PM_{10}, then kerb/roadside air pollution is deemed high. In Figure A11-5 the maximum band for all sites is used to show the proportion of days that air pollution in London is within each band. This is shown separately for background and kerb/roadside sites. Given the lack of available FDMS $PM_{2.5}$ measurements, TEOM measurements have also been used to estimate $PM_{2.5}$ within the index. It is, however, accepted that TEOM $PM_{2.5}$ measurements will lead to an underestimate of the Moderate or above days due to $PM_{2.5}$ within the overall index.

For the proposed system, at background sites, the majority of days with air pollution at Moderate or above are caused by O_3. At kerb/roadside sites, Moderate or above days are dominated by PM_{10}, $PM_{2.5}$ and NO_2.

At background sites in London, the overall proportion of days of Low air pollution would fall from 82% in the current system to 67% in the proposed system. The proportion of Low days at kerb/roadside sites in London would also reduce, changing from 42% to 15%.

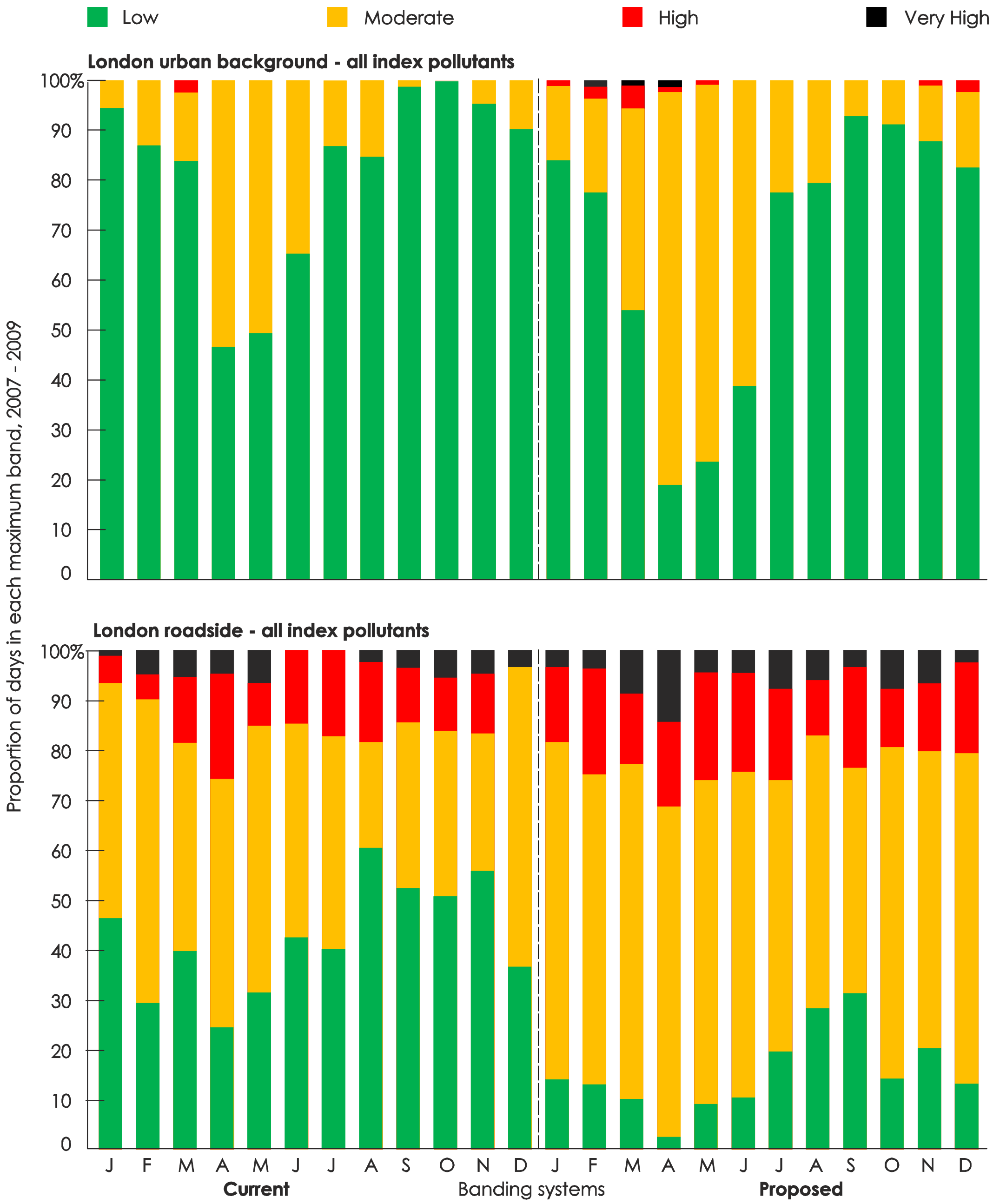

Figure A11-5: Comparison between the current and proposed banding systems for overall pollution

The upper panel shows background air pollution from 32 sites and the lower panel shows kerb/roadside air pollution from 40 kerb/roadside sites in London

Annex 12

Comparison of Air Quality Indices and Health Descriptors

The following pages illustrate air quality indices and health descriptors used in various countries.

A12.1 Air quality indices

The approaches that various European and English speaking countries have taken in developing their air quality indices are summarised in the table below.

The index value relates to the 'scale' on which the pollution is measured; for example, Australia has a 'scale' or index value of 0–200, while France uses a 1–10 scale. The banding relates to the number of categories or named bands which are usually presented to the public, while the final column indicates which pollutants are included in calculating the specific indices. It is clear, therefore, that there is no common, consistent approach to air quality indices.

Approaches to developing air quality indices

Country	Index value	Named bandings	Pollutants
Australia	200	6	CO, NO_2, O_3, PM_{10}, SO_2
Belgium	10	10	NO_2, O_3, PM_{10}, SO_2
Canada	100	10 (4 named)	CO, NO_2, O_3, PM_{10}, SO_2
CITEAIR *	100	5	CO, NO_2, O_3, PM_{10}, SO_2
France	10	6	NO_2, O_3, PM_{10}, SO_2
Germany	100	6	CO, NO_2, O_3, PM_{10}, SO_2
Ireland	100	5	NO_2, O_3, PM_{10}, SO_2
UK	10	4	CO, NO_2, O_3, PM_{10}, SO_2
USA	500	6	CO, NO_2 ,O_3, $PM_{2.5}$, PM_{10}, SO_2

CO Carbon monoxide
NO_2 Nitrogen dioxide
O_3 Ozone
$PM_{2.5}$ Particulate matter less than 2.5 µm in diameter
PM_{10} Particulate matter less than 10 µm in diameter
SO_2 Sulphur dioxide
* An EU-funded project to develop a common air quality index for Europe

A12.2 Health advice

Most, but not all, air quality indices are accompanied by health advice containing information on exposure avoidance and health protection. Again, there is no standardised approach as shown in the table below.

For example, Canada provides health advice for the 'at-risk' and the general population, while Australia provides combined health advice which varies by pollutant. The European CITEAIR index does not have health advice associated with each 'band', while the French advice relates to the EU alert values, rather than the air quality index.

Accompanying health advice

Country	Separate advice by pollutant	Separate advice for vulnerable and non-vulnerable population	Available on the internet
Australia	✓	✓	✓
Belgium *	None	None	Not available
Canada	×	✓	✓
CITEAIR †	None	None	Not available
France	None	None	Not available
Germany	×	×	✓
Ireland *	Under review	Under review	Under review
UK	×	✓	✓
USA	×	×	✓

* Health advice is currently being reviewed and therefore not available

† An EU-funded project to develop a common air quality index for Europe

A12.3 Examples of health advice

The following pages provide examples of the variety of the health advice that accompanies air quality indices. They have been taken from English speaking countries only to avoid translation issues.

Three types of health advice are presented to demonstrate the different approaches that have been taken. These are from Australia, Canada and the USA.

Australia

In New South Wales, Australia, the air quality index provides separate health advice for various population groups (young children and the elderly). The advice is also separated by pollutant. The following two tables indicate the health advice for older adults and for children. Available at http://ambulance.nsw.gov.au/PublicHealth/environment/air/sensitive_groups.asp *

Banding	Numerical value	Health advice for older adults Particles
Very Good	0–33	Ideal conditions to enjoy outdoor activities
Good	34–66	Ideal conditions to enjoy outdoor activities
Fair	67–99	Unusually sensitive people should consider reducing prolonged outdoor exertion
Poor	100–149	Older adults, especially those with heart or lung disease should avoid exercising outdoors. Levels will be lower indoors. If you have chest pain, shortness of breath or cough, use your reliever medicine. If symptoms persist, seek medical advice
Very Poor	150–199	Older adults should avoid outdoor exertion and stay inside as much as possible. Levels will be lower indoors. If you have chest pain, shortness of breath or cough, you should rest, take your reliever medicine or seek medical advice
Hazardous	200+	Everyone should avoid outdoor exertion and stay inside as much as possible. Levels will be lower indoors. If you have chest pain, shortness of breath or cough, you should rest, take your reliever medicine, or seek medical advice

* At the time of writing, the New South Wales air quality index has been updated. The revised index is now available at http://www.cleartheair.nsw.gov.au/air_and_you/warnings.aspx

Banding	Numerical value	Health advice for children	
		Ozone	Particles
Very Good	0–33	Ideal conditions to enjoy outdoor activities	Ideal conditions to enjoy outdoor activities
Good	34–66	Ideal conditions to enjoy outdoor activities	Ideal conditions to enjoy outdoor activities
Fair	67–99	Unusually sensitive kids should consider limiting prolonged outdoor exertion to mornings	Unusually sensitive kids should consider limiting prolonged outdoor exertion to mornings
Poor	100–149	Avoid exercising outdoors in the evening. Levels will be lower indoors. If there are symptoms of asthma, shortness of breath or cough, the child should rest and use their reliever medicine. If symptoms persist, seek medical advice	Reduce exercising outdoors. If there are symptoms of asthma, wheeze, shortness of breath or cough, the child should rest and use their reliever medicine. If symptoms persist, seek medical advice
Very Poor	150–199	Avoid prolonged outdoor exertion. Levels will be lower indoors. If there are symptoms of asthma, shortness of breath or cough, the child should rest and use their reliever medicine. If symptoms persist, seek medical advice	Should avoid exercising outdoors. If there are symptoms of asthma, wheeze, shortness of breath or cough, the child should rest and use their reliever medicine. If symptoms persist, seek medical advice
Hazardous	200+	Avoid outdoor exertion and stay inside as much as possible. If there are symptoms of asthma, shortness of breath or cough, the child should rest and use their reliever medicine. If symptoms persist, seek medical advice	Avoid outdoor exertion and stay inside as much as possible. If there are symptoms of asthma, wheeze, shortness of breath or cough, the child should rest and use their reliever medicine. If symptoms persist, seek medical advice

Canada

The Canadian air quality index and health advice is provided by Environment Canada, a division of the Canadian Government. The advice provides separate health advice for the 'at-risk' population and the general population. Available at http://www.ec.gc.ca/cas-aqhi/default.asp?Lang=En

Banding	Numerical value	Health advice	
		At-risk population*	**General population**
Low Health Risk	1–3	Enjoy your usual outdoor activities	Ideal conditions for outdoor activities
Moderate Health Risk	4–6	If you have heart or breathing problems, and experience symptoms, consider reducing physical exertion outdoors or rescheduling activities to times when the index is lower	No need to modify your usual outdoor activities, unless you experience symptoms
High Health Risk	7–10	Children, the elderly and people with heart or breathing problems should reduce physical exertion outdoors or reschedule activities to times when the index is lower, especially if they experience symptoms	Anyone experiencing discomfort such as coughing or throat irritation should consider reducing physical exertion outdoors or rescheduling strenuous activities to periods when the index is lower
Very High Health Risk	Above 10	Children, the elderly and people with heart or breathing problems should avoid physical exertion outdoors	Everyone should consider reduce physical exertion outdoors or reschedule strenuous activities to times when the index is lower, especially if they experience symptoms

* People with heart or breathing problems are at greater risk. Follow your doctor's usual advice about exercising and managing your condition

USA

The following health advice from the US Environmental Protection Agency (US EPA) provides combined air pollution and health advice for the general public and the 'at-risk' populations. Available at http://www.airnow.gov

Banding	Numerical value	Health advice
Good	0–50	Air quality is considered satisfactory, and air pollution poses little or no risk
Moderate	51–100	Air quality is acceptable; however, for some pollutants there may be a moderate health concern for a very small number of people who are unusually sensitive to air pollution
Unhealthy for Sensitive Groups	101–150	Members of sensitive groups may experience health effects. The general public is not likely to be affected
Unhealthy	151–200	Everyone may begin to experience health effects; members of sensitive groups may experience more serious health effects
Very Unhealthy	201–300	Health alert: everyone may experience more serious health effects
Hazardous	301–500	Health warnings of emergency conditions. The entire population is more likely to be affected

Glossary of Terms and Abbreviations

ACS	American Cancer Society
Air pollution episode	A period of elevated air pollution, usually lasting up to several days, extending over a large geographical area
Air quality index (UK)	A ten-point scale with four bands indicating 'Low', 'Moderate', 'High' and 'Very High' levels of air pollution. It is used to communicate information about real-time and forecast levels of outdoor air pollution
Air Quality Objective	Policy targets generally expressed as a maximum ambient concentration to be achieved, either without exception or with a permitted number of exceedances, within a specified timescale. The Objectives are set out in the UK Government's Air Quality Strategy for the key air pollutants
Air Quality Standards	Concentrations recorded over a given time period, which are considered to be acceptable in terms of what is scientifically known about the effects of each pollutant on health and on the environment. They can also be used as a benchmark to indicate whether air pollution is getting better or worse
Air Quality Strategy	The Air Quality Strategy for England, Scotland, Wales and Northern Ireland describes the plans drawn up by the Government and the Devolved Administrations to improve and protect ambient air quality in the UK in the medium-term. The Strategy sets Objectives for the main air pollutants to protect health
Alert threshold	A level beyond which there is a risk to human health from brief exposure for the population as a whole
Ambient air	Outdoor air
AURN	Automatic Urban and Rural Network
Black smoke (BS)	Non-reflective (dark) particulate matter, measured by the smoke stain method. it provides a method used for monitoring the concentration of particles in the air, originating from the era of domestic coal burning in cities. The method relies upon collecting particles via a size-selective sampling head which are then deposited onto a filter paper which becomes blackened – the degree of this blackening provides the basis of the particle measurement
CAFE	Clean Air for Europe
Carbon monoxide (CO)	A poisonous gas produced by incomplete oxidation of fossil fuels

Cardiovascular disease	Disorders of the heart and circulatory system
Chamber studies	Studies involving the exposure of volunteers to controlled concentrations of gases or aerosols
Chronic obstructive pulmonary disease	Long-standing disease of the airways of the lung associated with increased production of phlegm and shortness of breath and often caused by cigarette smoking
COMEAP	Committee on the Medical Effects of Air Pollutants
Confidence interval	If it is possible to define two statistics t_1 and t_2 (functions of sample values only) such that, θ being a parameter under estimate, $P\ (t_1 \leq \theta > t_2) = \alpha$ where α is some fixed probability (e.g. 0.95 or 95%), the interval between t_1 and t_2 is called a confidence interval. The assertion that θ lies in this interval will be true, on average, in a proportion α of the cases when the assertion is made. For example, 95% confidence intervals are calculated in such a way that, in the absence of bias, 95% of such intervals will include the parameter that is being estimated
CSAS	COMEAP Standards Advisory Subgroup
EPAQS	Expert Panel on Air Quality Standards
Epidemiological studies	Investigations of diseases conducted at a population level
European (EU) Directives	The European Union has been legislating to control emissions of air pollutants and to establish air quality objectives since the early 1970s. European Directives on ambient air quality require the UK to undertake air quality assessment, and to report the findings to the European Commission on an annual basis
EU Limit Values	EU Limit values are legally binding EU parameters that must not be exceeded. Limit Values are set for individual pollutants and are made up of a concentration value, an averaging time over which it is to be measured, the number of exceedances allowed per year, if any, and a date by which it must be achieved. Some pollutants have more than one Limit Value covering different endpoints or averaging times
EU target values	Used in some EU Directives and are set out in the same way as limit values. They are to be attained where possible by taking all necessary measures not entailing disproportionate costs
Euro Standards	European regulation of pollutant emissions from road vehicles
FDMS	The Filter Dynamics Measurement System (FDMS) monitors the core and volatile fractions of airborne particulate matter
MAAPE	Advisory Group on the Medical Aspects of Air Pollution Episodes
Meta-analysis	A statistical method used to combine the results of a number of individual studies
Nitrogen dioxide (NO_2)	A gas produced during combustion by the oxidation of atmospheric nitrogen

Ozone (O_3)	A strongly oxidant gas produced from oxygen
Particle	A minute portion of matter – frequently a very small solid or liquid particle (or droplet) of micrometre or nanometre dimensions
Parts per billion	Parts per billion, ppb, describes the concentration of a pollutant in air in terms of volume ratio. A concentration of 1 ppb means that for every billion (10^9) units of air, there is one unit of pollutant present
PM	Particulate matter
$PM_{2.5}$	Mass per cubic metre of particles passing through the inlet of a size selective sampler with a transmission efficiency of 50% at an aerodynamic diameter of 2.5 micrometres
PM_{10}	As above, with 10 micrometres
Relative risk (RR)	Relative risk is used in this report to compare age-specific death rates in two groups that differ in terms of exposure or other characteristics, e.g. in terms of their average annual exposure to $PM_{2.5}$. It is derived as the ratio of age-specific death rates in the two groups (assuming other factors are equal) because exposure is expected to increase age-specific death rates by some multiplicative factor, to be estimated from epidemiological studies. Relative risk is a measure of that factor
Six Cities Study	A long-term cohort study conducted in the USA
Sulphur dioxide (SO_2)	An acidic gas formed by oxidation of sulphur found in fossil fuel
TEOM	Tapered element oscillating microbalance. A method of measuring mass of particles in real time
Time-series studies	Studies of the health effects of short-term exposure to air pollution. Time-series studies estimate the influence of daily variations in air pollutant concentrations on deaths (mortality) and illness by linking daily counts of health events (mortality, hospital admissions, visits to emergency departments, etc) within a geographically defined population with daily measures of air pollution and other variables
Trigger concentrations	Hourly pollution measurements that indicate a period of 'Moderate', 'High' or 'Very High' air pollution may be taking place or is likely to happen soon *(see also air quality index)*
TSP	Total suspended particles
UNECE	United Nations Economic Commission for Europe
µm	Abbreviation for micrometre or micron (a unit of length). 1 µm = one thousandth of a millimetre
µg m^{-3}	Micrograms per cubic metre. 1 µg = 1 millionth of a gram
WHO	World Health Organization

Appendix

Membership of the Committee on the Medical Effects of Air Pollutants

Chairman	Professor Jon G Ayres BSc MD FRCP FRCPE FFOM FRCPSG
Members	Professor H Ross Anderson MD MSc FFPH FRCP FMedSci
	Mr Benedict Armstrong BA MSc PhD *(until August 2010)*
	Dr Richard Atkinson MSc PhD PG Cert HE
	Dr Paul Cullinan MD MSc FRCP FFOM
	Professor Richard G Derwent OBE MA PhD
	Professor Ken Donaldson BSc PhD DSc FIBiol FRCPath FFOM *(until August 2010)*
	Professor Roy Harrison OBE PhD DSc CChem FRSC FRMetS HonFFOM HonMFPH HonMCIEH
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	Professor Frank J Kelly BSc PhD FRSA
	Dr Tim J King MA DPhil DipStat CBiol FIBiol FRGS FLS
	Professor Duncan Laxen BSc MSc PhD
	Professor David E Newby FRCP FRSE FMedSci
	Dr Geoffrey H Pigott BSc PhD
	Mr John Stedman BA
	Professor Vicki Stone BSc PhD FIBiol CBiol ILTM
	Professor Dafydd Walters BSc MB BS FRCP FRCPCH *(until August 2010)*
Secretariat	Professor Robert L Maynard CBE FRCP FRCPath FFOM (Medical)
	Dr Heather Walton BSc DPhil (Scientific) *(until March 2010)*
	Ms Alison Gowers BSc MSc (Scientific) *(from March 2010)*
	Dr Karen Exley BSc MSc PhD (Scientific)
	Miss Britta Gadeberg BSc MSc (Scientific) *(from April 2010)*
	Miss Inga Mills BSc MSc (Scientific)
	Mrs Isabella Myers BSc MSc (Scientific)

Membership of the Committee on the Medical Effects of Air Pollutants Standards Advisory Subgroup

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Professor Jon G Ayres BSc MD FRCP FRCPE FFOM FRCPSG

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