Report

UK air quality modelling for annual reporting 2002 on ambient air quality assessment under Council Directives 96/62/EC and 1999/30/EC

Report to The Department for Environment, Food and
Rural Affairs, Welsh Assembly Government, the
Scottish Executive and the Department of the
Environment for Northern Ireland

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Executive Summary

Directive 96/62/EC on Ambient Air Quality Assessment and Management (the Framework Directive) establishes a framework under which the EU sets limit values or target values for the concentrations of specified air pollutants. Directive 1999/30/EC (the first Daughter Directive) sets the limit values to be achieved for sulphur dioxide, nitrogen dioxide and oxides of nitrogen, particles and lead.

2002 is the second year for which an annual air quality assessment for the first Daughter Directive pollutants is required. A questionnaire has been completed for submission to the EU containing the results of this air quality assessment. The assessment takes the form of comparisons of measured and modelled air pollutant concentrations with the limit values set out in the Directive. Air quality modelling has been carried out to supplement the information available from the UK national air quality monitoring networks.

This report provides a summary of key results from the questionnaire and additional technical information on the modelling methods that have been used to assess SO_2, NO_2 and NO_x and PM_{10} concentrations throughout the UK. This includes:

- Details of modelling methods
- Information on the verification of the models used and comparisons with data quality objectives
- Detailed modelling results and comparison with limit values.

Maps of background concentrations of SO_2, NO_2 and PM_{10} in 2002 on a 1 km x 1 km grid have been prepared. Maps of roadside concentrations of NO_2 and PM_{10} have been prepared for 9360 built-up major road links (A-roads and motorways).

The dominant contributions to measured SO_2 concentrations in the UK are typically from major point sources such as power stations and refineries, particularly in terms of high percentile concentrations. Emissions of SO_2 from point sources were therefore modelled in some detail. Area sources have been modelled using a dispersion kernel approach. For NO_2, NO_x and PM_{10} there is also an important contribution to ambient concentrations from area sources, particularly traffic sources and a slightly different modelling approach has therefore been adopted. The area source contribution has been modelled using a kernel based area source model, which has been calibrated empirically using automatic measurement data. Roadside concentrations of NO_2, NO_x and PM_{10} have been estimated by adding a roadside increment to the modelled background concentrations. This roadside increment has been calculated from road link emission estimates using dispersion coefficients derived empirically using data from roadside monitoring sites.

The UK has been divided into 43 zones for air quality assessment. There are 28 agglomeration zones and 15 non-agglomeration zones. The status of the zones in relation to the limit values for all of the first Daughter Directive pollutants have been listed and reported to the EU in the questionnaire. The status has been determined from a combination of monitoring data and model results. The results of this assessment are summarised in Table E1 in terms of exceedences of limit values + margins of tolerance (LV + MOT) and limit values (LV).

Table E1 Summary results of air quality assessment for 2002

Pollutant	**Averaging time**	**Number of zones exceeding limit value + margin of tolerance**	**Number of zones exceeding limit value**[1]
SO_2	1-hour	none	none
SO_2	24-hour[2]	none	none
SO_2	annual[3]	n/a	none
SO_2	winter[3]	n/a	none
NO_2	1-hour[4]	none	1 zone measured (Glasgow Urban Area)
NO_2	annual	19 Zones (5 measured + 14 modelled)	36 zones (6 measured + 30 modelled)
NO_x	annual[3]	n/a	none
PM_{10}	24-hour	1 zone modelled (Greater London Urban Area)	18 zones (1 measured + 17 modelled)
PM_{10}	annual	1 zone modelled (Greater London Urban Area)	2 zones (Greater London Urban Area measured, Eastern modelled)
PM_{10}	24-hour[5]	n/a	21 zones (21 measured)
PM_{10}	annual[6]	22 Zones (3 measured + 18 modelled)	42 zones (16 measured, 26 modelled)
Lead	annual	none	None

[1] Includes zones exceeding LV + MOT
[2] No MOT defined, LV + MOT = LV
[3] No MOT defined for vegetation and ecosystem LVs, which are already in force
[4] No modelling for 1-hour LV
[5] Stage 2 indicative LV, no MOT defined for 24-hour stage 2 LV, no modelling for 24-hour stage 2 LV
[6] Stage 2 indicative LV

Contents

Appendices

1 Introduction

1.1 THE FRAMEWORK AND FIRST DAUGHTER DIRECTIVES

Directive 96/62/EC on Ambient Air Quality Assessment and Management (the Framework Directive (Council Directive 96/62/EC)) establishes a framework under which the EU sets limit values or target values for the concentrations of specified air pollutants. Directive 1999/30/EC (the first Daughter Directive, AQDD1 (Council Directive1999/30/EC)) sets the limit values to be achieved for sulphur dioxide, nitrogen dioxide and oxides of nitrogen, particles and lead.

The Framework Directive includes a requirement (Article 5) for Member States to undertake preliminary assessments of ambient air quality, prior to the implementation of the Daughter Directives. The objectives of these assessments are to establish estimates for the overall distribution and levels of pollutants, and to identify additional monitoring required to fulfil obligations under the Framework Directive. A report describing the preliminary assessment for the UK for AQDD1 has been prepared (Bush 2000). AQDD1 defines the number of air quality monitoring sites required on the basis of the concentrations of pollutants and population statistics. The number of monitoring sites required is significantly reduced if other means of assessment, in addition to fixed monitoring sites, are also available. Air quality modelling has therefore been carried out to supplement the information available from the UK national air quality monitoring networks and contribute to the assessments required by the Framework and first Daughter Directives.

1.2 THIS REPORT

2002 is the second year for which an annual air quality assessment for the first Daughter Directive pollutants is required. A questionnaire has been completed for submission to the EU containing the results of this air quality assessment. The assessment takes the form of comparisons of measured and modelled air pollutant concentrations with the limit values set out in the Directive. This report provides a summary of key results from the questionnaire and additional technical information on the modelling methods that have been used to assess concentrations throughout the UK.

Sections 2, 3 and 4 describe the modelling methods for SO_2, NO_2 and NO_x and PM_{10}. This includes

- Details of modelling methods
- Information on the verification of the models used and comparisons with data quality objectives
- Detailed modelling results.

The status of zones in relation to the limit values for all of the first Daughter Directive pollutants have been listed and reported to the EU in the questionnaire and copies of these lists are included in Section 5. The status has been determined from a combination of monitoring data and model results. Section 5 also includes a comparison of the results of the air quality assessment for 2002 with the results reported for 2001 (Stedman et al, 2002).

1.3 PRELIMINARY ASSESSMENT AND DEFINITION OF ZONES

The preliminary assessment carried for AQDD1 (Bush, 2000) defined a set of zones to be used for air quality assessments in the UK. These zones are listed in Table 1.1 and illustrated in Figure 1.1. Information on the definition of zones is included in form 2 of the questionnaire. The zone codes listed in Table 1.1 are used throughout the questionnaire. The population (1991 census), area and the number of built-up major road links in each zone are also shown. The zones are of two types: agglomeration zones (continuous urban areas with populations in excess of 250,000) and non-agglomeration zones. There are 28 agglomeration zones and 15 non-agglomeration zones, giving a total of 43. The non-agglomeration zones in England correspond to the Government Office Regions, while those in Scotland, Wales and Northern Ireland were defined in conjunction with the Devolved Administrations.

Figure 1.1. UK zones and agglomerations for 2002 (red = agglomeration zones)

Table 1.1 Zones for AQDD1 reporting

Zone	Zone code	Ag or nonag*	Population	Area (km^2)	Number of built –up road links	Length of built –up road links (km)
Greater London Urban Area	UK0001	ag	7650944	1624	1926	1785.7
West Midlands Urban Area	UK0002	ag	2296180	599	411	569.5
Greater Manchester Urban Area	UK0003	ag	2277330	538	549	644.3
West Yorkshire Urban Area	UK0004	ag	1445981	352	269	396.1
Tyneside	UK0005	ag	885981	212	131	158.8
Liverpool Urban Area	UK0006	ag	837998	181	270	211.3
Sheffield Urban Area	UK0007	ag	633362	168	98	145.2
Nottingham Urban Area	UK0008	ag	613726	151	102	102.8
Bristol Urban Area	UK0009	ag	522784	131	117	118.5
Brighton/Worthing/Littlehampton	UK0010	ag	437592	89	44	78.8
Leicester Urban Area	UK0011	ag	416601	92	63	87.9
Portsmouth Urban Area	UK0012	ag	409341	83	47	67.1
Teesside Urban Area	UK0013	ag	369609	102	45	59.0
The Potteries	UK0014	ag	367976	91	113	118.4
Bournemouth Urban Area	UK0015	ag	358321	109	46	54.4
Reading/Wokingham Urban Area	UK0016	ag	335757	94	63	74.9
Coventry/Bedworth	UK0017	ag	331248	74	26	27.2
Kingston upon Hull	UK0018	ag	310636	78	37	43.1
Southampton Urban Area	UK0019	ag	276752	74	55	65.2
Birkenhead Urban Area	UK0020	ag	270207	62	58	49.3
Southend Urban Area	UK0021	ag	266749	66	32	50.2
Blackpool Urban Area	UK0022	ag	261355	64	45	58.4
Preston Urban Area	UK0023	ag	256411	67	33	45.0
Glasgow Urban Area	UK0024	ag	1315544	442	185	286.8
Edinburgh Urban Area	UK0025	ag	416232	127	54	98.7
Cardiff Urban Area	UK0026	ag	306904	70	33	48.6
Swansea Urban Area	UK0027	ag	272456	87	26	57.7
Belfast Urban Area	UK0028	ag	475987	113	16	107.9
Eastern	UK0029	nonag	4788766	19106	532	1062.8
South West	UK0030	nonag	3728319	23516	495	1077.0
South East	UK0031	nonag	3702634	18677	839	1681.1
East Midlands	UK0032	nonag	2923045	15521	395	871.6
North West & Merseyside	UK0033	nonag	2823559	13186	549	1167.2
Yorkshire & Humberside	UK0034	nonag	2446545	14797	325	926.2
West Midlands	UK0035	nonag	2154783	12189	324	616.2
North East	UK0036	nonag	1287979	8296	154	283.8
Central Scotland	UK0037	nonag	1628460	9228	161	354.7
North East Scotland	UK0038	nonag	933485	18596	147	331.0
Highland	UK0039	nonag	364639	37997	39	152.6
Scottish Borders	UK0040	nonag	246659	11145	43	124.0
South Wales	UK0041	nonag	1623660	12220	244	620.7
North Wales	UK0042	nonag	713762	8368	95	254.9
Northern Ireland	UK0043	nonag	1101868	13567	124	902.2
Total			55088127	242349	9360	16036.9

* ag = agglomeration zone, nonag = non-agglomeration zone

The preliminary assessment also defined the monitoring and modelling requirements for each zone based on an assessment of concentrations in relation to upper and lower assessment threshold concentrations for AQDD1. The minimum monitoring requirement for most pollutants in the majority of zones was found to be at least one monitoring site per zone, with the monitoring results to be supplemented with information from modelling studies. The preliminary assessment for lead indicated that concentrations in many zones were less than the lower assessment threshold. There is therefore no requirement to monitor lead concentrations in these zones (Bush 2000).

The limit values for the protection of ecosystems and vegetation only apply in ecosystems and vegetation areas, which are defined in the Directive as areas which are 20 km from agglomerations and 5 km from motorways, other urban areas and industrial installations.

1.4 MONITORING SITES

The sites and measurements operating during 2002 for the purpose of AQDD1 reporting are listed in Table A1.1 in Appendix 1. This information is included in form 3 of the questionnaire. Not all sites had sufficient data capture during 2002 for data to be reported. The data quality objective for AQDD1 measurements is 90 % data capture. We have included all measurements with at least 75 % data capture in the analysis in order to ensure that we can make maximum use of data from the monitoring sites operational during 2002 specifically for AQDD1 reporting purposes. Table A1.2 in Appendix 1 lists the measurements with more than 75% but less than 90 % data capture and therefore included in the analysis. Table A1.3 in Appendix 1 lists measurements with less than 75 % data capture. Lead data is reported for sites with greater than 75 % data capture.

Sites with less than 75 % data capture which ceased operation during 2002 have not been included in Form 3, Table A1.1 or Table A1.3. These are Brookside 1 Lead Site, Cottered Lead Site, Elsewick 1 Lead Site, Elswick 2 Lead Site, Hull Centre, IMI 1 Lead Site, IMI 5 Lead Site, Liverpool Centre, London Sutton, Newcastle Lead Site,Stockport and Sutton Roadside. Sites which commenced operation during 2002 but have data capture less than 75 % are included in form 3 and Table A1.1.

A detailed scrutiny of the exceedence status of each zone with respect to the limit values listed in Section 5 and the list of sites with data capture between 75% and 90% has been carried out and the results are summarised in Table A1.4 in Appendix 1. This has shown that the exceedence status of the zones has not been changed significantly by the inclusion of these sites in the analysis. Exclusion of these sites would have left several zones without monitoring data. This would either place a heavier reliance on the modelling results, where these are available, or left the zone with no assessment, where modelling results are unavailable.

1.5 LIMIT VALUES AND MARGINS OF TOLERANCE

The limit values (LV) and limit values + margins of tolerance (LV + MOT) included in AQDD1 are listed in Tables 1.2, 1.3, 1.4 and 1.5. Stage 1 limit values for achievement by 2005 and indicative stage 2 limit values for achievement by 2010 have been set for PM_{10}. The limit value + margin of tolerance varies from year to year from the date the Directive came into force until the date by which the limit value is to be met. Values for 2002 are listed in these tables. Where no margin of tolerance has been defined the limit value + margin of tolerance is effectively the same as the limit value. There are no margins of tolerance for the ecosystem and vegetation limit values because these limit values are already in force. The stage 2 annual mean limit value + margin of tolerance for PM_{10} is 30 $\mu g\ m^{-3}$ from 2001 until 2005. All exceedences of the limit value must be reported to the EU. Exceedences of the limit value + margin of tolerance (or limit value if no limit value + margin of tolerance has been set) must be reported to the EU and trigger the preparation of a ‘plan and programme’ for attaining the limit value within the specified time limit and a report to the EU on this ‘plan and programme’.

Table 1.2. Limit values for SO_2

	Averaging period	LV	LV + MOT 2002	Date by which LV is to be met
1. Hourly LV for the protection of human health	1 hour	350 μg m^{-3}, not to be exceeded more than 24 times a calendar year	440 μg m^{-3}, not to be exceeded more than 24 times a calendar year	1 January 2005
2. Daily LV for the protection of human health	24 hour	125 μg m^{-3}, not to be exceeded more than 3 times a calendar year	None	1 January 2005
3. LV for the protection of ecosystems	Calendar year and winter	20 μg m^{-3}	None	19 July 2001

Table 1.3. Limit values for NO_2 and NO_x

	Averaging period	LV	LV + MOT 2002	Date by which LV is to be met
1. Hourly LV for the protection of human health	1 hour	200 μg m^{-3} NO_2 not to be exceeded more than 18 times a calendar year	280 μg m^{-3}, NO_2 not to be exceeded more than 18 times a calendar year	1 January 2010
2. Annual LV for the protection of human health	Calendar year	40 μg m^{-3} NO_2	56 μg m^{-3}, NO_2	1 January 2010
3. LV for the protection of vegetation	Calendar year	30 μg m^{-3} NO_x, as NO_2	None	19 July 2001

Table 1.4a. Limit values for PM_{10} (Stage 1)

	Averaging period	LV	LV + MOT 2002	Date by which LV is to be met
1. 24-hour LV for the protection of human health	24 hour	50 μg m^{-3} not to be exceeded more than 35 times a calendar year	65 μg m^{-3} not to be exceeded more than 35 times a calendar year	1 January 2005
2. Annual LV for the protection of human health	Calendar year	40 μg m^{-3}	45 μg m^{-3}	1 January 2005

Table 1.4b. Indicative limit values for PM_{10} (Stage 2)

	Averaging period	LV	LV + MOT 2002	Date by which LV is to be met
1. 24-hour LV for the protection of human health	24 hour	50 µg m^{-3} not to be exceeded more than 7 times a calendar year	N/A	1 January 2010
2. Annual LV for the protection of human health	Calendar year	20 µg m^{-3}	30 µg m^{-3}	1 January 2010

Table 1.5. Limit values for lead

	Averaging period	LV	LV + MOT 2002	Date by which LV is to be met
Annual LV for the protection of human health	Calendar year	0.5 µg m^{-3}	0.8 µg m^{-3}	1 January 2005

1.6 DATA QUALITY OBJECTIVES FOR MODELLING RESULTS AND MODEL VERIFICATION

The first Daughter Directive sets data quality objectives for the required accuracy of assessment methods to guide quality assurance programmes. These are 50-60% (we have compared with 50%) for hourly averages, 50% for daily averages and 30 % for annual averages of SO_2, NO_2 and NO_x. For PM_{10} and lead the data quality objective for annual averages is 50%, none have been defined for daily averages at present. The accuracy for modelling is defined in the Directive as the maximum deviation of the measured and calculated concentration levels, over the period considered by the limit value, without taking into account the timing of events.

The empirical models used to calculate the maps of air pollutant have been calibrated using the national network monitoring data (from sites listed in Appendix 1 of this report). Data from these sites alone cannot, therefore, be used to assess the reliability of the mapped estimates in relation to the data quality objectives for modelling. Measurement data from sites not included in the calibration are required to make this assessment. Data from sites quality assured by netcen under contract, but not part of the national network, including Local Authority sites in the netcen Calibration Club, have therefore been used for the verification of the modelled estimates. The description 'Verification Sites' is used to describe all the monitoring sites included in the verification analysis, because only a subset of these sites quality assured under contract by netcen are formally members of the Calibration Club. The monitoring sites used for this comparison are listed in Appendix 2. Sites with a data capture of at least 50% have been included in the verification analysis. A higher data capture threshold of 75% has been applied for the national network sites used to calibrate the models. Model verification results are listed in the following sections on each pollutant.

1.7 AIR QUALITY MODELLING

Full details of the modelling methods used are given in the sections below. A brief introduction is presented here. Maps of background concentrations of SO_2, NO_2 and PM_{10} have been prepared on a 1 km x 1 km grid for the 2002 calendar year. Maps of roadside concentrations of NO_2 and PM_{10} have also been prepared for 9360 built-up major road links (A-roads and motorways).

The dominant contributions to measured SO_2 concentrations in the UK are typically from major point sources such as power stations and refineries, particularly in terms of high percentile concentrations. Emissions of SO_2 from point sources were therefore modelled explicitly in some detail. Area sources have been modelled using a dispersion kernel approach. The residual contribution to ambient annual mean concentration from sources not modelled has been estimated from measurements, corrected for the contributions to concentrations at these locations from the modelled sources. A dispersion kernel describes the contributions to ambient concentrations of a pollutant at a central receptor location from a regular array of sources of unit emission strength.

For NO_2, NO_x and PM_{10} there is also an important contribution to ambient concentrations from area sources, particularly traffic sources and a slightly different modelling approach has therefore been adopted. Point sources have been modelled explicitly and rural network measurements used to define regional concentrations. The area source contribution has been modelled using a dispersion kernel approach. The coefficients calibrating this area source model have been determined empirically using automatic measurement data. Roadside concentrations of NO_2, NO_x and PM_{10} have been estimated by adding a roadside increment to the modelled background concentrations. The roadside increment has been calculated from road link emission estimates using dispersion coefficients derived empirically using data from roadside monitoring sites.

Emissions estimates for the UK are provided by the National Atmospheric Emission Inventory (NAEI, Goodwin, et al, 2002). Emission maps from the 2001 NAEI have been used for the modelling work described here. Emission estimates for area sources have been scaled to values appropriate to 2002, using UK sector total emissions from 2001 and 2002. Emissions from point sources for 2001 have been applied directly to model concentrations in 2002 because it is not practicable to adjust the emissions from individual point sources.

2 SO_2

2.1 INTRODUCTION

Maps of annual mean, winter mean, 99.73 percentile of hourly values and 99.18 percentile of daily mean SO_2 concentration has been calculated using methods based on those described by Abbott and Vincent (1999). (These percentile concentrations correspond to the number of allowed exceedences of the 1-hour and 24-hour limit values for SO_2.) Emissions from point and area sources have been modelled separately. Emissions from larger point sources were modelled explicitly using the dispersion model ADMS 3.1. Emissions from smaller point sources and area sources were modelled using 1 km x 1 km emission grids and a dispersion kernel approach.

A number of receptor areas were defined, which together covered the country. Each receptor area was 150 km x 150 km. For larger point sources (sources with emissions greater than or equal to 500 tonnes per year) all sources within the receptor area and sources in the adjoining 150 km x 150 km squares were included. Concentrations were calculated on a regular 5 km x 5 km grid throughout the receptor areas using ADMS 3.1 and sequential meteorological data for 2002 from Waddington. This ensures that the combined impact of several sources on ambient high percentile concentrations is estimated correctly (it is not possible to add together the percentiles from different sources at an individual receptor because the percentiles are unlikely to correspond to the same hour of the year).

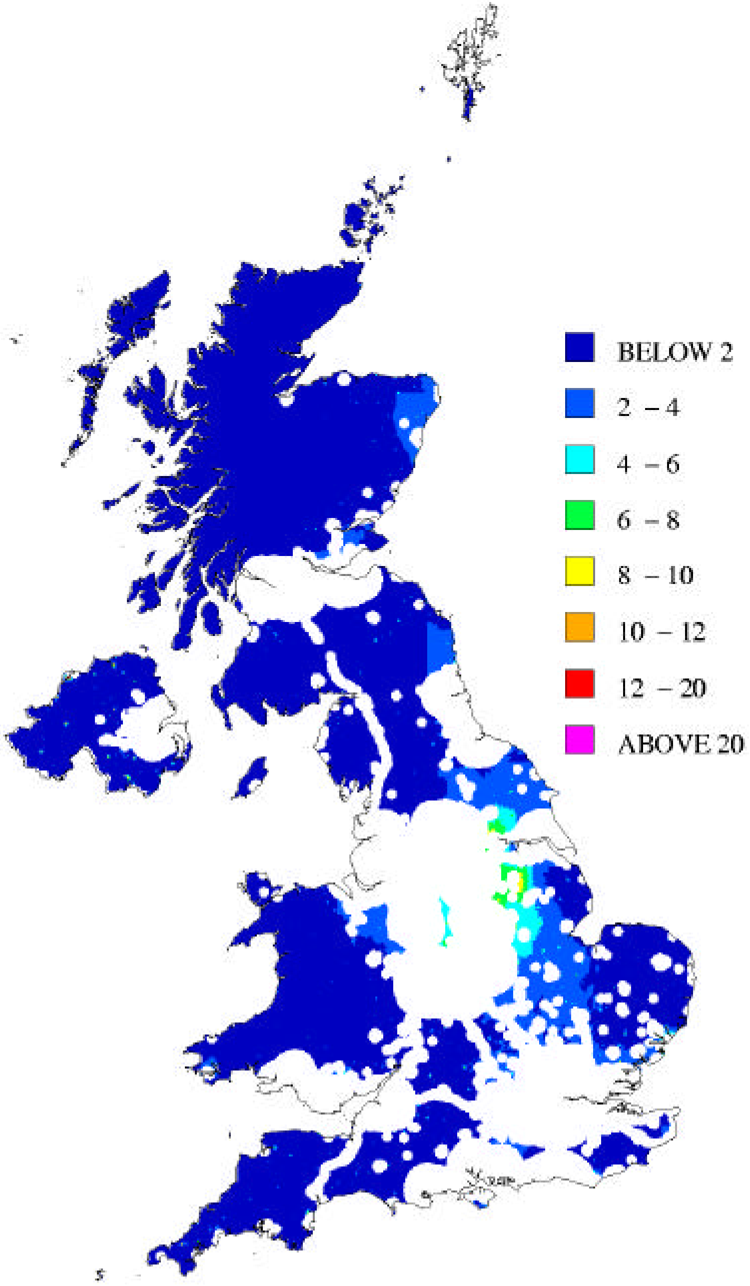
The contribution to ambient annual mean SO_2 concentrations from emissions from small point sources (sources with emissions less than 500 tonnes per year) was calculated using the dispersion kernel based small point model described in Appendix 3. The contribution from area sources to annual mean SO_2 concentrations was also estimated using a dispersion kernel based approach. The derivation of the area source model kernels is described in Appendix 4. Dispersion kernels were calculated using ADMS 3.1 and sequential meteorological data for the ten year period 1993 – 2002 from Heathrow.

The contributions to annual mean and high percentile concentrations from the different sources were then summed and calibrated as described below. A different method was used to calculate the high percentile concentrations in Northern Ireland, where the dominant source for peak SO_2 concentrations is domestic emissions. The map of winter mean SO_2 concentrations was derived from the annual mean map.

2.2 MAPS OF AND WINTER ANNUAL MEAN CONCENTRATIONS

A map of annual mean SO_2 concentration for 2002 in ecosystem areas is shown in Figure 2.1.

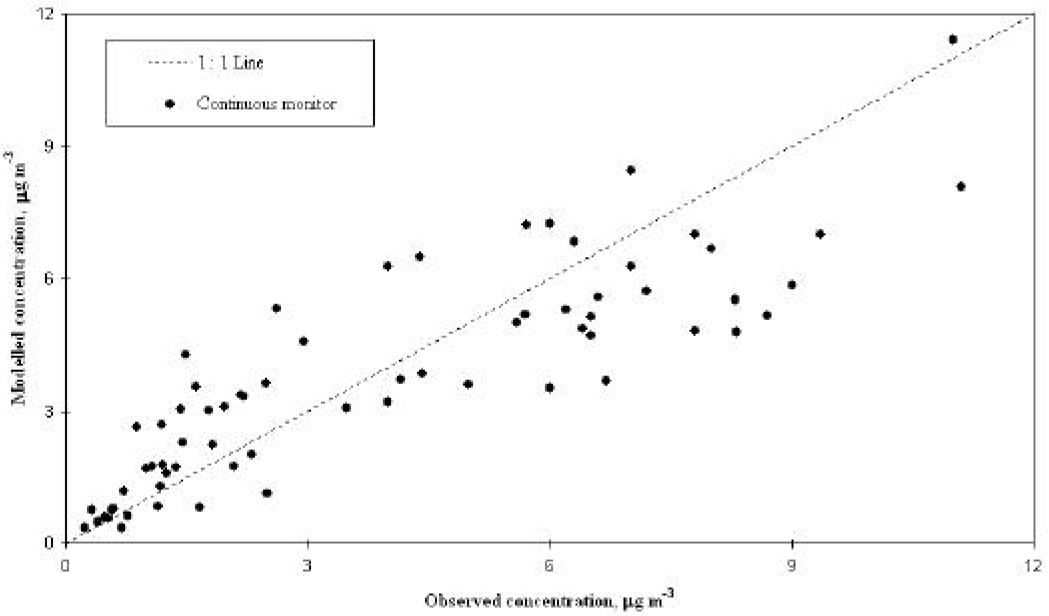
Figure 2.1. Annual mean SO_2 concentration, 2002 ($\mu g\ m^{-3}$) in ecosystem areas



Measured annual mean SO_2 concentrations were used to calibrate the annual mean SO_2 model output to ensure that the final predicted concentrations matched the concentrations measured at these sites. Measured concentrations from Rural SO_2 Monitoring Network (Hasler et al, 2001) sites, rural, suburban and industrial sites in the national automatic monitoring networks and rural automatic monitoring sites maintained by the electricity generating companies were used to calibrate the model. A list of the sites maintained by the electricity generating companies is included in Appendix 2. The calibration plot for 2002 is shown in Figure 2.2. Linear regression analysis of modelled and measured concentrations at rural monitoring sites was carried out to establish the values of the coefficient and constant in the following equation:

Annual average = Modelled Area and Small Point Sources + 0.905 × Modelled Part A – 0.15

Figure 2.2. Calibration plot for 2002 annual mean SO_2 concentration



The residual concentrations were then calculated at each of the calibration monitoring sites:

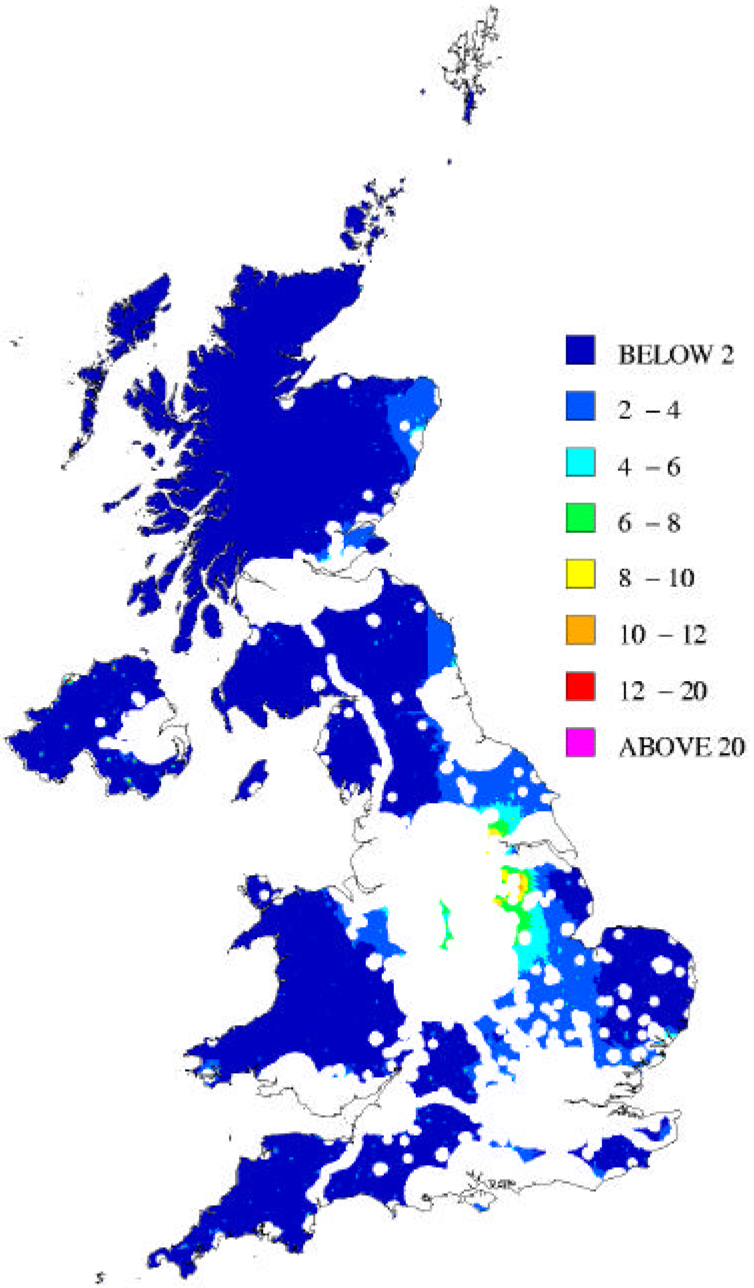
Residual = Measured - Regression Model

These residual contributions are associated partly with errors in the model and partly with the contributions from more distant sources, not modelled in this study. They include, for example, contributions from emissions from sources on continental Europe. The residual concentrations were interpolated across the country to provide a map of residuals using simple kriging. The final map was calculated from:

Mapped Value = Modelled Area and Small Point Sources + 0.905 ´ Modelled Part A – 0.15 + Residual

A map of winter mean SO_2 concentrations for the period October 2001 to March 2002 has also been calculated and is shown in Figure 2.3. This map was calculated by multiplying the annual mean map for 2002 by 1.16, the average ratio between the 2001-2002 winter and 2002 annual means measured at Rural SO_2 monitoring sites (Hasler et al, 2001).

Figure 2.3. Winter mean SO_2 concentration, 2001-2002 (mg m^{-3}) in ecosystem areas



2.3 MAPS OF PERCENTILE CONCENTRATIONS FOR COMPARISON WITH THE 1-HOUR AND 24-HOUR LIMIT VALUES

Maps of 99.73 percentile of 1-hour mean and 99.18 percentile of 24-hour mean SO_2 concentration in 2002 are shown in Figures 2.4 and 2.5 and were calculated for comparison with the 1-hour and 24-hour limit values for SO_2.

Figure 2.4. 99.73 percentile of 1-hour mean SO_2 concentration, 2002 (mg m^{-3})

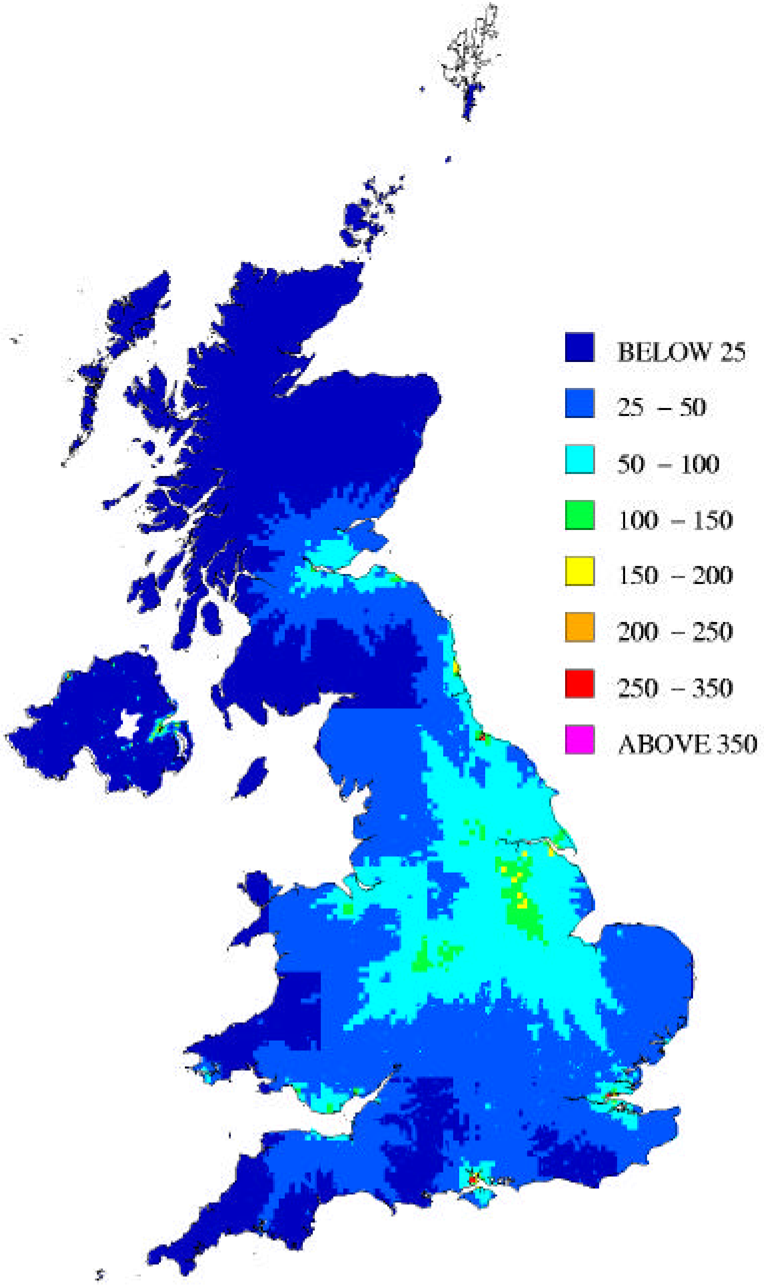
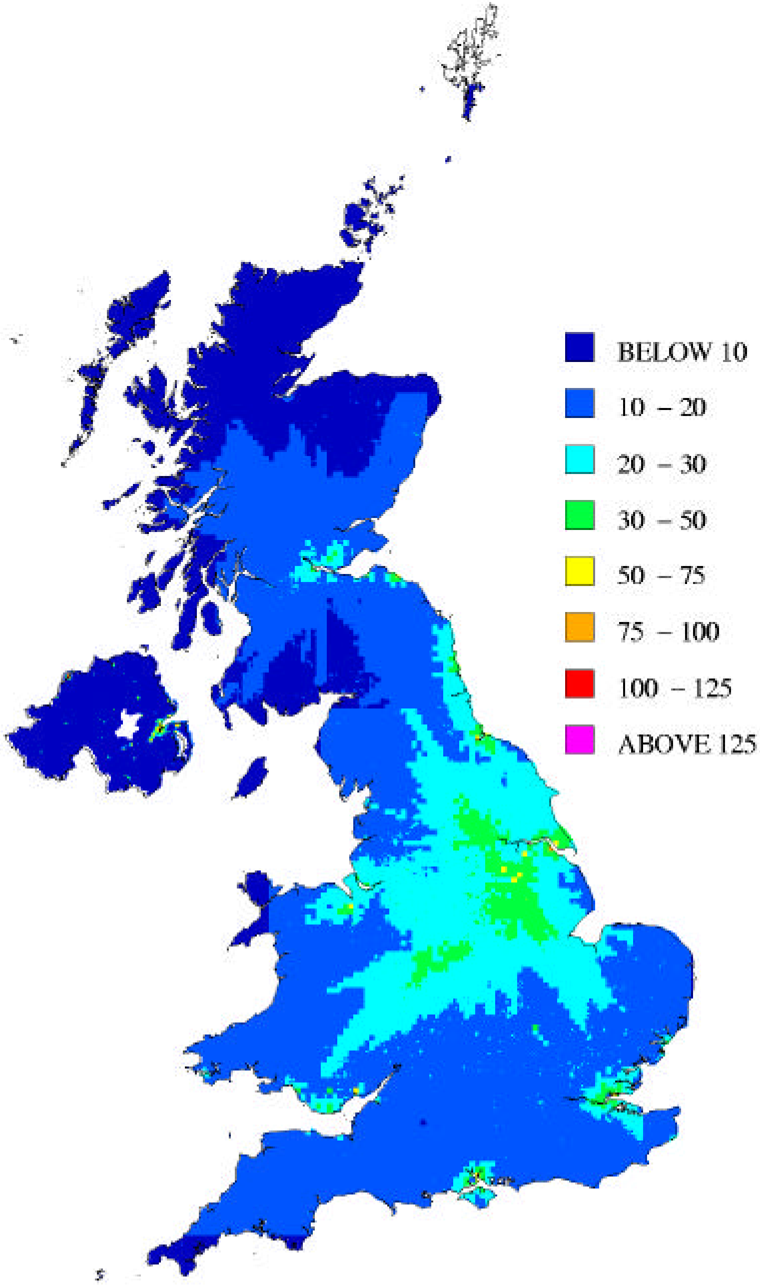


Figure 2.5. 99.18 percentile of 24-hour mean SO_2 concentration, 2002 (mg m^{-3})



Measured concentrations from rural, suburban and industrial sites in the national automatic monitoring networks and rural automatic monitoring sites maintained by the electricity generating companies were used to calibrate the percentile models. The calibration plots for the 99.73 percentile of hourly mean concentrations and 99.18 percentile of daily means are presented in Figures 2.6 and 2.7, respectively. The values of the coefficients and constants in the following equations were determined to find the best fit to the measured values:

Predicted 99.73 %ile = 1.05 × Modelled Point Sources 99.73 %ile +
Modelled Annual Mean for Area and Small Point Sources × 2
+ 4.0

Predicted 99.18 %ile = 1.20 × Modelled Point Sources 99.18 %ile +
Modelled Annual Mean for Area and Small Point Sources
+ 5.0

Figure 2.6. Calibration plot for 2002 99.73 percentile of 1-hour mean SO_2 concentrations

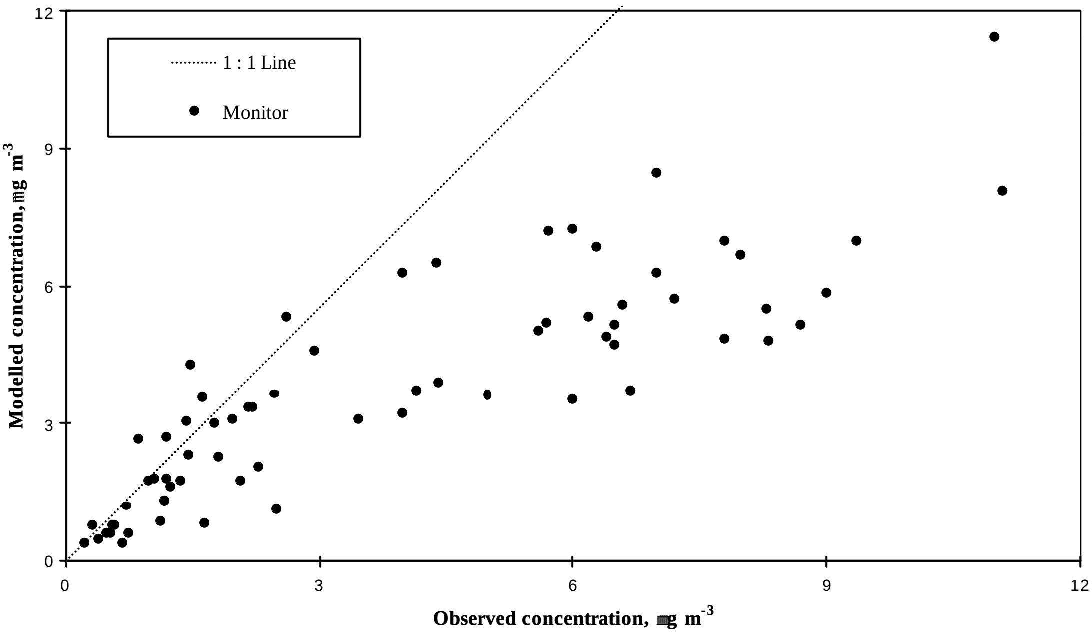
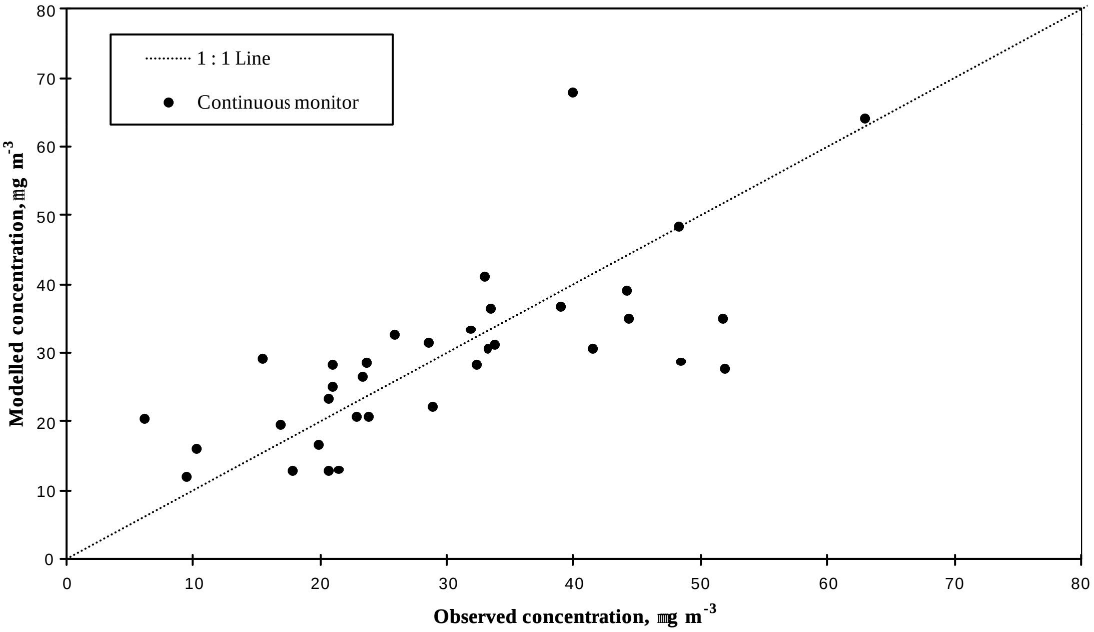


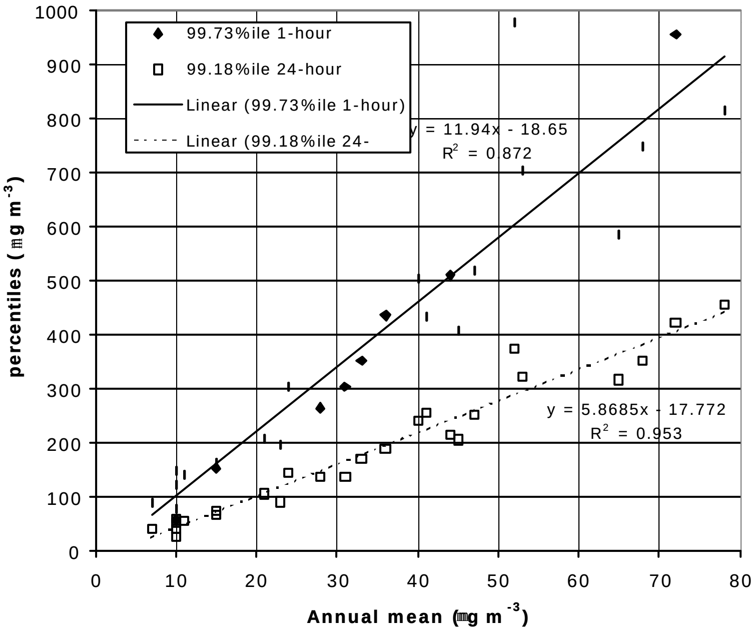
Figure 2.7. Calibration plot for 2002 99.18 percentile of 24-hour mean SO_2 concentrations



An alternative method was used to predict the high percentile concentrations in Northern Ireland. This was required because area sources, predominately consisting of emission from domestic coal fires, make a more significant contribution to observed high percentile concentrations in Northern Ireland than in the rest of the United Kingdom. Conversely, the smaller number of point sources in Northern Ireland means that these sources make a smaller contribution to the observed high percentiles.

Maps of high percentile concentrations in Northern Ireland have been calculated from the mapped annual mean SO_2 concentrations using relationships between measured annual mean and measured high percentile concentrations in Northern Ireland. These relationships are illustrated in Figure 2.8. The relationships in Northern Ireland are considerably more robust than in other parts of the UK because the dominant source for both annual mean and peak concentration is the same.

Figure 2.8. The relationships between measured annual mean and 99.73 percentiles of 1-hour mean and 99.18 percentiles of 24-hour mean SO_2 concentrations in Northern Ireland 1990-2002



2.4 VERIFICATION OF MAPPED VALUES

Figures 2.9, 2.10 and 2.11 show comparisons of modelled and measured annual mean, 99.73 percentile of 1-hour mean and 99.18 percentile of 24-hour mean SO_2 concentration in 2002 at monitoring site locations in the UK. Both the national network sites used to calibrate the models and the verification sites are shown. Lines representing y = x – 30 % and y = x + 30% and y = x – 50 % and y = x + 50% are also shown (the AQDD1 data quality objective for modelled annual mean and percentile SO_2 concentrations respectively).

Figure 2.9. Verification of annual mean SO_2 model 2002

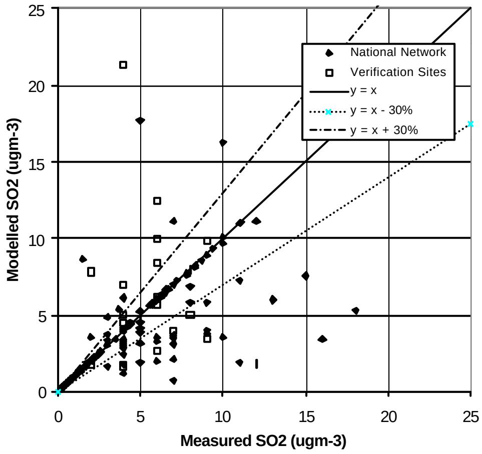


Figure 2.10. Verification of 99.73 percentile of 1-hour mean SO_2 model 2002

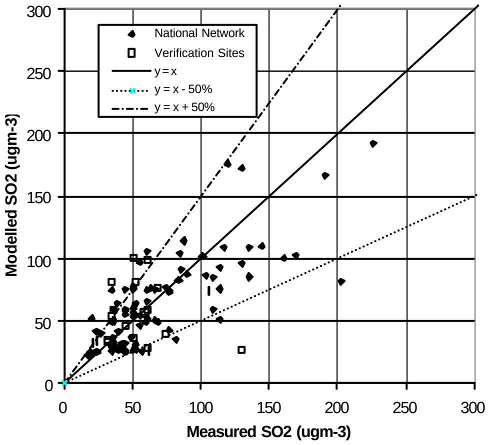
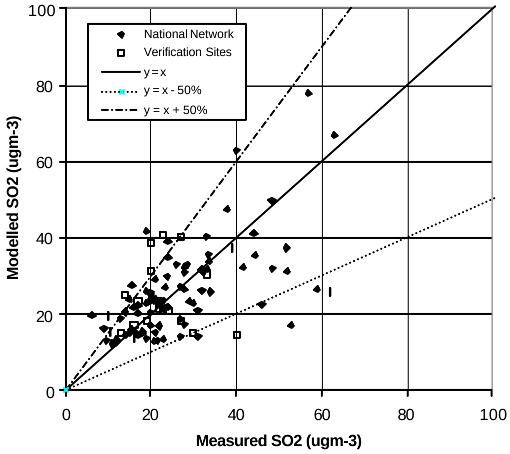


Figure 2.11. Verification of 99.18 percentile of 24-hour mean SO_2 model 2002



The agreement between modelled and measured annual mean SO_2 is poor, particularly at the higher modelled or measured concentrations. This is thought to be largely due to the poor characterisation of emission sources in each locality. This is a particular issue in locations where area sources such as domestic heating or part B industrial emissions make a significant contribution to ambient concentrations. The information available from the NAEI at a 1 km x 1 km level is insufficiently detailed to characterise domestic emissions at the level of fuel use within individual housing estates. The annual mean SO_2 map is, however, only required for comparison with the limit value for the protection of ecosystems in ecosystem areas, which are outside of urban areas. Indeed the great majority of the measured and modelled annual mean SO_2 concentrations, even in urban areas, are below 20 μgm^{-3}, the limit value for ecosystem areas.

The agreement between modelled and measured high percentile SO_2 concentrations is much better than for annual means. This shows that the emissions from the major point sources are well characterised within the inventory and that the modelling methods are able to estimate the impact of these emissions on high percentile concentrations. Summary statistics for the comparison between modelled and measured SO_2 concentrations and the percentage of sites for which the modelled values are outside the data quality objectives are listed in Tables 2.1, 2.2 and 2.3.

Table 2.1. Summary statistics for comparison between modelled and measured annual mean concentrations of SO_2 at background sites

	Mean of measurements ($\mu g m^{-3}$)	Mean of model estimates ($\mu g m^{-3}$)	r^2	% outside data quality objectives	Number of sites
National Network	5.1	4.2	0.39	28%	127
Verification Sites	5.5	6.9	0.00	65%	17

Table 2.2 Summary statistics for comparison between modelled and measured 99.73 percentile of 1-hour mean concentrations of SO_2 at background sites

	Mean of measurements ($\mu g m^{-3}$)	Mean of model estimates ($\mu g m^{-3}$)	r^2	% outside data quality objectives	Number of sites
National Network	69.5	63.5	0.60	17%	88
Verification Sites	55.6	57.0	0.04	47%	17

Table 2.3 Summary statistics for comparison between modelled and measured 99.18 percentile of 24-hour mean concentrations of SO_2 at background sites

	Mean of measurements ($\mu g m^{-3}$)	Mean of model estimates ($\mu g m^{-3}$)	r^2	% outside data quality objectives	Number of sites
National Network	26.4	25.5	0.42	15%	88
Verification Sites	22.9	24.4	0.00	29%	17

2.5 DETAILED COMPARISON OF MODELLING RESULTS WITH LIMIT VALUES

Modelling results for SO_2 have not been tabulated here because the modelled and measured SO_2 concentrations were below the limit values for all zones.

3 NO_2 / NO_x

3.1 INTRODUCTION

Maps of annual mean NO_2 concentrations at background and roadside locations in 2002 are presented in Figures 3.1 and 3.2. A detailed description of the modelling methods used is available from earlier publications (Stedman et al, 1997, Stedman et al, 2001c, Stedman and Bush, 2000, Stedman et al, 2001b, Stedman et al, 2002). A summary is provided here with a particular emphasis given to revisions to the methods for the 2002 maps.

Figure 3.1. Annual mean background NO_2 concentration, 2002 ($\mu g\ m^{-3}$)

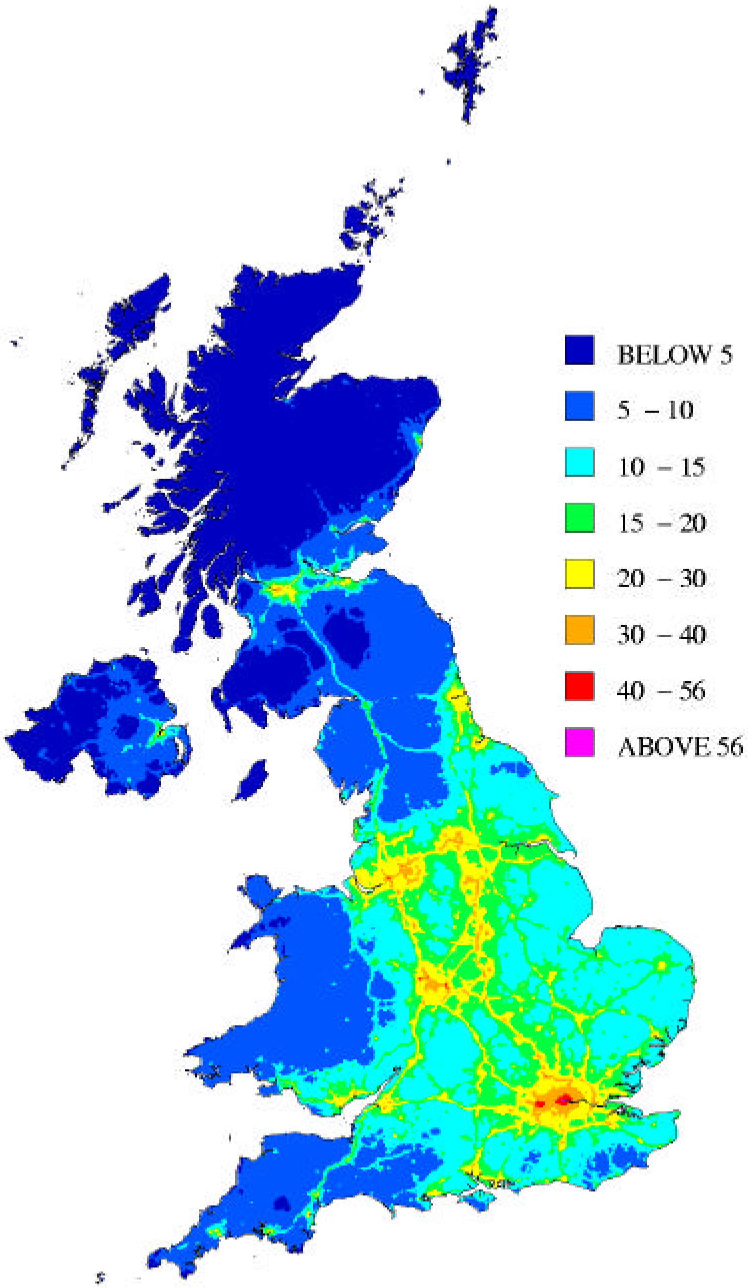
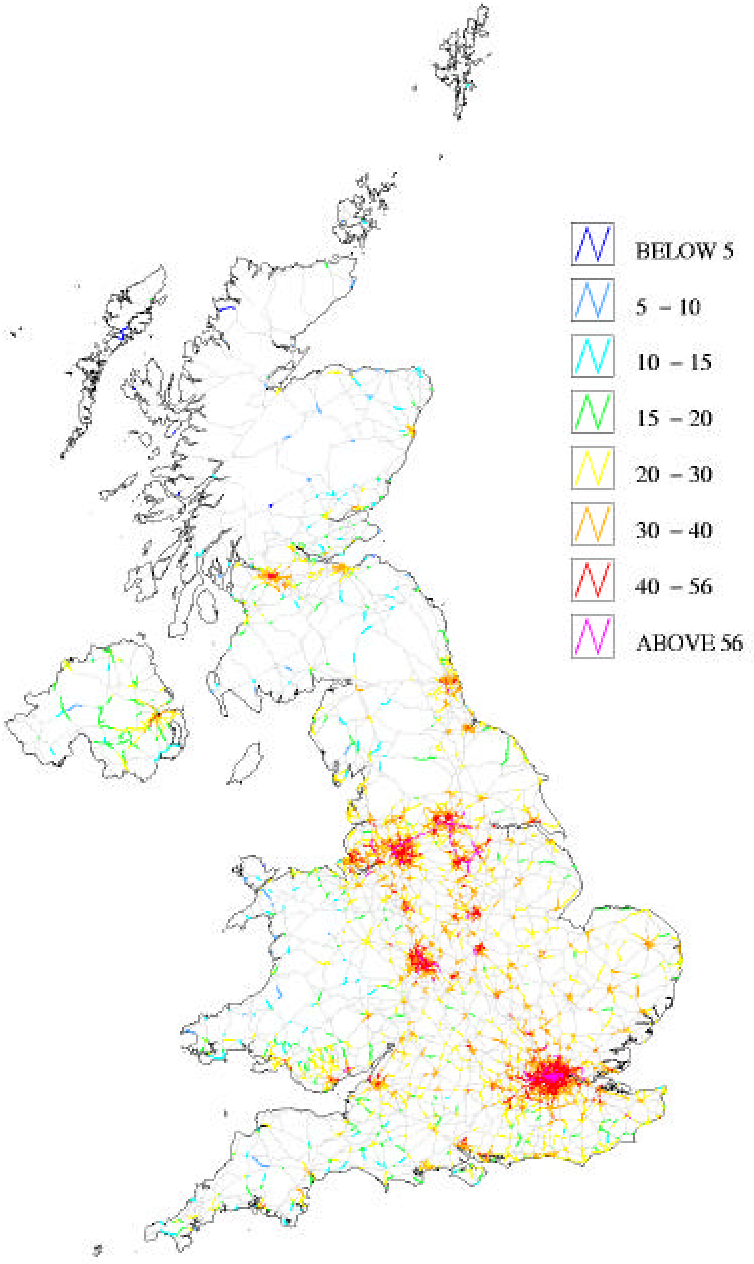

BELOW 5
5 – 10
10 – 15
15 – 20
20 – 30
30 – 40
40 – 56
ABOVE 56

Figure 3.2. Major built-up roads, annual mean roadside NO_2 concentration, 2002 (mg m^{-3})



The modelling presented in this report for NO_x and NO_2 has been restricted to estimation of annual mean concentrations for comparison with the annual mean limit value. No attempt has been made to model hourly concentrations for comparison with the 1-hour limit value. The annual mean limit value is expected to be more stringent than the 1-hour limit value in the majority of situations (AQEG, 2003).

It has been considered that annual mean background NO_x concentrations are made up of contributions from

- Distant sources (characterised by the rural background concentration)
- Large point sources
- Small point sources

- Local area sources

Hence, NO_x concentrations at locations away from busy roads may be estimated as:

Estimated background NO_x concentration ($\mu g/m^3$, as NO_2) = corrected rural NO_x concentration ($\mu g/m^3$, as NO_2) + contributions from large point sources ($\mu g/m^3$, as NO_2) + contributions from small point sources ($\mu g/m^3$, as NO_2) + contributions from area sources ($\mu g/m^3$, as NO_2)

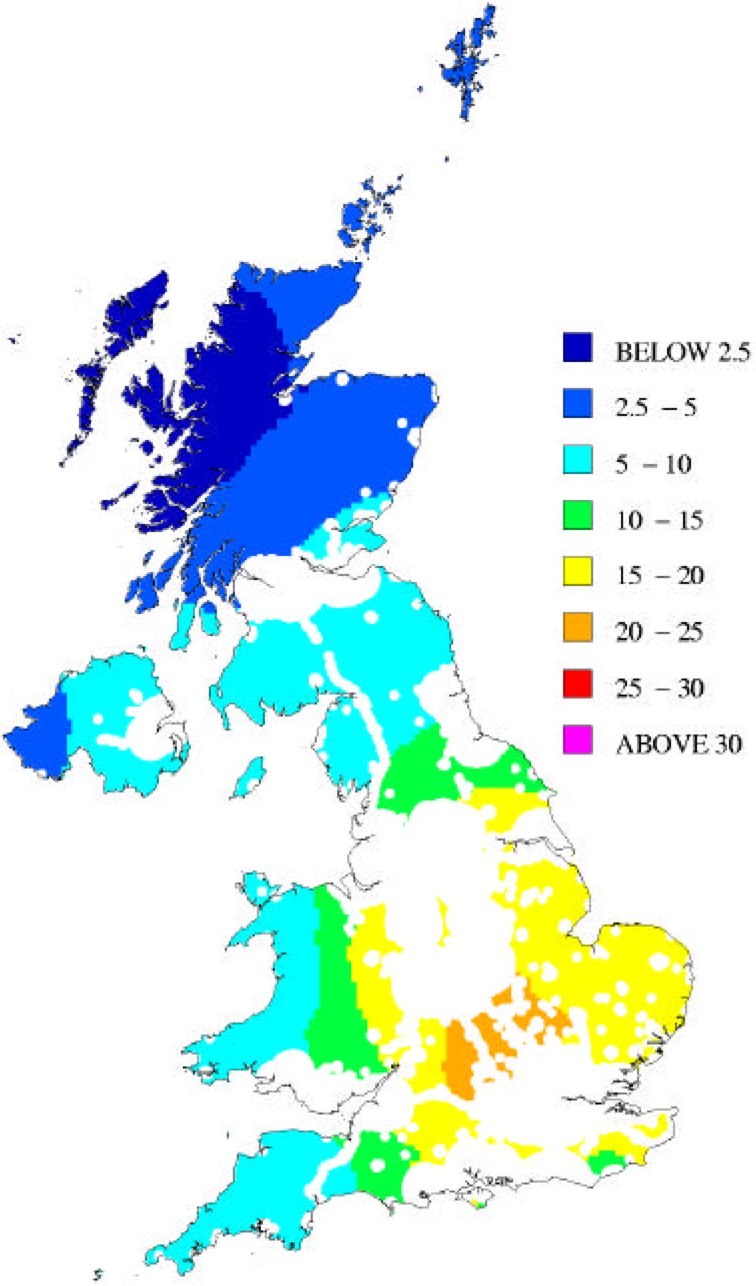
The area source model has been calibrated using data from the national automatic monitoring networks.

At locations close to busy roads an additional roadside contribution was added to account for contributions to total NO_x from road traffic sources.

In order to estimate the NO_2 concentrations, modelled NO_x concentrations estimated by the approach outlined above must then be converted to NO_2 using empirically derived conversion factors.

A map of annual mean NO_x concentrations in vegetation areas is presented in Figure 3.3. This map has been calculated by interpolation of rural NO_2 measurements followed by multiplication by the empirically derived factor (described in Section 3.2) to estimate rural NO_x from the interpolated NO_2 concentration.

Figure 3.3. Annual mean Rural NO_x concentration, 2002 (mg m^{-3}, as NO_2)



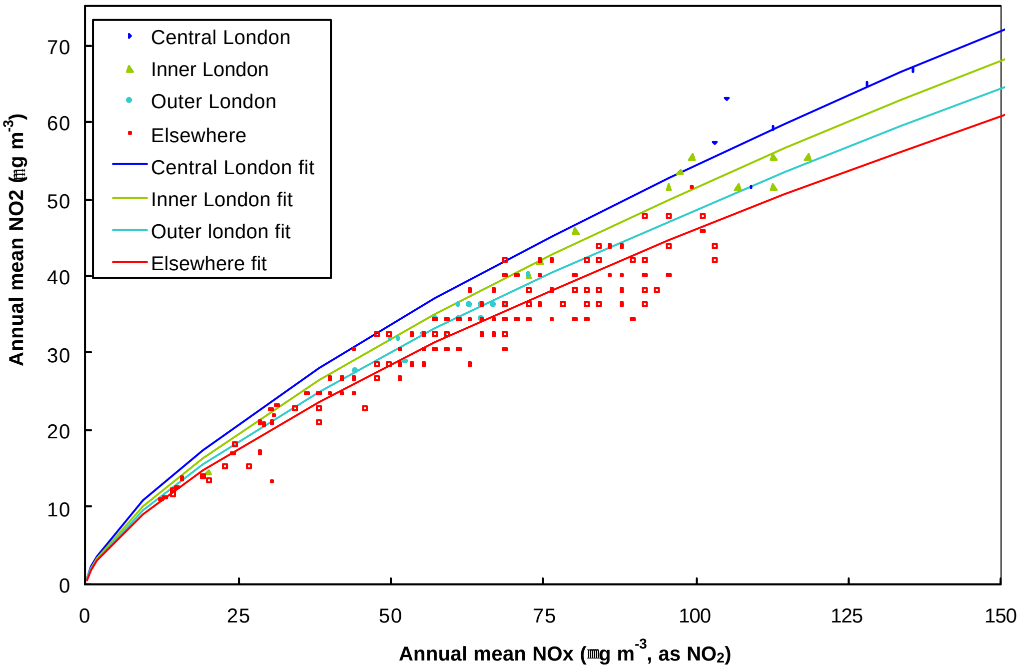
3.2 EMPRICAL RELATIONSHIPS BETWEEN NO_2 AND NO_X CONCENTRATIONS

The map of estimated annual mean background NO_2 concentration shown in Figure 3.1 was calculated from modelled NO_x concentration using the following relationships:

Rural Background NO_2 *(mg/m*^{3}*) = 0.7835.*NO_x *(mg/m*^{3}*, as* NO_2*)*
Central London Background NO_2 *(mg/m*^{3}*) = 2.28.(*NO_x *(mg/m*^{3}*, as* NO_2*))*$^{0.6887}$
Inner London Background NO_2 *(mg/m*^{3}*) = 2.16.(*NO_x *(mg/m*^{3}*, as* NO_2*))*$^{0.6887}$
Outer London Background NO_2 *(mg/m*^{3}*) = 2.04.(*NO_x *(mg/m*^{3}*, as* NO_2*))*$^{0.6887}$
Elsewhere Urban Background NO_2 *(mg/m*^{3}*) = 1.9301.(*NO_x *(mg/m*^{3}*, as* NO_2*))*$^{0.6887}$

The relationship for rural background concentrations was derived from monitoring data from 1998 to 2001 inclusive. The relationships for urban areas have been derived from monitoring data from 1998 to 2002 inclusive and are presented in Figure 3.4. The relationships reflect the contrast between the behaviour of NO_x, which can be treated as a conserved pollutant, and NO_2 for which the ambient concentration is dependent on the availability of oxidant and the distance from source. The majority of NO_x is present as NO_2 at rural background locations because such areas are generally distant from sources and oxidant (ozone) is available in excess. Annual mean NO_2 concentrations in urban areas (Figure 3.4) are, however, limited by the availability of oxidant. From Figure 3.4 it is can also been seen that measured NO_2 concentrations at the same measured NO_x concentration increase from elsewhere, through Outer and Inner to Central London. This is thought to be due to the large size of the Greater London urban area, which enables relatively aged NO_x from other parts of London to contribute to NO_2 in Central London. We have used the definitions of Outer, Inner and Central London adopted within the DfT transport models (DfT, 2003).

Figure 3.4. Relationship between annual mean NO_x and NO_2 concentrations measured at urban background sites in the national networks 1998-2002



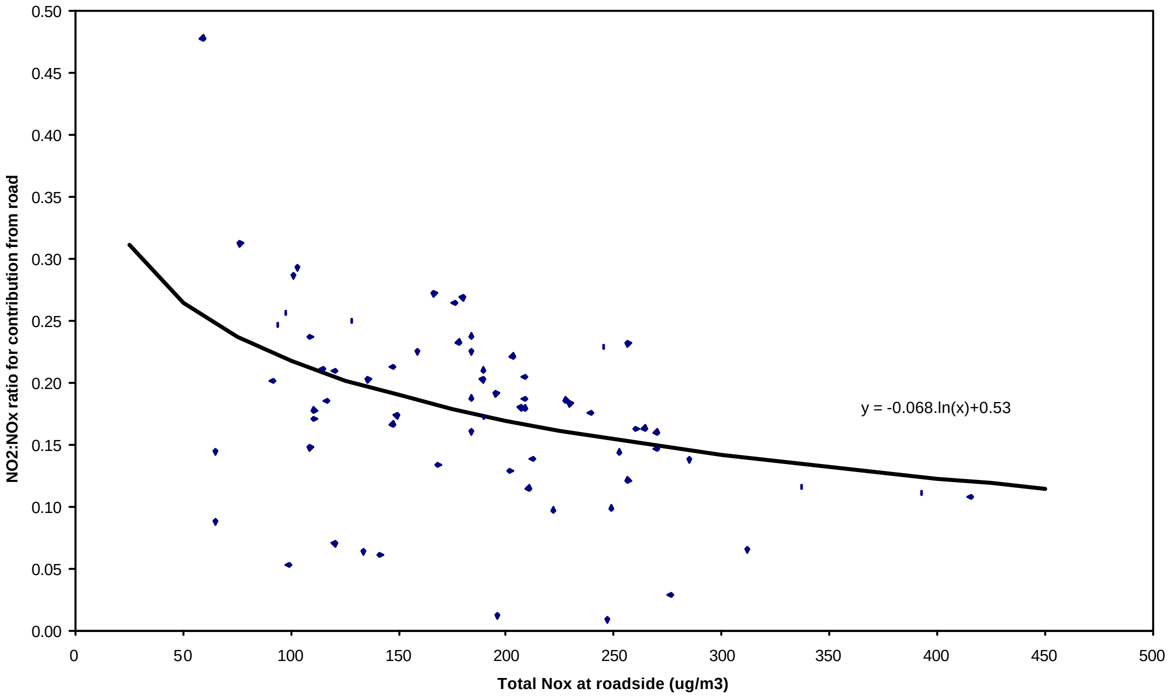
The map of estimated annual mean roadside NO_2 concentration shown in Figure 3.2 was calculated as the sum of the modelled background NO_2 concentration and an NO_2 roadside increment derived from a modelled NO_x roadside increment using the following equation:

NO_2 Roadside increment (mg/m^3) = NO_x Roadside increment (mg/m^3, as NO_2) .
(0.53 - 0.068.ln(total roadside NO_x concentration (mg/m^3, as NO_2)))

This method (developed by Laxen and Wilson (2002) from a method proposed by Stedman et al (2001c)) takes into account that the NO_2 to NO_x ratio at high NO_x locations (close to major roads) will be lower than the same ratio at lower NO_x areas as a result of oxidant limiting. The NO_x to NO_2 relationship for the roadside increment is based on a natural logarithmic best-fit curve as shown in Figure 3.5. Thus the percentage of the roadside increment of NO_x represented by NO_2 falls from about 25% at low total NO_x concentrations to about 10% at the highest concentrations close to busy roads in large urban areas.

Figure 3.5. Relationship between the NOx: NO_2 ratio and NO_x concentrations at locations close to busy roads national network and TRL road and kerbside sites

1999-2001



3.3 CONTRIBUTIONS FROM LARGE POINT SOURCES

Contributions to ground level annual mean NO_x concentrations from large point sources (those with annual emission greater than or equal to 500 tonnes) in the 2001 NAEI were estimated by modelling each source explicitly using an atmospheric dispersion model. Prior to the modelling exercise a survey of Part A authorisation notices held by the Environment Agency was conducted for all point sources with annual emissions greater than 500 tonnes as identified in the 2001 NAEI. Parameters characterising the release to atmosphere were collected. Parameters collected were:

- Stack height
- Stack diameter
- Discharge velocity
- Discharge temperature.

Where release parameters were unavailable, engineering assumptions were applied. Previously collated datasets on emission release parameters from large SO_2 point sources were also used to characterise the release of emission (Abbott and Vincent, 1999).

The contribution to annual mean NO_x concentrations from NO_x point sources with greater than 500 tonnes per annum emission, was modelled using ADMS 3.1 and sequential meteorological data for 2002 from Waddington. A total of 169 point sources were modelled. Surface roughness was assumed to be 0.1 metres. Concentrations were calculated for a 100 km x 100 km square composed of a regularly spaced 5 km x 5 km resolution receptor grid. Each receptor grid was centred on the point source.

3.4 CONTRIBUTIONS FROM SMALL POINT SOURCES

Contributions from NO_x point sources with less than 500 tonnes per annum emissions were modelled using the small points model described in Appendix 3.

3.5 CONTRIBUTIONS FROM RURAL BACKGROUND CONCENTRATIONS

Diffusion tube measurement data from the Acid Deposition Monitoring Network (Hayman et al, 2001) were used to estimate rural annual mean background NO_2 concentrations. In a number of instances, measurements from this network are influenced by contributions from nearby point and area sources. Hence, for this modelling exercise, in which contributions to ground level concentrations are modelled explicitly by dispersion modelling techniques, it is necessary to remove contributions from point and area sources from the rural background measurement data to avoid double counting of these contributions. The correction procedure is as follows:

Corrected rural background (mg/m^3) = Uncorrected rural background (mg/m^3) – (A + B + C)

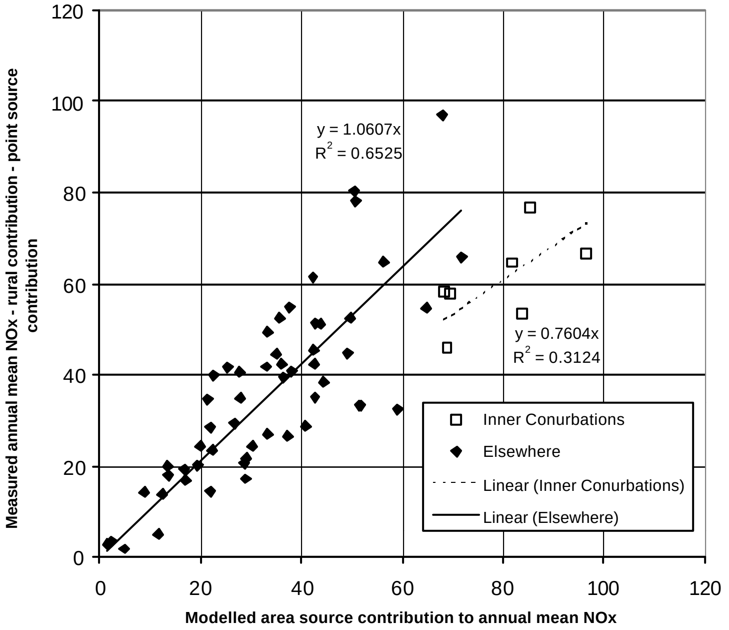
Where: A = an estimate of the contribution from area source components, derived using the area source model described below but with the empirical coefficients derived from a comparison of 2001 monitoring data and emissions.
B = sum of contributions from large point sources
C = sum of contributions from small point sources

Corrected rural measurement data were interpolated to obtain estimates of the regional background concentration throughout the UK.

3.6 CONTRIBUTIONS FROM AREA SOURCES

Figure 3.6 shows the calibration of the area source model. The modelled large point and small point source and corrected rural NO_x concentrations have been subtracted from the measured annual mean NO_x concentration at background sites. This is compared with the modelled area source contribution to annual mean NO_x concentration. We have used an empirical method, in which an ADMS derived dispersion kernel is applied to calculate the contribution to ambient concentrations at a central receptor location from emissions from area sources within a 33 km x 33 km square surrounding each monitoring site. 10-year average meteorological data for 1993-2002 from Heathrow has been used to construct the dispersion kernels, as described in Appendix 4.

Figure 3.6. Calibration of NO_x area source model



Examination of Figure 3.6 shows that the monitoring sites fall into two groups:

- Inner conurbations
- Elsewhere.

'Inner conurbations' includes Inner and Central London and central Birmingham and Manchester (as defined by DfT (2003). The elsewhere slope is close to unity, showing that in these locations the un-calibrated model is quite successful in predicting the concentration. The inner conurbations slope lower, reflecting the different meteorological and dispersion conditions in the centres of larger cites. Meteorological data from Heathrow is not expected to be representative of central London, for example. The effective roughness in large urban areas is also greater than in rural or smaller urban areas, leading to more efficient dispersion of pollutants.

Adjustment factors were applied to the emissions from selected sources. NO_x emission from aircraft were multiplied by 0.36, the proportion total that takes place while the aircraft wheels are on the ground. The contribution to ground level concentrations from emissions while the aircraft is airborne will be much smaller and has not been modelled. (By convention, emission inventories include emissions from aircraft both on the ground and on take off and landing up to 1000 m.) An empirical factor of 0.25 was applied to NO_x emissions from ships.

The modelled area source contribution was multiplied by the relevant empirical coefficient to calculate the calibrated area source contribution for each grid square in the country. The corrected rural and point source contributions were then added, resulting in a map of background NO_x concentrations. The map of background NO_2 concentrations was then calculated from this NO_x map using the NO_x to NO_2 relationships.

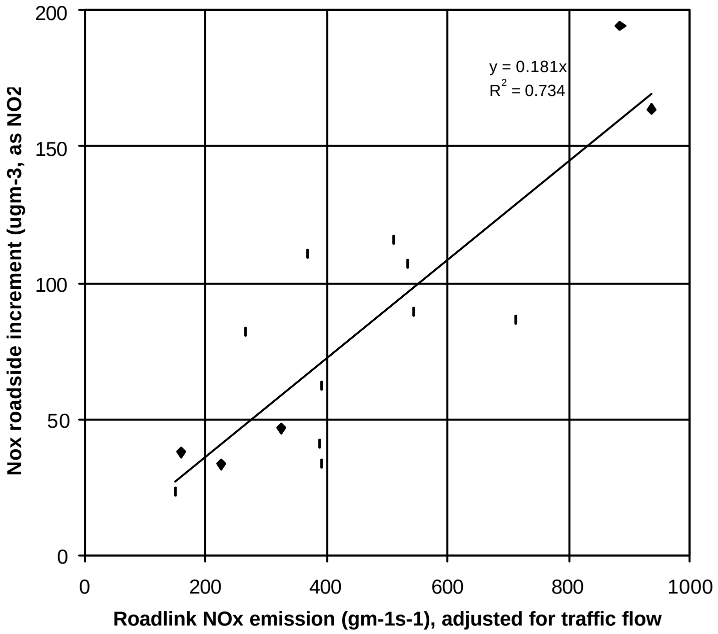
3.7 ROADSIDE CONCENTRATIONS

We have considered that the annual mean concentration of NO_x at a roadside location is made up of two parts: the background concentration (as described above) and a roadside increment:

roadside NO_x *concentration = background* NO_x *concentration +* NO_x *roadside increment*

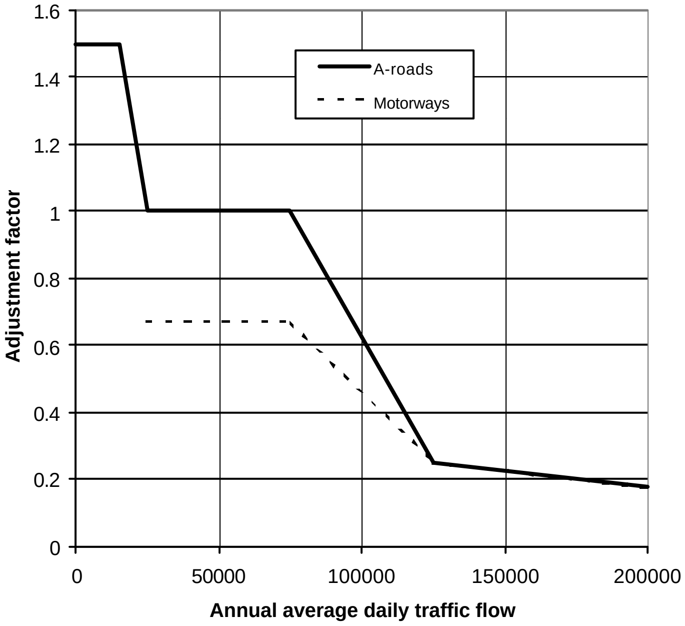
The NAEI provides estimates of NO_x emissions for major road links in the UK for 2001 (Goodwin et al, 2002) and these have been adjusted to provide estimates of emissions in 2002. Figure 3.7 shows a comparison of the roadside increment of annual mean NO_x concentrations at roadside or kerbside national automatic monitoring sites with NO_x emission estimates for the individual road links alongside which these sites are located. The background NO_x component at these roadside monitoring sites was derived from the map described above. The roadside increment is calculated by multiplying the adjusted road link emission by the empirical dispersion coefficient determined from this graph. Roadside concentrations for built-up roads only are reported to the EU and included in this report.

Figure 3.7. Calibration of NO_x roadside increment model



The dispersion of emissions from vehicles travelling along a road is influenced by a number of different factors, which include the width of the road other factors related to the dispersion of emissions being less efficient on roads with lower flows. This is probably because roads with lower flows are more likely to have slower moving traffic giving less initial dispersion, due to mechanical and thermal turbulence, and because roads with lower flows are more likely to be in built up urban areas with properties close to the road, giving a more confined setting and reduced dispersion. Detailed information on the dispersion characteristics of each built-up major road link within the NAEI is not available. Dispersion will, however, tend to be more efficient on wider roads, such as motorways than on smaller roads in town centres. We have therefore adopted an approach similar to that used within the DMRB Screening Model (Highways Agency, 2003) and applied adjustment factors to the estimated emissions. These adjustment factors are illustrated in Figure 3.8 and depend on the total traffic flow on each link and are higher for the roads with the lowest flow and lower for roads with the highest flow. Thus the traffic flow is used as a surrogate for road width and other factors influencing dispersion. Motorways are generally wider than A-roads and the emission have therefore been adjusted accordingly, as illustrated in Figure 3.8

Figure 3.8 The adjustment factors applied to road link emissions



The roadside increment of NO_2 was calculated from the roadside increment of NO_x using the relationships described in Section 3.2. This was then added to the mapped background NO_2 concentration:

roadside NO_2 concentration = background NO_2 concentration + NO_2 roadside increment

3.8 VERIFICATION OF MAPPED VALUES

Figures 3.9 and 3.10 show comparisons of modelled and measured annual mean NO_x and NO_2 concentration in 2002 at background monitoring site locations. Figure 3.11 and 3.12 show similar comparisons for roadside sites. Both the national network sites used to calibrate the models and the verification sites are shown. Lines representing y = x – 30 % and y = x + 30% are also shown (this is the AQDD1 data quality objective for modelled annual mean NO_2 and NO_x concentrations). There is no requirement to report modelled annual mean NO_x concentrations for comparison with limit values for the protection of human health (the NO_x limit value for the protection of vegetation only applies in vegetation areas). However, comparisons of modelled and measured NO_x concentrations and of the modelled NO_x concentrations with the data quality objectives are presented alongside the comparisons for NO_2. This provides an additional check on the reliability of our modelled estimates of NO_2 because the non-linear relationships between NO_x and NO_2 tend to cause modelled NO_2 concentrations to be relatively insensitive to errors in the dispersion modelling of NO_x.

Figure 3.9. Verification of background annual mean NO_x model 2002

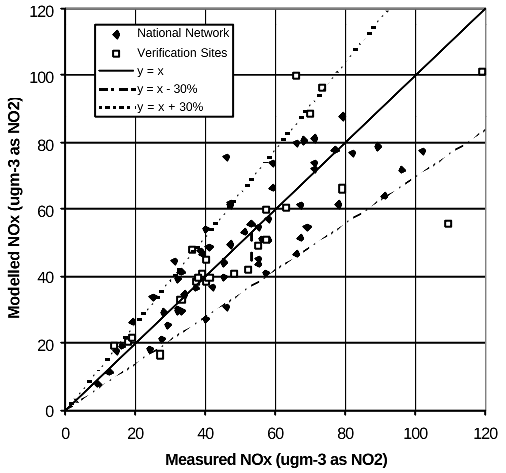


Figure 3.10. Verification of background annual mean NO_2 model 2002

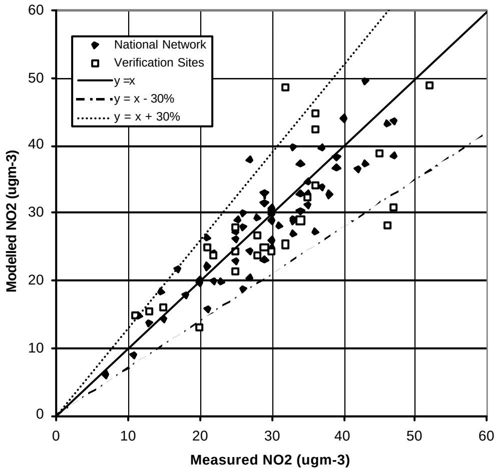


Figure 3.11. Verification of roadside annual mean NO_x model 2002

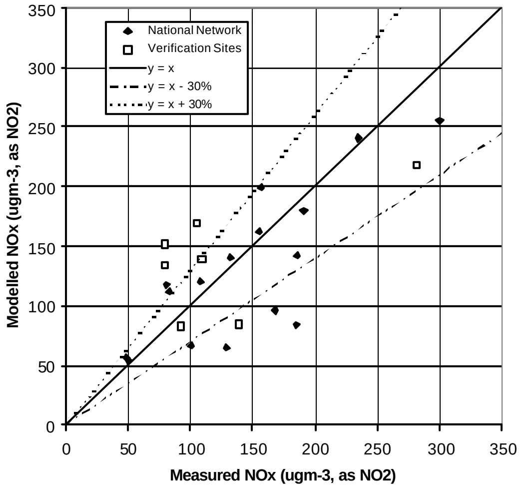
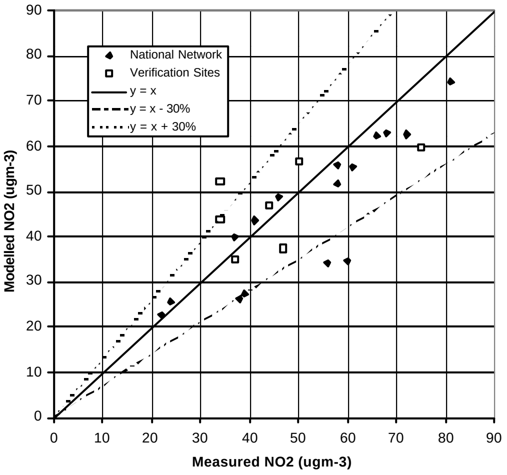


Figure 3.10. Verification of roadside annual mean NO_2 model 2002



Summary statistics for the comparison between modelled and measured NO_x and NO_2 concentrations are listed in Tables 3.1 and 3.2. The percentages of monitoring sites for which the modelled annual mean concentrations fall outside the data quality objectives is generally greater for NO_x than for NO_2, for the reasons discussed above. It is also greater for the verification sites. This is, in part, due uncertainties surrounding the estimates at monitoring sites close to airports, where more detailed emission inventory and dispersion modelling studies would be required to fully characterise the ambient concentration.

Table 3.1. Summary statistics for comparison between modelled and measured NO_x and NO_2 concentrations at background sites (μgm^{-3}, as NO_2)

		Mean of measurements (μgm^{-3}, as NO_2)	Mean of model estimates (μgm^{-3}, as NO_2)	r^2	% outside data quality objectives	Number of sites
National Network	**NO_x**	50.5	49.4	0.74	15%	62
Verification Sites	**NO_x**	51.3	50.6	0.64	25%	24
National Network	**NO_2**	28.8	28.2	0.80	2%	62
Verification Sites	**NO_2**	30.1	28.5	0.57	21%	24

Table 3.2. Summary statistics for comparison between modelled and measured NO_x and NO_2 concentrations at roadside sites (μgm^{-3}, as NO_2)

		Mean of measurements (μgm^{-3}, as NO_2)	Mean of model estimates (μgm^{-3}, as NO_2)	r^2	% outside data quality objectives	Number of sites
National Network	**NO_x**	145.9	130.8	0.64	35%	17
Verification Sites	**NO_x**	126.4	140.0	0.36	57%	7
National Network	**NO_2**	52.1	45.5	0.76	18%	17
Verification Sites	**NO_2**	45.9	47.4	0.22	14%	7

3.9 DETAILED COMPARISON OF MODELLING RESULTS WITH LIMIT VALUES

The modelling results, in terms of a comparison of modelled concentrations with the annual mean limit value by zone, are summarised in Table 3.3. These data have also been presented in form 11 of the questionnaire. We have added the number of road links exceeding the limit value for comparison with other UK studies. The NO_x annual mean limit value for the protection of vegetation was not exceeded in vegetation areas in any of the non-agglomeration zones in 2002. This limit value does not apply in agglomeration zones, according to the definition in the Directive (see Section 1.3). Method A in this table refers to the modelling method described in this report.

Table 3.3 Tabular results of and methods used for supplementary assessment (1999/30/EC Article 7(3) and Annex VIII(II))

- Form 11b Results of and methods used for supplementary assessment for NO_2/NO_x

Zone	Zone code	Above LV for health (annual mean)						
		Area		Road length			Population exposed	
		km^2	Method	links	km	Method	Number	Method
Greater London Urban Area	UK0001	148	A	1602	1337.5	A	1168320	A
West Midlands Urban Area	UK0002	13	A	240	294.8	A	43670	A
Greater Manchester Urban Area	UK0003	1	A	319	293.4	A	3385	A
West Yorkshire Urban Area	UK0004	0	A	149	171.8	A	0	A
Tyneside	UK0005	0	A	29	26.0	A	0	A
Liverpool Urban Area	UK0006	0	A	104	65.9	A	0	A
Sheffield Urban Area	UK0007	0	A	66	76.4	A	0	A
Nottingham Urban Area	UK0008	0	A	76	59.7	A	0	A
Bristol Urban Area	UK0009	0	A	43	39.7	A	0	A
Brighton/Worthing/Littlehampton	UK0010	0	A	0	0	A	0	A
Leicester Urban Area	UK0011	0	A	34	36.4	A	0	A
Portsmouth Urban Area	UK0012	0	A	10	9.9	A	0	A
Teesside Urban Area	UK0013	0	A	3	3.2	A	0	A
The Potteries	UK0014	0	A	29	25.1	A	0	A
Bournemouth Urban Area	UK0015	0	A	0	0	A	0	A
Reading/Wokingham Urban Area	UK0016	0	A	12	14.6	A	0	A
Coventry/Bedworth	UK0017	0	A	13	11.0	A	0	A
Kingston upon Hull	UK0018	0	A	12	12.8	A	0	A
Southampton Urban Area	UK0019	0	A	10	13.6	A	0	A
Birkenhead Urban Area	UK0020	0	A	1	0.6	A	0	A
Southend Urban Area	UK0021	0	A	5	5.5	A	0	A
Blackpool Urban Area	UK0022	0	A	0	0	A	0	A
Preston Urban Area	UK0023	0	A	5	6.3	A	0	A
Glasgow Urban Area	UK0024	0	A	49	69.6	A	0	A
Edinburgh Urban Area	UK0025	0	A	4	6.1	A	0	A
Cardiff Urban Area	UK0026	0	A	3	3.1	A	0	A
Swansea Urban Area	UK0027	0	A	2	3.4	A	0	A
Belfast Urban Area	UK0028	0	A	7	46.0	A	0	A
Eastern	UK0029	1	A	41	73.5	A	1129	A
South West	UK0030	0	A	3	2.3	A	0	A
South East	UK0031	17	A	76	136.6	A	14755	A
East Midlands	UK0032	0	A	30	52.3	A	0	A
North West & Merseyside	UK0033	5	A	110	193.2	A	8061	A
Yorkshire & Humberside	UK0034	0	A	66	176.2	A	0	A
West Midlands	UK0035	8	A	29	47.3	A	6242	A
North East	UK0036	0	A	7	6.6	A	0	A
Central Scotland	UK0037	0	A	5	6.7	A	0	A
North East Scotland	UK0038	0	A	3	4.6	A	0	A
Highland	UK0039	0	A	0	0	A	0	A
Scottish Borders	UK0040	0	A	0	0	A	0	A
South Wales	UK0041	0	A	7	14.5	A	0	A
North Wales	UK0042	0	A	0	0	A	0	A
Northern Ireland	UK0043	0	A	0	0	A	0	A
Total		193		3204	3346		1245562	

4 PM_{10}

4.1 INTRODUCTION

Maps of annual mean PM_{10} in 2002 at background and roadside locations are shown in Figures 4.1 and 4.2. Detailed descriptions of the modelling methods used are available (Stedman and Bush, 2000, Stedman, et al 2001b, Stedman, et al 2002). A summary is provided here with a particular emphasis given to revisions to the methods for the 2002 maps.

Figure 4.1. Annual mean background PM_{10} concentration, 2002 (μg m^{-3}, gravimetric)

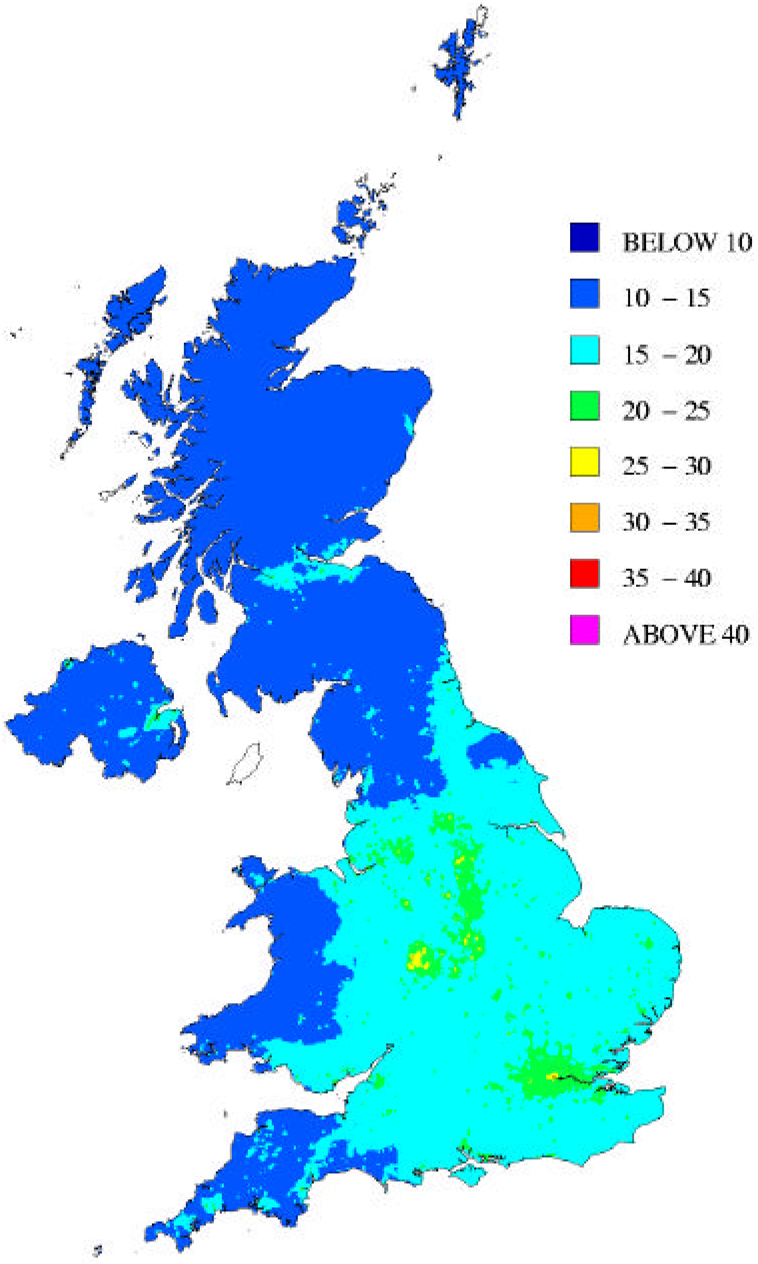
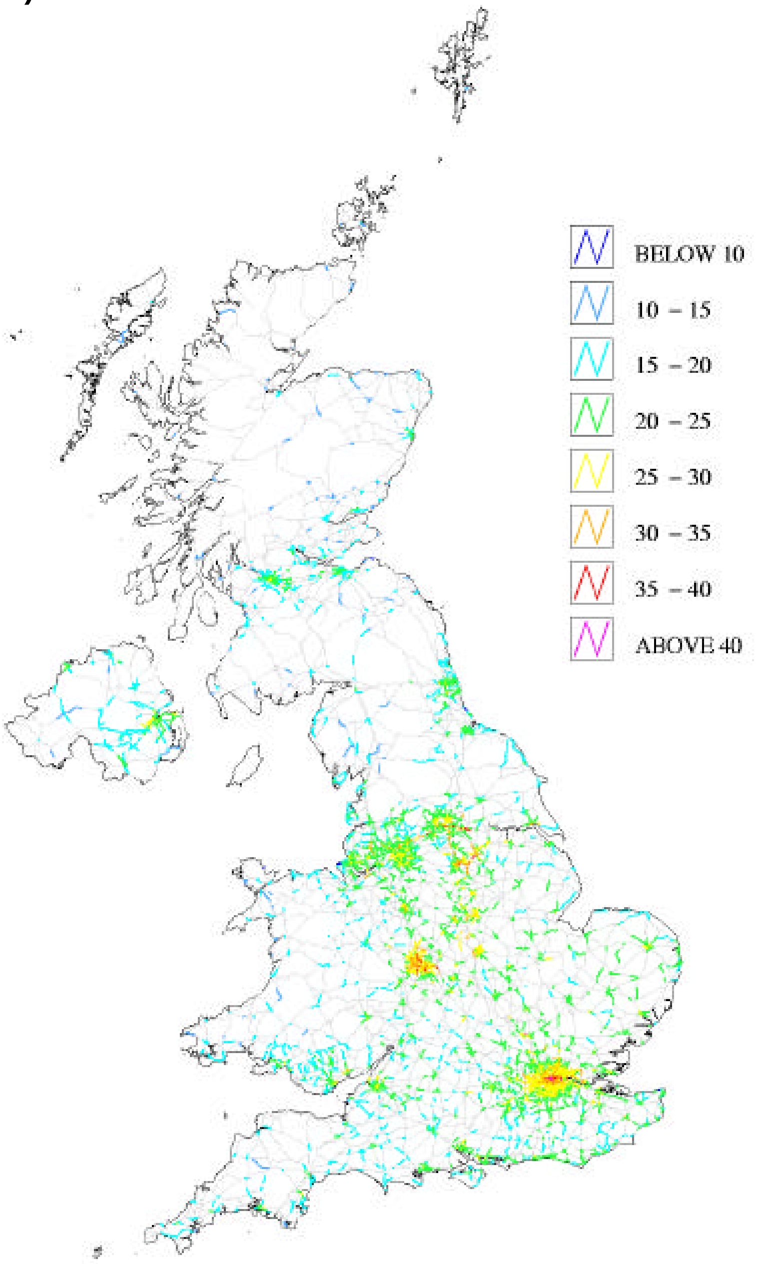


Figure 4.2. Major built-up roads, annual mean roadside PM_{10} concentration, 2002 (μg m^{-3}, gravimetric)



The information on the source apportionment of ambient particle concentrations in the UK available from the APEG receptor model (APEG, 1999, Stedman et al, 2001a) has been applied to the calculation of maps of annual mean concentrations. A regression analysis has been carried out to divide measured daily average PM_{10} concentrations (as measured by TEOM or equivalent monitor at selected monitoring sites) into three components:

- primary combustion PM_{10} (from co-located NO_x measurements)
- secondary PM_{10} (from rural sulphate measurements)
- 'other' PM_{10} (the residual).

The regression analysis was carried out for the calendar year of monitoring data for each site to determine the coefficients A and B:

[measured PM$_{10}$ (mg m^{-3}, TEOM)] = A [measured NO$_x$ (mg m^{-3}, as NO$_2$)] + B [measured sulphate (mg m^{-3})] + C (mg m^{-3}, TEOM)

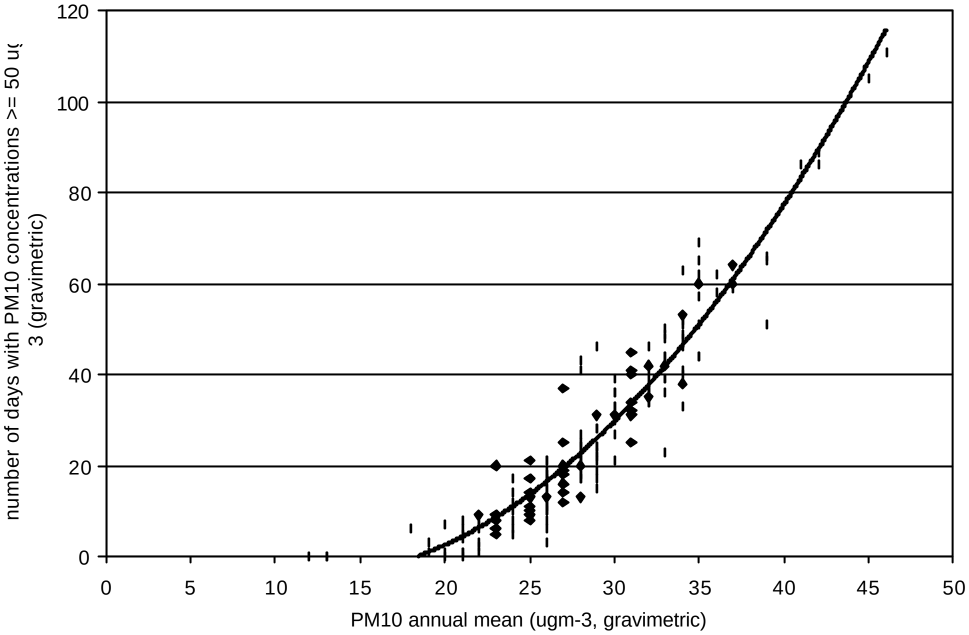
These coefficients can then be used to divide the measured concentration into the three components and the contributions from each component to the annual mean concentration can be calculated. The maps of background concentrations are made up of contributions from

- Large point sources of primary particles
- Small point sources of primary particles
- Area sources of primary particles
- Secondary particles
- Coarse particles.

An additional roadside increment is added for roadside locations.

24-hour mean concentrations have not been explicitly modelled for comparison with the 24-hour limit values. An annual mean concentration of 31.5 µgm^{-3}, gravimetric has been taken to be equivalent to 35 days with 24-hour mean concentrations greater than 50 µgm^{-3} gravimetric (the stage 1 24-hour limit value). This equivalence is derived from an analysis of recent monitoring data (Stedman et al, 2001b) and is reproduced in Figure 4.3. The relationship between the number of days with concentrations greater than 50 µgm^{-3}, gravimetric and annual mean is less certain at lower numbers of exceedences and no attempt has been made to model exceedences of the indicative stage 2 24-hour limit value of 7 exceedences of 50 µgm^{-3}, gravimetric. The stage 2 annual mean limit value is expected to be as stringent than the stage 2 24-hour limit value in any case.

Figure 4.3. The relationship between the number of days with PM$_{10}$ concentrations greater than or equal to 50 mgm^{-3} and annual mean concentration (1992 –1999)



The reference method for the limit values for PM$_{10}$ is the use of a gravimetric instrument. The analysis presented here is based on TEOM (Tapered Element Oscillating Microbalance) instruments, which are currently widely used with in the UK national monitoring networks. We have applied a scaling factor of 1.3 to all data before comparing with the limit value, as suggested by APEG (1999), and recommended as an interim measure by the EC Working Group set up to address the issue of scaling automatic PM_{10} measurements in advance of Member States undertaking their own detailed inter-comparisons with the Directive Reference Method. Measurements of PM_{10} concentrations using gravimetric instruments are now available for a number of sites in the UK. These measurements provide an additional independent verification of the model results.

4.2 SECONDARY PARTICLE CONTRIBUTIONS

For simplicity secondary particles are assumed to consist of sulphates and nitrates only. A map of secondary PM_{10} particle concentrations across the UK has been calculated from rural measurements of sulphate and nitrate concentrations by interpolation onto a 20 km x 20 km grid. Sulphate and nitrate particle concentrations were measured on a monthly basis at 12 rural sites using a denuder method during 2002 (CEH, 2003).

Sulphate was assumed to be largely present as ammonium sulphate and sulphate concentrations were multiplied by 1.354 to take the presence of the counter ion into account. The mean value of the APEG receptor model coefficient, B, relating secondary PM_{10} concentrations to sulphate concentrations in 2002 was 2.71, averaged over 11 background monitoring sites. A comparison of interpolated sulphate and nitrate concentrations at these locations indicates that a scaling factor for nitrate concentrations of 1.0 is equivalent (along with a sulphate scaling factor of 1.354) to the sulphate to nitrate ratio implied by the coefficient derived from the APEG receptor model. (An equivalent B factor derived from the interpolated concentration fields at these 11 locations was 2.76). TEOM instruments are known to be subject to partial losses of the more volatile particle components, such as ammonium nitrate. This is the reason why a scaling factor of greater than 1.0 is not required to take account of the counter ions associated with the measured nitrate concentrations. In this instance the losses of nitrate mass have been found to be approximately equivalent to the mass of the counter ions associated with the remaining nitrate. It is quite possible that a scaling factor different from 1.0 would be found for other years or locations.

4.3 CONTRIBUTIONS FROM LARGE POINT SOURCES

Contributions to ground level annual mean PM_{10} concentrations from large point sources (those with annual emission greater than or equal to 200 tonnes) in the 2001 NAEI were estimated by modelling each source explicitly using an atmospheric dispersion model.

The contribution to annual mean PM_{10} concentrations from PM_{10} point sources with greater than 200 tonnes per annum emission, was modelled using ADMS 3.1 and sequential meteorological data for 2002 from Waddington. A total of 58 point sources were modelled. Surface roughness was assumed to be 0.1 metres. Concentrations were calculated for a 100 km x 100 km square composed of a regularly spaced 5 km x 5 km resolution receptor grid. Each receptor grid was centred on the point source.

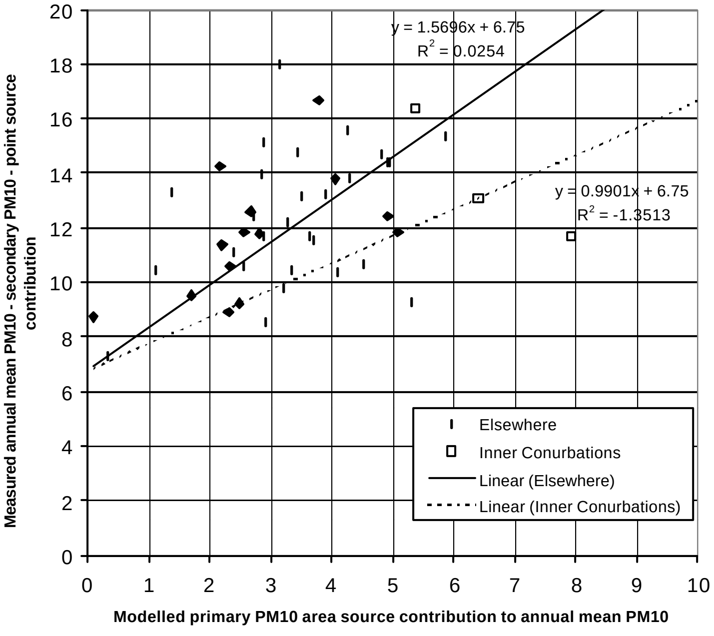
4.4 CONTRIBUTIONS FROM SMALL POINT SOURCES

Contributions from PM_{10} point sources with <200 tonnes per annum release were modelled using the small points model described in Appendix 3.

4.5 CONTRIBUTIONS FROM AREA SOURCES

Figure 4.4 shows the calibration of the area source model. The modelled large point and small point source and mapped secondary PM_{10} has been subtracted from the measured annual mean PM_{10} concentration at background sites. This is compared with the modelled area source contribution to annual mean PM_{10} concentration. Calibration plots are shown in $\mu g\ m^{-3}$, TEOM, since TEOM measurements have been used to calibrate the models. (Concentrations have been converted to μgm^{-3}, gravimetric before comparison with the limit values.) We have used an empirical method, in which an ADMS derived dispersion kernel is applied to calculate the contribution to ambient concentrations at a central receptor location from emissions from area sources within a 33 km x 33 km square surrounding each monitoring site. 10-year average meteorological data for 1993-2002 from Heathrow has been used to construct the dispersion kernels, as described in Appendix 4.

Figure 4.4. Calibration of PM_{10} area source model



Following the same approach as for NO_x, the monitoring sites fall into two groups:

- Inner conurbations
- Elsewhere.

Adjustment factors were applied to the emissions from selected sources. Particle emission from aircraft were multiplied by 0.5, the proportion total that takes place while the aircraft wheels are on the ground. The contribution to ground level concentrations from emissions while the aircraft is airborne will be much smaller and has not been modelled. (By convention, emission inventories include emissions from aircraft both on the ground and on take off and landing up to 1000 m.) Factors of 0.25 and 0.5 were applied to particle emissions from ships and quarries. These factors were chosen empirically to provide the best fit to measured concentrations data.

The modelled area source contribution was multiplied by the relevant empirical coefficient to calculate the calibrated area source contribution for each grid square in the country. The modelled point source and mapped secondary particle concentrations were then added.

4.6 COARSE PARTICLES

A constant coarse particle concentration of 8.8 μgm^{-3}, gravimetric (6.75 μgm^{-3}, TEOM) is the final component of the mapped PM_{10} concentration at background locations. This value was derived from the intercept of the regression analyses to determine the empirical dispersion coefficients. It is somewhat smaller the residuals obtained from the 2002 APEG receptor modelling. This is because of the inclusion of some coarse particle emissions in the area source modelling (principally from quarries, construction and break and tyre wear). These contributions were assigned to the residual in the APEG receptor modelling approach. Emissions of coarse particles form other sources such as wind blown dusts, sea salt and agricultural activities are not well characterised in emission inventories and are therefore included in this constant 8.8 μgm^{-3}, gravimetric contribution, and not modelled explicitly.

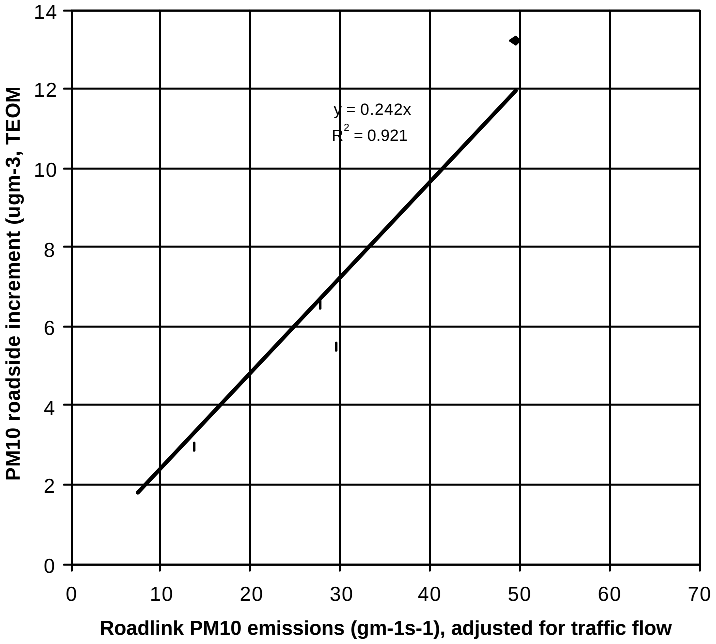
4.7 ROADSIDE CONCENTRATIONS

We have considered that the annual mean concentration of PM_{10} at a roadside location is made up of two parts: the background concentration (as described above) and a roadside increment

roadside concentration = background concentration + roadside increment

The NAEI provides estimates of PM_{10} emissions for major road links in the UK for 2001 (Goodwin et al, 2002) and these have been adjusted to provide estimates of emissions in 2002. Figure 4.5 shows a comparison of the roadside increment of annual mean PM_{10} concentrations at roadside or kerbside national automatic monitoring sites with PM_{10} emission estimates for the individual road links alongside which these sites are located. Emission were adjusted for annual average daily traffic flow using the method described in section 3.7. Roadside concentrations for built-up roads only are reported to the EU and included in this report.

Figure 4.5. Calibration of PM_{10} roadside increment model



4.8 VERIFICATION OF MAPPED VALUES

Figures 4.6 and 4.7 show comparisons of modelled and measured annual mean PM_{10} concentration in 2002 at both background and roadside monitoring site locations. Both the national network sites used to calibrate the models and verification sites are shown. Lines representing y = x – 50 % and y = x + 50% are also shown because 50% is the AQDD1 data quality objective for modelled annual mean PM_{10} concentrations. Summary statistics for the comparison between modelled and measured PM_{10} concentrations are listed in Tables 4.1 and 4.2. All of the modelled values are within the data quality objectives.

Figure 4.6. Verification of background annual mean PM_{10} model 2002

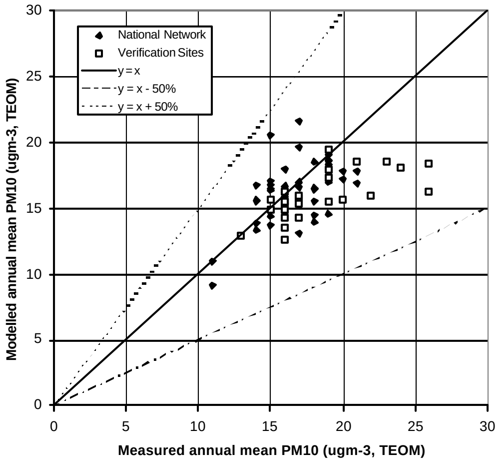


Figure 4.7. Verification of roadside annual mean PM_{10} model 2002

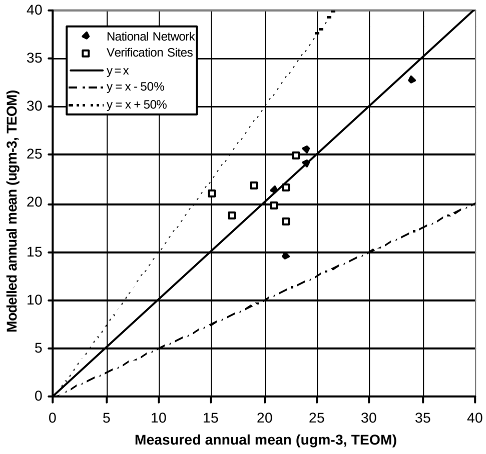


Table 4.1 Summary statistics for comparison between modelled and measured concentrations of PM_{10} at background sites

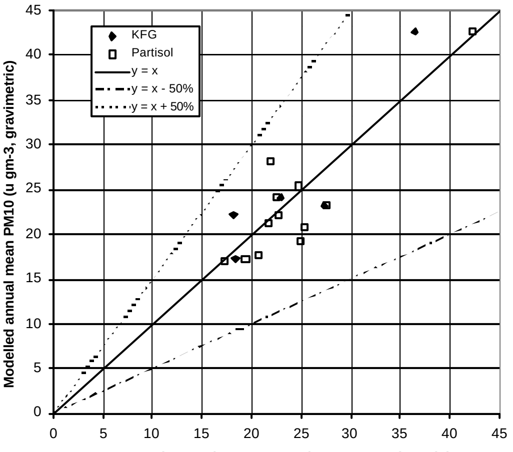
	Mean of measurements (μgm^{-3}, TEOM)	Mean of model estimates (μgm^{-3}, TEOM)	r^2	% outside data quality objectives	Number of sites
National Network	16.9	16.4	0.29	0%	46
Verification Sites	18.3	15.9	0.46	0%	27

Table 4.2 Summary statistics for comparison between modelled and measured concentrations of PM_{10} at roadside sites

	Mean of measurements (μgm^{-3}, TEOM)	Mean of model estimates (μgm^{-3}, TEOM)	r^2	% outside data quality objectives	Number of sites
National Network	23.7	23.7	0.71	0%	5
Verification Sites	19.9	20.9	0.08	0%	7

The PM_{10} models were calibrated using measurement data from TEOM instruments. Measurements of PM_{10} concentrations using gravimetric instruments (Kleinfiltergerat (KFG) and Partisol instruments) are now available for a number of sites in the UK. These measurements provide an additional independent verification of the model results. A comparison of measured annual mean concentrations in 2002 with estimates calculated by multiplying the modelled PM_{10} concentrations by 1.3 is shown in Figure 4.8. All of the estimates are well within the data quality objectives.

Figure 4.8. Verification of annual mean TEOM PM_{10} x 1.3 model 2002: comparison with gravimetric measurements



4.9 DETAILED COMPARISON OF MODELLING RESULTS WITH LIMIT VALUES

The modelling results, in terms of a comparison of modelled concentrations with the stage 1 and stage limit 2 values by zone, are summarised in Tables 4.3 and 4.4. These data are also presented in form 11 of the questionnaire. We have added the number of road links exceeding the limit value for comparison with other UK studies. We have not modelled 24-hour mean concentrations for comparison with the stage 2 24-hour limit value, as discussed in Section 4.1. Method A in this table refers to the annual mean modelling methods described in this report. Method C refers to the annual mean modelling methods described in this report and the use of an annual mean threshold concentration as equivalent to the stage 1 24-hour limit value.

Table 4.3 Tabular results of and methods used for supplementary assessment (1999/30/EC Article 7(3) and Annex VIII(II))

- Form 11c.1 Results of and methods used for supplementary assessment for PM_{10} (Stage 1)

Zone	Zone code	Above LV (24hr mean)							Above LV (annual mean)						
		Area		Road length			Population exposed		Area		Road length			Population exposed	
		km^2	Method	links	km	Method	Number	Method	km^2	Method	links	km	Method	Number	Method
Greater London Urban Area	UK0001	0	C	448	230.6	C	0	C	0	A	44	24.1	A	0	A
West Midlands Urban Area	UK0002	1	C	98	127.7	C	1956	C	0	A	0	0	A	0	A
Greater Manchester Urban Area	UK0003	0	C	0	0	C	0	C	0	A	0	0	A	0	A
West Yorkshire Urban Area	UK0004	0	C	11	9.0	C	0	C	0	A	0	0	A	0	A
Tyneside	UK0005	0	C	0	0	C	0	C	0	A	0	0	A	0	A
Liverpool Urban Area	UK0006	0	C	0	0	C	0	C	0	A	0	0	A	0	A
Sheffield Urban Area	UK0007	1	C	19	27.7	C	944	C	0	A	0	0	A	0	A
Nottingham Urban Area	UK0008	0	C	2	1.5	C	0	C	0	A	0	0	A	0	A
Bristol Urban Area	UK0009	0	C	3	1.7	C	0	C	0	A	0	0	A	0	A
Brighton/Worthing/Littlehampton	UK0010	0	C	0	0	C	0	C	0	A	0	0	A	0	A
Leicester Urban Area	UK0011	0	C	3	1.9	C	0	C	0	A	0	0	A	0	A
Portsmouth Urban Area	UK0012	0	C	0	0	C	0	C	0	A	0	0	A	0	A
Teesside Urban Area	UK0013	0	C	0	0	C	0	C	0	A	0	0	A	0	A
The Potteries	UK0014	0	C	11	9.3	C	0	C	0	A	0	0	A	0	A
Bournemouth Urban Area	UK0015	0	C	0	0	C	0	C	0	A	0	0	A	0	A
Reading/Wokingham Urban Area	UK0016	0	C	0	0	C	0	C	0	A	0	0	A	0	A
Coventry/Bedworth	UK0017	0	C	0	0	C	0	C	0	A	0	0	A	0	A
Kingston upon Hull	UK0018	0	C	2	1.5	C	0	C	0	A	0	0	A	0	A
Southampton Urban Area	UK0019	0	C	1	0.8	C	0	C	0	A	0	0	A	0	A
Birkenhead Urban Area	UK0020	0	C	0	0	C	0	C	0	A	0	0	A	0	A
Southend Urban Area	UK0021	0	C	0	0	C	0	C	0	A	0	0	A	0	A
Blackpool Urban Area	UK0022	0	C	0	0	C	0	C	0	A	0	0	A	0	A
Preston Urban Area	UK0023	0	C	0	0	C	0	C	0	A	0	0	A	0	A
Glasgow Urban Area	UK0024	0	C	0	0	C	0	C	0	A	0	0	A	0	A
Edinburgh Urban Area	UK0025	0	C	0	0	C	0	C	0	A	0	0	A	0	A
Cardiff Urban Area	UK0026	0	C	0	0	C	0	C	0	A	0	0	A	0	A

Table 4.3 Tabular results of and methods used for supplementary assessment (1999/30/EC Article 7(3) and Annex VIII(II))

- Form 11c.1 Results of and methods used for supplementary assessment for PM_{10} (Stage 1)

Zone	Zone code	Above LV (24hr mean)							Above LV (annual mean)						
		Area		Road length			Population exposed		Area		Road length			Population exposed	
		km^2	Method	links	km	Method	Number	Method	km^2	Method	links	km	Method	Number	Method
Swansea Urban Area	UK0027	0	C	0	0	C	0	C	0	A	0	0	A	0	A
Belfast Urban Area	UK0028	0	C	1	3.9	C	0	C	0	A	0	0	A	0	A
Eastern	UK0029	0	C	5	10.7	C	0	C	0	A	1	0.3	A	0	A
South West	UK0030	0	C	0	0	C	0	C	0	A	0	0	A	0	A
South East	UK0031	0	C	2	8.5	C	0	C	0	A	0	0	A	0	A
East Midlands	UK0032	0	C	2	6.8	C	0	C	0	A	0	0	A	0	A
North West & Merseyside	UK0033	0	C	4	4.1	C	0	C	0	A	0	0	A	0	A
Yorkshire & Humberside	UK0034	0	C	24	91.3	C	0	C	0	A	0	0	A	0	A
West Midlands	UK0035	0	C	8	11.4	C	0	C	0	A	0	0	A	0	A
North East	UK0036	0	C	0	0	C	0	C	0	A	0	0	A	0	A
Central Scotland	UK0037	0	C	0	0	C	0	C	0	A	0	0	A	0	A
North East Scotland	UK0038	0	C	0	0	C	0	C	0	A	0	0	A	0	A
Highland	UK0039	0	C	0	0	C	0	C	0	A	0	0	A	0	A
Scottish Borders	UK0040	0	C	0	0	C	0	C	0	A	0	0	A	0	A
South Wales	UK0041	0	C	1	2.4	C	0	C	0	A	0	0	A	0	A
North Wales	UK0042	0	C	0	0	C	0	C	0	A	0	0	A	0	A
Northern Ireland	UK0043	0	C	0	0	C	0	C	0	A	0	0	A	0	A
Total		2		645	550.7		2900		0		45	24.4		0	

Table 4.4 Tabular results of and methods used for supplementary assessment (1999/30/EC Article 7(3) and Annex VIII(II))

- Form 11c.2 Results of and methods used for supplementary assessment for PM_{10} (Stage 2)

Zone	Zone code	Above LV (24hr mean)							Above LV (annual mean)						
		Area		Road length			Population exposed		Area		Road length			Population exposed	
		km^2	Method	links	km	Method	Number	Method	km^2	Method	links	km	Method	Number	Method
Greater London Urban Area	UK0001								1491	A	1923	1781.7	A	7034197	A
West Midlands Urban Area	UK0002								570	A	411	569.5	A	1998977	A
Greater Manchester Urban Area	UK0003								334	A	546	636.0	A	1225401	A
West Yorkshire Urban Area	UK0004								221	A	266	390.0	A	704423	A
Tyneside	UK0005								18	A	109	122.1	A	44006	A
Liverpool Urban Area	UK0006								57	A	269	205.5	A	242848	A
Sheffield Urban Area	UK0007								139	A	98	145.2	A	419081	A
Nottingham Urban Area	UK0008								149	A	102	102.8	A	495611	A
Bristol Urban Area	UK0009								89	A	114	112.8	A	338356	A
Brighton/Worthing/Littlehampton	UK0010								26	A	43	76.0	A	159220	A
Leicester Urban Area	UK0011								91	A	63	87.9	A	335825	A
Portsmouth Urban Area	UK0012								37	A	47	67.1	A	165678	A
Teesside Urban Area	UK0013								10	A	40	46.8	A	15552	A
The Potteries	UK0014								68	A	112	113.9	A	215767	A
Bournemouth Urban Area	UK0015								14	A	46	54.4	A	47993	A
Reading/Wokingham Urban Area	UK0016								56	A	63	74.9	A	172310	A
Coventry/Bedworth	UK0017								65	A	26	27.2	A	254276	A
Kingston upon Hull	UK0018								13	A	37	43.1	A	31574	A
Southampton Urban Area	UK0019								53	A	55	65.2	A	184145	A
Birkenhead Urban Area	UK0020								7	A	51	41.1	A	24359	A
Southend Urban Area	UK0021								51	A	32	50.2	A	174598	A
Blackpool Urban Area	UK0022								0	A	16	17.3	A	0	A
Preston Urban Area	UK0023								10	A	30	38.7	A	26852	A
Glasgow Urban Area	UK0024								13	A	122	180.4	A	36902	A

Table 4.4 Tabular results of and methods used for supplementary assessment (1999/30/EC Article 7(3) and Annex VIII(II))

- Form 11c.2 Results of and methods used for supplementary assessment for PM_{10} (Stage 2)

Zone	Zone code	Above LV (24hr mean)							Above LV (annual mean)						
		Area		Road length			Population exposed		Area		Road length			Population exposed	
		km^2	Method	links	km	Method	Number	Method	km^2	Method	links	km	Method	Number	Method
Edinburgh Urban Area	UK0025								0	A	23	42.9	A	0	A
Cardiff Urban Area	UK0026								17	A	32	47.2	A	49363	A
Swansea Urban Area	UK0027								1	A	15	32.0	A	3011	A
Belfast Urban Area	UK0028								50	A	15	99.4	A	170746	A
Eastern	UK0029								1557	A	495	894.1	A	2081961	A
South West	UK0030								157	A	249	343.4	A	167912	A
South East	UK0031								1071	A	654	1139.7	A	1521399	A
East Midlands	UK0032								2047	A	358	695.6	A	1574324	A
North West & Merseyside	UK0033								435	A	380	688.1	A	619655	A
Yorkshire & Humberside	UK0034								853	A	258	584.5	A	948067	A
West Midlands	UK0035								774	A	262	425.8	A	849910	A
North East	UK0036								18	A	89	105.3	A	12040	A
Central Scotland	UK0037								22	A	20	32.7	A	23647	A
North East Scotland	UK0038								0	A	32	48.5	A	0	A
Highland	UK0039								0	A	0	0	A	0	A
Scottish Borders	UK0040								0	A	0	0	A	0	A
South Wales	UK0041								71	A	65	125.1	A	82333	A
North Wales	UK0042								47	A	23	31.3	A	39685	A
Northern Ireland	UK0043								51	A	44	263.9	A	148774	A
Total									10753		7635	10649.3		22640776	

5 Lists of zones in relation to Limit Values and Margins of Tolerance

5.1 RESULTS FOR 2002

The tables included in this section are from form 5 of the questionnaire. A '+' indicates that the concentration of the pollutant with respect to the limit value in that zone has been determined by measurements. A 'm' indicates that the concentration of the pollutant with respect to the limit value in that zone has been determined by modelling. If both measurements and model calculations show that a threshold has been exceeded then the measurements are regarded as the primary basis for compliance status and '+' is therefore used. An 'm' in the columns marked >LV + MOT or ≤LV + MOT; > LV indicates that modelled concentrations were higher than measured concentrations or on rare occasions that measurements were not available for that zone and modelled values were therefore used. Modelled concentration may be higher than measured concentrations because the modelling studies provide estimates of concentrations over the entire zone. It is possible that the locations of the monitoring sites do not correspond to the location of the highest concentration in the zone. There may, for example, be no roadside monitoring sites in a zone. An 'm' in the columns marked ≤LV indicates that measurements were not available for that zone and modelled values were therefore used. A blank cell indicates that no assessment has been made.

The results of the air quality assessments for SO_2, NO_2 and NO_x, PM_{10} and lead are listed in Tables 5.1 to 5.4.

Table 5.1. List of zones and agglomerations where levels exceed or do not exceed limit values (LV) or limit values plus margin of tolerance (LV+MOT) (96/62/EC Articles 8, 9 and 11 and 1999/30/EC Annexes I, II, III and IV)

- Form 5a List of zones in relation to limit value exceedences for SO_2

Zone	Zone code	LV for health (1hr mean)			LV for health (24hr mean)		LV for ecosystems (annual mean)		LV for ecosystems (winter mean)	
		>LV+ MOT	≤LV+MOT; >LV	≤LV	>LV	≤LV	>LV	≤LV	>LV	≤LV
Greater London Urban Area	UK0001			+		+				
West Midlands Urban Area	UK0002			+		+				
Greater Manchester Urban Area	UK0003			+		+				
West Yorkshire Urban Area	UK0004			+		+				
Tyneside	UK0005			+		+				
Liverpool Urban Area	UK0006			m		m				
Sheffield Urban Area	UK0007			+		+				
Nottingham Urban Area	UK0008			+		+				
Bristol Urban Area	UK0009			+		+				
Brighton/Worthing/Littlehampton	UK0010			+		+				
Leicester Urban Area	UK0011			+		+				
Portsmouth Urban Area	UK0012			+		+				
Teesside Urban Area	UK0013			+		+				
The Potteries	UK0014			+		+				
Bournemouth Urban Area	UK0015			+		+				
Reading/Wokingham Urban Area	UK0016			+		+				
Coventry/Bedworth	UK0017			+		+				
Kingston upon Hull	UK0018			m		m				
Southampton Urban Area	UK0019			m		m				
Birkenhead Urban Area	UK0020			+		+				
Southend Urban Area	UK0021			+		+				

Table 5.1. List of zones and agglomerations where levels exceed or do not exceed limit values (LV) or limit values plus margin of tolerance (LV+MOT) (96/62/EC Articles 8, 9 and 11 and 1999/30/EC Annexes I, II, III and IV)

- Form 5a List of zones in relation to limit value exceedences for SO_2

Zone	Zone code	LV for health (1hr mean)			LV for health (24hr mean)		LV for ecosystems (annual mean)		LV for ecosystems (winter mean)	
		>LV+ MOT	≤LV+MOT; >LV	≤LV	>LV	≤LV	>LV	≤LV	>LV	≤LV
Blackpool Urban Area	UK0022			+		+				
Preston Urban Area	UK0023			+		+				
Glasgow Urban Area	UK0024			+		+				
Edinburgh Urban Area	UK0025			+		+				
Cardiff Urban Area	UK0026			+		+				
Swansea Urban Area	UK0027			+		+				
Belfast Urban Area	UK0028			+		+				
Eastern	UK0029			+		+		+		+
South West	UK0030			+		+		m		m
South East	UK0031			+		+		+		+
East Midlands	UK0032			+		+		m		m
North West & Merseyside	UK0033			+		+		m		m
Yorkshire & Humberside	UK0034			+		+		m		m
West Midlands	UK0035			+		+		m		m
North East	UK0036			+		+		m		m
Central Scotland	UK0037			m		m		m		m
North East Scotland	UK0038			+		+		m		m
Highland	UK0039			m		m		m		m
Scottish Borders	UK0040			m		m		m		m
South Wales	UK0041			+		+		m		m
North Wales	UK0042			m		m		m		m
Northern Ireland	UK0043			+		+		m		m

Table 5.2. List of zones and agglomerations where levels exceed or do not exceed limit values (LV) or limit values plus margin of tolerance (LV+MOT) (96/62/EC Articles 8, 9 and 11 and 1999/30/EC Annexes I, II, III and IV)

- Form 5b List of zones in relation to limit value exceedences for NO_2/NOx

Zone	Zone code	LV for health (1hr mean)			LV for health (annual mean)			LV for vegetation	
		>LV+MOT	≤LV+MOT; >LV	≤LV	>LV+MOT	≤LV+MOT; >LV	≤LV	>LV	≤LV
Greater London Urban Area	UK0001			+	+				
West Midlands Urban Area	UK0002			+	m				
Greater Manchester Urban Area	UK0003			+	+				
West Yorkshire Urban Area	UK0004			+	m				
Tyneside	UK0005			+		m			
Liverpool Urban Area	UK0006					m			
Sheffield Urban Area	UK0007			+	m				
Nottingham Urban Area	UK0008			+		m			
Bristol Urban Area	UK0009			+	m				
Brighton/Worthing/Littlehampton	UK0010			+			+		
Leicester Urban Area	UK0011			+		m			
Portsmouth Urban Area	UK0012			+		m			
Teesside Urban Area	UK0013			+		m			
The Potteries	UK0014			+	m				
Bournemouth Urban Area	UK0015			+			+		
Reading/Wokingham Urban Area	UK0016			+		m			
Coventry/Bedworth	UK0017			+		m			
Kingston upon Hull	UK0018				m				
Southampton Urban Area	UK0019			+	m				
Birkenhead Urban Area	UK0020			+		m			
Southend Urban Area	UK0021			+		m			
Blackpool Urban Area	UK0022			+			+		
Preston Urban Area	UK0023			+		m			
Glasgow Urban Area	UK0024		+		+				
Edinburgh Urban Area	UK0025			+		+			
Cardiff Urban Area	UK0026			+		m			

Table 5.2. List of zones and agglomerations where levels exceed or do not exceed limit values (LV) or limit values plus margin of tolerance (LV+MOT) (96/62/EC Articles 8, 9 and 11 and 1999/30/EC Annexes I, II, III and IV)

- Form 5b List of zones in relation to limit value exceedences for NO_2/NOx

Zone	Zone code	LV for health (1hr mean)			LV for health (annual mean)			LV for vegetation	
		>LV+MOT	≤LV+MOT; >LV	≤LV	>LV+MOT	≤LV+MOT; >LV	≤LV	>LV	≤LV
Swansea Urban Area	UK0027			+		m			
Belfast Urban Area	UK0028			+		m			
Eastern	UK0029			+	m				+
South West	UK0030			+	+				m
South East	UK0031			+	+				+
East Midlands	UK0032			+	m				m
North West & Merseyside	UK0033			+	m				m
Yorkshire & Humberside	UK0034			+	m				m
West Midlands	UK0035			+	m				m
North East	UK0036			+	m				m
Central Scotland	UK0037					m			m
North East Scotland	UK0038			+		m			m
Highland	UK0039			+			+		m
Scottish Borders	UK0040			+			+		m
South Wales	UK0041			+	m				+
North Wales	UK0042			+			+		m
Northern Ireland	UK0043			+			+		m

Table 5.3. List of zones and agglomerations where levels exceed or do not exceed limit values (LV) or limit values plus margin of tolerance (LV+MOT) (96/62/EC Articles 8, 9 and 11 and 1999/30/EC Annexes I, II, III and IV)

- Form 5c List of zones in relation to limit value exceedences for PM_{10}

Zone	Zone code	LV (24hr mean) Stage 1			LV (annual mean) Stage 1			LV (24hr mean) Stage 2			LV (annual mean) Stage 2		
		>LV+ MOT	≤LV+ MOT; >LV	≤LV	>LV+ MOT	≤LV+ MOT; >LV	≤LV	>LV+ MOT	≤LV+ MOT; >LV	≤LV	>LV+ MOT	≤LV+ MOT; >LV	≤LV
Greater London Urban Area	UK0001	m			m				+		+		
West Midlands Urban Area	UK0002		m				+		+		m		
Greater Manchester Urban Area	UK0003			+			+		+		+		
West Yorkshire Urban Area	UK0004		m				+		+		m		
Tyneside	UK0005			+			+			+	m		
Liverpool Urban Area	UK0006			m			m				m		
Sheffield Urban Area	UK0007		m				+		+		m		
Nottingham Urban Area	UK0008		m				+			+	m		
Bristol Urban Area	UK0009		m				+		+		m		
Brighton/Worthing/Littlehampton	UK0010			m			m					m	
Leicester Urban Area	UK0011		m				+			+	m		
Portsmouth Urban Area	UK0012			+			+			+		+	
Teesside Urban Area	UK0013			+			+		+			+	
The Potteries	UK0014		m				+			+	m		
Bournemouth Urban Area	UK0015			+			+		+			+	
Reading/Wokingham Urban Area	UK0016			+			+			+		m	
Coventry/Bedworth	UK0017			+			+			+		+	
Kingston upon Hull	UK0018		m				m				m		
Southampton Urban Area	UK0019		m				+		+		m		
Birkenhead Urban Area	UK0020			+			+			+		+	

Table 5.3. List of zones and agglomerations where levels exceed or do not exceed limit values (LV) or limit values plus margin of tolerance (LV+MOT) (96/62/EC Articles 8, 9 and 11 and 1999/30/EC Annexes I, II, III and IV)

- Form 5c List of zones in relation to limit value exceedences for PM_{10}

Zone	Zone code	LV (24hr mean) Stage 1			LV (annual mean) Stage 1			LV (24hr mean) Stage 2			LV (annual mean) Stage 2		
		>LV+ MOT	≤LV+ MOT; >LV	≤LV	>LV+ MOT	≤LV+ MOT; >LV	≤LV	>LV+ MOT	≤LV+ MOT; >LV	≤LV	>LV+ MOT	≤LV+ MOT; >LV	≤LV
Southend Urban Area	UK0021			+			+			+		m	
Blackpool Urban Area	UK0022			+			+			+		+	
Preston Urban Area	UK0023			+			+			+		m	
Glasgow Urban Area	UK0024			+			+		+			+	
Edinburgh Urban Area	UK0025			+			+		+			+	
Cardiff Urban Area	UK0026			+			+		+			+	
Swansea Urban Area	UK0027			+			+		+			+	
Belfast Urban Area	UK0028		m				+		+		m		
Eastern	UK0029		m			m			+		m		
South West	UK0030			+			+			+		m	
South East	UK0031		m				+		+		m		
East Midlands	UK0032		m				+			+	m		
North West & Merseyside	UK0033		m				+			+	m		
Yorkshire & Humberside	UK0034		+				+		+		+		
West Midlands	UK0035		m				+			+	m		
North East	UK0036			+			+		+		m		
Central Scotland	UK0037			m			m					m	
North East Scotland	UK0038			m			m					m	
Highland	UK0039			m			m						m
Scottish Borders	UK0040			+			+		+			+	
South Wales	UK0041		m				+			+	m		
North Wales	UK0042			+			+		+			+	
Northern Ireland	UK0043			+			+		+			+	

Table 5.4. List of zones and agglomerations where levels exceed or do not exceed limit values (LV) or limit values plus margin of tolerance (LV+MOT) (96/62/EC Articles 8, 9 and 11 and 1999/30/EC Annexes I, II, III and IV)

- Form 5d List of zones in relation to limit value exceedences for lead

Zone	Zone code	LV		
		>LV+MOT	≤LV+MOT; >LV	≤LV
Greater London Urban Area	UK0001			+
West Midlands Urban Area	UK0002			+
Greater Manchester Urban Area	UK0003			+
West Yorkshire Urban Area	UK0004			
Tyneside	UK0005			+
Liverpool Urban Area	UK0006			
Sheffield Urban Area	UK0007			
Nottingham Urban Area	UK0008			
Bristol Urban Area	UK0009			
Brighton/Worthing/Littlehampton	UK0010			
Leicester Urban Area	UK0011			
Portsmouth Urban Area	UK0012			
Teesside Urban Area	UK0013			
The Potteries	UK0014			
Bournemouth Urban Area	UK0015			
Reading/Wokingham Urban Area	UK0016			
Coventry/Bedworth	UK0017			
Kingston upon Hull	UK0018			
Southampton Urban Area	UK0019			
Birkenhead Urban Area	UK0020			
Southend Urban Area	UK0021			
Blackpool Urban Area	UK0022			
Preston Urban Area	UK0023			
Glasgow Urban Area	UK0024			+
Edinburgh Urban Area	UK0025			
Cardiff Urban Area	UK0026			+
Swansea Urban Area	UK0027			

Table 5.4. List of zones and agglomerations where levels exceed or do not exceed limit values (LV) or limit values plus margin of tolerance (LV+MOT) (96/62/EC Articles 8, 9 and 11 and 1999/30/EC Annexes I, II, III and IV)				
- Form 5d List of zones in relation to limit value exceedences for lead				
Zone	Zone code	LV		
		>LV+MOT	≤LV+MOT; >LV	≤LV
Belfast Urban Area	UK0028			
Eastern	UK0029			+
South West	UK0030			
South East	UK0031			+
East Midlands	UK0032			+
North West & Merseyside	UK0033			+
Yorkshire & Humberside	UK0034			
West Midlands	UK0035			
North East	UK0036			
Central Scotland	UK0037			
North East Scotland	UK0038			
Highland	UK0039			
Scottish Borders	UK0040			+
South Wales	UK0041			+
North Wales	UK0042			
Northern Ireland	UK0043			

5.2 MEASURED EXCEEDENCES OF LIMIT VALUES + MARGINS TOLERANCE

The reasons associated with the measured exceedences of the limit value + margin of tolerance are listed in form 7 of the questionnaire. This information is summarised in Table 5.5. Measured exceedences of the limit value + margin of tolerance were only identified for annual mean NO_2.

Table 5.5. Measured exceedences of limit values plus margin of tolerance, 2002

Limit value + MOT	**Site**	**Zone**	**Level (μgm^{-3})**	**Reason code**	**Reason**
NO_2 annual	Camden Kerbside	Greater London Urban Area	66	S2	Proximity to a major road
NO_2 annual	Hounslow Roadside	Greater London Urban Area	58	S2	Proximity to a major road
NO_2 annual	London A3 Roadside	Greater London Urban Area	58	S2	Proximity to a major road
NO_2 annual	London Cromwell Road 2	Greater London Urban Area	72	S2	Proximity to a major road
NO_2 annual	London Marylebone Road	Greater London Urban Area	81	S2	Proximity to a major road
NO_2 annual	Southwark Roadside	Greater London Urban Area	58	S2	Proximity to a major road
NO_2 annual	Tower Hamlets Roadside	Greater London Urban Area	61	S2	Proximity to a major road
NO_2 annual	Bury Roadside	Greater Manchester Urban Area	68	S2	Proximity to a major road
NO_2 annual	Glasgow Kerbside	Glasgow Urban Area	74	S2	Proximity to a major road
NO_2 annual	Bath Roadside	South West	57	S2	Proximity to a major road
NO_2 annual	Oxford Centre	South East	60	S2	Proximity to a major road

5.3 COMPARISON WITH 2001

Tables 5.6 and 5.7 provide a comparison of the monitoring and modelling results for 2002 with the results of the air quality assessment reported to the EU for 2001 (Stedman, et al 2002). In contrast to 2001, there were no exceedences of any of the limit values for SO_2 during 2002. The patterns of exceedences of limit values and limit values + margins of tolerance for NO_2 and PM_{10} were broadly similar in 2001 and 2002. Some zones changed status between 2001 and 2002 in terms of the annual mean limit value + margin of tolerance for NO_2. The following zones exceeded this threshold in 2001 but not in 2002: Tyneside, Liverpool Urban Area, Nottingham Urban Area, Leicester Urban Area, Belfast Urban Area. The following zones exceeded in 2002 but not in 2001: South West, North East, South Wales. There were no exceedences for Lead in 2001 or 2002.

Table 5.6 Exceedences of limit values plus margins of tolerance

Pollutant	**Averaging time**	**2002**	**2001**
SO_2	1-hour	None	none
SO_2	24-hour[1]	None	1 Zone measured (Belfast Urban Area)
SO_2	annual[2]	n/a	n/a
SO_2	winter[2]	n/a	n/a
NO_2	1-hour[3]	none	none
NO_2	annual	19 Zones (5 measured + 14 modelled)	21 Zones (4 measured + 17 modelled)
NO_x	annual[2]	n/a	n/a
PM_{10}	24-hour	1 zone modelled (Greater London Urban Area)	1 zone modelled (Greater London Urban Area)
PM_{10}	annual	1 zone modelled (Greater London Urban Area)	1 zone modelled (Greater London Urban Area)
PM_{10}	24-hour[4]	n/a	n/a
PM_{10}	annual[5]	22 Zones (3 measured + 18 modelled)	not assessed
Lead	annual	none	none

[1] No MOT defined, LV + MOT = LV

[2] No MOT defined for vegetation and ecosystem LVs, which are already in force

[3] No modelling for 1-hour LV

[4] Stage 2 indicative LV, no MOT defined for 24-hour LV, no modelling for 24-hour Stage 2 LV

[5] Stage 2 indicative LV

Table 5.7 Exceedences of limit values

Pollutant	**Averaging time**	**2002**	**2001**
SO_2	1-hour	none	none
SO_2	24-hour	none	1 Zone measured (Belfast Urban Area)
SO_2	annual	none	none
SO_2	winter	none	not assessed
NO_2	1-hour[3]	1 zone measured (Glasgow Urban Area)	4 zones measured
NO_2	annual	36 zones (6 measured + 30 modelled)	38 zones (6 measured + 32 modelled)
NO_x	annual	none	none
PM_{10}	24-hour	18 zones (1 measured + 17 modelled)	26 zones (5 measured + 21 modelled)
PM_{10}	annual	2 zones (Greater London Urban Area measured, Eastern modelled)	2 zones (Greater London Urban Area measured, Greater Manchester Urban Area modelled)
PM_{10}	24-hour[4]	21 zones (21 measured)	25 zones (25 measured)
PM_{10}	annual[5]	42 zones (16 measured, 26 modelled)	43 zones (28 measured, 15 modelled)
Lead	annual	None	none

[3] No modelling for 1-hour LV

[4] Stage 2 indicative LV, no modelling for24-hour Stage 2 LV

[5] Stage 2 indicative LV

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APPENDIX 1. NATIONAL NETWORK MONITORING SITES

Table A1.1. Monitoring sites operating during 2002 for AQDD1 reporting.

Station code	Local station code	Zone code	Zone	Use for Directive				Use for Directive / Measuring method
				SO_2	NO_2	NO_x	Lead	PM_{10}
GB0729A	Aberdeen	UK0038	North East Scotland	+	+			M3
	Avesta Polarit Rotherham	UK0007	Sheffield Urban Area				+	
GB0600A	Barnsley 12	UK0034	Yorkshire & Humberside	+				
GB0681A	Barnsley Gawber	UK0034	Yorkshire & Humberside	+	+			
GB0647A	Bath Roadside	UK0030	South West		+			
GB0567A	Belfast Centre	UK0028	Belfast Urban Area	+	+			M3
GB0696A	Belfast Clara St	UK0028	Belfast Urban Area					M1
GB0514A	Belfast East	UK0028	Belfast Urban Area	+				
GB0421A	Billingham	UK0013	Teesside Urban Area		+			
GB0569A	Birmingham Centre	UK0002	West Midlands Urban Area	+	+			M3
GB0595A	Birmingham East	UK0002	West Midlands Urban Area	+	+			M3
GB0727A	Blackpool	UK0022	Blackpool Urban Area	+	+			M3
GB0654A	Bolton	UK0003	Greater Manchester Urban Area	+	+			M3
GB0741A	Bournemouth	UK0015	Bournemouth Urban Area	+	+			M2
GB0689A	Bradford Centre	UK0004	West Yorkshire Urban Area	+	+			M3
GB0693A	Brighton Roadside	UK0010	Brighton/Worthing/Littlehampton		+			
GB0585A	Bristol Centre	UK0009	Bristol Urban Area	+	+			M3
GB0639A	Bristol Old Market	UK0009	Bristol Urban Area		+			
	Brittania Recycling Wakefield	UK0004	West Yorkshire Urban Area				+	
GB0417A	Brookside 2 lead site	UK0002	West Midlands Urban Area				+	
GB0652A	Bury Roadside	UK0003	Greater Manchester Urban Area	+	+			M3
GB0789A	BZL Hallen	UK0030	South West				+	
GB0726A	Cambridge Roadside	UK0029	Eastern		+			
GB0636A	Camden Kerbside	UK0001	Greater London Urban Area		+			M3
GB0737A	Canterbury	UK0031	South East		+			M3
GB0580A	Cardiff Centre	UK0026	Cardiff Urban Area	+	+			M3
GB0369A	Cardiff lead site	UK0026	Cardiff Urban Area				+	
GB0537A	Central London lead site	UK0001	Greater London Urban Area				+	
GB0194A	Chilton lead site	UK0031	South East				+	
GB0739A	Coventry Memorial Park	UK0017	Coventry/Bedworth	+	+			M3
GB0744A	Cwmbran	UK0041	South Wales	+	+			M3
GB0673A	Derry	UK0043	Northern Ireland	+	+			M3
GB0740A	Dumfries	UK0040	Scottish Borders		+			M2
GB0581A	Edinburgh Centre	UK0025	Edinburgh Urban Area	+	+			M3
GB0419A	Elswick 6 lead site	UK0005	Tyneside				+	
GB0361A	Eskdalemuir lead	UK0040	Scottish Borders				+	

Station code	Local station code	Zone code	Zone	Use for Directive				Use for Directive / Measuring method
				SO_2	NO_2	NO_x	Lead	PM_{10}
	site							
GB0640A	Exeter Roadside	UK0030	South West	+	+			
GB0641A	Glasgow Centre	UK0024	Glasgow Urban Area	+	+			M3
GB0452A	Glasgow City Chambers	UK0024	Glasgow Urban Area		+			
GB0657A	Glasgow Kerbside	UK0024	Glasgow Urban Area		+			M3
GB0260A	Glasgow lead site	UK0024	Glasgow Urban Area				+	
GB0735A	Grangemouth	UK0037	Central Scotland	+	+			M3
GB0637A	Haringey Roadside	UK0001	Greater London Urban Area		+			M3
GB0036R	Harwell	UK0031	South East	+	+	+		
GB0685A	Hounslow Roadside	UK0001	Greater London Urban Area		+			
GB0686A	Hove Roadside	UK0010	Brighton/Worthing/Littlehampton	+	+			
GB0776A	Hull Freetown	UK0018	Kingston upon Hull	+	+			M3
GB0382A	IMI 2 lead site	UK0002	West Midlands Urban Area				+	
GB0742A	Inverness	UK0039	Highland		+			M2
GB0037R	Ladybower	UK0032	East Midlands	+	+			
GB0643A	Leamington Spa	UK0035	West Midlands	+	+			M3
GB0584A	Leeds Centre	UK0004	West Yorkshire Urban Area	+	+			M3
GB0248A	Leeds lead site	UK0004	West Yorkshire Urban Area				+	
GB0597A	Leicester Centre	UK0011	Leicester Urban Area	+	+			M3
GB0659A	London A3 Roadside	UK0001	Greater London Urban Area		+			M3
GB0608A	London Bexley	UK0001	Greater London Urban Area	+	+			M3
GB0566A	London Bloomsbury	UK0001	Greater London Urban Area	+	+			M3
GB0616A	London Brent	UK0001	Greater London Urban Area	+	+			M3
GB0635A	London Brent Park lead site	UK0001	Greater London Urban Area				+	
GB0697A	London Bromley	UK0001	Greater London Urban Area		+			
GB0695A	London Cromwell Road 2	UK0001	Greater London Urban Area	+	+			
GB0332A	London Cromwell Road lead site	UK0001	Greater London Urban Area				+	
GB0586A	London Eltham	UK0001	Greater London Urban Area	+	+			M3
GB0650A	London Hackney	UK0001	Greater London Urban Area		+			
GB0642A	London Hillingdon	UK0001	Greater London Urban Area	+	+			M3
GB0672A	London Lewisham	UK0001	Greater London Urban Area	+	+			
GB0682A	London Marylebone Road	UK0001	Greater London Urban Area	+	+			M3
GB0620A	London N. Kensington	UK0001	Greater London Urban Area	+	+			M3
GB0656A	London Southwark	UK0001	Greater London Urban Area	+	+			

Station code	Local station code	Zone code	Zone	Use for Directive				Use for Directive / Measuring method
				SO_2	NO_2	NO_x	Lead	PM_{10}
GB0644A	London Teddington	UK0001	Greater London Urban Area	+	+			
GB0622A	London Wandsworth	UK0001	Greater London Urban Area		+			
GB0743A	London Westminster	UK0001	Greater London Urban Area	+	+			
GB0006R	Lough Navar	UK0043	Northern Ireland					M3
GB0038R	Lullington Heath	UK0031	South East	+	+			
GB0370A	Manchester lead site	UK0003	Greater Manchester Urban Area				+	
GB0613A	Manchester Piccadilly	UK0003	Greater Manchester Urban Area	+	+			M3
GB0649A	Manchester South	UK0003	Greater Manchester Urban Area	+	+			
GB0453A	Manchester Town Hall	UK0003	Greater Manchester Urban Area		+			
GB0583A	Middlesbrough	UK0013	Teesside Urban Area	+	+			M3
GB0241A	Motherwell lead site	UK0024	Glasgow Urban Area				+	
GB0043R	Narberth	UK0041	South Wales	+	+	+		M3
GB0568A	Newcastle Centre	UK0005	Tyneside	+	+			M3
GB0738A	Northampton	UK0032	East Midlands	+	+			M3,M2
GB0684A	Norwich Centre	UK0029	Eastern	+	+			M3
GB0678A	Norwich Roadside	UK0029	Eastern		+			
GB0646A	Nottingham Centre	UK0008	Nottingham Urban Area	+	+			M3
GB0633A	Oxford Centre	UK0031	South East	+	+			
GB0687A	Plymouth Centre	UK0030	South West	+	+			M3
GB0198A	Pontardawe lead site	UK0041	South Wales				+	
GB0651A	Port Talbot	UK0027	Swansea Urban Area	+	+			M3
GB0733A	Portsmouth	UK0012	Portsmouth Urban Area	+	+			M3
GB0731A	Preston	UK0023	Preston Urban Area	+	+			M3
GB0683A	Reading	UK0016	Reading/Wokingham Urban Area	+	+			M3
GB0679A	Redcar	UK0013	Teesside Urban Area	+	+			M3
GB0617A	Rochester	UK0031	South East	+	+			M3
GB0677A	Rotherham Centre	UK0007	Sheffield Urban Area	+	+			
GB0660A	Salford Eccles	UK0003	Greater Manchester Urban Area	+	+			M3
GB0698A	Sandwell West Bromwich	UK0002	West Midlands Urban Area	+	+			
GB0690A	Scunthorpe	UK0034	Yorkshire & Humberside	+				M3
GB0615A	Sheffield Centre	UK0007	Sheffield Urban Area	+	+			M3
GB0538R	Sheffield Tinsley	UK0007	Sheffield Urban Area		+			
GB0598A	Southampton Centre	UK0019	Southampton Urban Area	+	+			M3
GB0728A	Southend-on-Sea	UK0021	Southend Urban Area	+	+			M3
GB0667A	Southwark Roadside	UK0001	Greater London Urban Area	+	+			
GB0754A	St Osyth	UK0029	Eastern		+	+		
GB0775A	Stockport Shaw Heath	UK0003	Greater Manchester Urban Area	+	+			M3
GB0734A	Stockton-on-	UK0036	North East		+			M3

Station code	Local station code	Zone code	Zone	Use for Directive				Use for Directive / Measuring method
				SO_2	NO_2	NO_x	Lead	PM_{10}
	Tees Yarm							
GB0658A	Stoke-on-Trent Centre	UK0014	The Potteries	+	+			M3
GB0193A	Styrrup lead site	UK0032	East Midlands				+	
GB0582A	Sunderland	UK0036	North East	+				
GB0609A	Swansea	UK0027	Swansea Urban Area	+	+			M3
GB0645A	Thurrock	UK0029	Eastern	+	+			M3
GB0642A	Tower Hamlets Roadside	UK0001	Greater London Urban Area		+			
GB0455A	Walsall Alumwell	UK0002	West Midlands Urban Area		+			
GB0674A	Walsall Willenhall	UK0002	West Midlands Urban Area		+			
GB0420A	West London	UK0001	Greater London Urban Area		+			
GB0045R	Wicken Fen	UK0029	Eastern	+	+	+		
GB0736A	Wigan Leigh	UK0033	North West & Merseyside	+	+			M3
GB0730A	Wirral Tranmere	UK0020	Birkenhead Urban Area	+	+			M3
GB0614A	Wolverhampton Centre	UK0002	West Midlands Urban Area	+	+			M3
GB0192A	Wraymires lead site	UK0033	North West & Merseyside				+	
GB0755A	Wrexham	UK0042	North Wales	+	+			M2

+ = monitoring for the Directive at that site

M1 = Beta Attenuation Monitor, M2 =Gravimetric, M3 = TEOM measurements for PM_{10}

Table A1.2. Measurements with between 75 % and 90 % data capture (included in analysis)

Site	Zone code	Data capture SO_2 %	Data capture NO_2 %	Data capture PM_{10} %
Barnsley Gawber	UK0034	86.2	86.4	nm
Birmingham Centre	UK0002	77.9	+	+
Coventry Memorial Park	UK0017	+	87.8	+
Edinburgh Centre	UK0025	86.1	86.0	82.1
Glasgow Centre	UK0024	85.3	+	+
Hounslow Roadside	UK0001	nm	82.4	nm
Leeds Centre	UK0004	+	87.1	+
Leicester Centre	UK0011	+	+	79.3
London A3 Roadside	UK0001	nm	88.0	+
London Bexley	UK0001	86.8	89.6	+
London Bloomsbury	UK0001	89.9	-	-
London Cromwell Road 2	UK0001	85.2	+	nm
London Hackney	UK0001	nm	88.2	nm
London Southwark	UK0001	+	84.0	nm
Manchester South	UK0003	+	88.5	nm
Middlesbrough	UK0013	+	82.1	79.1
Narberth	UK0041	-	85.7	+
Nottingham Centre	UK0008	+	+	88.9
Reading	UK0016	80.4	+	+
Scunthorpe	UK0034	+	nm	84.4
Southampton Centre	UK0019	-	+	88.4
Southwark Roadside	UK0001	85.4	86.6	nm
Thurrock	UK0029	+	+	82.0
Wicken Fen	UK0029	+	85.0	nm
Wolverhampton Centre	UK0002	77.0	+	+
Wrexham	UK0042	-	77.8	78.1

+ means data capture above 90%, - means less than 75% and nm means not measured at this site.

Table A1.3. Measurements with less than 75 % data capture (not included in analysis but listed in Table A1.1 and form 3)

Site	**Zone code**	**Data capture SO_2 %**	**Data capture NO_2 %**	**Data capture PM_{10} %**	**Data capture Lead**
Aberdeen	UK0038	+	+	72.3	nm
Bristol Old Market	UK0009	nm	0.0	nm	nm
Brittania Recycling, Wakefield	UK0004	nm	nm	nm	-
Avesta Polarit Rotherham	UK0007	nm	nm	nm	-
BZL Hallen	UK0029	nm	nm	nm	-
Central London	UK0001	nm	nm	nm	-
Grangemouth	UK0037	57.3	57.3	57.3	nm
Hull Freetown	UK0018	15.3	14.9	13.9	nm
Inverness	UK0039	nm	+	65.8	nm
London Bloomsbury	UK0001	+	9.3	35.5	nm
Narberth	UK0041	44.3	=	+	nm
Northampton (Gravimetric)	UK0032	nm	nm	70.4	nm
Rochester	UK0031	+	+	60.7	nm
Southampton Centre	UK0019	65.7	+	=	nm
St Osyth	UK0029	nm	61.8	nm	nm
Stockport Shaw Heath	UK0003	22.5	22.4	22.0	nm
Wrexham	UK0042	69.6	=	=	nm

+ means data capture above 90%, = means between 75 and 90% data capture and nm means not measured at this site.

Table A1.4. The effect of applying a data capture threshold of 90% on the results listed in form 5. (NB this has not been done).

		Number of zones		
Pollutant	**Averaging time**	**No change in status of zone[**]**	**+ becomes m in this zone**	**+ becomes blank in this zone**
SO_2	1-hour	3	3	
SO_2	24-hour	3	3	
NO_2	1-hour	6		4
NO_2	annual	8	2	
PM_{10}	24-hour	3	5	
PM_{10}	annual	2	6	
PM_{10}[*]	24-hour	1		7
PM_{10}[*]	annual	5	3	

* Stage 2

** No change in the status of the zone for which monitoring data for a site was between 75 % and 90 %. There would also be no effect in zones for which all sites had data capture greater than 90 %, which is the case in the majority of zones.

APPENDIX 2. MONITORING SITES USED TO VERIFY THE MAPPED ESTIMATES

Table A2.1. Monitoring sites used to verify the mapped estimates (all PM_{10} measurements by TEOM).

Site	**Authority or Company**	**Site Type**	**SO_2**	**NO_2**	**PM_{10}**
Abingdon	Vale of White Horse DC	URBAN BACKGROUND	+	+	+
Bacton Gas Terminal	BP Amoco Exploration	RURAL		+	
Birmingham Airport	Birmingham International Airport	URBAN BACKGROUND	+	+	+
Bracknell Bagshot Road	Bracknell Forest BC	ROADSIDE		+	+
Bracknell Foxhill	Bracknell Forest BC	URBAN BACKGROUND		+	
Brentwood	Brentwood BC	URBAN BACKGROUND		+	
Cambridge Gonville Place	Cambridge City Council	ROADSIDE		+	+
Gatwick LGW3	BAA	URBAN BACKGROUND		+	+
Heathrow Bedfont Court	BAA	URBAN BACKGROUND			+
Heathrow Green Gates	BAA	URBAN BACKGROUND		+	+
Heathrow LHR2	BAA	URBAN BACKGROUND		+	+
Heathrow Main Road	BAA	URBAN BACKGROUND	+	+	+
Heathrow Moorbridge	BAA	URBAN BACKGROUND			+
Heathrow Oaks Road	BAA	URBAN BACKGROUND			+
Liverpool Islington	Liverpool City Council	ROADSIDE	+	+	+
Liverpool Vauxhall	Liverpool City Council	URBAN BACKGROUND	+	+	+
Liverpool Victoria Street	Liverpool City Council	ROADSIDE	+	+	+
Newham Cam Road	London Borough of Newham	ROADSIDE	+	+	+
Newham Tant Avenue	London Borough of Newham	URBAN BACKGROUND	+	+	+
Newry Monaghan Row	Newry and Mourne DC	URBAN BACKGROUND	+		+
Newry Trevor Hill	Newry and Mourne DC	ROADSIDE	+		
Oldham West Endhouse	Oldham Metropolitan Borough Council	URBAN BACKGROUND	+	+	+
Oxford East	Oxford City Council	URBAN BACKGROUND		+	+
Oxford St Ebbes	Oxford City Council	URBAN BACKGROUND		+	+
Ribble Valley Chatburn	Ribble Valey Borough Council	RURAL	+	+	+
Ribble Valley Lillands	Ribble Valey Borough Council	RURAL	+	+	+
Salford M60	Salford MBC	ROADSIDE	+	+	+
Slough Colnbrook	Slough Borough Council	URBAN BACKGROUND		+	+
Slough Town Centre A4	Slough Borough Council	ROADSIDE		+	+
South Bucks Gerrards Cross	South Bucks District Council	KERBSIDE		+	+
South Cambs Bar Hill	South Cambridgeshire DC	KERBSIDE		+	
South Holland	South Holland DC	URBAN BACKGROUND		+	+
Stockport Bredbury	Stockport Metropolitan BC	URBAN BACKGROUND		+	+
Stockport Cheadle	Stockport Metropolitan BC	URBAN BACKGROUND		+	+
Stockport Marple	Stockport Metropolitan BC	URBAN BACKGROUND		+	+
Strabane Springhill Park	Strabane DC	URBAN BACKGROUND	+		
Sutton Bridge (Petts Lane)	South Holland DC	URBAN BACKGROUND			+
Tameside Two Trees School	Tameside Metropolitan BC	SUBURBAN	+	+	+

Site	**Authority or Company**	**Site Type**	**SO_2**	**NO_2**	**PM_{10}**
Trafford	Trafford Metropolitan BC	URBAN BACKGROUND	+	+	+
Wigan	Wigan Metropolitan BC	URBAN BACKGROUND		+	+
Wokingham Earley	Wokingham DC	ROADSIDE		+	+
Wokingham Winnersh	Wokingham DC	URBAN BACKGROUND			+

Table A2.2. Additional monitoring sites maintained by the electricity generating companies used calibrate the SO_2 models.

Site	**Company**
Bexleyheath	Innogy
Lower Shorne	Innogy
Didcot North	Innogy
Didcot South	Innogy
Font-y-gary	Innogy
Downes Grounds	Innogy
Carr Lane Drax	Innogy
Hemingbrough	Innogy
North Featherstone	Innogy
Smeathalls Farm	Innogy
West Bank	Innogy
Bottesford	PowerGen
Cromwell	PowerGen
Grove Reservoir	PowerGen
Marton School	PowerGen
Ruddington	PowerGen
Stanton	PowerGen
Thorney	PowerGen
Weston on Trent	PowerGen
Bass Burton Brewery	PowerGen
Gainsborough Cemetery	PowerGen

APPENDIX 3. SMALL POINT SOURCE MODEL

INTRODUCTION

Small industrial sources have generally been represented in earlier maps (Stedman et al, 2002) as 1 km square volume sources. However, this approach has in some cases lead to unreasonably high concentrations close to the source. The overestimation arises because the release height, buoyancy and momentum of discharges from industrial chimneys is not taken into account. A revised small point source model has been developed which uses dispersion kernels that will take these factors into account.

The dispersion model ADMS 3.1 was used to prepare the dispersion kernels.

DISCHARGE CONDITIONS

The National Atmospheric Emission Inventory contains limited information concerning the discharge characteristics of individual emission sources. In many cases the information is limited to data on the total annual emission of individual pollutants. It is therefore necessary to make some general assumptions concerning the discharge height, the discharge temperature, the volumetric flowrate of the discharge and the discharge velocity. Our approach has been to make reasonable, but generally conservative assumptions corresponding to industrial practice.

Sulphur dioxide

For sulphur dioxide, it was assumed that the plant operates continuously throughout the year. The stack height was estimated using the following equations taken from the 3rd edition of the Chimney Heights Memorandum:

If the sulphur dioxide emission rate, R_A kg/h, is less 10 kg/h, the chimney height, U m, is given by:

$$U = 6R_A^{0.5}$$

If R_A is in the range 10-100 kg/h:

$$U = 12R_A^{0.2}$$

Emission rates in excess of 100 kg/h were not considered in this study.

No account was taken of the effects of buildings: it was assumed that the increase in chimney height to take account of building effects provided by the Memorandum would compensate for the building effects.

It was then assumed that the sulphur dioxide concentration in the discharge would be at the limit for indigenous coal and liquid fuel for new and existing plant provided by Secretary of States Guidance-Boilers and Furnaces, 20-50 MW net rated thermal input PG1/3(95). The limit is 3000 mg m^{-3} at reference conditions of 273 K, 101.3 kPa, 6% oxygen for solid fuel firing and 3% oxygen for liquid firing and dry gas. It was assumed that the oxygen content in the discharge corresponds with the reference condition. The moisture content of the discharge was ignored. It was assumed that the temperature of discharge was 373 K: higher temperatures would lead to improved buoyancy and hence lower ground level concentrations while lower temperatures usually result in unacceptable water condensation. A discharge velocity of 10 m/s was selected to be representative of most combustion source discharges. The discharge diameter d m was calculated from;

$$d = \sqrt{\frac{4qT}{273\pi cv}}$$

where q is the sulphur dioxide emission rate, g/s
T is the discharge temperature, 373K
c is the emission concentration at reference conditions, 3 g m^{-3}
v is the discharge velocity, 10 m/s

Table A3.1 shows the modelled stack heights and diameters.

Table A3.1 Modelled stack heights and diameters for sulphur dioxide

Emission rate			Stack height, m	Stack diameter, m
g/s	kg/h	t/a		
0.1	0.36	3.2	3.60	0.08
0.2	0.72	6.3	5.09	0.11
0.5	1.8	15.8	8.05	0.17
1	3.6	31.5	11.38	0.24
2	7.2	63.1	16.10	0.34
5	18	157.7	21.39	0.54
10	36	315.4	24.57	0.76
20	72	630.7	28.23	1.08

Oxides of nitrogen

For nitrogen dioxide, it was assumed that the plant operates continuously throughout the year. The stack height was estimated using the following equation taken from the 3rd edition of the Chimney Heights Memorandum for very low sulphur fuels:

$$U = 1.36Q^{0.6}\left(1 - 4.7\times10^{-5}Q^{1.69}\right)$$

where Q is the gross heat input in MW.

This relationship applies for heat inputs up to 150 MW. For larger heat inputs a fixed height of 30 m was used corresponding to an approximate lower limit derived from available data on stack heights for large sources.

The gross heat input used in the above equation was calculated from the oxides of nitrogen emission rate using an emission factor of 10600 kg/MTh (0.100 g/MJ) for oxides of nitrogen emitted from natural gas combustion in non-domestic non-power station sources taken from the NAEI.

For fuels containing significant sulphur, the actual stack height will be greater to allow for the dispersion of sulphur dioxide so that the approach taken is expected to lead to an overestimate of ground level concentrations.

The emission limits for oxides of nitrogen provided by Secretary of States Guidance-Boilers and Furnaces, 20-50 MW net rated thermal input PG1/3(95) depend on the type of fuel and are in the range 140-650 mg m^{-3} at reference conditions. A value of 300 mg m^{-3} was used in the calculation of the stack discharge diameter. Other assumptions concerning discharge conditions followed those made for sulphur dioxide above.

Table A3.2 shows the modelled stack heights and diameters.

Table A3.2 Modelled stack heights and diameters for oxides of nitrogen

Emission rate		Height, m	Diameter, m
g/s	t/a		
0.1	3.2	1.36	0.24
0.2	6.3	2.06	0.34
0.5	15.8	3.57	0.54
1	31.5	5.40	0.76
2	63.1	8.15	1.08
5	157.7	13.72	1.70
10	315.4	19.12	2.41
20	630.7	21.34	3.41
50	1576.8	30.00	5.38
100	3153.6	30.00	7.61

Particulate matter, PM_{10}

The stack heights and diameters used for oxides of nitrogen were also used to provide the kernels for particulate matter PM_{10}. This will provide a conservative assessment of PM_{10} concentrations for the following reasons. The emission limits for total particulate matter provided by Secretary of States Guidance-Boilers and Furnaces, 20-50 MW net rated thermal input PG1/3(95) depend on the type of fuel and are in the range 5-300 mg m^{-3} at reference conditions. The emission limit for total particulate matter includes but is not limited to the contribution from PM_{10}.

DISPERSION MODELLING

The dispersion model ADMS3.1 was used to predict ground level concentrations on two receptor grids:

- an “in-square” grid covering an area 1 km x 1 km with the source at the centre and with receptors at 33.3 m intervals;
- an “outer-grid” covering an area 30 km x 30 km with the source at the centre and with receptors at 1 km intervals.

A surface roughness value of 0.5 m was used, corresponding to areas of open suburbia. Meteorological data for Heathrow for the years 1993-2002 was used in the assessment, with most model runs using the 2000 data.

RESULTS

Sulphur dioxide

Table A3.3 shows the predicted “in-square average” concentration for the 1 km square centred on the emission source for 2000 meteorological data.

Table A3.3 Predicted in-square concentration, for sulphur dioxide

Emission rate, g/s	Average in square concentration , µg m^{-3}
0.1	0.599
0.2	0.934
0.5	1.555
1	2.19
2	2.92
5	4.57
10	6.56
20	8.86

The results shown in Table A3.3 may be approximated by the relationship

$C=Aq^{0.5}$

where C is the in-square concentration, µg m^{-3} and q is the emission rate, g/s. A is a proportionality factor (2.07 in 2000)

Table A3.4 shows the predicted in-square concentration for an emission rate of 10 g/s for meteorological years 1993-2002. Table A3.4 also shows the inter-annual variation in the factor A.

Table A3.4 In-square concentrations for 10 g/s emissions

Year	In-square concentration, µg m^{-3}	Factor A
1993	6.21	1.96
1994	6.01	1.90
1995	6.12	1.94
1996	6.23	1.97
1997	6.10	1.93
1998	6.18	1.95
1999	6.49	2.05
2000	6.56	2.07
2001	6.32	2.00
2002	6.51	2.06

Figure A3.1 shows the predicted “outer-grid” concentration along the east-west axis through the source for 2000 meteorological data for a range of rates of emission (in g/s). Figure A3.1 does not include results for the 1 km source square.

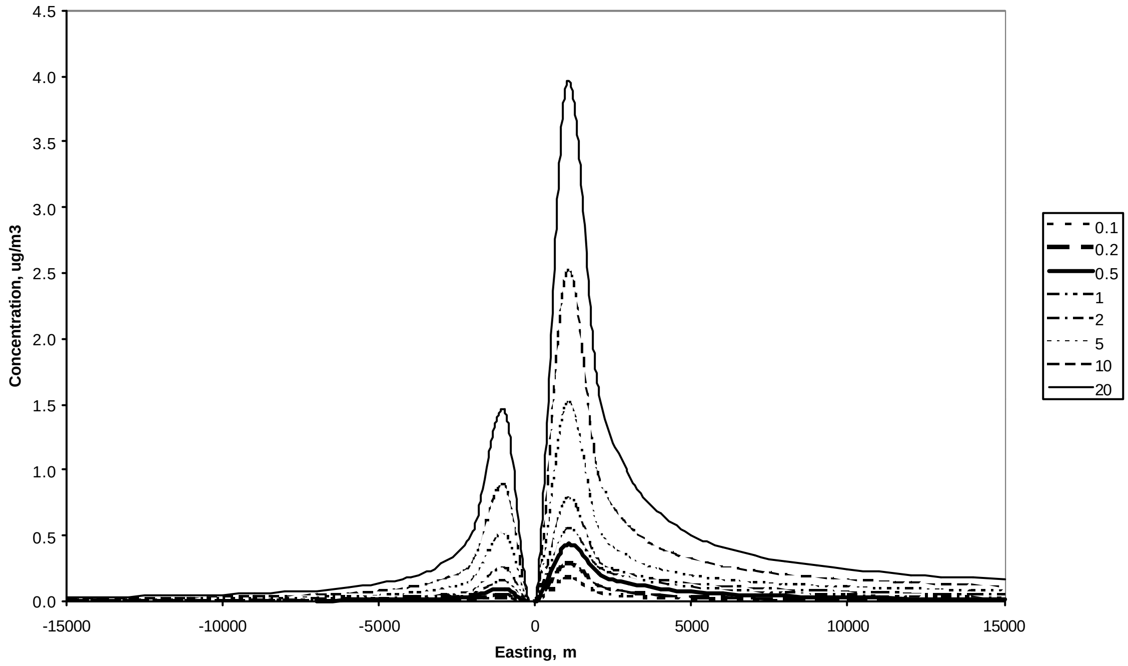


Figure A3.1 Sulphur dioxide concentration on east-west axis, 2000 meteorological data

Figure A3.2 shows the same model results plotted as $C/q^{2/3}$. The spread of the model results is greatly reduced so that as a reasonable approximation all the model results may be reduced to a single line.

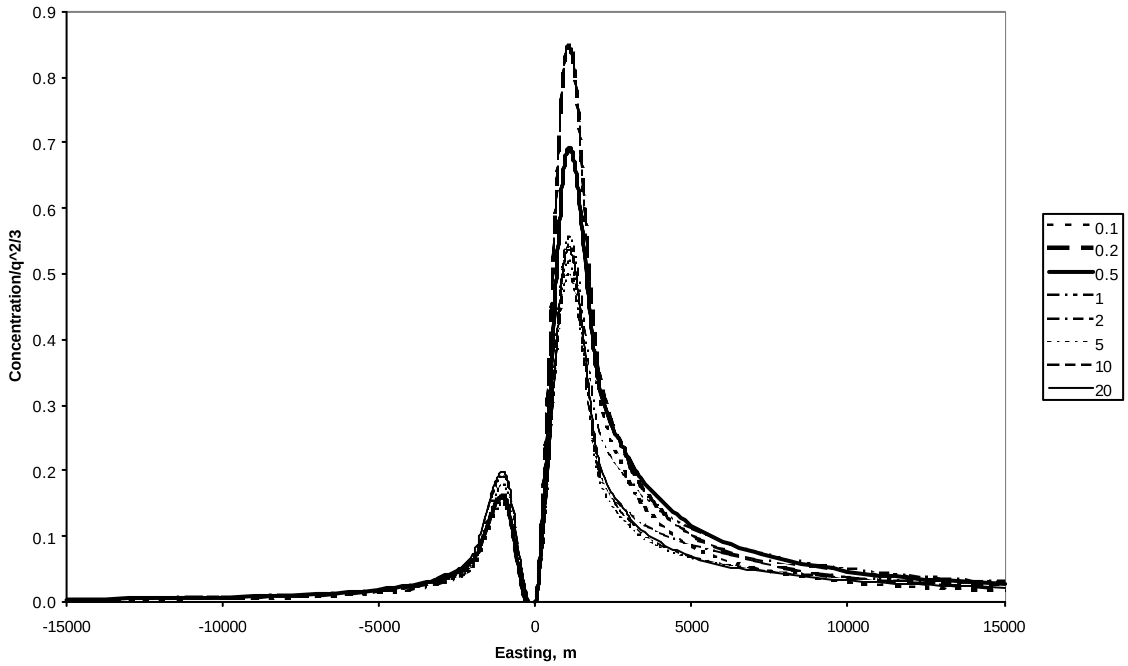


Figure A3.2 Reduced sulphur dioxide concentrations on the east-west axis, 2000 meteorological data

Thus it is proposed to use the results for an emission rate of 10 g/s for all emission rates in the range 0.1-20 g/s in the preparation of dispersion kernels for industrial sulphur dioxide emissions. The dispersion kernel will be multiplied by $10.(q/10)^{2/3}$ to provide estimates of the impact of emission q g/s at each receptor location. Separate kernels have been created from each meteorological data year 1993-2002.

Oxides of nitrogen

Table A3.5 shows the predicted “in-square average” concentration for the 1 km square centred on the emission source for 2000 meteorological data.

Table 3.5 In-square oxides of nitrogen concentrations, 2000

Emission rate, g/s	In square concentration, µg m^{-3}
0.1	0.464
0.2	0.764
0.5	1.37
1	1.97
2	2.6
5	3.31
10	3.58
20	4.34
50	3.745
100	4.3

The results shown in Table A3.5 may be approximated in the range 0.1-20 g/s by the relationship

$C=B \log_{10}(10q)+0.464$

where C is the in-square concentration, µg m^{-3} and q is the emission rate, g/s. and B is a numerical constant, 1.68 in 2000.

For emission rates in the range 20-100 g/s , the in-square concentration is approximately 4 µg m^{-3}.

Table A3.6 shows the predicted in-square concentration for an emission rate of 20 g/s for meteorological years 1993-2002. Table A3.6 also shows the inter-annual variation in the factor B.

Table A3.6 Inter annual variation in in-square oxides of nitrogen concentration

Year	In-square concentration ,µg m^{-3}	Factor B
1993	3.62	1.37
1994	3.88	1.48
1995	3.74	1.42
1996	4.3	1.67
1997	3.66	1.39
1998	3.64	1.38
1999	4.14	1.60
2000	4.34	1.68
2001	4.02	1.55
2002	4.68	1.83

Figure A3.3 shows the predicted “outer-grid” oxides of nitrogen concentration along the east-west axis through the source for a range of rates of emission (in g/s).

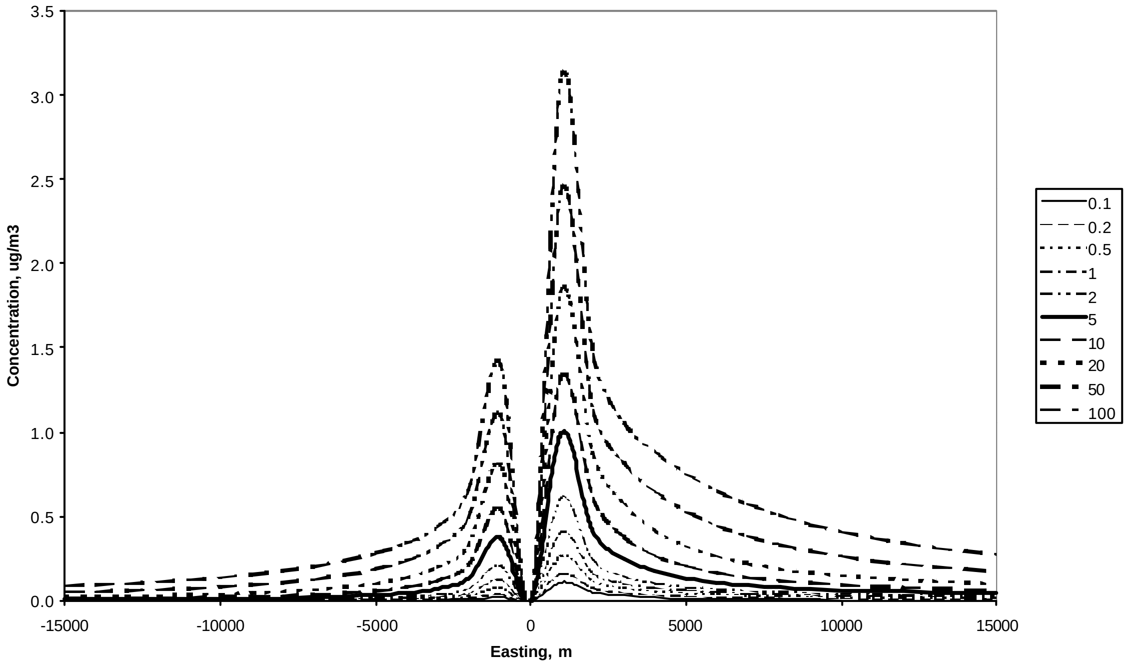


Figure A3.3 Oxides of nitrogen concentration on east-west axis, 2000 meteorological data

Figure A3.4 shows the same model results plotted as $C/q^{0.6}$. The spread of the model results is greatly reduced so that as a reasonable approximation all the model results may be reduced to a single line.

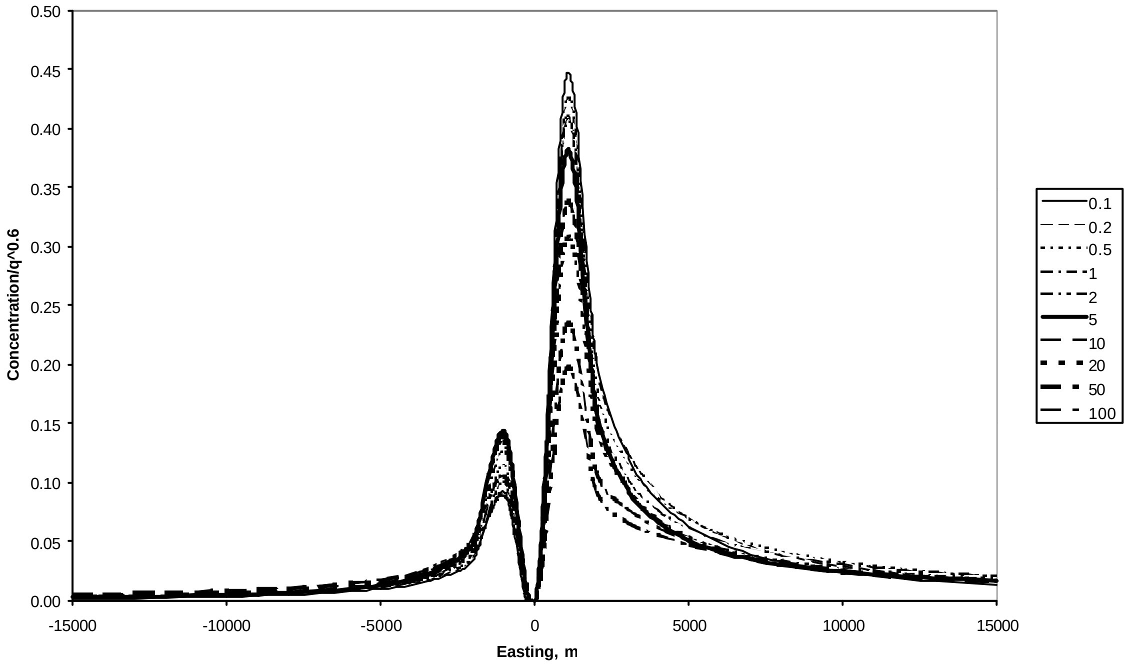


Figure A3.4 Reduced oxides of nitrogen concentrations on the east-west axis, 2000 meteorological data

Thus it is proposed to use the results for an emission rate of 20 g/s for all emission rates in the range 0.1-100 g/s in the preparation of dispersion kernels for oxides of nitrogen emissions. The dispersion kernel will be multiplied by $20.(q/20)^{0.6}$ to provide estimates of the impact of emission q g/s at each receptor location. Separate kernels have been created for each meteorological data year 1993-2002.

METHOD

Sulphur dioxide

Point sources with emissions greater than or equal to 500 tonnes per year (15.85 g/s) have been modelled explicitly using ADMS. Point sources with emissions less than 500 tonnes per year have been modelled using the small points model. This model has two components.

The in-square concentration for each source has been calculated using the following function:

$$C=1.98.q^{0.5}$$

where C is the in-square concentration, $\mu g\ m^{-3}$ and q is the emission rate, g/s and 1.98 is a numerical constant, calculated as the average value over the years 1993-2002 for met data at Heathrow.

The outer-grid concentration has been calculated by adjusting the emissions for each source using the function:

$$Q = 10.(q/10)^{0.667}$$

where q is the emission rate, g/s and Q is the adjusted emissions. The sum of the adjusted emission was then calculated for each grid square and the outer-grid concentration calculated using a small points dispersion kernel (which was calculated as the average over the years 1993-2002 for met data at Heathrow).

The in-square and outer-grid concentrations were then summed to calculate the total contribution to ambient annual mean concentrations from these small point sources.

Oxides of nitrogen

Point sources with emissions greater than or equal to 500 tonnes per year (15.85 g/s) have been modelled explicitly using ADMS. Point sources with emissions less than 500 tonnes per year have been modelled using the small points model. This model has two components.

The in-square concentration for each source has been calculated using the following function:

$$C=1.54.\ \log_{10}(10q)+0.464$$

where C is the in-square concentration, µg m^{-3} and q is the emission rate, g/s and 1.54 is a numerical constant, calculated as the average value over the years 1993-2002 for met data at Heathrow.

The outer-grid concentration has been calculated by adjusting the emissions for each source using the function:

$$Q = 20.\ (q/20)^{0.6}$$

where q is the emission rate, g/s and Q is the adjusted emissions. The sum of the adjusted emission was then calculated for each grid square and the outer-grid concentration calculated using a small points dispersion kernel (which was calculated as the average over the years 1993-2002 for met data at Heathrow).

The in-square and outer-grid concentrations were then summed to calculate the total contribution to ambient annual mean concentrations from these small point sources.

PM_{10}

The method for PM_{10} was the same as for NO_x, except that point sources with emissions greater than or equal to 200 tonnes per year (6.34 g/s) have been modelled explicitly using ADMS. Point sources with emissions less than 200 tonnes per year have been modelled using the small points model.

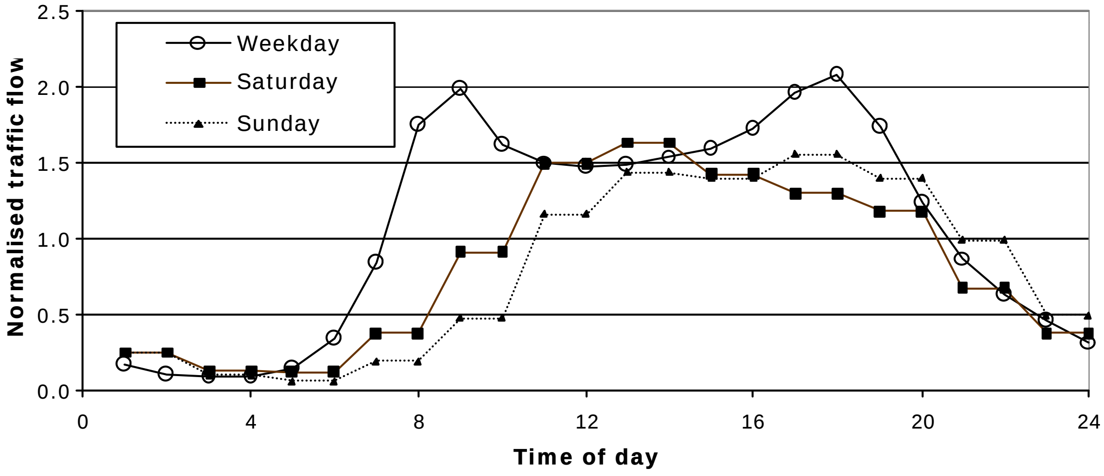
APPENDIX 4. DISPERSION KERNELS FOR AREA SOURCE MODEL

Dispersion kernels for calculating the annual mean contribution of emissions from area sources to ambient annual mean concentrations were calculating using ADMS. Separate kernels were calculated for traffic and other area sources (which were assumed to have a constant temporal profile of emissions). Kernels were generated for all years 1993 to 2002 using sequential meteorological data from Heathrow. A single 10-year average kernel was then calculated as the average of the kernels calculated for each year. The dispersion parameters used to calculate the kernels are listed in Table A4.1. The emission profile used to represent traffic emissions for the traffic kernels is shown in Figure A4.1. This was obtained from a distribution of all traffic in the United Kingdom by time of day (Road Traffic Statistics, 1999, Department of Transport).

Table A4.1 Dispersion parameters used to calculate area source kernels

	Traffic kernel	Constant kernel
Surface roughness	1 m	1 m
Emission factors	Varying (see below)	Constant
Height of well mixed source	10 m	30 m
Hourly sequential meteorological data	Yes	Yes
Monin-Obukhov height	30 m	30 m
Emission from each volume source	1 g s^{-1}	1 g s^{-1}
Number of receptor grids (model extent):		
1 km area source model	31 (31 km)	31 (31 km)
3 km area source model	11 (33 km)	11 (33 km)
5 km area source model	7 (35 km)	7 (35 km)

Figure A4.1 Temporal profile of traffic emisisons



Dispersion kernels were calculated at spatial resolutions of 1 km x 1 km, 3 x 3 km and 5 km x 5 km, representing the size of emission and receptor squares modelled. Previous modelling studies (Stedman et al, 2002) used kernels at a resolution of 5 km x 5 km for NO_x and PM_{10}. A comparison of the fit between modelled and measured concentrations of NO_x for the three different kernel resolutions showed that the 3 km x 3 km kernels provided the most robust calibration plots for the area source model. These kernels were therefore used for NO_x and PM_{10}. 1 km x 1 km kernels were used for SO_2.

Appendices

CONTENTS

Appendix 1
Title

CONTENTS

Appendix 2
Title

CONTENTS

Appendix 3
Title

CONTENTS