AIR QUALITY EXPERT GROUP

Nitrogen Dioxide in the United Kingdom

Summary

Prepared for:
Department for Environment, Food and Rural Affairs;
Scottish Executive; Welsh Assembly Government; and
Department of the Environment in Northern Ireland

This is the first report produced by the Air Quality Expert Group.

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Introduction

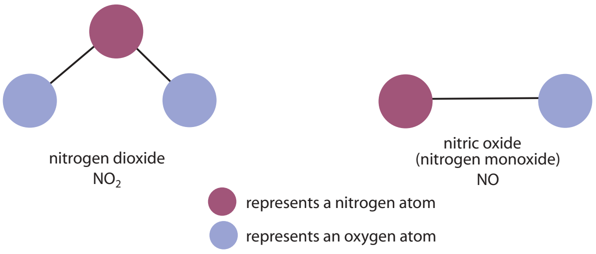
Following the publication of the ‘Air Quality Strategy for England, Scotland, Wales and Northern Ireland’, the Air Quality Expert Group (AQEG) was set up in 2002. It aims to help the UK Governments tackle air pollution by examining where pollutants come from and what their **concentrations** are in the UK.

This is a summary of AQEG’s first report on nitrogen dioxide that is aimed at the general public. We have also included a glossary at the back to explain certain terms (these are shown in **bold** the first time they appear in the document).

What is nitrogen dioxide and how does it affect the environment?

Nitrogen dioxide is a brown gas, with the chemical formula NO_2. It is chemically related to nitric oxide (nitrogen monoxide), a colourless gas with the chemical formula NO (Figure 1). These abbreviations are often used instead of writing the names of the chemicals in full. We will follow this practice in this report.

Figure 1 A diagram of the structures of NO_2 and NO.



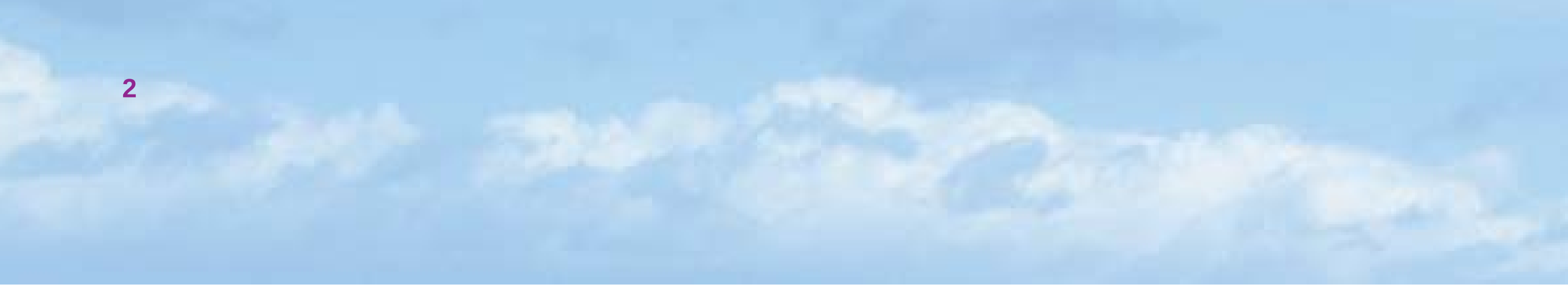
Together, NO and NO_2 are known as NO_X. NO_X is released into the atmosphere when fuels are burned (for example, petrol or diesel in a car engine, or natural gas in a domestic central-heating boiler or power station). NO_2 can affect our health. There is evidence that high levels of it can inflame the airways in our lungs and, over a long period of time, affect how well our lungs work. People with asthma are particularly affected. NO_2 can also affect vegetation.

NO_2 and the UK Air Quality Strategy

The concentration of NO_2 is measured in **micrograms** in each cubic metre of air **($\mu g\ m^{-3}$)**. A microgram **(μg)** is one millionth of a gram. A concentration of 1 $\mu g\ m^{-3}$ means that one cubic metre of air contains one microgram of pollutant. To protect our health, the UK Governments set two **air quality objectives** for NO_2 in their **Air Quality Strategy**:

1. The hourly objective, which is the concentration of NO_2 in the air, averaged over a period of one hour. This is designed to make sure that we are not exposed to high concentrations of NO_2 for short periods of time. High concentrations can arise in **episodes**, which are usually associated with particular weather conditions.
2. The annual objective, which is the concentration of NO_2 in the air, averaged over a period of a year. This aims to protect us from being exposed to NO_2 over a long time.

The European Union (EU) has also developed legislation to limit our exposure to air pollutants, through what are known as **limit values**. Table 1 shows the objectives and limit values for NO_2. The values of both are the same, but the UK Air Quality Strategy aims to achieve its objectives earlier than the EU has set. Local authorities must identify areas where NO_2 concentrations are



higher than the objectives (and limit values) and develop local measures to put things right. Legislation is also set at national and European levels to limit **emissions** of NO_X, for example from road vehicles and power stations, in order to control concentrations of NO_2 in the air.

Table 1 EU limit values and the UK Air Quality Strategy objectives for NO_2.

Legislation	Hourly	Annual	Achieve by
EU First Daughter Directive (99/30/EC)	200 µg m^{-3} with no more than 18 exceedences per year	40 µg m^{-3}	2010
Air Quality Strategy (2000)	200 µg m^{-3} with no more than 18 exceedences per year	40 µg m^{-3}	2005

For the hourly objective, it is appropriate to have an allowed number of **exceedences** for the objective. This allows for situations where it is not practical to expect hourly average concentrations to always be within the allowed limit (for example, where bad weather conditions can affect concentrations).

Where does NO_2 come from?

NO_X is produced when fossil fuels (coal, natural gas and so on) are burned. When a pollutant is released directly into the atmosphere it is known as an emission. Figure 2 shows the total emissions of NO_X in the UK since 1970, with predictions through to 2020. The emissions are divided into their different sources. The figure shows that overall emissions of NO_X fell by 37% from 1990 to 2000, mainly due to reductions in emissions from road transport and power stations. We expect emissions to reduce by a further 25% by 2010.

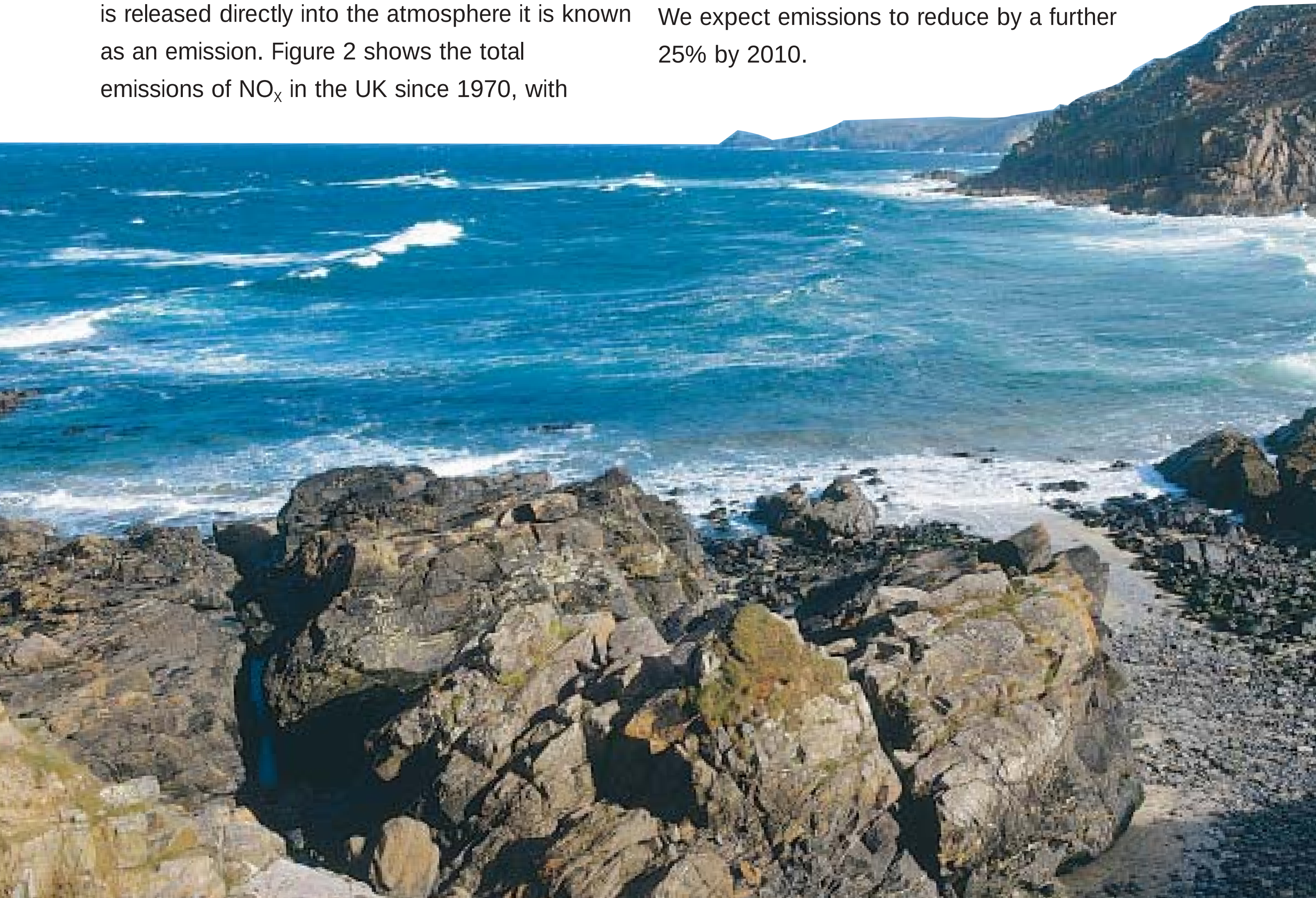
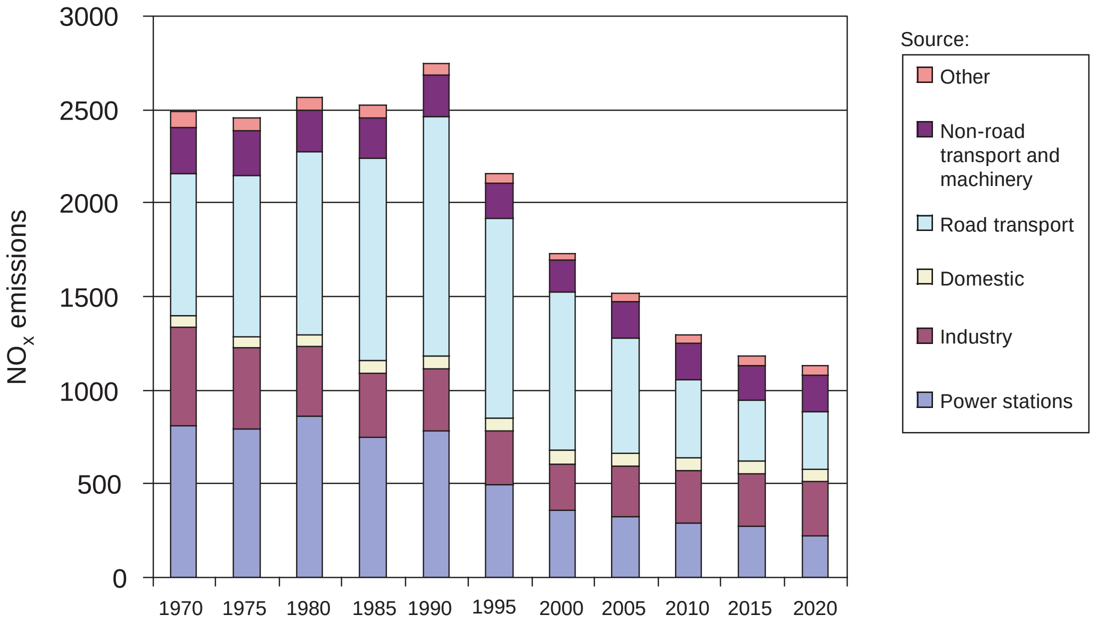


Figure 2 NO_X emissions in kilotonnes in the UK by source from 1970 to 2020.



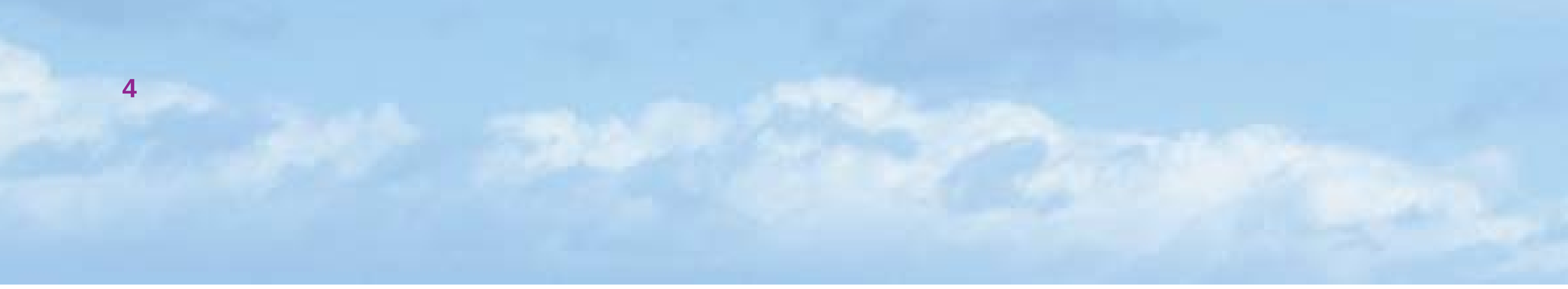
Road transport is the largest source of NO_X emissions in the UK, contributing 49% of total emissions in 2000. However, emissions from road transport have fallen by 34% between 1990 and 2000. This is due to improvements in engine design and fitting **three-way catalysts** to petrol cars, to meet increasingly strict European standards. The importance of road transport is even greater in urban areas, but we expect these emissions to reduce greatly by 2010 (by about 50%, in London, for example, compared with 1999 values). By contrast, we expect domestic and commercial emissions in central London (mainly from heating), which currently contribute 25%, to increase over the next 10 years.

NO_X emissions from burning fossil fuels are mainly as NO, but some sources can release a lot of NO_X as NO_2. These **primary** NO_2 emissions are particularly important from diesel vehicles (especially when moving slowly), and can make up as much as 25% of the total NO_X emissions from this source. One reason for this is as a side-effect of measures that have been developed to reduce emissions of **particulate matter** from diesel vehicles by treating the exhaust using diesel **particulate filters**. These primary NO_2 emissions can lead to high concentrations of NO_2 at the roadside, especially where there are many diesel vehicles.

NO_2 is also formed in the atmosphere in a chemical reaction between NO and **ozone** (O_3):

$$\underset{\text{ozone}}{NO + O_3} \rightarrow NO_2 + \underset{\text{oxygen}}{O_2}$$

Because this NO_2 is not released straight into the atmosphere, but is formed there by a chemical reaction, it is known as **secondary** NO_2. Sometimes this reaction cannot take place because there is not enough O_3 for the NO to react with. This is most common close to where NO is released, for example, near to busy roads.



Box 1

The formation of ground-level ozone

Like NO_X, **volatile organic compounds (VOCs)** are emitted into the atmosphere through the burning of fossil fuels. They also come from several other sources, both domestic and industrial, such as the production and use of paints. Vegetation also emits VOCs. Sunlight causes chemical reactions to occur between VOCs and NO_X, which leads to ozone formation. Ozone also affects your health, especially if you have asthma.

The chemical reactions occur quite slowly, over hours or days. During this time, winds can move the air over considerable distances – hundreds of kilometres. As a result, measures to control ozone have to be developed internationally, since, for example, emissions in continental Europe can influence ozone concentrations in the UK.

As air containing ozone crosses a city, it gets mixed with air containing NO_X from the urban emissions. A reaction then occurs between NO and ozone, forming NO_2. The formation of this secondary NO_2 depends on the amount of ozone that is brought to the city from background locations. Importantly, measures to reduce NO_X can lead to reductions in NO_2, but may also increase ozone, because there is less NO to react with it and hence remove it from the air.

How is NO_2 measured and how much is there in the atmosphere?

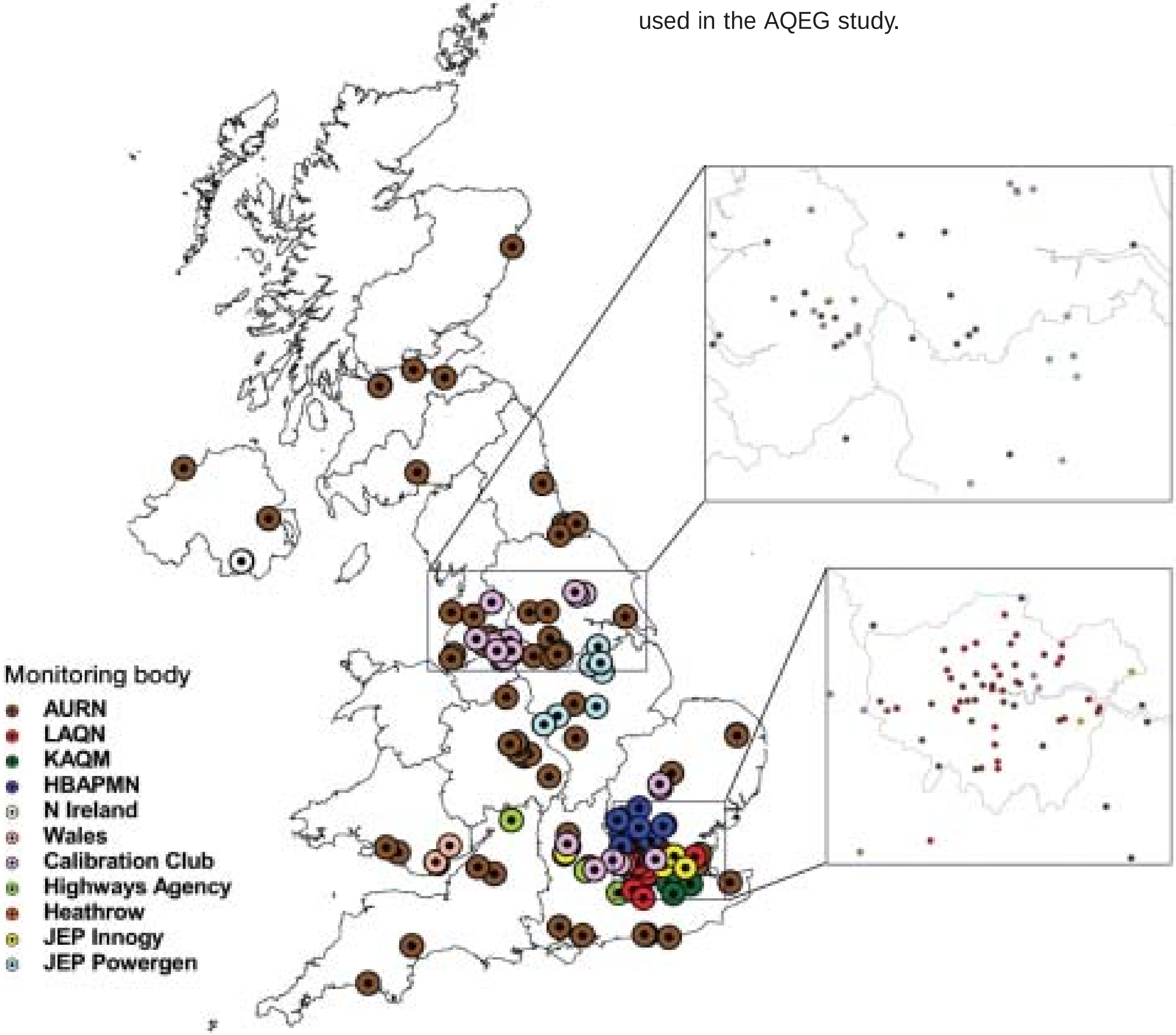
Nitrogen dioxide is measured continuously using an instrument called a chemiluminescence analyser. There are networks of over 200 monitoring sites, using chemiluminescence analysers, throughout the UK (Figure 3).
The main networks are:

- The Automatic Urban and Rural Network (AURN) – funded mainly by the UK Governments, but with some local authority sites.
- The London Air Quality Network (LAQN), which is made up only of local authority sites.

Other monitoring sites are run by groups such as local authorities, the Highways Agency and the electricity generating companies.

As part of their report, AQEG assessed NO_2 concentrations during 2001 for 212 automatic monitoring sites, and then looked at information from 15 of these sites in detail. The analysis showed that annual average NO_2 concentration above 40 µg m^{-3} (the objective for 2005 and limit value for 2010, see Table 1) were measured at most roadside and kerbside sites in London and at about half of the background sites (see Box 2 for an explanation of these terms). Exceedences outside London were mainly at roadside and kerbside monitoring sites. The measurements show that the annual average is the most important assessment objective for NO_2 – that is, it is much more difficult to meet the annual average objective than the hourly objective (see Table 1).

Figure 3 Location of NO_2 monitoring sites in 2001 used in the AQEG study.



AURN, Automatic Urban and Rural Network; LAQN, London Air Quality Network; KAQN, Kent Air Quality Network; HBAPMN, Hertfordshire and Bedfordshire Air Pollution Monitoring Network; Calibration club, run by Local Authorities but with data handling managed by a single company; Heathrow, run by Heathrow Airport Ltd.; JEP Innogy and JEP Powergen, run by power generators.

Box 2

Definition of the types of monitoring site

Monitoring sites within the networks are located across the UK. These range from sites that are strongly affected by local pollution sources (such as road traffic or industrial processes) to sites within remote or rural areas.

Kerbside

Sites with **sample inlets** within one metre of the edge of a busy road. For example, Marylebone Road, London.

Roadside

Sites with sample inlets between one metre of the edge of a busy road and the back of the pavement (usually five metres from the roadside). For example, Hounslow Roadside, London.

Urban Centre

Sites away from roads in city and town centres (for example, pedestrian precincts and shopping areas). For example, Glasgow Centre, Scotland.

Urban Background

Urban locations (for example, parks and urban residential areas) away from emission sources. These locations broadly represent city-wide background concentrations. For example, Londonderry, Northern Ireland.

Urban Industrial

Sites where industrial emissions make an significant contribution to measured pollution concentrations. For example, Grangemouth, Scotland.

Suburban

Sites typical of residential areas on the outskirts of a town or city. For example, Hillingdon, London.

Rural

Sites in the open country away from roads, industrial areas and where people live. For example, Aston Hill, Wales.

Remote

Sites in the open country in isolated rural areas, that only have regional background pollution concentrations for most of the time. For example, Strath Vaich, Scotland.

Trends in concentrations of NO and NO_2

An analysis of measured concentrations of NO and NO_2 over the last 10 years shows that annual average concentrations of NO_X at urban background and urban centre sites (Figure 4) have gone down faster than NO_2 concentrations (Figure 5).

An assessment of **rolling annual average** concentrations at 11 background and roadside sites in London since 1996 shows that, on average, NO_X concentrations have dropped to 70% of the 1996 values. By contrast, NO_2 in 2001 were, on average, 88% of their 1996 values. This fall in concentrations of NO_X measured in the atmosphere matches the fall in the amount of NO_X that was emitted from the burning of fossil-fuels.

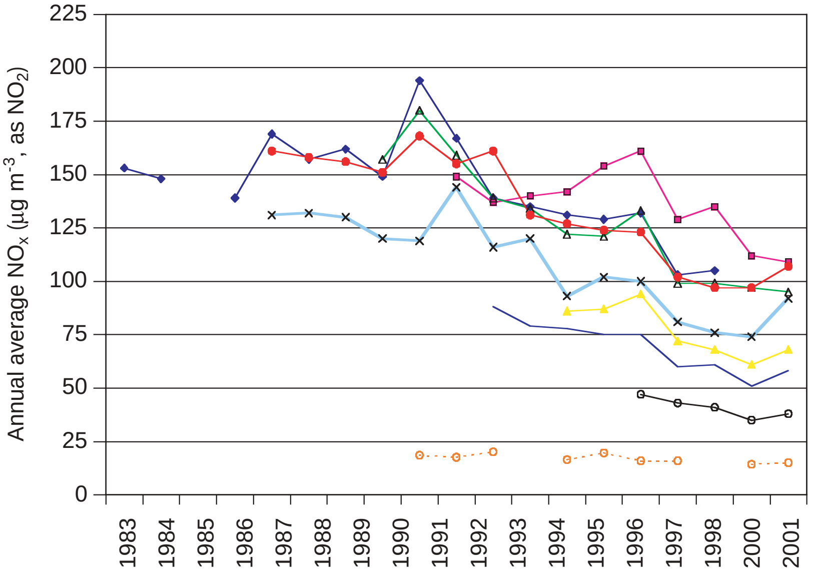


Figure 4 Annual average NO_X concentrations at selected urban centre and urban background sites.

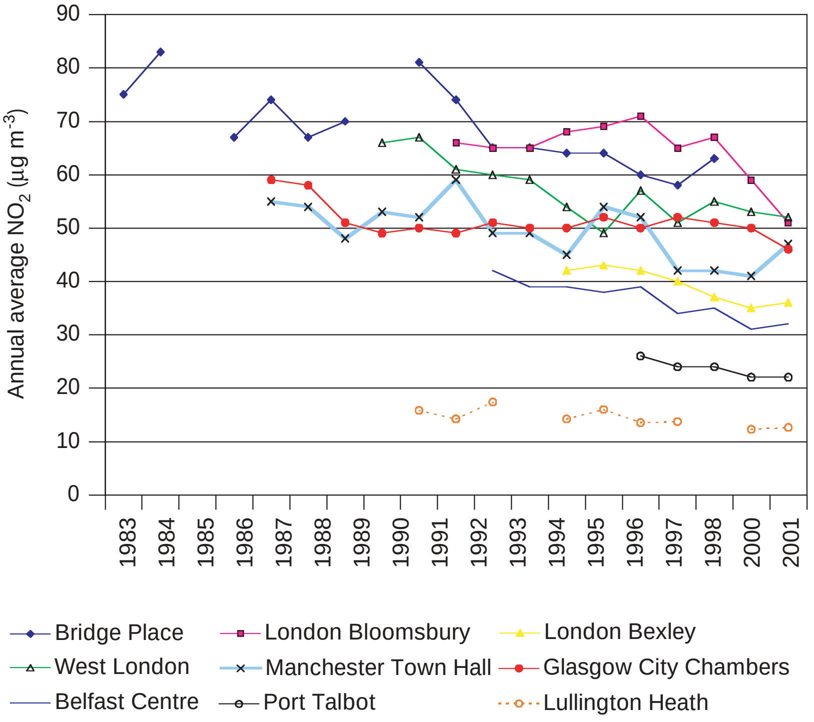
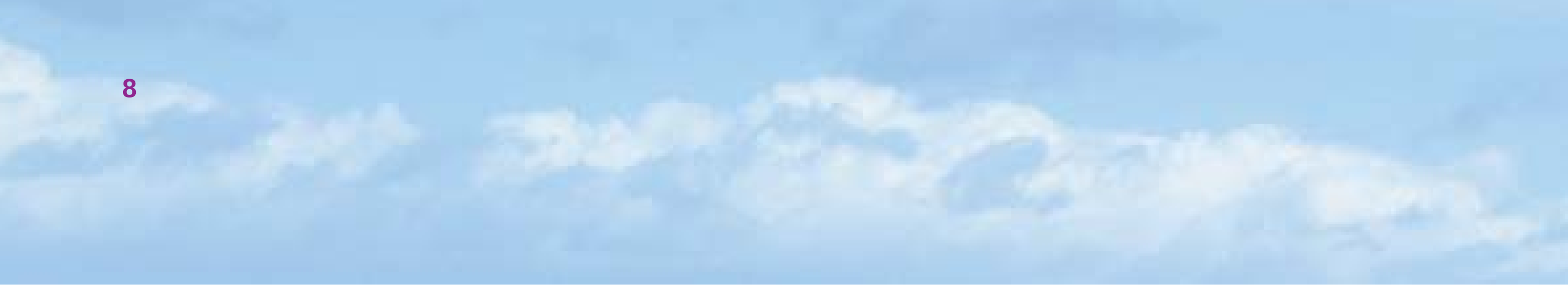


Figure 5 Annual average NO_2 concentrations at selected urban centre and urban background sites.



Similar trends (a smaller decrease in NO_2 concentrations than in NO_X concentrations) were also seen for roadside and kerbside sites, although these results are for a shorter period of time. The smaller fall in NO_2 concentrations is due to both increases in emissions of primary NO_2 over the last few years and details of the chemistry by which secondary NO_2 is formed.

Annual average NO_2 concentrations monitored at urban background sites in the United Kingdom broadly compare with those monitored across Europe. Being close to traffic appears to be the major influence on the annual average NO_2 concentrations monitored at over 1600 sites across Europe. Annual average exceedences of 40 µg m^{-3} NO_2 are widespread in urban centres across Europe.

What are the concentrations in places without monitoring sites? How do you predict future concentrations?

We use computer **models** to assess concentrations in places without monitoring sites and to predict future concentrations of NO_2. These models are of two types:

- Empirical models that are mainly based on analysing the concentrations of different air pollutants measured at monitoring sites. They can be used to estimate NO_X concentrations in a range of locations and link these concentrations to emissions sources. The models are then used to predict future concentrations on the basis of estimates of future emissions.
- Deterministic models that rely on mathematical descriptions of the physical and chemical processes that take place in the atmosphere.

The report draws on both types of model, and on models based on a combination of the two approaches.

Figure 6 shows a map of the estimated annual average background concentrations of NO_2. We can also develop a map for roadside concentrations. The model used to make these maps is called the **national empirical model.** In London, maps have also been made using a model that is a combination of the empirical and deterministic methods (Figure 7).

These results show that annual average exceedences of 40 µg m^{-3} are widespread throughout London near roads with a lot of traffic (Table 2). In the centre of London, exceedences also take place in the areas between main roads and motorways. Outside London, exceedences are mainly in roadside locations. In England roughly one third of the total length of built-up major roads had modelled concentrations of NO_2 higher than 40 µg m^{-3} (in London, this figure is 90%). There are fewer roadside exceedences in Scotland, Wales and Northern Ireland.

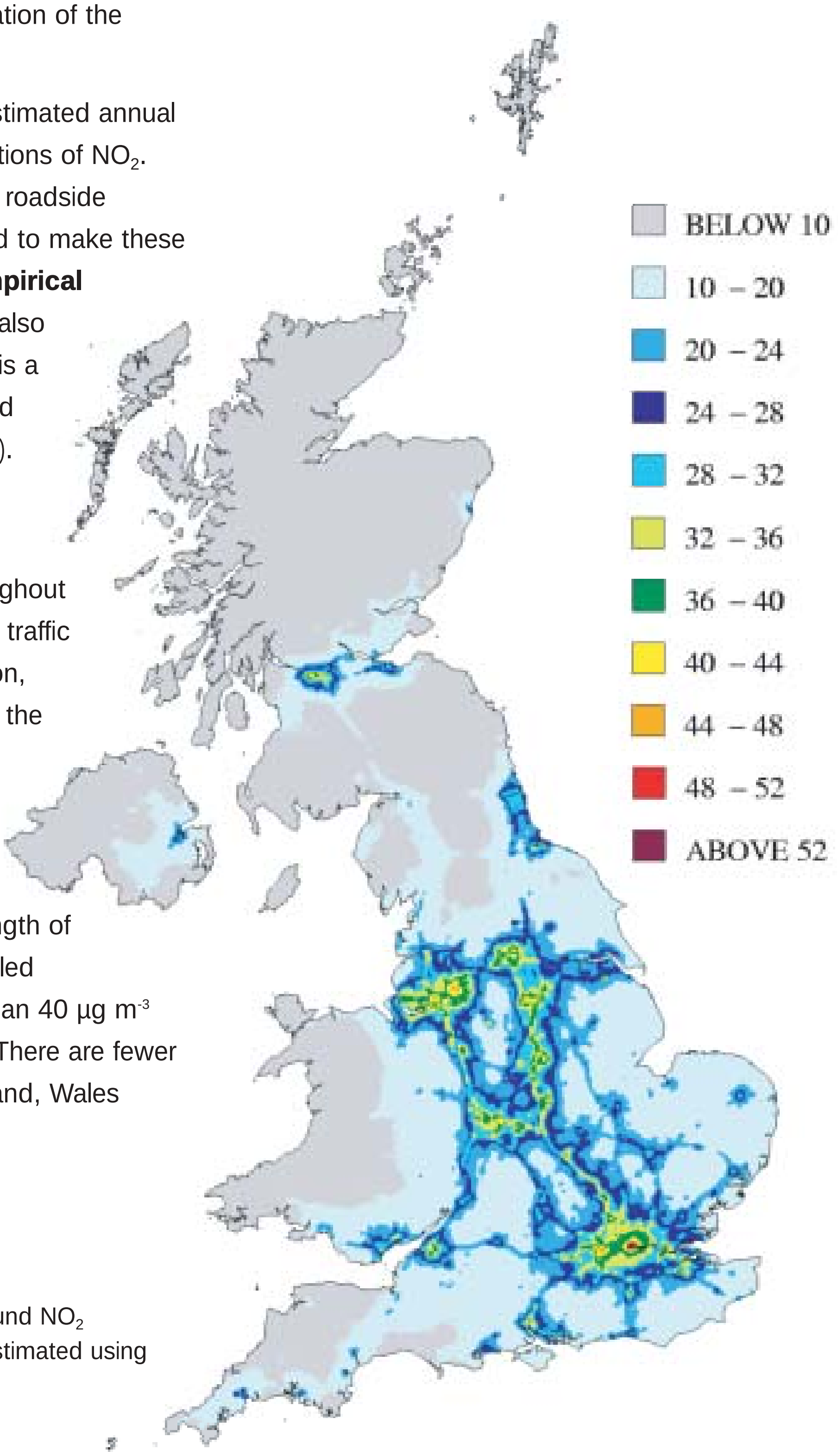
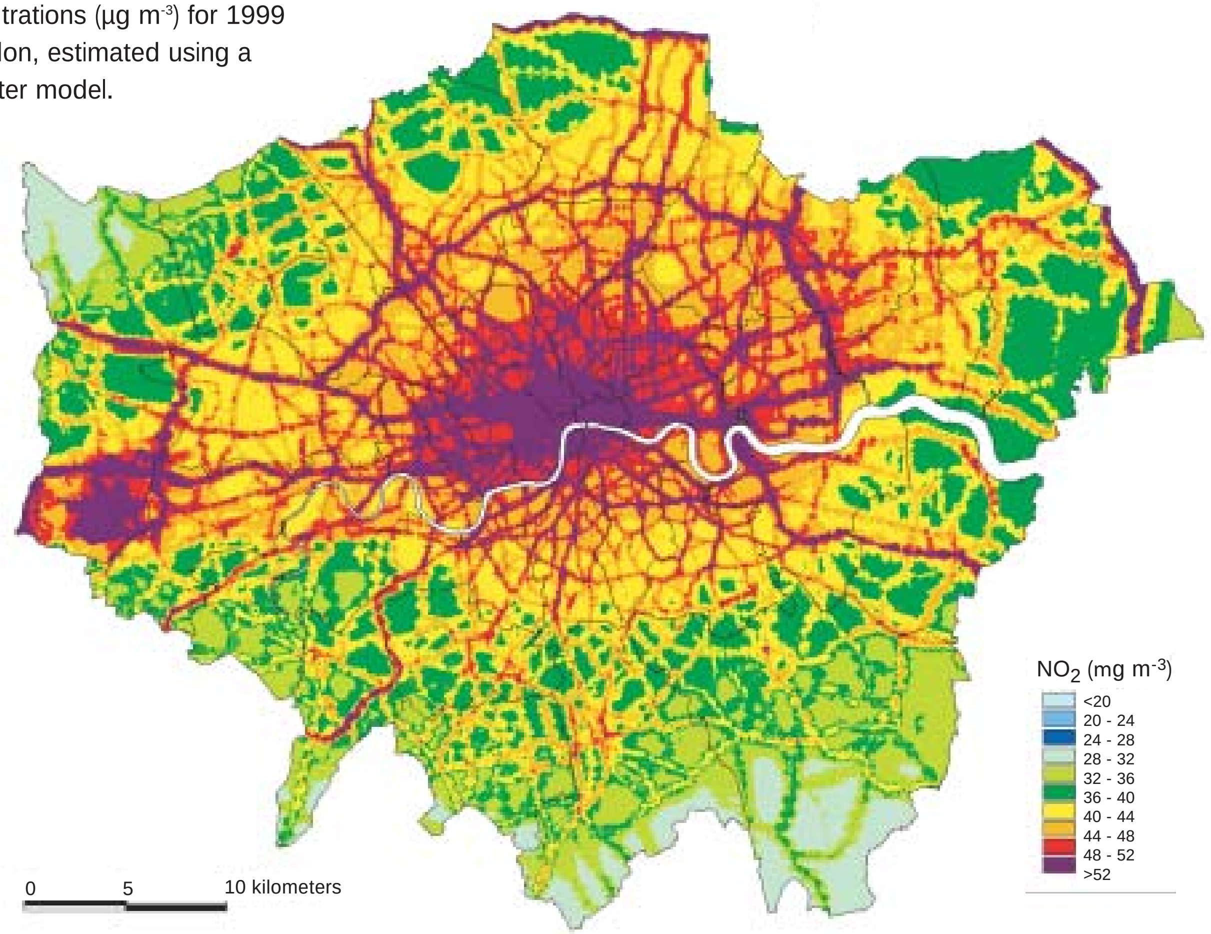


Figure 6 Annual average background NO_2 concentrations (µg m^{-3}) for 2001 estimated using the national empirical model.

Figure 7 Annual average NO_2 concentrations (µg m^{-3}) for 1999 in London, estimated using a computer model.



Are there conditions that lead to very high concentrations of NO_2?

Pollution episodes are short periods of very high levels of pollution. On these occasions it is likely that hourly average NO_2 concentrations higher than 200 µg m^{-3} (see Table 1) will occur. There are two types of episode:

- In winter, when the ground is cold and there is little wind, emissions are trapped near to the ground. Winter episodes took place in 1991 in London and in 2001 in several locations (including Belfast, Glasgow and Manchester), with hourly average NO_2 concentrations reaching 700 µg m^{-3}.
- Summer episodes take place when the weather is hot and sunny and wind speeds are low. High concentrations of ozone are created (by the chemical reactions described in Box 1) and in turn convert more NO into NO_2 in areas where high NO emissions are produced, for example, at roadsides.

A study of NO_2 episodes since 1988 shows that they have become less common. Over the last few years, summer episodes have become relatively less important than winter episodes in terms of their contribution to the number of hours with concentrations of NO_2 over 200 µg m^{-3}.

How are NO_2 concentrations predicted to change in the future?

We can predict future concentrations of NO_2 using models together with estimates of future emissions. Studies show that reductions in NO_X emissions will lead to a significant reduction in annual average exceedences of 40 µg m^{-3} NO_2 at roadside and in background locations, nationally and in London.

Table 2 shows the extent of predicted roadside exceedences for 2005 and 2010, using the national empirical model. These predictions are similar to those made by a different model that looked at London in detail. Predictions of the number of exceedences in background locations are less consistent between different models. They predict exceedence areas in Greater London of between 5% and 32% for 2005 and 3% and 13% for 2010.

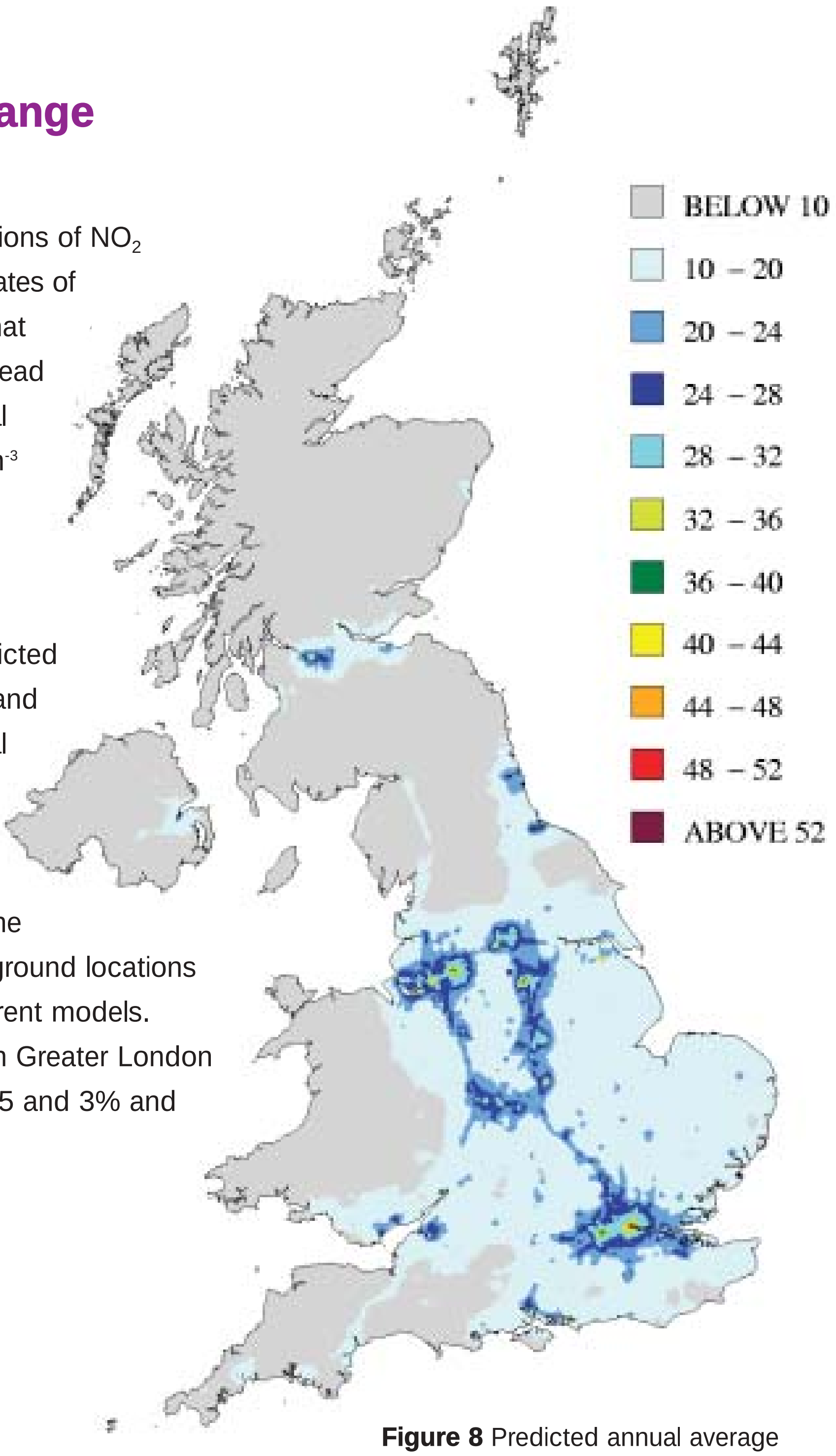


Figure 8 Predicted annual average background NO_2 concentration (µg m^{-3}) for 2001 estimated using the national empirical model.

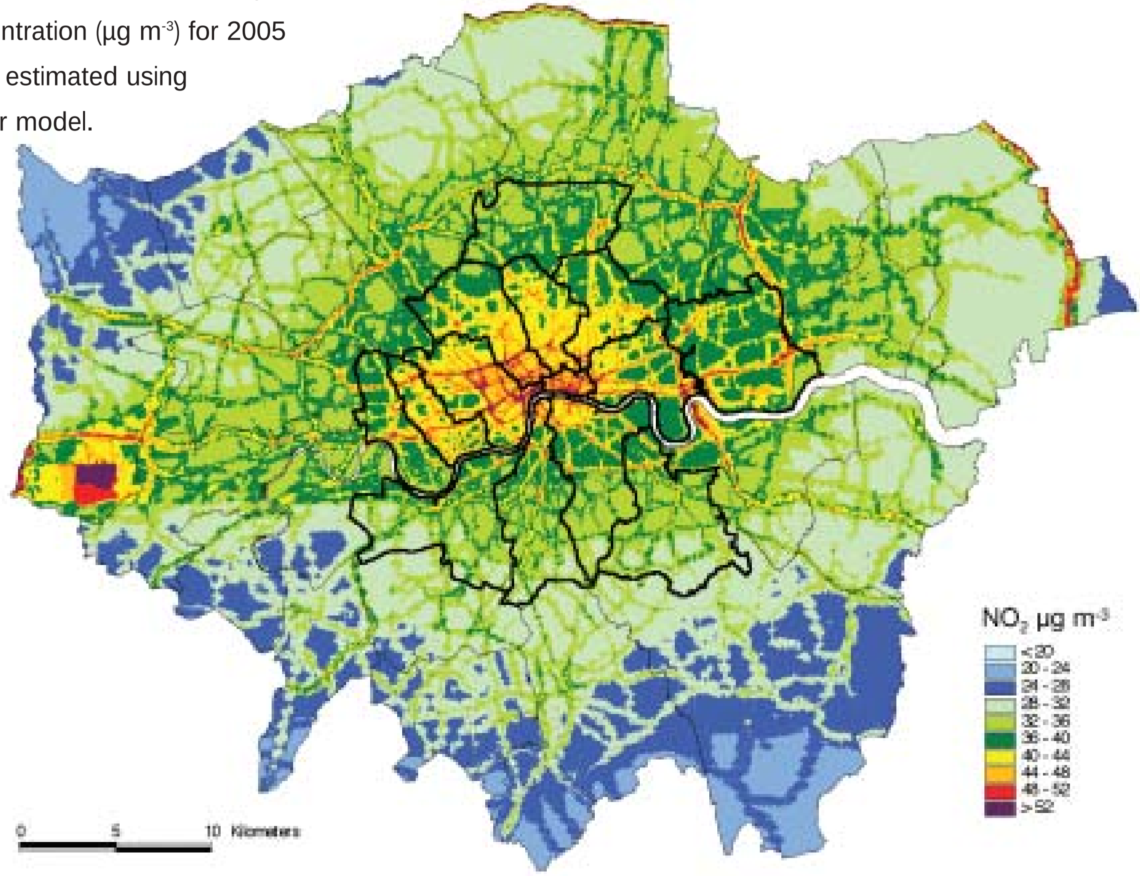
Table 2 Percentage of major road lengths where annual average concentrations of NO_2 are likely to be more than 40 µg m^{-3}.

	2001	2005	2010
Scotland	17	8	2
Wales	5	2	0
Northern Ireland	5	3	0
London	90	65	23
Rest of England	33	18	5
UK	35	20	6

Figures 8 and 9 show the predicted annual average national background concentrations for 2010 calculated using the national empirical model and the annual average concentrations for London in 2005 calculated with the London model. These figures can be compared with those for the UK in 2001 (Figure 6) or for London in 1999 (Figure 7). They clearly show the predicted reductions in NO_2 concentrations.

The emissions estimates show a significant change in the sources of NO_X in central London by 2010. Traffic and the total of domestic and commercial emissions are each predicted to contribute roughly one third of the total annual average NO_X concentrations, with the final third coming from a range of other sources.It is clear from Table 2 that we need much greater reductions in NO_X emissions than those predicted for 2005 and 2010 if an annual average concentration of 40 µg m^{-3} is to be met at all locations (including the most highly polluted areas). To reduce emissions enough to meet the objectives of the Air Quality Strategy by 2005 and the EU limit value by 2010 (Table 1), current national policies need to change.

Figure 9 Predicted annual average NO_2 concentration (µg m^{-3}) for 2005 in London, estimated using a computer model.



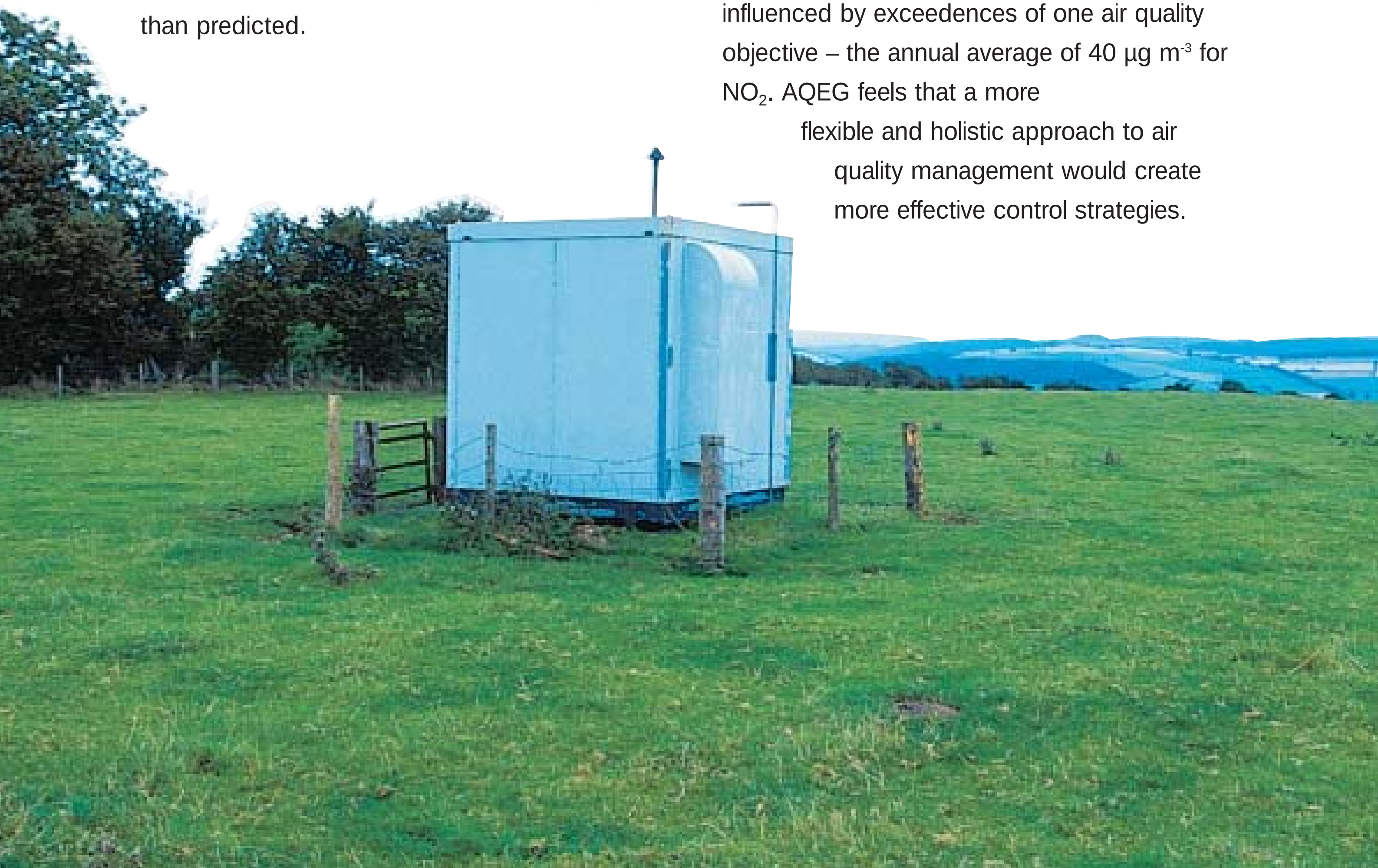
In the national empirical model, predictions are based on the modelled relationship between current NO_X and NO_2 concentrations. Two things could lead to the breakdown in this relationship and to higher NO_2 concentrations than predicted.

- More NO_X emitted as NO_2 (for example, from increased sales of diesel vehicles together with no improvements in the primary NO_2 emissions from particulate filters) would lead to changes in the relationship between NO_X and NO_2 and to increases in predicted NO_2 concentrations.
- There is evidence that background concentrations of ground-level ozone are increasing. This increase seems to come from changes in emissions of NO_X and in atmospheric chemistry in the northern hemisphere. This increase in background ozone would lead to more NO being converted into secondary NO_2, and so to increases in predicted NO_2 concentrations.

These issues highlight the difficulties of predicting future NO_2 concentrations. The changes occurring in the background ozone depend on emissions occurring worldwide, while primary NO_2 influences air quality in the immediate vicinity of the emissions. Both have to be taken into account in predictions of future concentrations of NO_2.

Conclusions

- There are still widespread exceedences of 40 µg m^{-3} NO_2 as an annual average, despite 10 years of decreasing NO_X concentrations. Annual average NO_2 concentrations show significantly smaller reductions than NO_X concentrations. This is due to both increases in emissions of primary NO_2 over the last few years and details of the chemistry by which secondary NO_2 is formed.
- With current national policies, some exceedences of the annual average objectives and limit values for NO_2 will remain in 2005 and 2010. These will be less widespread than at present but will still be appreciable. If the volume of traffic in the future is higher than expected, or if technology to reduce levels of pollutants does not have the effect we expect it to have, exceedences will be more widespread than predicted.
- There is strong evidence that heavy-duty diesel vehicles make a major contribution to NO_X emissions from UK road transport and to primary NO_2 emissions.
- There is evidence that background concentrations of ground-level ozone are increasing. This could lead to increases in future NO_2 concentrations, all other things being equal.
- NO_2 should not be considered separately from other pollutants. When developing air pollution controls, there may be trade-offs between different pollutants. For example, some measures to reduce particle emissions from diesel vehicles can lead to increased primary emissions of NO_2. Reductions of NO_X emissions in cities can lead to increases in ozone, because less ozone is used up in reactions with NO. AQEG also has concerns that much of local air quality management at present is influenced by exceedences of one air quality objective – the annual average of 40 µg m^{-3} for NO_2. AQEG feels that a more flexible and holistic approach to air quality management would create more effective control strategies.



Glossary

Air quality objective	A target to reduce the concentration of a pollutant below a certain level. Sometimes, a set maximum number of exceedences are allowed within a specified timescale.
Air Quality Strategy	Report published by the UK Governments, describing plans to improve and protect air quality in the UK. A copy can be found at: http://www.defra.gov.uk/environment/airquality/strategy/index.htm
Concentration	The amount of a pollutant in a given volume of air.
Emission	Direct release of a pollutant into the atmosphere.
Episode	A short period of very high concentrations of pollution.
Exceedence	A period of time when the concentration of a pollutant is higher than the appropriate air quality objective.
Limit value	Target set by the European Union to reduce the concentration of a pollutant below a certain level.
Microgram (µg)	One millionth of a gram.
Model	A mathematical or theoretical way to convert NO_X emissions into NO_2 concentrations.
µg m^{-3}	A unit for describing the concentration of air pollutants in the atmosphere. A concentration of 1 µg m^{-3} means that one cubic metre of air contains one microgram of pollutant.
National empirical model	Computer model used to estimate pollutant concentrations at background and roadside sites across all of the UK.
Ozone	Toxic, unstable gas, made up of three oxygen atoms. The chemical formula for ozone is O_3. At ground-level, ozone is formed by sunlight-driven chemical reactions of NO_X with VOCs.
Particulate filter	Device for reducing emissions of particulate matter from diesel vehicles.
Particulate matter	General term used for a mixture of solid particles and liquid droplets found in the air.
Primary	A pollutant released straight into the atmosphere.

Rolling annual average	Average, or series of averages, calculated for overlapping time periods. A rolling annual average NO_2 concentration calculated every month uses concentrations from the previous 12 months. The period of averaging is stepped forward one month for each value. For example, 01/04/02 – 31/03/03 and then 01/05/02 – 30/04/03. There are therefore 12 possible monthly rolling annual averages in a year.
Sample inlet	Point, usually at the end of a sampling tube, from where air is taken to be measured by air pollution monitoring instruments.
Secondary	A pollutant formed in the atmosphere by chemical reactions.
Three-way catalyst	Device fitted to the exhaust of petrol cars to reduce emissions of carbon monoxide, NO_X and VOCs.
VOCs	See volatile organic compounds.
Volatile organic compounds	Chemicals containing carbon that easily evaporate at room temperature, for example, benzene. Volatile organic compounds (VOCs) are released into the air from burning fossil fuels and other sources. Some VOCs, such as isoprene, are emitted by vegetation.

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