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UK air quality modelling for annual reporting 2005 on ambient air quality assessment under Council Directives 96/62/EC, 1999/30/EC and 2000/69/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. Directive 2000/69/EC (the second Daughter Directive) set limits to be achieved for benzene and carbon monoxide. Directive 2002/3/EC (the third Daughter Directive) sets targets and long-term objectives to be achieved for ozone.

2005 is the fifth year for which an annual air quality assessment for the first Daughter Directive pollutants is required and the third year for which an annual air quality assessment has been undertaken for the second Daughter Directive pollutants. 2005 is the second year for which an annual air quality assessment has been undertaken for the third Daughter Directive. 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 Directives. Air quality modelling has been carried out to supplement the information available from the UK national air quality monitoring networks.

The accompanying technical report (Bush *et al.*, 2007) contains a summary of key results from the questionnaire for ozone (covered by the third Daughter Directive) and additional technical information on the modelling methods that have been used to assess ozone concentrations throughout the UK.

This report provides a summary of key results from the questionnaire for pollutants included in the first and second Daughter Directives and additional technical information on the modelling methods that have been used to assess SO_2, NO_2 and NO_x, PM_{10}, benzene and CO 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 comparisons with limit values.

Maps of background concentrations of SO_2, NO_2, PM_{10}, benzene and CO in 2005 on a 1km x 1km grid have been prepared. Maps of roadside concentrations of NO_2, PM_{10}, benzene and CO have been prepared for a total of 9967 urban major road links (A-roads and motorways) across the UK.

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, PM_{10}, benzene and CO there are also important contributions to ambient concentrations from area sources, particularly traffic; therefore a slightly different modelling approach has been adopted. The area source contribution has been modelled using a kernel-based area source model, which has been calibrated empirically using measurement data. Roadside concentrations of NO_2, NO_x, PM_{10}, benzene and CO have been estimated by adding a roadside increment to the modelled background concentrations. This roadside increment has been calculated using road link emission estimates and dispersion coefficients derived empirically from roadside monitoring data.

The UK has been divided into 43 zones for air quality assessment. There are 28 agglomeration zones (large urban areas) and 15 non-agglomeration zones. The status of the zones in relation to the limit values for all of the first and second 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 E2 contains details of exceedences of old directives.

Table E1. Summary results of air quality assessment for 2005.

Pollutant	Averaging time	Number of zones exceeding limit value + margin of tolerance	Number of zones exceeding limit value[1]
SO_2	1-hour[3]	n/a	1 zone modelled (Eastern)
SO_2	24-hour[2]	n/a	1 zone modelled (Eastern)
SO_2	annual[3]	n/a	none
SO_2	winter[3]	n/a	none
NO_2	1-hour[4]	1 zone measured (Greater London Urban Area)	2 zones measured (London, Bristol)
NO_2	annual	35 zones (6 measured + 29 modelled)	38 zones (8 measured + 30 modelled)
NO_x	annual[3]	n/a	none
PM_{10}	24-hour (Stage 1)[3]	n/a	29 zones (3 measured + 26 modelled)
PM_{10}	annual (Stage 1)[3]	n/a	4 zones (1 measured + 3 modelled)
PM_{10}	24-hour (Stage 2)[5]	n/a	13 zones (13 measured)
PM_{10}	annual (Stage 2)[6]	32 zones (3 measured + 29 modelled)	40 zones (26 measured + 14 modelled)
Lead	annual[3]	n/a	none
Benzene	annual	None	2 zones modelled (Yorkshire & Humberside, Central Scotland)
CO	8-hour[3]	n/a	none

[1] Includes zones exceeding LV + MOT
[2] No MOT defined, LV + MOT = LV
[3] No MOT. LVs are already in force in 2005
[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

Table E2. Exceedences of old Directives

Pollutant	Directive	Averaging time	Concentration (μg m-3)
NO_2	85/203/EEC	1-hour 98%ile	256 (measured at London Marylebone Road)

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Appendices

1 Introduction

1.1 The Framework and first and second Daughter Directives

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 in ambient air. Directive 1999/30/EC (the first Daughter Directive, AQDD1) sets the limit values to be achieved for sulphur dioxide, nitrogen dioxide and oxides of nitrogen, particles and lead. Directive 2000/69/EC (the second Daughter Directive, AQDD2) sets out the limit values to be achieved for benzene and carbon monoxide. Directive 2002/3/EC (the third Daughter Directive, AQDD3) sets target values and long-term objectives to be achieved for ozone.

The Framework Directive includes a requirement for Member States to undertake preliminary assessments of ambient air quality, prior to the implementation of the Daughter Directives under Article 5 this Directive. 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 within the Framework Directive. Reports describing the preliminary assessment for the UK for AQDD1 and AQDD2 have been prepared (Bush 2000 and 2002). AQDD1 and AQDD2 define 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 subsequent Daughter Directives.

1.2 This report

The first and second Daughter Directives make provision for an annual air quality assessment for SO_2, NO_x, NO_2, PM_{10}, benzene and CO. A questionnaire has been completed for submission to the EU containing the results of this air quality assessment. A copy of the completed questionnaire can be found on the Central Data Repository of the European Environment Agency (CDR, 2006, http://cdr.eionet.europa.eu/gb/eu/annualair). The assessment takes the form of comparisons of measured and modelled air pollutant concentrations with the limit values set out in the Directives. This report provides a summary of key results from the questionnaire for SO_2, NO_x, NO_2, PM_{10}, benzene and CO and additional information on the modelling methods that have been used to assess concentrations throughout the UK.

The third Daughter Directive includes a requirement for an annual air quality assessment for ozone. The ozone air quality assessment is covered in a separate technical report (Bush *et al.*, 2007).

Sections 2 to 6 describe the modelling methods used for estimation of SO_2, NO_2, PM_{10}, benzene and CO. These include:

- Details of the 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 the AQDD1 and AQDD2 pollutants have been listed and reported to the EU in the questionnaire (CDR, 2006) and copies of these lists are included in Section 7. The status has been determined from a combination of monitoring data and model results. Section 7 also includes a comparison of the results of similar assessments carried out for the calendar years 2004, 2003, 2002 and 2001 (Stedman *et al.*, 2006a; Stedman *et al.*, 2005; Stedman *et al.*, 2003; Stedman *et al.*, 2002).

1.3 Preliminary assessments and definition of zones

The preliminary assessment carried out for AQDD1 (Bush, 2000) defined a set of zones to be used for air quality assessment in the UK. Table 1.1 contains details of area, population (from 2001 census) and urban road length contained in each zone and agglomeration. The zones and agglomerations map for the UK is presented in Figure 1.1.

Figure 1.1. UK zones and agglomerations for 2005
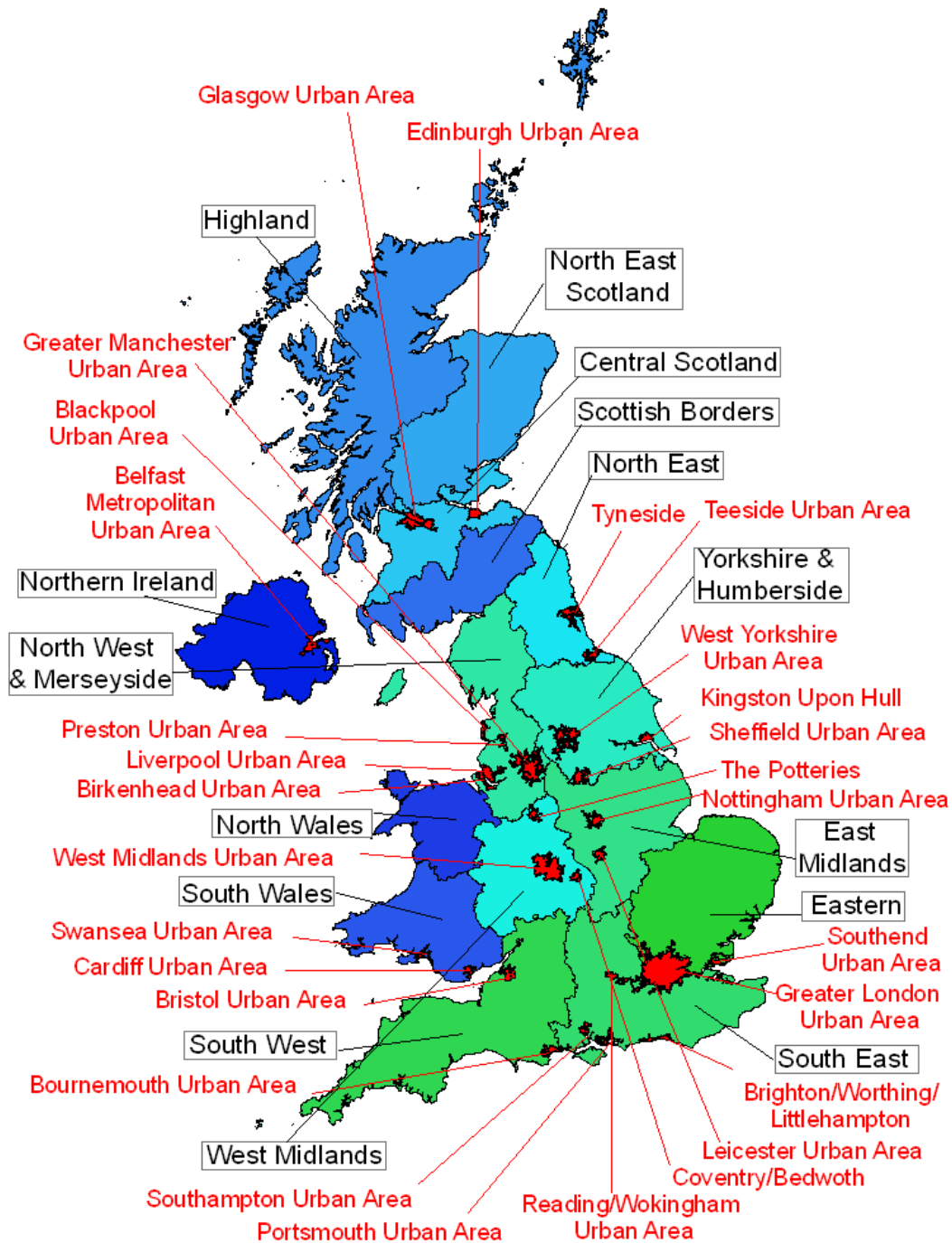
Agglomeration zones (red)
Non-agglomeration zones (blue/green)

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Table 1.1 Zones for AQDD1 reporting

Zone	Zone code	Ag or nonag*	Population	Area (km^2)	Number of urban road links	Length of urban road links (km)
Greater London Urban Area	UK0001	ag	8278251	1628	2021	1891.3
West Midlands Urban Area	UK0002	ag	2284093	594	408	560.8
Greater Manchester Urban Area	UK0003	ag	2244931	557	569	663.7
West Yorkshire Urban Area	UK0004	ag	1499465	363	289	425.1
Tyneside	UK0005	ag	879996	217	181	210.0
Liverpool Urban Area	UK0006	ag	816216	184	280	224.2
Sheffield Urban Area	UK0007	ag	640720	165	113	161.1
Nottingham Urban Area	UK0008	ag	666358	169	131	136.3
Bristol Urban Area	UK0009	ag	551066	142	122	118.7
Brighton/Worthing/Littlehampton	UK0010	ag	461181	97	54	84.3
Leicester Urban Area	UK0011	ag	441213	102	71	92.8
Portsmouth Urban Area	UK0012	ag	442252	91	54	72.6
Teesside Urban Area	UK0013	ag	365323	111	59	74.2
The Potteries	UK0014	ag	362403	91	113	130.0
Bournemouth Urban Area	UK0015	ag	383713	113	54	71.3
Reading/Wokingham Urban Area	UK0016	ag	369804	97	70	84.4
Coventry/Bedworth	UK0017	ag	336452	76	31	34.9
Kingston upon Hull	UK0018	ag	301416	80	34	43.6
Southampton Urban Area	UK0019	ag	304400	77	57	65.2
Birkenhead Urban Area	UK0020	ag	319675	88	69	69.3
Southend Urban Area	UK0021	ag	269415	64	33	49.8
Blackpool Urban Area	UK0022	ag	261088	63	49	65.7
Preston Urban Area	UK0023	ag	264601	58	35	45.8
Glasgow Urban Area	UK0024	ag	1168270	366	190	301.6
Edinburgh Urban Area	UK0025	ag	452194	117	61	103.2
Cardiff Urban Area	UK0026	ag	327706	72	42	53.1
Swansea Urban Area	UK0027	ag	270506	84	30	68.4
Belfast Metropolitan Urban Area	UK0028	ag	580276	193	30	200.8
Eastern	UK0029	nonag	4850132	19113	629	886.8
South West	UK0030	nonag	3980991	23506	478	682.8
South East	UK0031	nonag	6016677	18645	884	1350.2
East Midlands	UK0032	nonag	3084598	15491	429	673.0
North West & Merseyside	UK0033	nonag	2826622	13149	580	988.8
Yorkshire & Humberside	UK0034	nonag	2514947	14787	357	772.7
West Midlands	UK0035	nonag	2271650	12192	368	547.5
North East	UK0036	nonag	1269803	8282	216	283.6
Central Scotland	UK0037	nonag	1813314	9305	226	355.4
North East Scotland	UK0038	nonag	1001499	18587	137	233.5
Highland	UK0039	nonag	380062	38269	11	34.5
Scottish Borders	UK0040	nonag	254690	11145	38	59.9
South Wales	UK0041	nonag	1578773	12221	212	366.4
North Wales	UK0042	nonag	720022	8368	91	160.6
Northern Ireland	UK0043	nonag	1104991	13579	61	335.4
Total			59211755	242698	9967	13833.0

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

1.4 Monitoring sites

The monitoring stations operating during 2005 for the purpose of AQDD1 and AQDD2 are listed in Form 3 of the questionnaire which can be found at on the CDR (2006). Not all sites had sufficient data capture during 2005 for data to be reported. The data quality objective (DQO) for AQDD1 and AQDD2 measurements is 90% data capture. We have, however, 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 2005 for reporting purposes. Data capture statistics for sites operational during 2005 are presented in Form 1 of the reporting questionnaire.

1.5 Limit Values and Margins of Tolerance

The limit values (LV) and limit values + margins of tolerance (LV + MOT) included in AQDD1 and AQDD2 are listed in Tables 1.2 to 1.7. 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 Directives came into force until the date by which the limit value is to be met. Values for 2005 are listed in Tables 1.2 to 1.7. 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. There is no applicable margin of tolerance for the hourly or 24-hourly SO_2 metric, the PM_{10} (Stage 1) 24-hour or annual metrics, the lead annual mean metric or the maximum daily 8-hour CO metric because these limit values all came into force in 2005. 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) also must be reported to the EU and trigger a requirement for the preparation of a 'plan and programme' for attaining the limit value within the specified time limit specified by the relevant Directive and a report to the EU on this 'plan and programme'.

Table 1.2. Limit values for SO_2

	Averaging period	LV	LV + MOT 2005	Date by which LV is to be met
1. Hourly LV for the protection of human health	1 hour	350 $\mu g\ m^{-3}$, not to be exceeded more than 24 times a calendar year	N/A	1 January 2005
2. Daily LV for the protection of human health	24 hour	125 $\mu g\ m^{-3}$, not to be exceeded more than 3 times a calendar year	N/A	1 January 2005
3. LV for the protection of ecosystems	Calendar year and winter	20 $\mu g\ m^{-3}$	N/A	19 July 2001

Table 1.3. Limit values for NO_2 and NO_x

	Averaging period	LV	LV + MOT 2005	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	250 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	50 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	N/A	19 July 2001

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

	Averaging period	LV	LV + MOT 2005	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	N/A	1 January 2005
2. Annual LV for the protection of human health	Calendar year	40 μg m^{-3}	N/A	1 January 2005

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

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

Table 1.6. Limit values for benzene

	Averaging period	LV	LV + MOT 2005	Date by which LV is to be met
Annual LV for the protection of human health	Calendar year	5 μg m^{-3}	10 μg m^{-3}	1 January 2010

Table 1.7. Limit values for CO

	Averaging period	LV	LV + MOT 2005	Date by which LV is to be met
8-hour LV for the protection of human health	Maximum daily 8-hour mean	10 mg m^{-3}	N/A	1 January 2005

1.6 Data quality objectives for modelling results and model verification

AQDD1 sets data quality objectives (DQOs) in terms of accuracy, which act as a guide for quality assurance programmes when identifying an acceptable level of accuracy for assessment methods appropriate for supplementary assessment under the first Daughter Directive. Accuracy is defined in the Directives 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.

DQOs have been set at 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 DQO for annual averages is 50%. DQOs have not been defined for daily averages of PM_{10} at present. The second Daughter Directive sets the DQOs applicable to assessment methods for annual average benzene and 8-hour average CO concentrations at 50%.

The empirical models used to calculate the maps of air pollutants presented in this report have been calibrated using the national network monitoring data, for sites listed in Form 3 of the reporting questionnaire. Data from these sites alone cannot, therefore, be used to assess the reliability of the mapped estimates in relation to the DQOs for modelling. Measurement data from sites not included in the calibration are required to make this assessment. Data from sites quality assured by AEA Energy & Environment under contract and not part of the national network, including Local Authority sites in the AEA Energy & Environment 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, as only a subset of these sites, quality assured under contract by AEA Energy & Environment, are formally members of the Calibration Club. The monitoring sites used for this comparison are listed in Appendix 1. Sites with a data capture of at least 75% have been included in the verification analysis. This is the same data capture threshold as that 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 implemented are given in the following sections. A brief introduction is presented here. Maps of background concentrations of SO_2, NO_2, PM_{10}, benzene and CO have been prepared on a 1km x 1km grid for the 2005 calendar year. Emissions estimates used in calculating pollutant concentrations have been taken from the National Atmospheric Emissions Inventory (Dore *et al.*, 2006). Maps of roadside concentrations of NO_2, PM_{10} and benzene and CO have also been prepared for 9,967 urban major road links (A-roads and motorways).

The dominant contributions to ambient 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, whereas area sources have been modelled using a dispersion kernel approach. 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, PM_{10}, benzene and CO there are also important contributions 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 for all these pollutants. For benzene contributions from large combustion sources have been modelled explicitly. Contributions from other point source have been modelled using a volume source dispersion kernel approach in order to represent the process and fugitive emission release characteristics of these sources. Rural network measurements have been used to define regional concentrations of NO_2, NO_x and secondary PM_{10}. Regional benzene concentrations have been estimated from rural NO_2 concentrations. The area source contribution to ambient NO_x, PM_{10}, benzene and CO concentrations has been modelled using a dispersion kernel approach. The coefficients calibrating these area source models have been determined empirically using measurement data from the national networks.

Roadside concentrations of NO_2, NO_x, PM_{10}, benzene and CO 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). Emission maps from the 2004 NAEI have been used for the modelling work described here. Emission estimates for area sources have been scaled to values appropriate to 2005, using UK sector total emissions from 2004 and 2005.

There were notable revisions to the methodology for the 2005 modelling for PM_{10} and NO_2. The sea salt component of particulate matter that the model adds to the area and point source modelled components is now derived from a sea salt map produced by the Met Office. Formerly this component was introduced into the model as a constant. The NO_2 modelling now includes a primary NO_2 emission fraction (f-NO_2) that is based on a specific primary NO_2 inventory that is linked to the proportion of traffic sources contributing. These developments are explained in detail in the following relevant sections.

2 SO$_2$

2.1 Introduction

Maps of annual mean, winter mean, 99.73 percentile of hourly mean SO$_2$ concentrations and 99.18 percentile of daily mean SO$_2$ concentrations have been calculated using methods based on those described by Abbott and Vincent (1999). The percentile concentrations presented here 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 (sources with emissions ≥500 tonnes per year) were modelled explicitly using the dispersion model ADMS 3.3 (CERC, 2005). Emissions from smaller point sources (< 500 tonnes) and area sources were modelled using 1km x 1km emission grids and a dispersion kernel approach, described more fully in Appendix 4. Emissions profiles and annual emissions for the power stations in England, Wales and Scotland were provided by either the Environment Agency or power generating companies. The emission profiles are derived using procedures agreed by the power generators and the Environment Agency. Emissions from power stations in Northern Ireland were modelled using emissions profiles typical of electricity generation in summer and winter. This information was provided from the National Grid Company and contained within the company's Seven Year Statement.

Emissions from non-power station point sources for 2005 were based upon data obtained from the Environment Agency for the modelling in 2004. Emission estimates for area sources have been scaled to values appropriate to 2005, using UK sector total emissions from 2004 and 2005.

A number of receptor areas were defined, which together covered the UK. The size of the receptor areas varied but were typically 150km x 150km, 150km x 100km or 100km x 100km. For larger point sources all sources within the receptor area and extending out to 100 km of square's border were assumed to influence concentrations within the receptor area. Within each receptor area concentrations were calculated on a regular 5km x 5km grid using ADMS 3.3 and sequential meteorological data for 2005 from Waddington in Lincolnshire. This site was chosen as most representative of meteorology in the vicinity of the largest concentration of major point sources in the UK. This approach 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 <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 3.3 and hourly sequential meteorological data for 2005 from Waddington.

The contributions to annual mean and high percentile concentrations from the different sources were then summed as described below. The map of winter mean SO$_2$ concentrations was derived from the annual mean map using a factor of 1.15, which is the ratio between the average concentration measured at rural SO$_2$ monitoring sites during the 2004-2005 winter period and annual concentration for during 2005, respectively.

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 (see Section 2.3).

2.2 Maps of winter and annual mean concentrations

A map of annual mean SO$_2$ concentration for 2005 in ecosystem areas is shown in Figure 2.1. This map has been calculated by removing non-ecosystem areas from the background SO$_2$ map and calculating the zonal mean of the 1km^2 grid squares for a 30km^2 grid.

Mean concentrations on a 30km^2 grid have been used to prevent the influence of any urban area appearing unrealistically large on adjacent vegetation areas. Thus the modelled concentrations in

vegetation areas should be representative of approximately 1000km^2 as specified in Directive 1999/30/EC for monitoring sites used to assess concentrations for the vegetation limit value.

Figure 2.1. Annual mean SO$_2$ concentration, 2005 (μg m^{-3}) in ecosystem areas
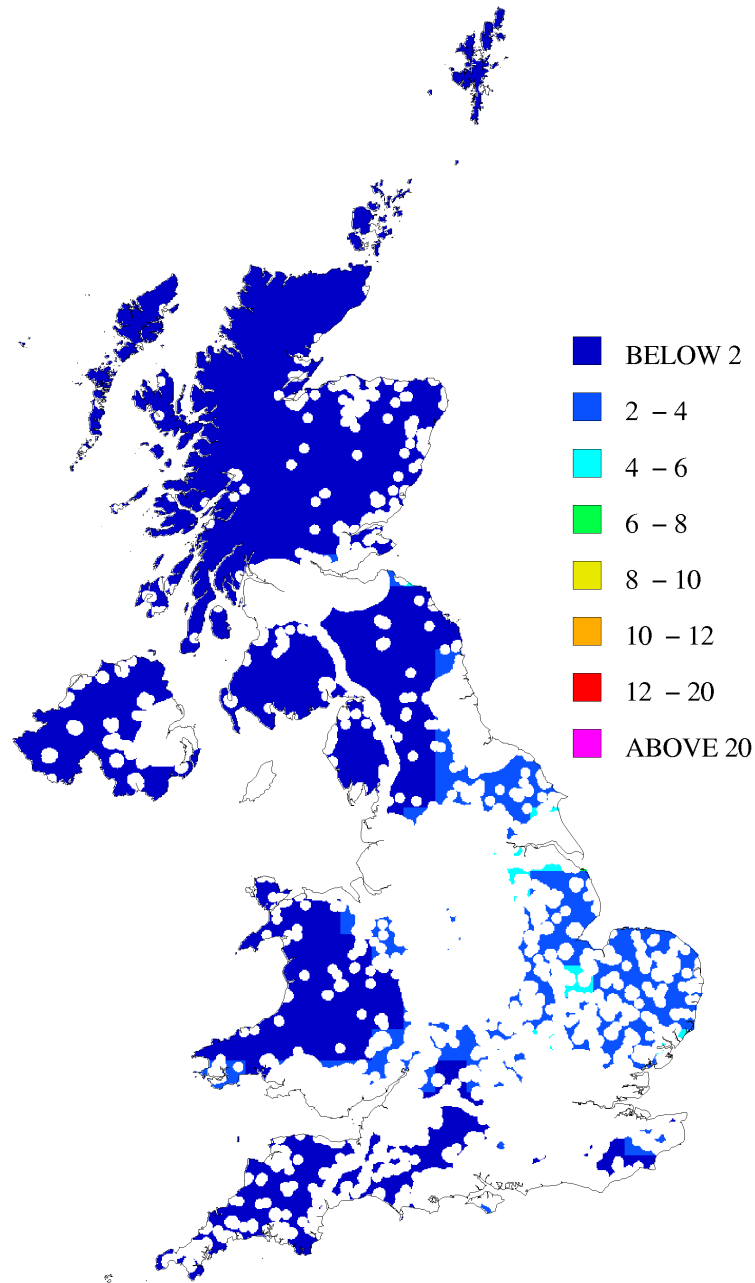
BELOW 2
2 – 4
4 – 6
6 – 8
8 – 10
10 – 12
12 – 20
ABOVE 20

The factors used to combine the point source and area source contributions are shown in Table 2.1. A residual concentration of 0.29 μg m^{-3} was added. This residual was derived by a linear least squares fit between the measured and modelled concentrations. The residual is associated with contributions from more distant sources, for example, from continental European sources that are not explicitly modelled.

Table 2.1 Coefficients for annual mean model

	Points coefficient	Area coefficient	Constant µg m^{-3}
Annual mean	1	1	0.29

Measured concentrations from Rural SO_2 Monitoring Network sites (Lawrence, *pers comm.* 2006), 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 check the method used to combine the modelled components. A list of the sites maintained by the electricity generating companies is included in Appendix 1. The comparison plot for 2005 is shown in Figure 2.2.

Figure 2.2. Comparison plot for 2005 annual mean SO_2 concentration
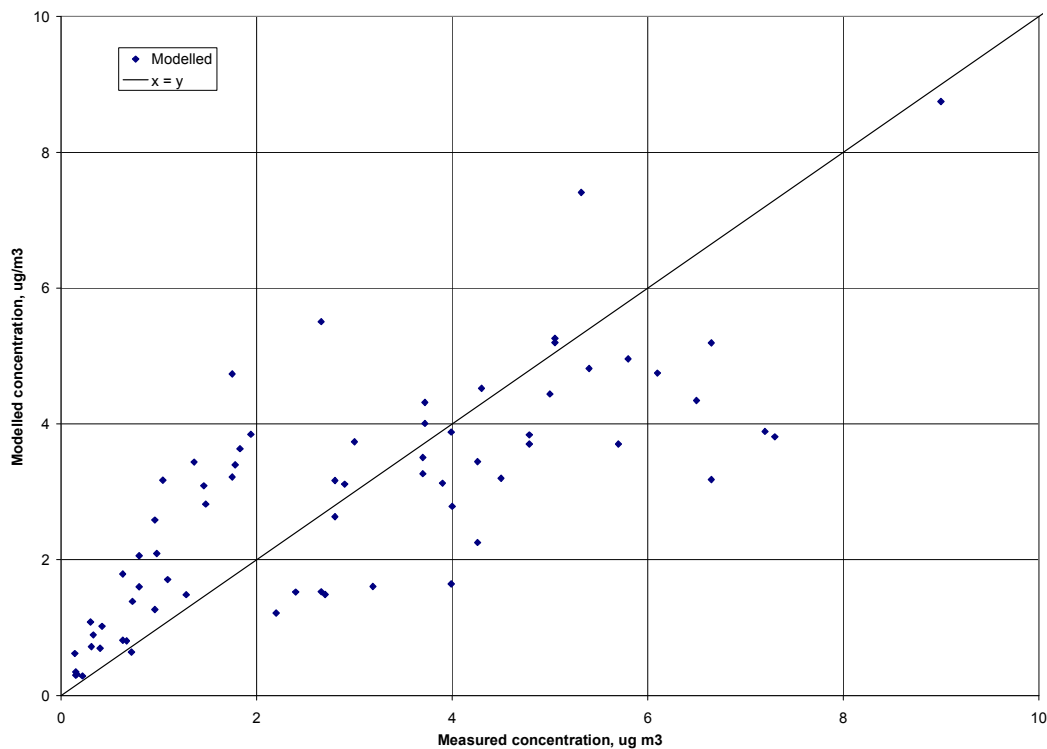
A map of winter mean SO_2 concentrations for the period October 2004 to March 2005 has also been calculated and is shown in Figure 2.3. This map was calculated by multiplying the annual mean map for 2005 by 1.15, which is the ratio between the average concentration measured at rural SO_2 monitoring sites during the 2004-2005 winter period and annual concentration for during 2005).

Figure 2.3. Winter mean SO$_2$ concentration, 2004-2005 (μg m^{-3}) in ecosystem areas
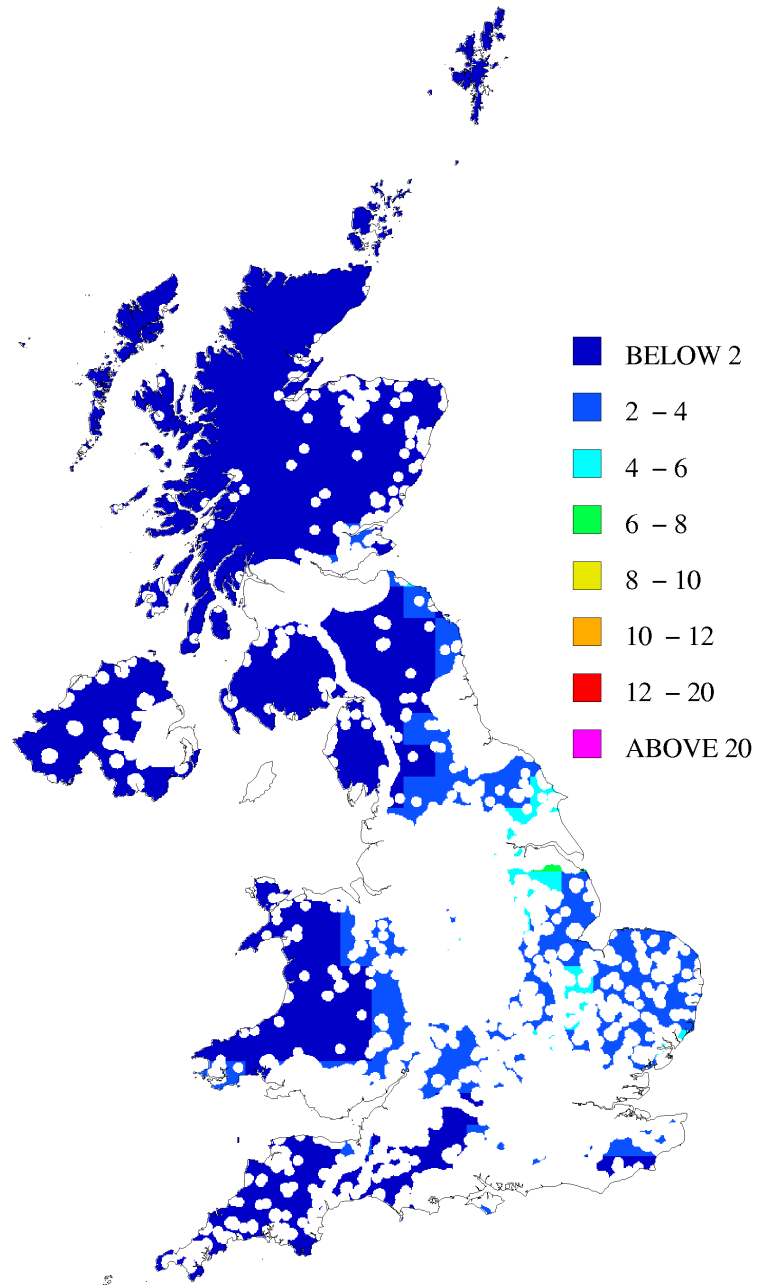
Legend:
- BELOW 2
- 2 – 4
- 4 – 6
- 6 – 8
- 8 – 10
- 10 – 12
- 12 – 20
- ABOVE 20

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 2005 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, 2005 ($\mu g\ m^{-3}$)
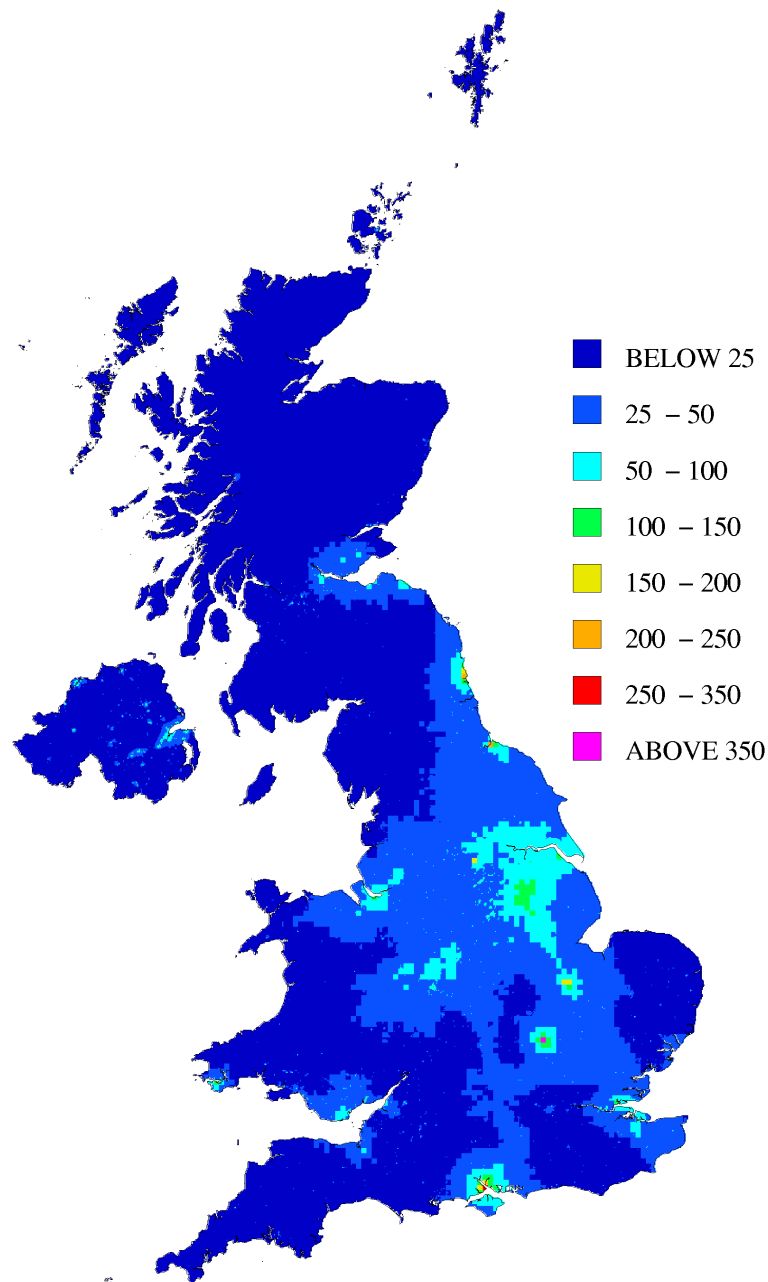
Figure 2.5. 99.18 percentile of 24-hour mean SO$_2$ concentration, 2005 (µg m^{-3})
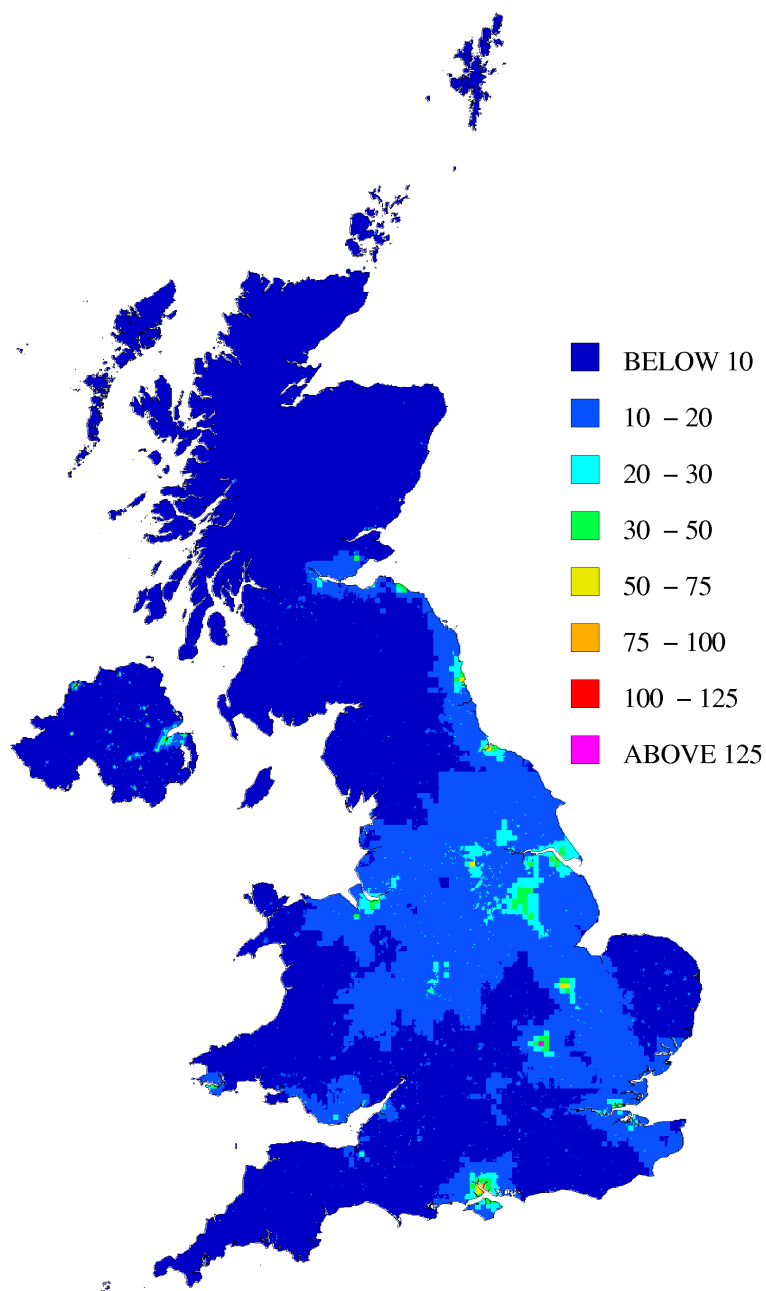
Legend:
- BELOW 10
- 10 – 20
- 20 – 30
- 30 – 50
- 50 – 75
- 75 – 100
- 100 – 125
- ABOVE 125

The methodology to produce the maps has been updated to include research on combining concentrations arising from area and industrial sources undertaken for the Environment Agency (Abbott and Vincent, 2006). This new methodology aims to derive a better estimate of the percentile concentrations at locations distant from the industrial sources. A weighted regression analysis was carried out assuming that the variance of the residuals was proportional to the modelled concentration. The regression model was of the form:

$$c_{measured} = \max \begin{bmatrix} Ac_{\text{mod}elled\_industrial,\%ile} + 2(c_{\text{mod}elled\_area} + c_{long\_range})_{annual} \\ 2Ac_{\text{mod}elled\_industrial,annual} + k(c_{\text{mod}elled\_area} + c_{long\_range})_{annual} \end{bmatrix}$$

The constant A was obtained from the regression analysis. The background multiplier factor, k, was derived from monitoring data. The factor "2", used to scale the $(c_{modelled\_area} + c_{long\_range})_{annual}$ and $c_{modelled\_industrial,annual}$ components, has been shown to be a robust factor that allows short-term average concentrations to be estimated from modelled annual mean concentrations arising from non-industrial or industrial sources (Abbott, et al., 2005). Table 2.2 presents the A and k factors used in the derivation of the maps.

Table 2.2 Factors for percentile models

Metric	Constant A	Background multiplier factor, k
99.18 percentile of 24-hour values	1.23	3.3
99.73 percentile of 1-hour values	1.09	10.1

The justification for treating industrial sources and area emissions seperately is because peaks in high percentile modelled contributions may not coincide with peaks in high percentile background concentrations – a problem that is more pronounced in emissions from large industrial point sources because the meteorological conditions that give rise to high concentrations from tall stacks can be very different from those that produce high concentrations from emissions at low level.

Figures 2.6 and 2.7 provide an intermediate quality check at rural and suburban sites which form part of the National Network and at sampling sites operated by the electricity supply companies.

Figure 2.6. Comparison plot for 2005 99.73 percentile of 1-hour mean SO$_2$ concentrations
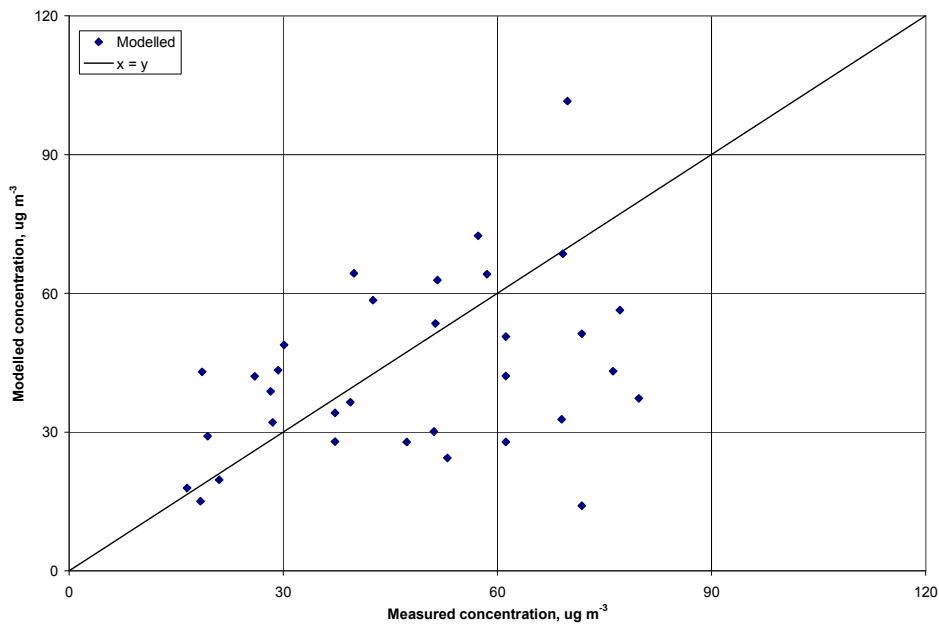
Figure 2.7. Comparison plot for 2005 99.18 percentile of 24-hour mean SO$_2$ concentrations
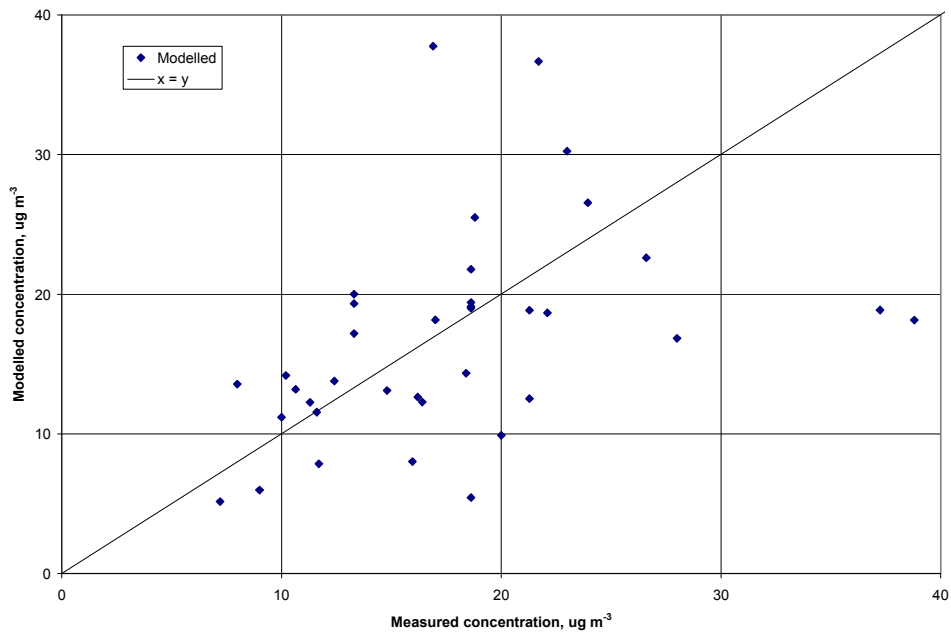
An alternative method was used to derive the high percentile concentrations in Northern Ireland. This was required because area sources, predominately emissions from domestic coal fires, make a more significant contribution to observed high percentile concentrations in Northern Ireland than in the rest of the United Kingdom. Additionally, the smaller number of point sources in Northern Ireland means that these sources make a much smaller contribution to the observed high percentile concentrations.

Maps of high percentile concentrations in Northern Ireland have been calculated from the mapped annual mean SO$_2$ concentrations using a linear least squares fit between measured annual mean and measured high percentile concentrations in Northern Ireland during 2005 at national network and AEA Energy & Environment Calibration Club monitoring sites. Figures 2.8a and 2.8b show the relationship between the annual mean and the 99.73 percentile of hourly mean values and the 99.18 percentile of daily mean values at the sampling sites in Northern Ireland.

The equations used to derive the high percentile maps are:

Predicted 99.73 %ile in Northern Ireland = 7.14 $\times$ *Modelled Annual Mean* + 11.48

Predicted 99.18 %ile in Northern Ireland = 4.01 $\times$ *Modelled Annual Mean* + 2.29

Figure 2.8a: Relationship between mean concentration and 99.73 percentile of hourly concentrations at sampling sites in Northern Ireland
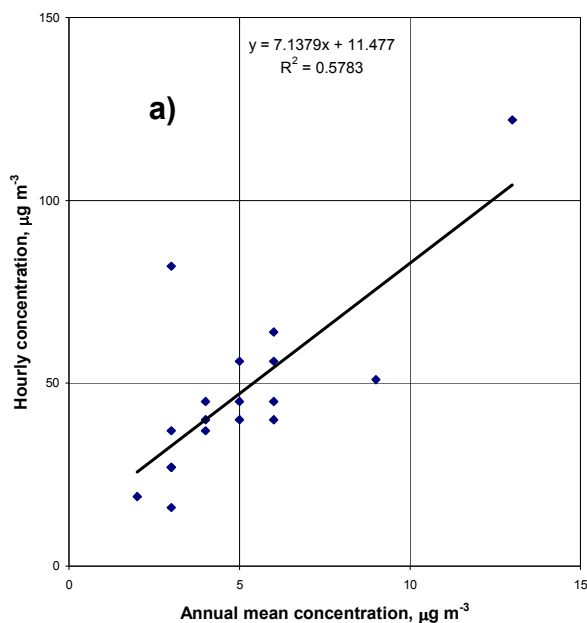
Figure 2.8b: Relationship between mean concentration and 99.18 percentile of daily concentrations at sampling sites in Northern Ireland

$y = 7.1379x + 11.477$
$R^2 = 0.5783$

a)

$y = 4.0086x + 2.2902$
$R^2 = 0.7474$

b)
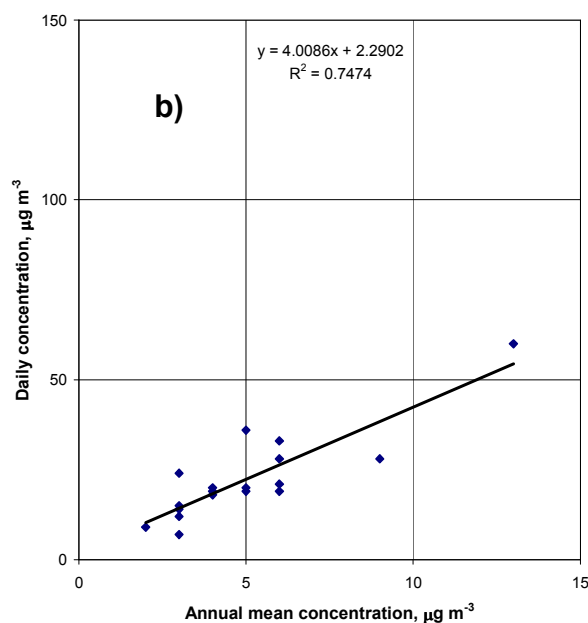
2.4 Verification of mapped values

Figures 2.9, 2.10 and 2.11 show comparisons of modelled and measured annual mean, 99.73 percentile of 1-hour means and 99.18 percentile of 24-hour means SO_2 concentrations in 2005 at monitoring site locations in the UK. Both the national network sites and the verification sites are shown. The 'quality check' sites include the electricity generating company sites and selected AURN sites. Urban background, centre and roadside AURN sites not used in the calibration process are also presented along with 'verification sites' that include ad-hoc monitoring sites and AEA Energy & Environment's Calibration Club monitoring sites. A complete list of the AURN sites used is presented in Form 3 of the reporting questionnaire. Details of verification sites are presented in Table A1.1 of Appendix 1 and the sites maintained by the electricity generating companies are listed in Table A1.2. 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 SO₂ model 2005
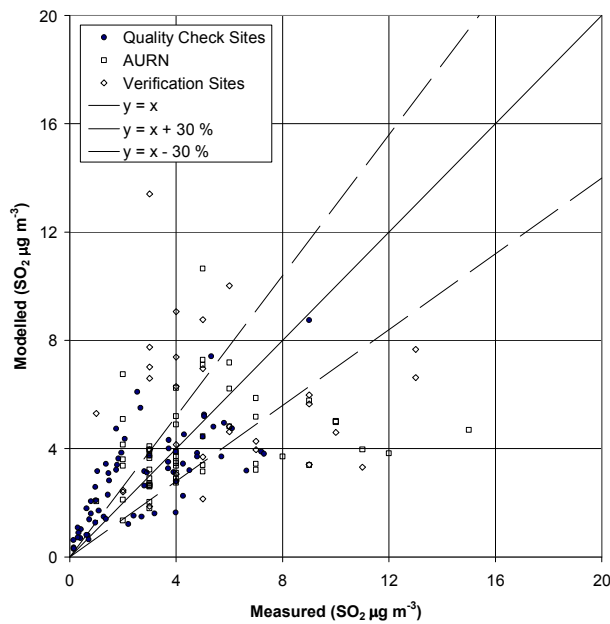
Figure 2.10. Verification of 99.73 percentile of 1-hour mean SO₂ model 2005
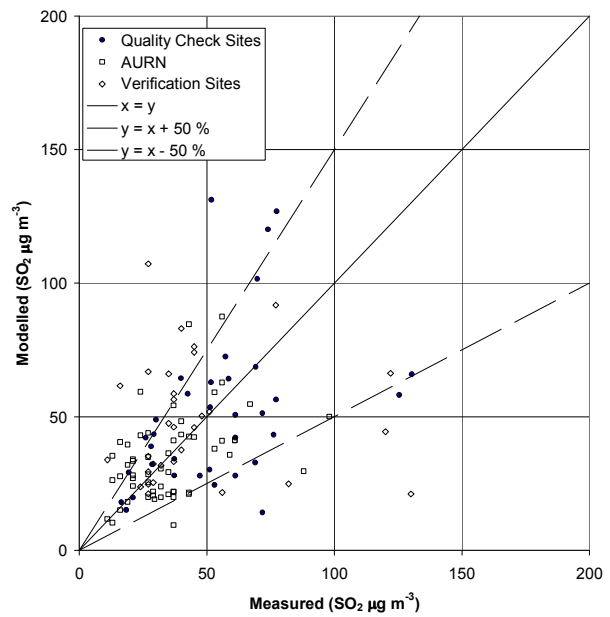
Figure 2.11. Verification of 99.18 percentile of 24-hour mean SO₂ model 2005
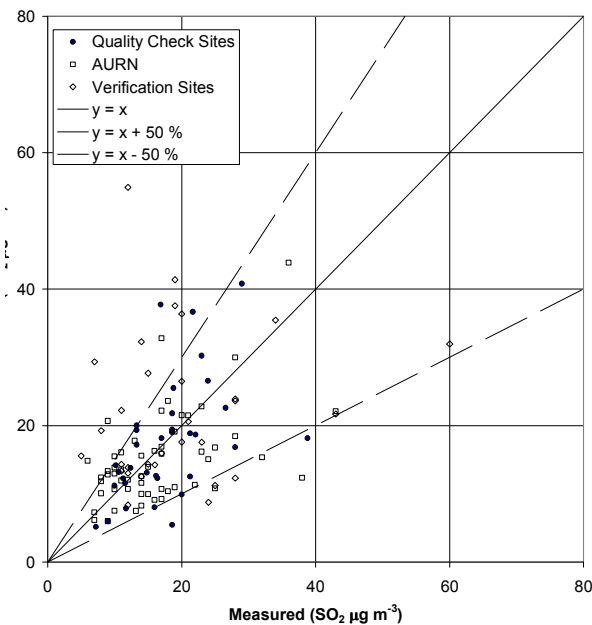
Summary statistics for modelled and measured SO₂ concentrations and the percentage of sites for which the modelled values are outside the data quality objectives (DQOs) and the total number of sites included in the analysis are listed in Tables 2.3, 2.4 and 2.5.

The mean measured and modelled concentrations for the each averaging time agrees reasonably well. For example, the annual mean measured concentration at the national network sites was 3.40 µg m⁻³, whereas, the annual modelled concentration was 3.25 µg m⁻³. However the agreement

between measured and modelled concentrations on a site-by-site basis (quantified using R^2) was poor for all averaging times for those sites in the national network and very poor at the verification sites. Note that the annual mean map is not compared directly with the annual mean limit value, the zonal mean of the $1km^2$ grid squares in ecosystem areas has been calculated for a $30km^2$ grid, as discussed above.

Reasons for this include:

- Emissions from large industrial emission sources are decreasing. This will result in an increase in the relative contribution from other sources. The emission characteristics of these sources are less well known;

- The receptor grid used in the model predictions (concentrations are predicted at 5 km intervals) may be too coarse for the smaller emission sources;

- The modelling method does not explicitly model concentrations arising from non-UK sources.

Methods to improve the prediction would include:

- Improve emission characteristics for smaller emission sources;

- Increase the resolution of the receptor area (5 km to 1 km or 2 km);

- Consider using region specific meteorological data;

- Use a long-range transport model to predict sulphur dioxide concentrations from non-UK sources.

Table 2.3. 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	% of sites outside DQO of ±30%	Number of sites in assessment
National Network	3.40	3.25	0.33	62	100[a]
Verification Sites	5.58	5.49	0.0004	74	31

a. includes measurement data from sites in Defra's AURN and Rural Acid Rain Monitoring Network

Table 2.4 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	% of sites outside DQO of ±50%	Number of sites in assessment
National Network	36.26	32.39	0.24	31	65[b]
Verification Sites	45.87	48.04	0.002	45	31

b. includes measurement data from sites in Defra's AURN only

Table 2.5 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	% of sites outside DQO of ±50%	Number of sites in assessment
National Network	16.35	13.00	0.25	14	65[c]
Verification Sites	19.48	22.18	0.026	42	31

c. includes measurement data from sites in Defra's AURN only

2.5 Detailed comparison of modelling results with limit values

The modelling results, in terms of a comparison of modelled concentrations with the hourly and daily limit value for each zone, are summarised in Table 2.6. These data have also been presented in Form 19a of the questionnaire. The SO_2 annual and winter mean limit value for the protection of ecosystems was not exceeded in ecosystem areas in any of the non-agglomeration zones in 2005. This limit value does not apply in agglomeration zones, according to the definition in the Directive (see Section 1.3). Method A in Table 2.6 refers to the modelling method described in this report.

Table 2.6 Tabular results of and methods used for supplementary assessment (1999/30/EC Article 7(3) and Annex VIII(II), 2000/69/EC Article 5(3) and Annex VI(II) and 2002/3/EC Article 9(1) and Annex VII(II))

Zone	Zone code	Above LV for health (1hr mean)				Above LV for health (24hr mean)			
		Area		Population exposed		Area		Population exposed	
		km^2	Method	Number	Method	km^2	Method	Number	Method
Greater London Urban Area	UK0001	0	A	0	A	0	A	0	A
West Midlands Urban Area	UK0002	0	A	0	A	0	A	0	A
Greater Manchester Urban Area	UK0003	0	A	0	A	0	A	0	A
West Yorkshire Urban Area	UK0004	0	A	0	A	0	A	0	A
Tyneside	UK0005	0	A	0	A	0	A	0	A
Liverpool Urban Area	UK0006	0	A	0	A	0	A	0	A
Sheffield Urban Area	UK0007	0	A	0	A	0	A	0	A
Nottingham Urban Area	UK0008	0	A	0	A	0	A	0	A
Bristol Urban Area	UK0009	0	A	0	A	0	A	0	A
Brighton/Worthing/Littlehampton	UK0010	0	A	0	A	0	A	0	A
Leicester Urban Area	UK0011	0	A	0	A	0	A	0	A
Portsmouth Urban Area	UK0012	0	A	0	A	0	A	0	A
Teesside Urban Area	UK0013	0	A	0	A	0	A	0	A
The Potteries	UK0014	0	A	0	A	0	A	0	A
Bournemouth Urban Area	UK0015	0	A	0	A	0	A	0	A
Reading/Wokingham Urban Area	UK0016	0	A	0	A	0	A	0	A
Coventry/Bedworth	UK0017	0	A	0	A	0	A	0	A
Kingston upon Hull	UK0018	0	A	0	A	0	A	0	A
Southampton Urban Area	UK0019	0	A	0	A	0	A	0	A
Birkenhead Urban Area	UK0020	0	A	0	A	0	A	0	A
Southend Urban Area	UK0021	0	A	0	A	0	A	0	A
Blackpool Urban Area	UK0022	0	A	0	A	0	A	0	A
Preston Urban Area	UK0023	0	A	0	A	0	A	0	A
Glasgow Urban Area	UK0024	0	A	0	A	0	A	0	A
Edinburgh Urban Area	UK0025	0	A	0	A	0	A	0	A
Cardiff Urban Area	UK0026	0	A	0	A	0	A	0	A
Swansea Urban Area	UK0027	0	A	0	A	0	A	0	A
Belfast Urban Area	UK0028	0	A	0	A	0	A	0	A
Eastern	UK0029	25	A	3864	A	25	A	3864	A
South West	UK0030	0	A	0	A	0	A	0	A
South East	UK0031	0	A	0	A	0	A	0	A
East Midlands	UK0032	0	A	0	A	0	A	0	A
North West & Merseyside	UK0033	0	A	0	A	0	A	0	A
Yorkshire & Humberside	UK0034	0	A	0	A	0	A	0	A
West Midlands	UK0035	0	A	0	A	0	A	0	A

Zone	Zone code	Above LV for health (1hr mean)				Above LV for health (24hr mean)			
		Area		Population exposed		Area		Population exposed	
North East	UK0036	0	A	0	A	0	A	0	A
Central Scotland	UK0037	0	A	0	A	0	A	0	A
North East Scotland	UK0038	0	A	0	A	0	A	0	A
Highland	UK0039	0	A	0	A	0	A	0	A
Scottish Borders	UK0040	0	A	0	A	0	A	0	A
South Wales	UK0041	0	A	0	A	0	A	0	A
North Wales	UK0042	0	A	0	A	0	A	0	A
Northern Ireland	UK0043	0	A	0	A	0	A	0	A
Total		25		3864		25		3864	

3 NO$_2$/NO$_x$

3.1 Introduction

Annual mean concentrations of NO$_X$ and NO$_2$ have been modelled for the UK for 2005 at background and roadside locations. Maps of annual mean NO$_2$ concentrations for these locations in 2005 are presented in Figures 3.1 and 3.2. The modelling methods for NOx and NO$_2$ have been developed over a number of years (Stedman and Bush, 2000, Stedman *et al.*, 2001b, Stedman *et al.*, 2001c, Stedman *et al.*, 2002, Stedman *et al.*, 2003 Stedman *et al.*, 2005, Stedman *et al.*, 2006a).

Figure 3.1. Annual mean background NO$_2$ concentration, 2005 (μg m^{-3})
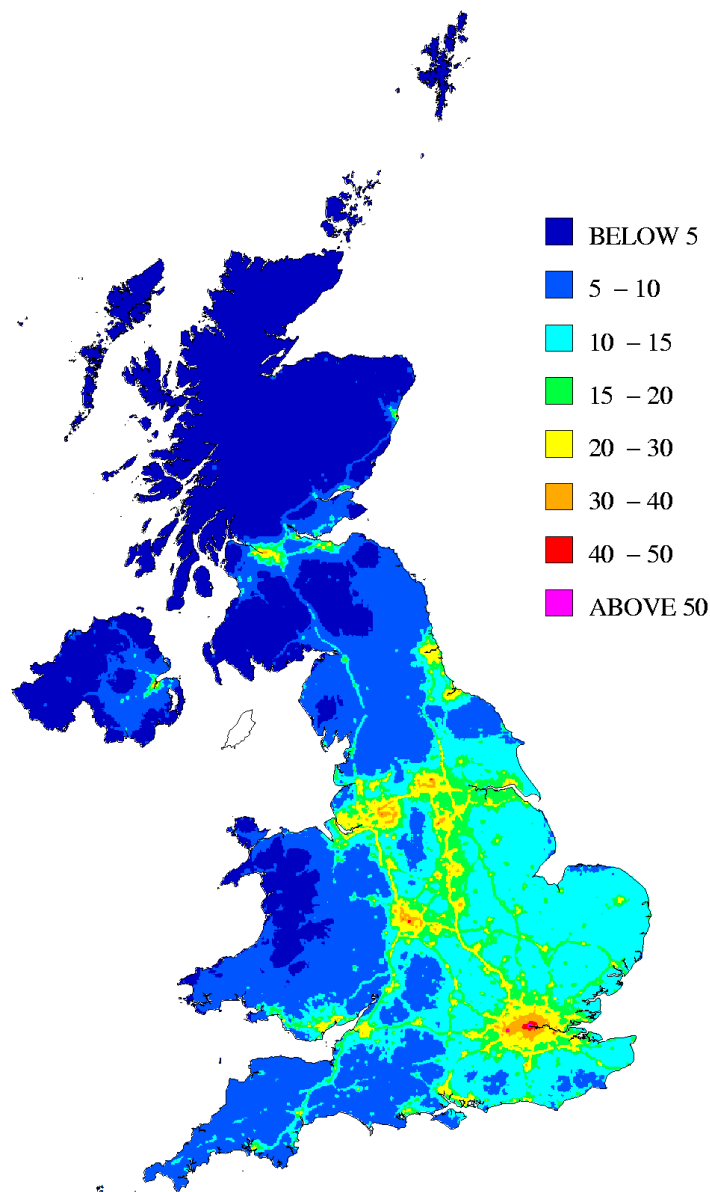
Figure 3.2. Urban major roads, annual mean roadside NO$_2$ concentration, 2005 (μg m^{-3})
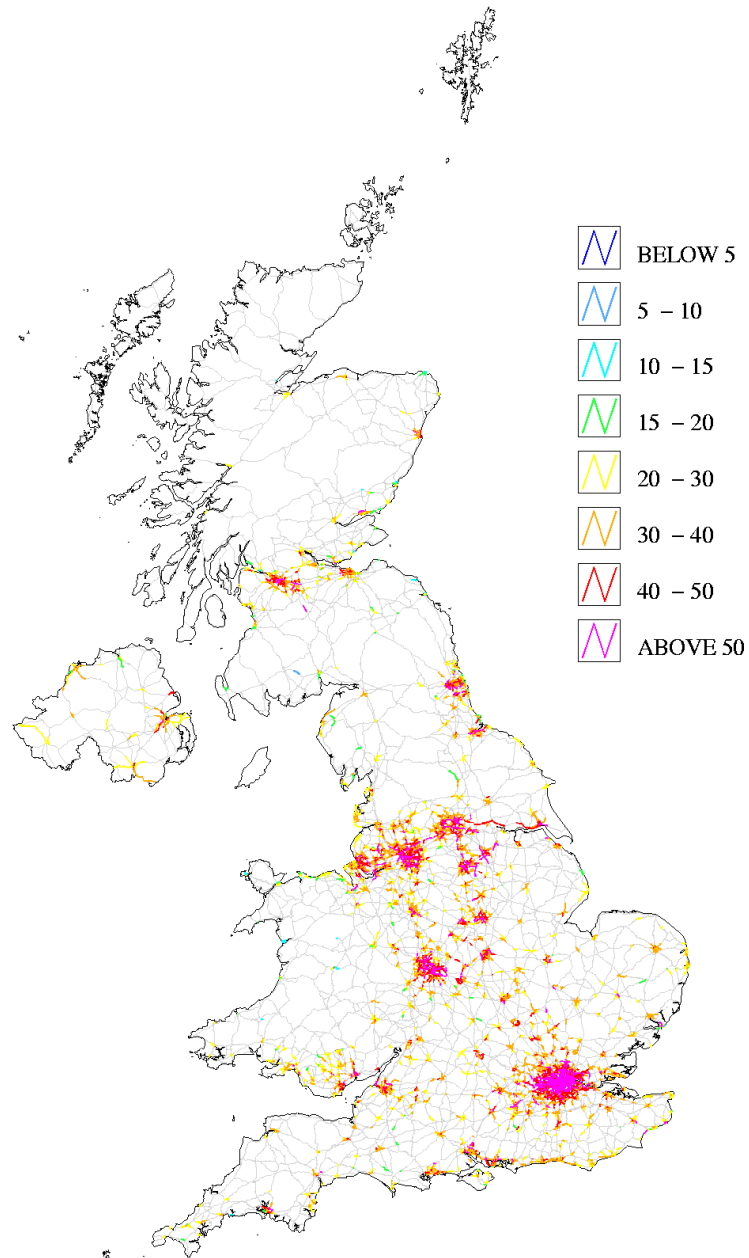
BELOW 5
5 – 10
10 – 15
15 – 20
20 – 30
30 – 40
40 – 50
ABOVE 50

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 values. No attempt has been made to model hourly concentrations for comparison with the 1-hour limit value. This is due to the considerable uncertainties involved in modelling at such a fine temporal scale. The annual mean limit value is expected to be more stringent than the 1-hour limit value in the majority of situations (AQEG, 2004) – this is illustrated in Figure 3.3 which is a scatter plot of the annual mean metric in 2005 against the 99.8[th] percentile hourly mean concentration. This plot shows a significantly higher number of sites exceeding the annual mean limit value of 40 μg m^{-3} than the 200 μg m^{-3} hourly limit value.

Figure 3.3. Plot of annual mean against 99.8th percentile hourly NO$_2$ concentrations in 2005
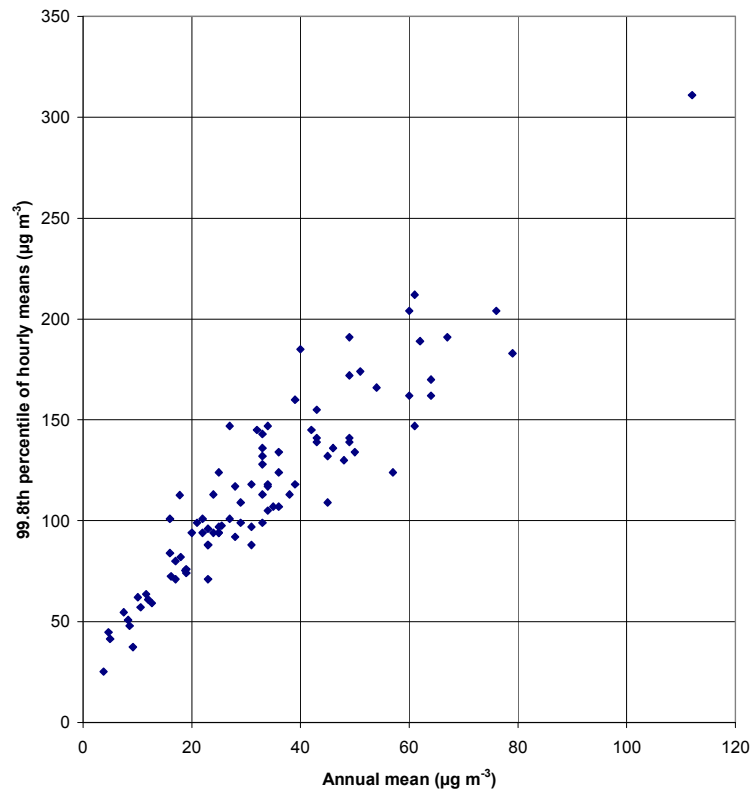
A map of NO$_x$ concentrations from all sources was calculated. This map was then used to calculate a map of NO$_2$ concentrations for comparison with the limit values for the protection of human health and a map of NO$_x$ concentrations in vegetation areas for comparison with the limit value for the protection of vegetation. The map of annual mean NO$_x$ concentrations in vegetation areas is presented in Figure 3.4. This map has been calculated by removing non-vegetation areas from the background NO$_x$ map and calculating the zonal mean of the 1km^2 grid squares for a 30km^2 grid. Mean concentrations on a 30km^2 grid have been used to prevent the influence of any urban area appearing unrealistically large on adjacent vegetation areas. Thus the modelled concentrations in vegetation areas should be representative of approximately 1000km^2 as specified in Directive 1999/30/EC for monitoring sites used to assess concentrations for the vegetation limit value.

Figure 3.4. Annual mean Rural NO$_x$ concentration, 2005 (µg m^{-3}, as NO$_2$)
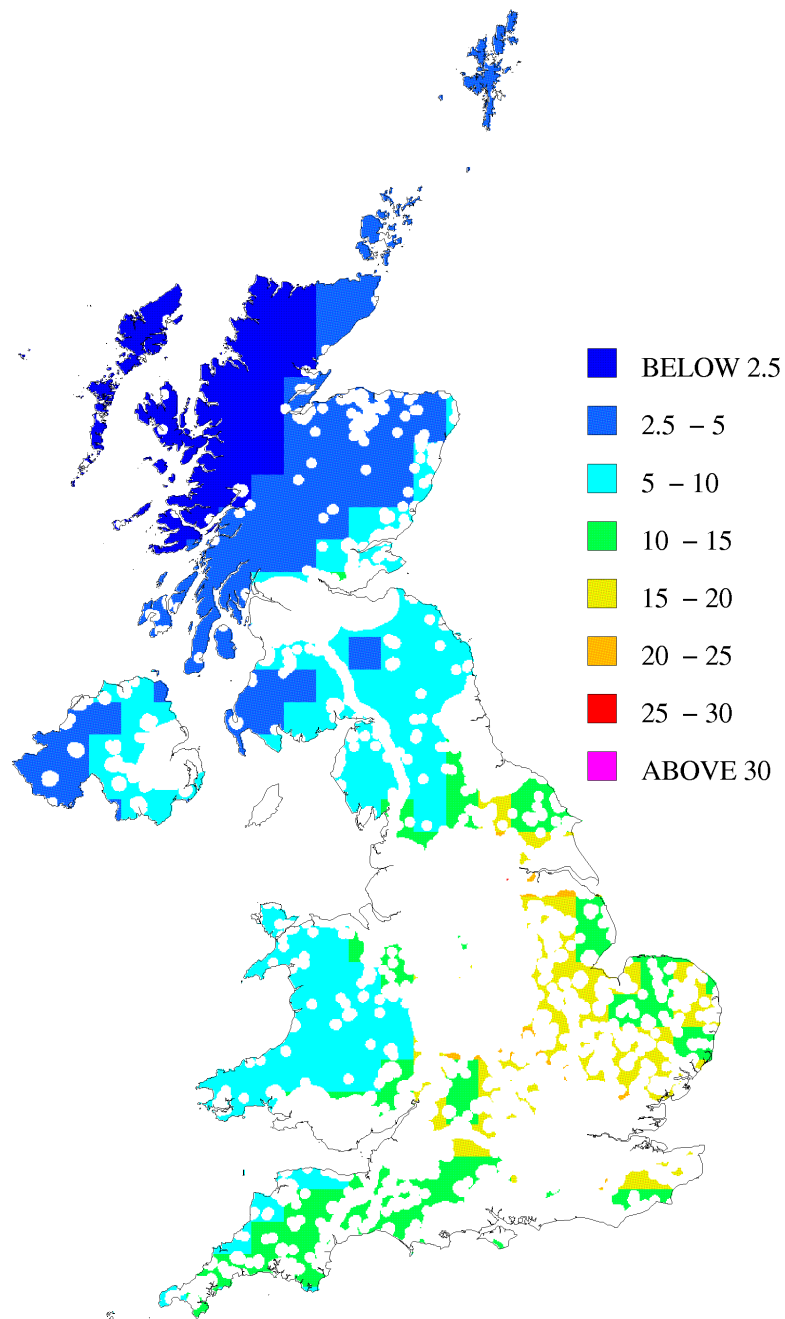
Legend:
- BELOW 2.5
- 2.5 − 5
- 5 − 10
- 10 − 15
- 15 − 20
- 20 − 25
- 25 − 30
- ABOVE 30

The annual mean background NO$_x$ concentration map has been calculated by summing the contributions from:

- Distant sources (characterised by the rural background concentration)

- Large point sources

- Small point sources

- Local area sources

The area source model has been calibrated using data from the national automatic monitoring networks for 2005. At locations close to busy roads an additional roadside contribution was added to account for contributions to total NO_x from road traffic sources. The contributions from each of these components are described in following sections.

In order to estimate the NO_2 concentrations, modelled NO_x concentrations derived from the approach outlined above are converted to using an oxidant partitioning model which describes the complex inter-relationships of NO, NO_2 and ozone as a set of chemically coupled species (Jenkins, 2004). This approach provides additional insights into the factors controlling ambient levels of NO_2 (and ozone), and how they may vary with NO_x concentration.

Details of the methods used to calculate ambient NO_x concentrations are presented in Section 3.2 to 3.6 below. Details of the methods used to estimate ambient NO_2 from these estimates of NO_x are presented in Sections 3.7 and 3.8.

3.2 Contributions from large point sources

Contributions to ground level annual mean NO_x concentrations from large point sources (those with annual emission greater than 500 tonnes) in the 2004 NAEI were estimated by modelling each source explicitly using an atmospheric dispersion model (ADMS 3.3) and sequential meteorological data for 2005 from Waddington. A total of 171 large point sources were modelled for NO_x. Surface roughness was assumed to be 0.1 metres. Concentrations were calculated for a 100km x 100km square composed of a regularly spaced 5km x 5km resolution receptor grid. Each receptor grid was centred on the point source. 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 2004 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).

3.3 Contributions from small point sources

Contributions from NO_x point sources with less than 500 tonnes per annum emissions in the 2004 NAEI were modelled using the small points model described in Appendix 3.

3.4 Contribution from rural background concentrations

Rural annual mean background NO_x concentrations have been estimated using:

- NO_x measurements at 11 selected rural AURN sites

- NO_x estimated from NO_2 measurements at 15 rural NO_2 diffusion tube sites from the Acid Deposition Monitoring Network (Lawrence, *pers comm. 2006*)

Figure 3.5 shows the locations of these monitoring sites.

Figure 3.5. Monitoring sites and concentrations used to interpolate rural background NO$_x$ concentrations (μg m^{-3}, as NO$_2$)
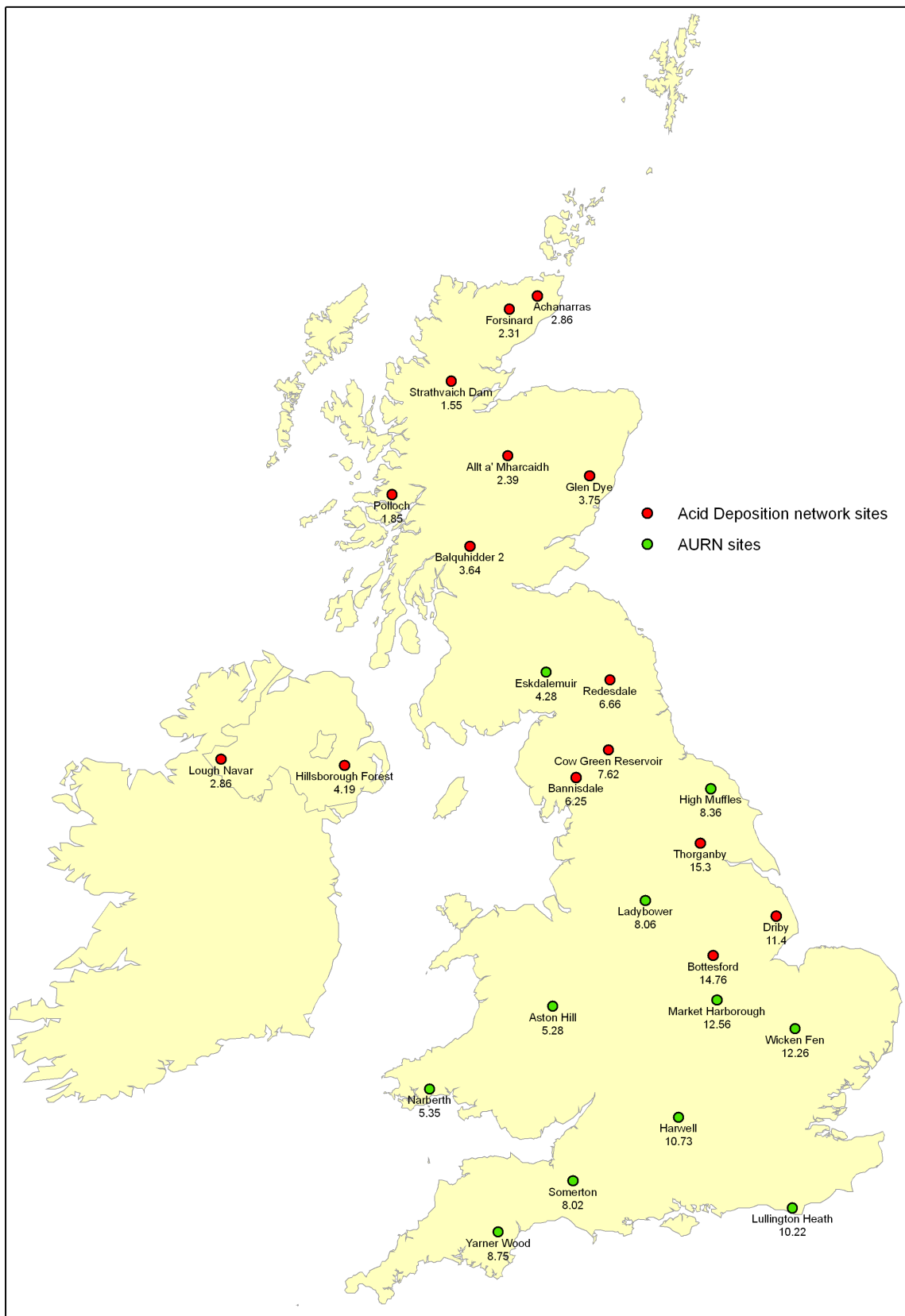
Rural NO$_x$ was estimated from rural NO$_2$ at diffusion tube sites by dividing by 0.7835 (the average value of the NO$_x$/NO$_2$ ratio measured at rural automatic monitoring sites) – this factor does not vary significantly across the country. Measurements have then been corrected to remove the contribution from point source and local area sources to avoid double counting these contributions later in the modelling process. The correction procedure is as follows:

Corrected rural background (μg m^{-3}) = Uncorrected rural background (μg m^{-3}) – (A + B + C)

Where: A = an estimate of the contribution from area source components, derived using the area source model empirical coefficients from the 2004 modelling

B = sum of contributions from large point sources in 2005 modelling

C = sum of contributions from small point sources in 2005 modelling

Automatic sites, where available have been used in preference to diffusion tubes as these are considered to be more accurate. A bi-linear interpolation of corrected rural measurement data has been used to map regional background concentrations throughout the UK.

3.5 Contributions from area sources

Figure 3.6 shows the calibration of the area source model. The modelled concentrations from all point sources and corrected rural NO$_x$ concentrations have been subtracted from the measured annual mean NO$_x$ concentration at background sites. This corrected background concentration is compared with the modelled area source contribution to annual mean NO$_x$. An empirical method has been used to calculate the contribution to ambient concentrations from area sources. This approach applies an ADMS derived dispersion kernel to calculate the contribution to ambient concentrations at a central receptor location from area source emissions within a 33km x 33km square surrounding each monitoring site. Hourly sequential meteorological data from Waddington in 2005 has been used to construct the dispersion kernels, as described in Appendix 4.

Figure 3.6. Calibration of area source NO$_x$ model, 2005 (μg m^{-3}, as NO$_2$)
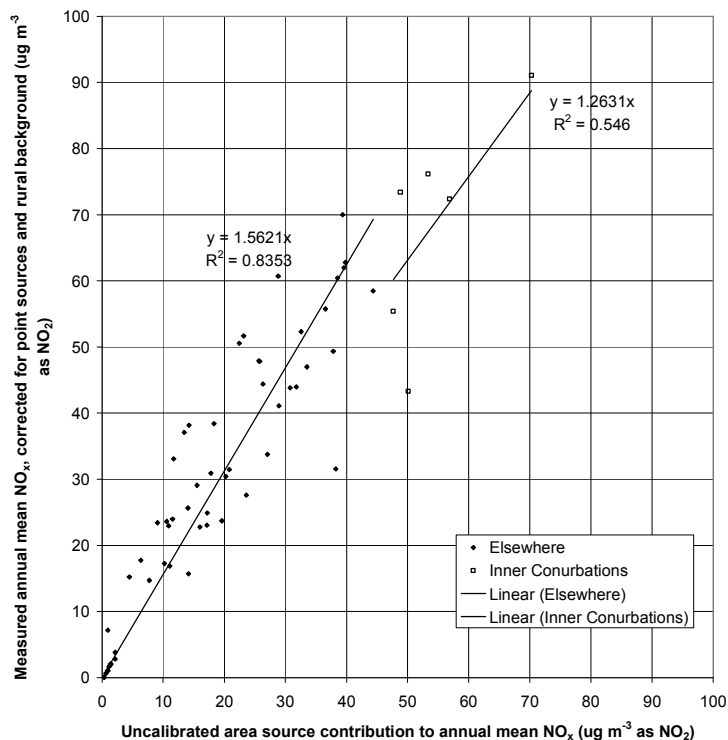
The monitoring sites fall into two groups: 'inner conurbations' and 'elsewhere'. 'Inner conurbations' includes central London (within the inner ring road) and central Birmingham, as defined by DfT (2003). The lower coefficients for the inner conurbations suggest that dispersion is more efficient in these locations due to increased turbulence resulting from variable urban topography.

Adjustment factors were applied to the emissions from selected transport sources. Emissions from aircraft were multiplied by 0.36, representing the diminishing influence of aircraft emissions on ambient air quality at the surface with increasing altitude. This factor was derived from specific dispersion modelling studies to determine the proportion of aircraft emissions released near the surface. A factor of 0.25 was applied to emissions from ships to represent the diminishing influence of emissions on ambient air quality with increasing distance from the coast. This factor was empirically derived to fit monitoring data at coastal locations.

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 point source contributions and constant regional rural concentration were then added, resulting in a map of background annual mean NO_x concentrations.

3.6 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 2004 (Dore *et al.*, 2006) and these have been adjusted to provide estimates of emissions in 2005. 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 in Section 3.5 above. The roadside increment is calculated by multiplying an adjusted road link emission (see below) by the empirical dispersion coefficient determined from this graph. Roadside concentrations for urban major road links (A-roads and motorways) only are reported to the EU and included in this report.

Figure 3.7. Calibration of NO$_x$ roadside increment model, 2005 (μg m^{-3}, as NO$_2$)
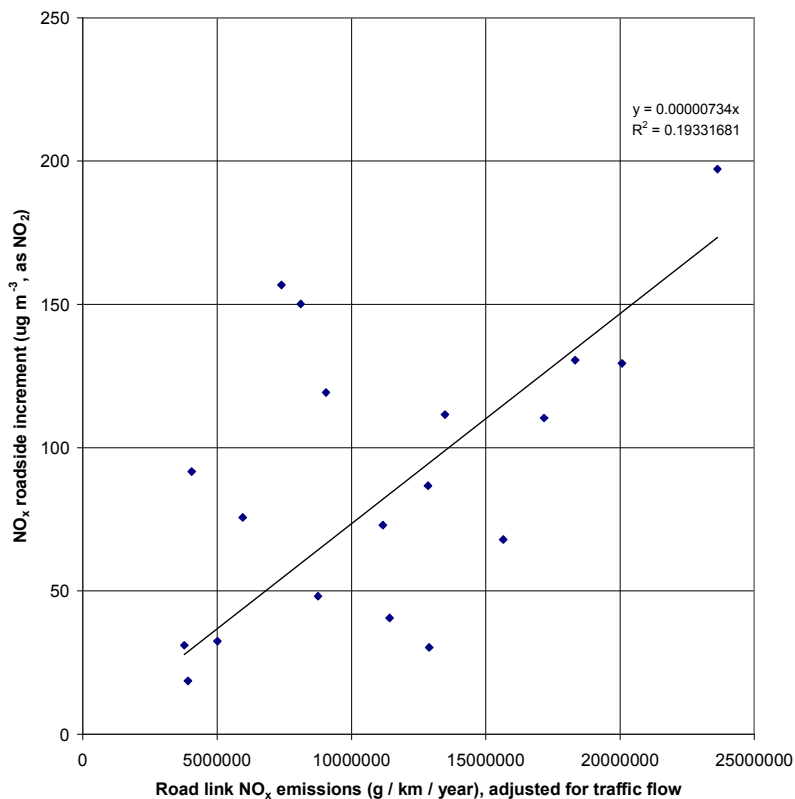
The dispersion of emissions from vehicles travelling along a road is influenced by a number of different factors, which include the width of the road and other factors, which contribute to make the dispersal of emissions less efficient on roads with lower flows. This is probably because roads with lower flows are more likely to have slower moving traffic which subsequently offers less initial dispersion due to mechanical and thermal turbulence, and also because roads with lower flows are more likely to be in built up urban areas with buildings close to the road, giving a more confined setting and reduced dispersion. Detailed information on the dispersion characteristics of each urban 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
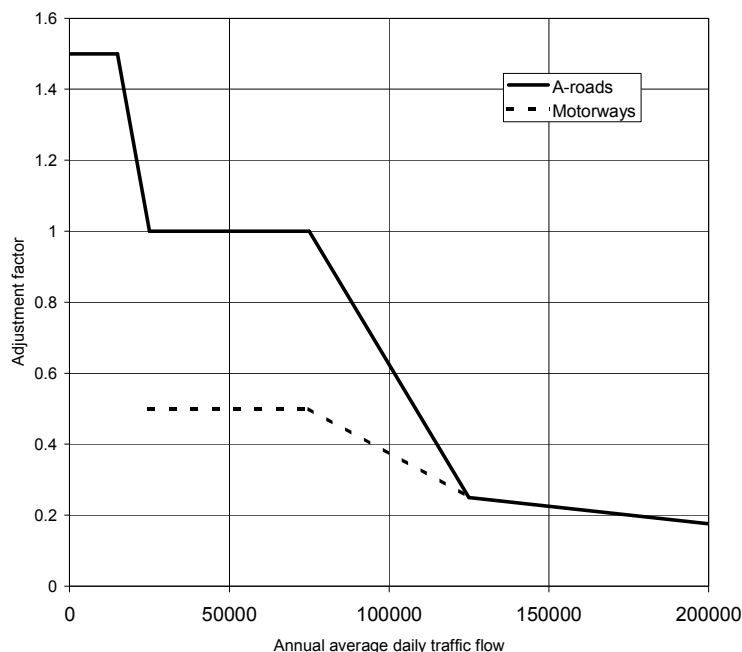
3.7 Empirical relationships between NO_2 and NO_x concentrations

Maps of estimated annual mean NO_2 concentrations (Figure 3.1 and 3.2) have been calculated from modelled NO_x concentration using relationships presented in the oxidant-partitioning model (Jenkins, 2004). Using this method for predicting NO_2 offers a way of treating the NO_x to NO_2 relationship via representative expressions which account for the chemical coupling of O_3, NO and NO_2 within the atmosphere. In particular, this approach has the advantage of enabling the models to address emission scenarios with varying regional oxidant levels or primary NO_2 emissions, expressed as the proportion of NO_x emitted as primary NO_2 (f-NO_2).

NO_2 concentrations were estimated as the sum of local primary NO_2, which is estimated from the modelled NO_x concentrations, and a secondary NO_2 contribution, which is derived from an estimate of regional total oxidant as a function of modelled NO_x. The expression presented below has been used to describe the variation of annual mean [NO_2] with [NOx] (in ppb, where 1 ppb NO_2 = 1.91 $\mu g\ m^{-3}$). Equation (i) being substituted for f(NOx) at locations directly influenced by roads and equation (ii) for f(NOx) at all other locations.

$$[NO_2] = (f\text{-}NO_2[NO_X] + B).f(NO_X)$$

$$[NO_2]/[OX] = (8.962 \times 10^{-2}) + (1.474 \times 10^{-2}\ [NO_X]) - (1.290 \times 10^{-4}\ [NO_X]^2) + (5.527 \times 10^{-7}\ [NO_X]^3) - (8.906 \times 10^{-10}\ [NO_X]^4) \qquad\text{(i)}$$

$$[NO_2]/[OX] = (1.015 \times 10^{-1}) + (1.367 \times 10^{-2}\ [NO_X]) - (6.127 \times 10^{-5}\ [NO_X]^2) - (4.464 \times 10^{-8}\ [NO_X]^3) \qquad\text{(ii)}$$

The appropriate values of regional oxidant (B, Oxidant [OX]) are given in Table 3.1. The values of f-NO_2 have been derived as described in Section 3.8.

Table 3.1 Summary of regional oxidant (OX) concentrations determined from an analysis of O_3 and NO_x in 13 UK areas (source Jenkins 2004)

Region	Zones	Regional oxidant (ppb)
1	Central Scotland / Highlands, Northern Ireland, North East	34.4
2	North West, Yorkshire and Humberside	33.8
3	West Midlands, East Midlands, Eastern	32.4
4	South Wales, South West, South East, London	34.7

The oxidant-partitioning model does not apply at NO_x concentrations lower than 17 μg m^{-3}, as NO_2. At NO_x concentrations of less than 17 μg m^{-3} as NO_2, NO_2 concentrations have been estimated using the relationship previously suggested by Stedman *et al.* (2003) for rural locations:

$$[NO_2] = [NO_x] \times 0.7835$$

In calculating the annual mean NO_2 concentrations at background locations for 2004, 0.5 ppb was added to the regional oxidant concentrations presented in Jenkin (2004), who considered concentrations up to 2001, because regional oxidant is thought to be increasing with time at a rate of about 0.2 ppb yr^{-1} (Derwent *et al.*, 2005). As a result of indications of a recent reduction in the rate of regional oxidant increase, an increase of 0.1 ppb was added to regional oxidant for the 2005 mapping.

A variable local oxidant proportion was applied to the background concentrations based on coefficients presented in Table 3.2 below to represent the influence of primary NO_2 at background locations.

Table 3.2 Local oxidant coefficient for background concentrations

Region	f-NO_2
Central London	0.14
Inner London	0.128
Elsewhere	0.093

Testing of the oxidant partitioning model for roadside monitoring sites outside London indicated that it tended to over-predict roadside NO_2 concentrations at roadside NO_x concentrations lower than about 150 μg m^{-3}, as NO_2. A variable local oxidant proportion was applied, with a value of 0.03 at a NO_x concentration of zero, rising linearly to the f-NO_2 values calculated as described in Section 3.8.

3.8 Primary NO_2 emission fractions

The primary component of NO_2 from road traffic sources is currently receiving a great deal of attention in the UK and throughout Europe as questions over the ability of legislative controls on NO_x to limit ambient NO_2 concentrations have arisen. The 2005 NO_x and NO_2 modelling has been developed to provide a more detailed representation of primary NO_2 that is more closely linked to emission inventories. In previous years, a primary NO_2 factor (f-NO_2) of 0.09 (i.e. 9% of NO_x as primary NO_2) was used as devised by Jenkin (2004) using the oxidant partitioning model. It is likely that primary NO_2 emission fractions have risen in recent years and also show considerable variation with location (AQEG, 2006, *in consultation*). For the 2005 modelling a primary NO_2 specific inventory has been developed which has been used to provide a 2005 specific value of the fraction of NO_x emitted by traffic as primary NO_2 (f-NO_2) within the oxidant partitioning model (described in Section 3.7). Estimates of f-NO_2 for London from work by Beevers and utilised in the AQEG Primary NO_2 report (AQEG, 2006, *in publication*) were used to adjust the values for London.

The primary NO_2 inventory used data from the NAEI to assess NO_x and NO_2 emissions from road transport in urban areas. This followed a similar approach and the same NO_2:NO_x ratios for different vehicle classes to that used by Beevers. Annual NO_x and NO_2 emissions were calculated for the years 2002 to 2010 for road transport in urban areas by vehicle type (See Figures 3.7 and 3.8 below).

The 10 year plan for transport (DfT, 2004) is accounted for by the NAEI which uses traffic forecasts from DfT's FORGE model. The NAEI also accounts for rate at which new vehicles penetrate the fleet and old ones are taken out, as calculated by a fleet turnover model using average survival rates and figures from DfT's Vehicle Market Model (VMM) on new car sales. The survival rates are based on averages of historical survival rates over the last 10 years. It has been assumed that diesel car sales will grow to 42% by 2010.

Figure 3.7: UK urban annual NO$_x$ emissions by vehicle type (2002-2010)
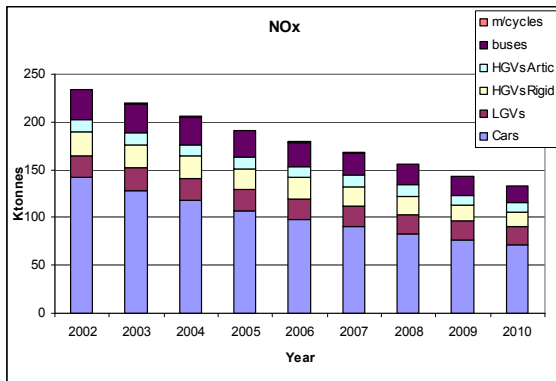
Figure 3.8: UK urban annual NO$_2$ emissions by vehicle type (2002-2010)
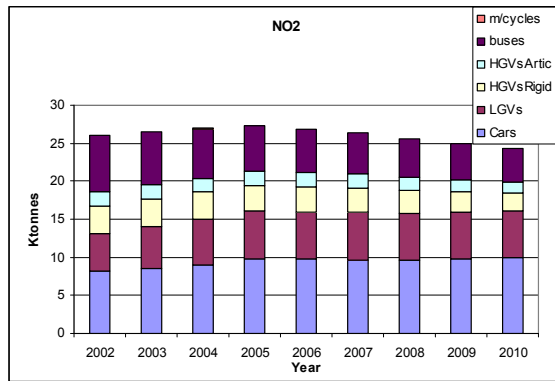
Figure 3.9: Changing percentage NO$_2$: NO$_x$ UK urban emission ratios (2002-2010)
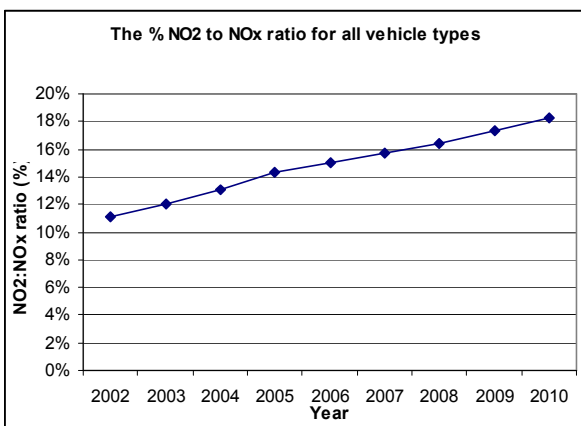
Figure 3.10: contribution to total UK urban NO$_2$ emissions by vehicle type (based on London, 2002-2010)
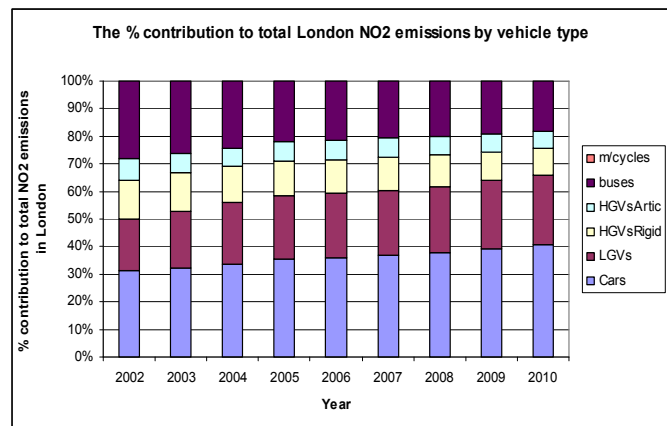
The emission calculations show that in urban areas, road transport NO$_x$ emissions show a decline from 233 Ktonnes in 2002 to 133 Ktonnes in 2010 (Figure 3.7). In contrast, NO$_2$ emissions are predicted to increase between 2002 and 2005. Following this, they are predicted to fall (Figure 3.8). This decline in NO$_2$ emissions post 2005 was also predicted by Beevers for London road transport emissions. This trend is the result of an increasing NO$_2$:NO$_x$ emission ratio (see Figure 3.9) in combination with declining NO$_x$ emissions from all vehicles. In 2002, the NO$_2$:NO$_x$ emissions ratio from all vehicles combined (Figure 3.9) was approximately 11% and this is predicted to increase to 18% by 2010. In London a similar increase is predicted over this period.

Figure 3.10 shows the proportion that each vehicle type contributes to the total NO$_2$ emissions in urban areas. The analysis shows that cars and LGVs will be of increasing importance in the future. This is as a result of the increasing numbers of diesel cars and increasing numbers of both cars and LGVs conforming to Euro III and Euro IV emission standards. The analysis has showed that HGVs and buses are of less importance as their contribution to total NO$_2$ emissions in urban areas is predicted to fall over time. This is because the NAEI forecasts at present assume that there is no widespread use of particulate traps on Euro IV and IV+ vehicles. This assumption obviously has large implications on the total NO$_2$ emissions predicted in urban areas.

The values of f-NO_2 were used within the oxidant partitioning model to calculate background NO_2 concentrations from the mapped background NO_x values. For traffic sources we used the 2005 specific f-NO_2 values derived from the emission inventory calculations. For non-traffic sources we used the values derived from the historical monitoring data by Jenkin (2004). Table 3.3 summarises the factors used.

Table 3.3. Coefficients used to obtain calculate background NO_2 concentrations from road traffic and non-road traffic sources

Area	Source	f-NO_2	Origin of coefficient
Outside London	Road traffic source	0.143	NAEI Primary NO_2 inventory
	Non-road traffic source	0.093	oxidant partitioning model (Mike Jenkins')
Outer London	Road traffic source	0.162	London-specific primary NO_2 inventory (Beevers)
	Non-road traffic source	0.128	oxidant partitioning model (Mike Jenkins')
Central London	Road traffic source	0.198	London-specific primary NO_2 inventory (Beevers)
	Non-road traffic source	0.140	oxidant partitioning model (Mike Jenkins')

The 2004 NAEI was used to calculate the proportion of road traffic sources to non-road traffic sources for each 1km square and this was used to scale each source for each area accordingly before adding the components together to create a single local oxidant grid representing f-NO_2 over the whole of the UK. The oxidant partitioning model was used to calculate the NO_2 concentrations from the background NO_x grid using the local oxidant grid as the primary NO_2 component.

A similar approach has been adopted for the modelling of roadside NO_2 concentrations. The primary NO_2 inventory was used to calculate link by link estimates of NO_2 emissions in 2005 by vehicle type which were then aggregated to provide a single NO_2 emission value for the road link. f-NO_2 was then calculated for each road link by dividing the estimated NO_2 emissions by the estimated NO_x emissions. Where specific road link emissions were not available the average of all road links was used instead. Road links in London were scaled according to values determined by Beevers' London-specific primary NO_2 inventory. Ambient NO_2 concentrations at roadside were calculated for each road link with the oxidant partitioning model using the modelled NO_x concentration, the regional oxidant concentration B and link f-NO_2.

3.9 Verification of mapped values

Figures 3.11 and 3.12 show comparisons of modelled and measured annual mean NO_x and NO_2 concentration in 2005 at background monitoring site locations. Figure 3.13 and 3.14 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 under AQDD1 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 here 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 3.11. Verification of background annual mean NO$_x$ model 2005
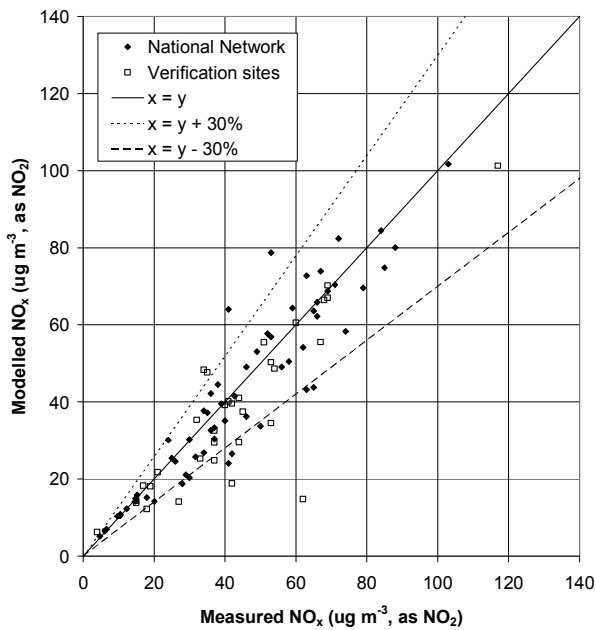
Figure 3.12. Verification of background annual mean NO$_2$ model 2005
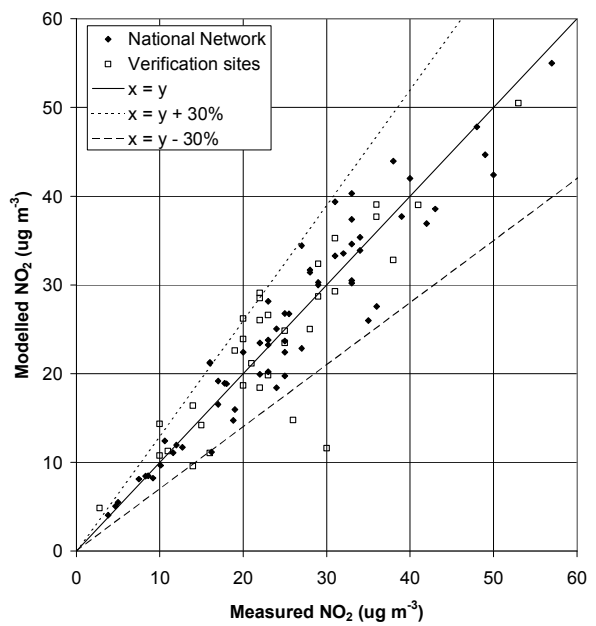
Figure 3.13. Verification of roadside annual mean NO$_x$ model 2005
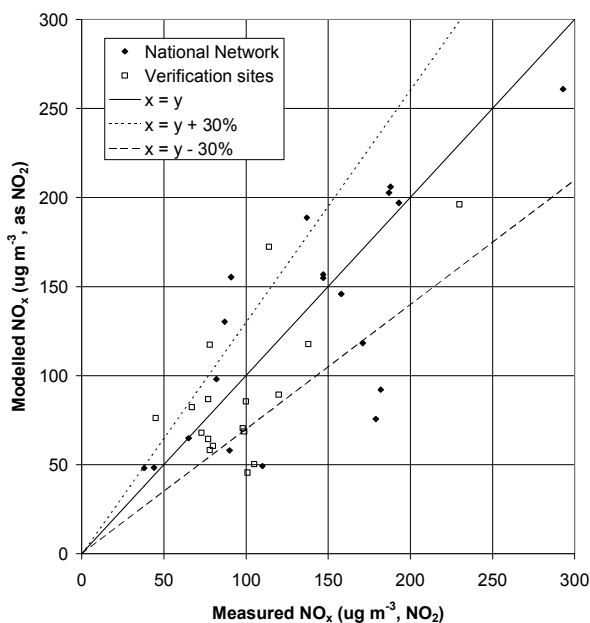
Figure 3.14. Verification of roadside annual mean NO$_2$ model 2005
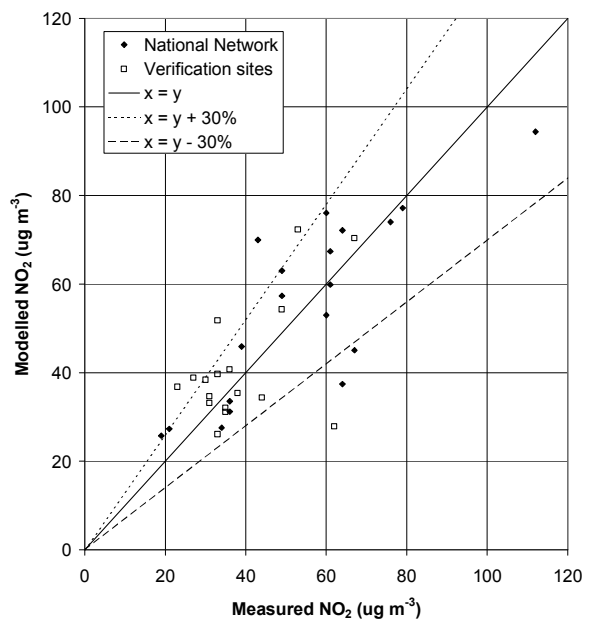
Summary statistics for the comparison between modelled and measured NO$_x$ and NO$_2$ concentrations are listed in Tables 3.4 and 3.5. The percentages of monitoring sites for which the modelled annual mean concentrations fall outside the data quality objectives is generally greater for NO$_x$ than for NO$_2$, for the reasons discussed above.

Table 3.4. Summary statistics for comparison between modelled and measured NO$_x$ and NO$_2$ concentrations at background sites (µg m^{-3}, as NO$_2$)

		Mean of measurements (µg m^{-3}, as NO$_2$)	Mean of model estimates (µg m^{-3}, as NO$_2$)	r^2	% outside data quality objectives	Number of sites in assessment
National Network	NO$_x$	43.1	41.3	0.91	14.5	62
Verification Sites	NO$_x$	42.5	37.4	0.76	30.3	33
National Network	NO$_2$	25.2	25.1	0.9	4.8	62
Verification Sites	NO$_2$	23.8	23.6	0.75	24.2	33

Table 3.5. Summary statistics for comparison between modelled and measured NO$_x$ and NO$_2$ concentrations at roadside sites (µg m^{-3}, as NO$_2$)

		Mean of measurements (µg m^{-3}, as NO$_2$)	Mean of model estimates (µg m^{-3}, as NO$_2$)	r^2	% outside data quality objectives	Number of sites in assessment
National Network	NO$_x$	136.3	129.0	0.53	42.1	19
Verification Sites	NO$_x$	98.8	88.7	0.51	35.3	17
National Network	NO$_2$	54.2	54.6	0.56	21.1	19
Verification Sites	NO$_2$	38.8	41.0	0.2	29.4	17

3.10 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 3.6. These data have also been presented in Form 19b of the questionnaire. 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 2005. 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.

Estimates of area and population exposed have been derived from the background maps only. No attempt has been made to derive estimates using maps of roadside concentrations as these maps will only apply to within approximately 10 metres from the road kerb.

Table 3.6 Tabular results of and methods used for supplementary assessment (1999/30/EC Article 7(3) and Annex VIII(II))

Zone	Zone code	Above LV for health (annual mean)					
		Area		Road length		Population exposed	
		km^2	Method	km	Method	Number	Method
Greater London Urban Area	UK0001	119	A	1606.3	A	1070760	A
West Midlands Urban Area	UK0002	10	A	382.1	A	23185	A
Greater Manchester Urban Area	UK0003	3	A	412.6	A	3651	A
West Yorkshire Urban Area	UK0004	4	A	187.5	A	3904	A
Tyneside	UK0005	0	A	83.0	A	0	A
Liverpool Urban Area	UK0006	0	A	121.0	A	0	A
Sheffield Urban Area	UK0007	3	A	111.3	A	4727	A

Zone	Zone code	Above LV for health (annual mean)					
		Area		Road length		Population exposed	
		km²	Method	km	Method	Number	Method
Nottingham Urban Area	UK0008	0	A	65.5	A	0	A
Bristol Urban Area	UK0009	0	A	50.2	A	0	A
Brighton/Worthing/Littlehampton	UK0010	0	A	9.5	A	0	A
Leicester Urban Area	UK0011	0	A	47.8	A	0	A
Portsmouth Urban Area	UK0012	0	A	28.2	A	0	A
Teesside Urban Area	UK0013	0	A	22.3	A	0	A
The Potteries	UK0014	0	A	32.9	A	0	A
Bournemouth Urban Area	UK0015	0	A	10.8	A	0	A
Reading/Wokingham Urban Area	UK0016	0	A	22.2	A	0	A
Coventry/Bedworth	UK0017	0	A	24.9	A	0	A
Kingston upon Hull	UK0018	0	A	28.1	A	0	A
Southampton Urban Area	UK0019	0	A	21.3	A	0	A
Birkenhead Urban Area	UK0020	0	A	5.1	A	0	A
Southend Urban Area	UK0021	0	A	8.3	A	0	A
Blackpool Urban Area	UK0022	0	A	0.0	A	0	A
Preston Urban Area	UK0023	0	A	6.7	A	0	A
Glasgow Urban Area	UK0024	0	A	159.7	A	0	A
Edinburgh Urban Area	UK0025	0	A	31.3	A	0	A
Cardiff Urban Area	UK0026	0	A	16.1	A	0	A
Swansea Urban Area	UK0027	0	A	0.0	A	0	A
Belfast Urban Area	UK0028	0	A	46.5	A	0	A
Eastern	UK0029	0	A	143.3	A	0	A
South West	UK0030	0	A	85.7	A	0	A
South East	UK0031	2	A	265.8	A	7502	A
East Midlands	UK0032	0	A	120.5	A	0	A
North West & Merseyside	UK0033	0	A	252.0	A	0	A
Yorkshire & Humberside	UK0034	0	A	318.4	A	0	A
West Midlands	UK0035	0	A	90.4	A	0	A
North East	UK0036	0	A	71.6	A	0	A
Central Scotland	UK0037	0	A	29.6	A	0	A
North East Scotland	UK0038	0	A	35.0	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	49.0	A	0	A
North Wales	UK0042	0	A	12.7	A	0	A
Northern Ireland	UK0043	0	A	0.0	A	0	A
Total		141		5015.0		1113729	

4 PM$_{10}$

4.1 Introduction

Maps of annual mean PM$_{10}$ in 2005 at background and roadside locations are shown in Figures 4.1 and 4.2. Continuing the methodology developed in 2004, the 2005 modelling has been undertaken in both gravimetric and in TEOM units. The methods used to derive the maps for 2004 have recently been described by Stedman *et al.*, 2006b. The methods used to derive the maps for 2005 are described below.

Figure 4.1. Annual mean background PM$_{10}$ concentration, 2005 (μg m^{-3}, gravimetric)
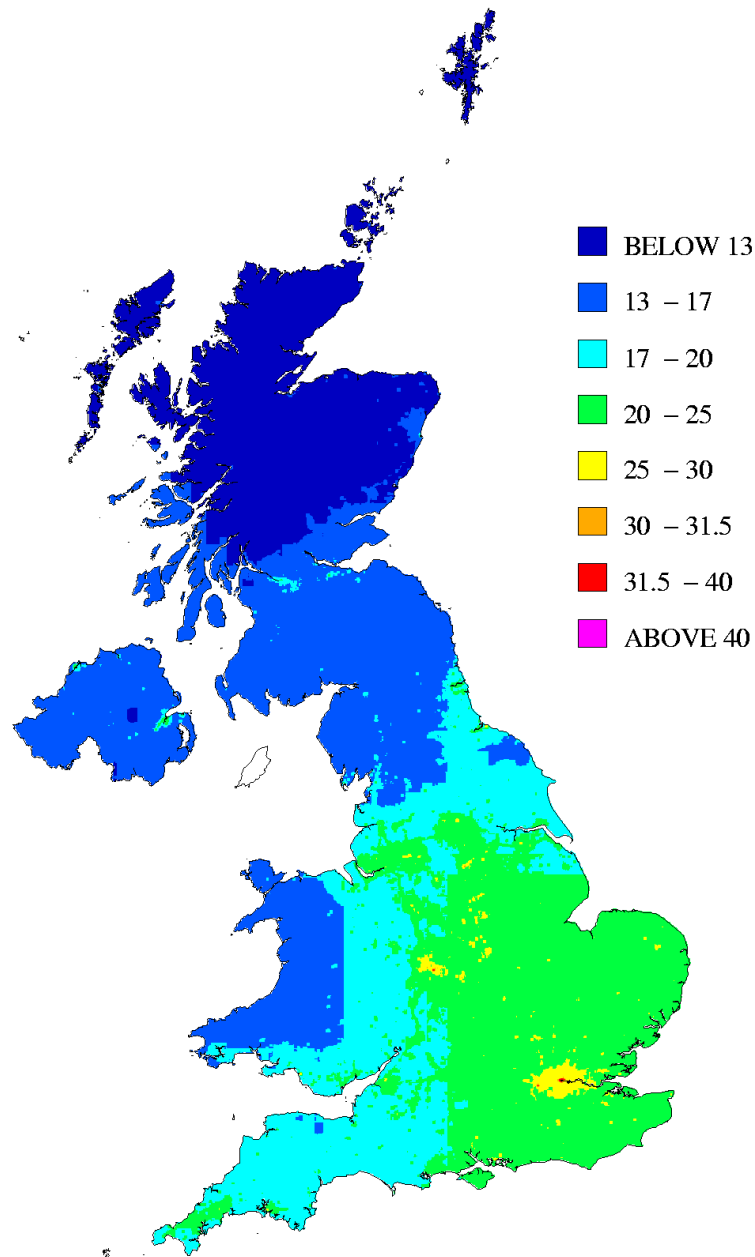
BELOW 13
13 – 17
17 – 20
20 – 25
25 – 30
30 – 31.5
31.5 – 40
ABOVE 40

Figure 4.2. Urban major roads, annual mean roadside PM$_{10}$ concentration, 2005 (μg m^{-3}, gravimetric)
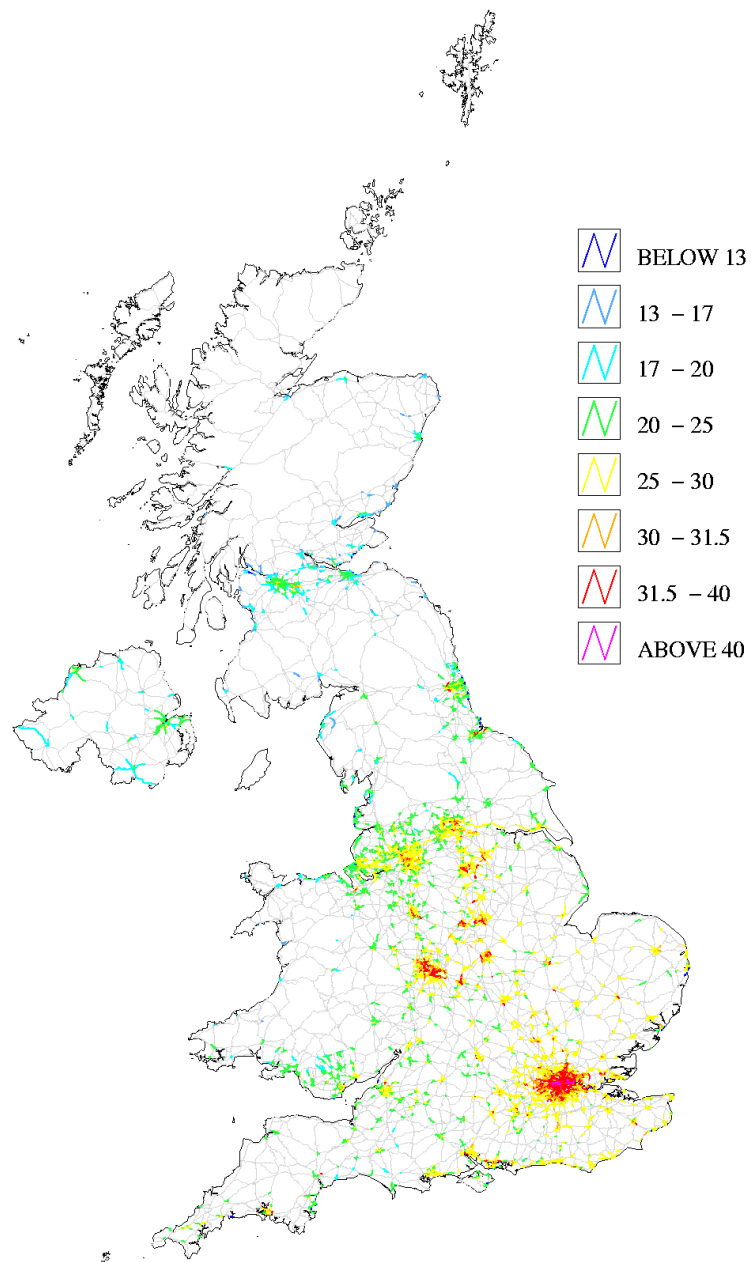
BELOW 13
13 − 17
17 − 20
20 − 25
25 − 30
30 − 31.5
31.5 − 40
ABOVE 40

The maps of background PM$_{10}$ concentrations have been calculated by summing contributions from different sources:

- Secondary inorganic aerosol (derived by scaling measurements of SO$_4$, NO$_3$ and NH$_4$)

- Secondary organic aerosol (semi-volatile organic compounds formed by the oxidation of non-methane volatile organic compounds. Estimates derived from results from the HARM/ELMO model)

- Large point sources of primary particles (modelled using ADMS and emissions estimates from the NAEI)

- Small point sources of primary particles (modelled using the small points model and emissions estimates from the NAEI)

- Regional primary particles (from results from the TRACK model and emissions estimates from the NAEI and EMEP)

- Area sources of primary particles (modelled using a dispersion kernel and emissions estimates from the NAEI)

- Sea salt (from ongoing work by the Met Office)

- Residual (assumed to be a constant value)

The concentrations of many of these components have been estimated separately for the fine and coarse fraction. This enables a consistent method to be adopted for estimation of PM_{10} (the sum of the fine and coarse fractions) and $PM_{2.5}$ (fine fractions only). These component pieces are then aggregated to a single 1x1 km background PM_{10} grid. An additional roadside increment is added for roadside locations. Estimates of the emissions of primary PM from the 2004 UK National Atmospheric Emission Inventory (NAEI) have been used in this study (Dore, *et al.*, 2006). The NAEI provides estimates for PM_{10}. Sector specific scaling factors have been used to scale the emissions to provide estimates for 2005. The NAEI provides emissions estimates and projections for a wide variety of different sources. Scaling factors for sectors such as road traffic, domestic combustion and processes were then derived by summing the emissions estimates for each source for 2004 and for the projection year (2005 in this case). The methods used to calculate ambient concentrations from the estimates of primary PM emissions are described below for point, area and regional sources.

24-hour mean concentrations have not been explicitly modelled for comparison with the 24-hour limit values. An annual mean concentration of 31.5 μg m^{-3}, gravimetric has been taken to be equivalent to 35 days with 24-hour mean concentrations greater than 50 μg m^{-3} gravimetric (the Stage 1 24-hour limit value). This equivalence is derived from an analysis of monitoring data (Stedman *et al.*, 2001b) and is reproduced Figure 4.3. Comparison with more recent monitoring data has confirmed that this relationship still holds (Stedman, *et al.* 2006b) and comparison against data obtained from Partisol instruments demonstrates that this relationship adequately describes genuine gravimetric data also (AQEG, 2005). The relationship between the number of days with concentrations greater than 50 μg m^{-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 μg m^{-3}, gravimetric. In any case, the Stage 2 annual mean limit value is expected to be as stringent as the Stage 2 24-hour limit value (AQEG, 2005).

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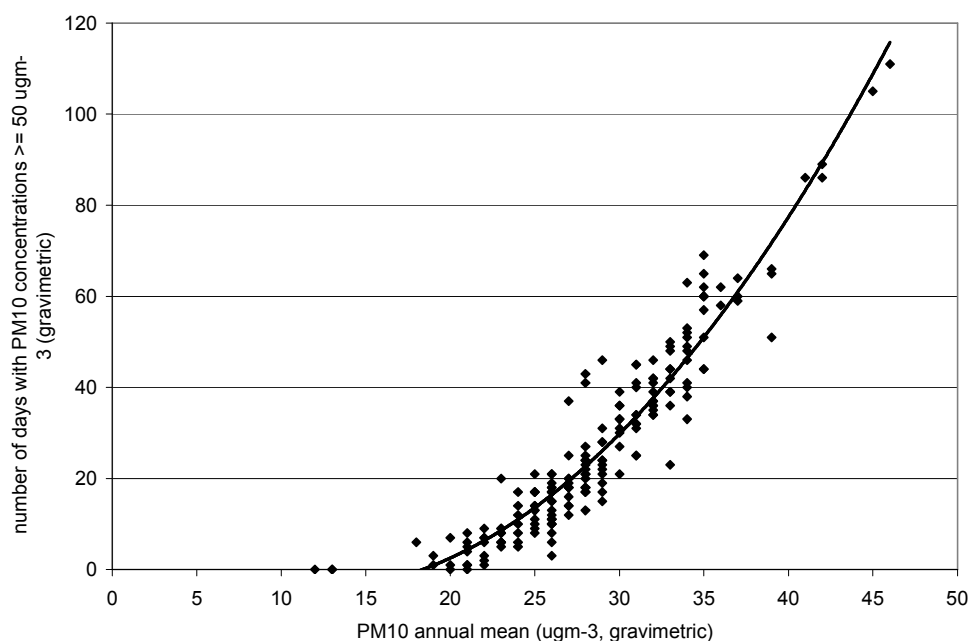
4.2 Contributions from secondary inorganic aerosol

Prior to 2004 secondary particles were assumed to consist of sulphates and nitrates only and were estimated from measured sulphate and nitrate concentrations using scaling factors derived from the APEG receptor model (APEG 1999; Stedman, *et al.,* 2001a). The revised methodology developed in 2004 is continued in the 2005 modelling. Maps of secondary inorganic aerosol (SIA) concentrations across the UK have been calculated from rural measurements of sulphate, nitrate and ammonium concentrations by interpolation onto a 20km x 20km grid. Bilinear interpolation has been used since this provides a relatively smooth surface and steep spatial gradients are not expected for these components. Sulphate, nitrate and ammonium particle concentrations were measured on a monthly basis at 12 rural sites using a denuder method during 2005 (Tang, *pers comm*. 2006).

These secondary components were then split into fine and coarse fractions and non-volatile and volatile components using coefficients derived with reference to the detailed PM sampling carried out during the PUMA campaign at the University of Birmingham urban background monitoring site in June and July 1999 (Harrison *et al.*, 2006; summarised in Appendix 2). The non-volatile secondary PM has been assumed to be sampled by a TEOM instrument, a gravimetric instrument should sample the sum of the non-volatile and volatile components. These secondary components were also scaled according to 'bound water' associated with the mass of water embedded within the particles (AQEG, 2005). Particle bound water is associated with the hygroscopic anions (Harrison *et al.*, 2006). This has been assumed to contribute to the fine and coarse components gravimetric but not the TEOM. Therefore a particle bound water scaling factor of 1.279 has been applied to the SIA components for the gravimetric maps (see Table 4.1). The factor for coarse nitrate is higher as this includes the mass of the counter-ion (sodium or calcium).

Table 4.1 Scaling factors for size fraction, bound water and counter ion mass for secondary inorganic and organic aerosol

Pollutant	Size fraction	Scaling factor for size fraction	Scaling factor for bound water and counter-ion mass	Scaling factor for bound water and counter-ion mass (non-volatile)
SO_4	Fine	0.94	1.279	1.00
	Coarse	0.06	1.279	1.00
NO_3	Fine	0.45	1.279	0.00
	Coarse	0.55	1.60	1.32
NH_4	Fine	0.97	1.279	0.86
	Coarse	0.03	1.279	1.00
SOA	Fine	0.75	1.0	0.00
	Coarse	0.25	1.0	0.00

4.3 Contributions from secondary organic aerosol

Estimates of the secondary organic aerosol (SOA) concentrations on a 10km x 10km grid have been taken from the HARM/ELMO model (Whyatt *et al.*, 2006). This is a receptor oriented, Lagrangian statistical model, which tracks the changing composition of a series of air parcels travelling across the EMEP and UK areas towards designated receptor sites. SOA has been generated within the model through the photo-oxidation of terpenes and isoprene from natural emissions and anthropogenic emissions of toluene. SOA concentrations are not routinely measured but can be estimated from campaign measurements of elemental and organic carbon (EC and OC). Measured OC includes both primary and secondary components. EC and OC were measured at Bush Estate in Scotland from July 2002 to July 2003 (EMEP, 2005). The EC/OC campaign data exhibit seasonal variations at Bush that can be explained most simply by EC and primary OC contributions that peak in the winter and reach a minimum in the summer and a secondary OC contribution that peaks in the summer and is zero in the winter. More complicated explanations could and most certainly are operating. However, with the data available this is the simplest explanation of what is observed. Similar behaviour has been found at some sites in the EMEP EC/OC campaign but not at all sites. Hence we assume that the assumptions concerning the seasonal cycle in secondary OC work all across the UK, but not necessarily across Europe. Estimated peak summer time monthly concentrations of SOA were found to be 0.94 $\mu g\ m^{-3}$ and the model predicted peak summer time monthly concentrations of 0.4-0.5 $\mu g\ m^{-3}$. Since summer mean concentrations would be expected to be about double the annual mean, we consider that the modelled summer time value to provide a reasonable estimate of the annual mean and we have chosen not to scale the results. SOA is assumed to be volatile (Pankow, 1995) and thus contributes to gravimetric but not TEOM PM concentrations (Table 4.1).

4.4 Contributions from large and small point sources

Contributions to ground level annual mean primary PM concentrations from large point sources (those with annual emission greater than 200 tonnes) have been estimated by modelling each source explicitly using the atmospheric dispersion model (ADMS 3.3). Hourly sequential meteorological data for 2005 from Waddington was applied. Surface roughness was assumed to be 0.1 metres. Concentrations were calculated for a 100km x 100km square composed of a regularly spaced 5 km x 5 km resolution receptor grid. Each receptor grid was centred on the point source. A total of 77 point sources were modelled explicitly.

Contributions from PM point sources with less than 200 tonnes per annum release were modelled using the 'small points' model described by Stedman *et al* (2005) and summarised in Appendix 3. This model consists of separate 'in-square' and 'out-of-square' components, in which concentrations are estimated using dispersion kernels, which have been calculated by using ADMS 3.3 to model the

dispersion of unit emissions from a central source to a grid of receptors at a spatial resolution of 1km x 1km squares.

4.5 Contributions from distant sources of primary particles

Contributions from long-range transport of primary particles on a 10km x 10km grid have been estimated using the TRACK receptor oriented, Lagrangian statistical model (Lee *et al*., 2000). Emissions of primary PM were taken from the NAEI for the UK sources and EMEP for sources in the rest of Europe. Primary PM was modelled as an inert tracer. All sources within 10km of the receptor point were excluded from the TRACK model to allow the area source model and the point source model to be nested within this long-range transport model without duplicating source contributions.

4.6 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} have been subtracted from the measured annual mean PM_{10} concentration at background sites and compared with the modelled area source contribution to annual mean PM_{10} concentration. Calibration plots are shown in gravimetric $\mu g\ m^{-3}$ because gravimetric measurements have been used to calibrate the model. An empirical method, utilising an ADMS derived dispersion kernel has been used to calculate the contribution to ambient concentrations at a central receptor location from area source emissions within a 33km x 33km square surrounding each monitoring site. Hourly sequential meteorological data from Waddington in 2005 was used to construct the dispersion kernels, as described in Appendix 4.

Figure 4.4. Calibration of PM_{10} area source model 2005 ($\mu g\ m^{-3}$, gravimetric)
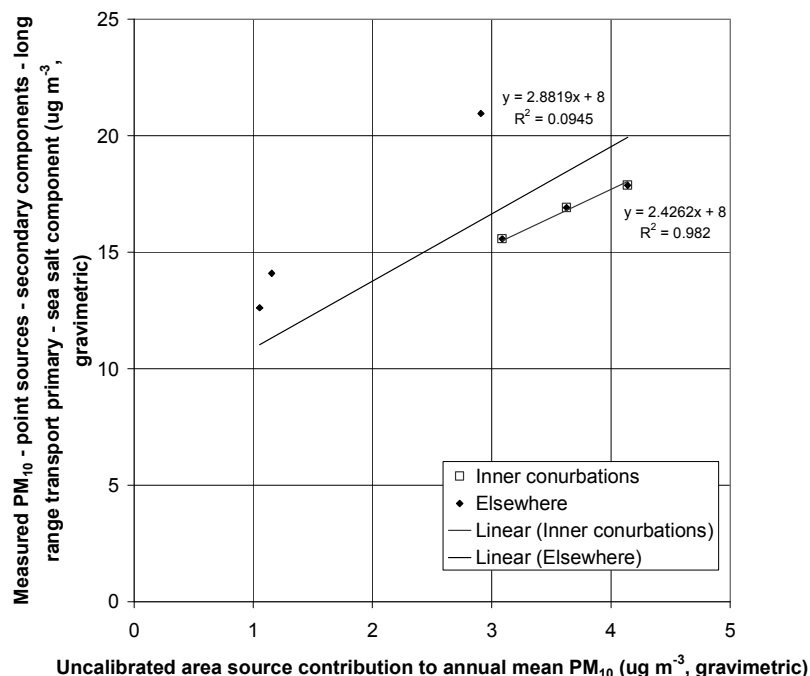
The area source model has been calibrated using ambient PM monitoring data from the UK national networks. The modelled large point and small point source, SIA, SOA and long range transport primary PM concentrations have been subtracted from the measured annual mean PM concentration at background sites and compared with the modelled area source contribution to annual mean PM concentration. The calibration coefficients used in the 2005 gravimetric background model are shown in Figure 4.4. The monitoring sites fall into two groups: 'inner conurbations' and 'elsewhere'. 'Inner conurbations' includes central London (within the inner ring road) and central Birmingham, as defined

by DfT (2003). The lower coefficients for the inner conurbations suggest that dispersion is more efficient in these locations. This is a consistent finding in our modelling assessments (Stedman *et al.*, 2001a) including for TEOM PM_{10} in both 2004 and 2005 for which many more monitoring sites are available than for gravimetric PM_{10}. It is consistent with greater surface roughness and urban heat island effects in the city centres and the likelihood that some emissions sources are more elevated in city centres due to the greater building heights. Intermediate values of the calibration coefficient were used in an annulus of width 15km surrounding the central conurbation areas. It is clear that if more gravimetric monitoring data were available then the inclusion of more sites for the calibrations should increase the reliability of the estimates. There are however many more monitoring sites for NO_x and the modelling method has been shown to be reliable for NO_x (Stedman *et al.*, 2001a; 2006a and in this report). This gives confidence in the application of the method to both TEOM and gravimetric PM.

Special consideration was given to the relationship used for areas outside large conurbations (classified as 'elsewhere' in the plot) in 2005. This was because the relationship was being strongly influenced by data from Manchester Piccadilly, which was creating an unrealistically high coefficient based on a single point. When used in the model this coefficient resulted in exceedences far in excess of what would be expected and what has been measured in the past. As a solution in 2005, the 'elsewhere' calibration relationship was based on all 6 gravimetric points (including those for inner conurbations') in order to make the relationship more realistic.

Adjustment factors were applied to the emissions from selected transport sources to represent the diminishing influence of emissions on air quality at the UK land surface, as described in Section 3.5. A factor of 0.36 was applied to aircraft emissions and a factor of 0.25 was applied to 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 area source contribution was then added to the contributions from secondary organic and inorganic particles, from small and large point sources, from regional primary particles, from sea salt and the residual, resulting in a map of background annual mean gravimetric PM_{10} concentrations.

4.7 Sea salt

Prior to 2005, contributions to coarse particles from sea salt was assumed to be constant – the fine sea salt component was set at 0.20 $\mu g\ m^{-3}$ and the coarse sea salt component was set at 0.56 $\mu g\ m^{-3}$. In 2005, ongoing work by the Met Office (Harrison, *pers comm.* March 2006) to model sea salt in the UK allowed the introduction of a specific sea salt grid into the model. A lower limit of 0.5 $\mu g\ m^{-3}$ was set on the sea salt map, below which concentrations were set at 0.5 for consistency with previous estimates and measured concentrations (APEG, 1999). The maximum modelled concentration on the sea salt map was 4.8 $\mu g\ m^{-3}$ and highest concentrations were around Northern Ireland, western Scotland and the Hebrides and off the coast of south Wales, Devon and Cornwall. The lowest modelled sea salt values were on the eastern coast of the UK. This pattern is consistent with the prevailing south westerly winds in the UK.

4.8 Residual (largely coarse particles)

Emissions of coarse particles from sources such as wind blown dusts and agricultural activities are not well characterised in emission inventories and have not been modelled explicitly. A constant residual concentration of 8 $\mu g\ m^{-3}$ (gravimetric) was therefore added as the final contribution to total particulate matter concentration. This value was chosen to provide the best fit to the measured total concentration. We consider this to be a genuine residual representing natural PM rather than an artefact of assumptions made in other aspects of the modelling.

4.9 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 2004 (Dore *et al*, 2006) and these have been adjusted to provide estimates of emissions in 2005. 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. Emissions were adjusted for annual average daily traffic flow using the method described in Section 3.7. Roadside concentrations for urban major road links (A-roads and motorways) only are reported to the EU and included in this report.

Figure 4.5. Calibration of PM_{10} roadside increment model 2005 (μg m^{-3}, gravimetric)
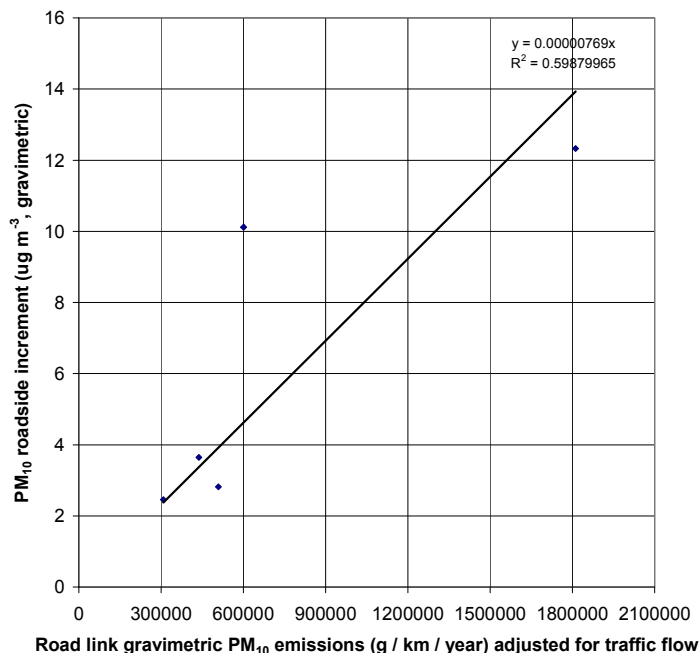
4.10 Verification of mapped gravimetric values

Figures 4.6 and 4.7 show comparisons of gravimetric PM_{10} modelled and measured annual mean PM_{10} concentration in 2004 at both background and roadside monitoring site locations. There were no genuine gravimetric monitoring data outside the AURN to use to verify the model so only the national network sites used to calibrate the models are shown along with verification data for the two sites with KFG instruments operating in 2004. 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 presented in Tables 4.2 and 4.3. All of the modelled values are within the data quality objectives.

Figure 4.6. Verification of background annual mean PM$_{10}$ (gravimetric) model 2005
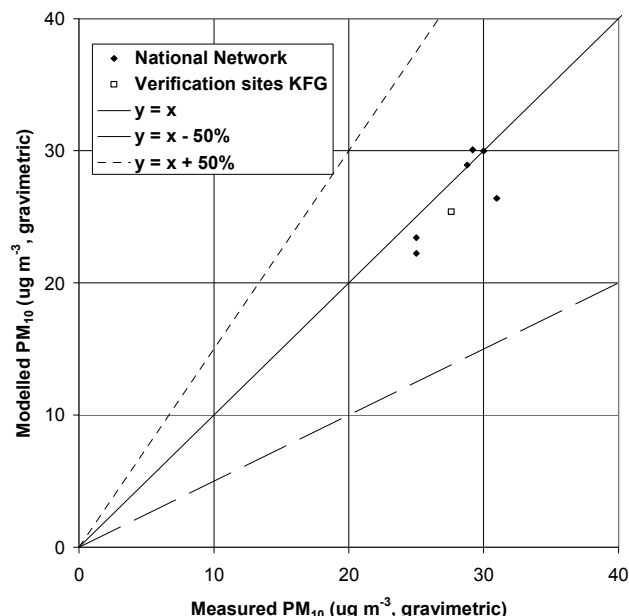
Figure 4.7. Verification of roadside annual mean PM$_{10}$ (gravimetric) model 2005
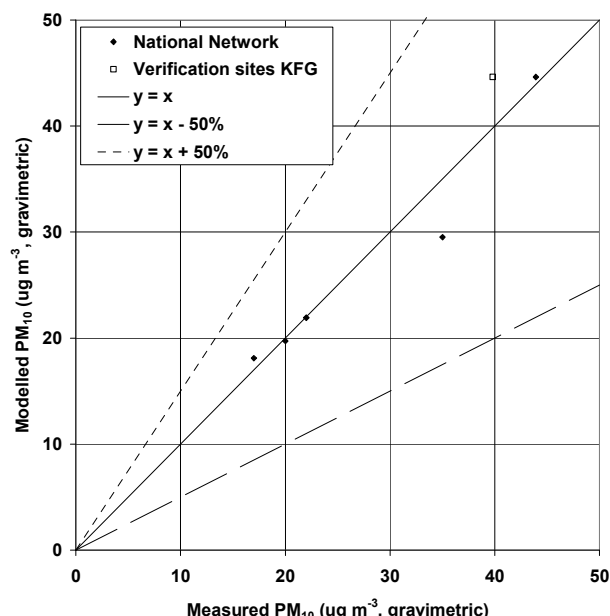
Table 4.2 Summary statistics for comparison between gravimetric modelled and measured concentrations of PM$_{10}$ at background sites

	Mean of measurements (µg m^{-3}, grav)	Mean of model estimates (µg m^{-3}, grav)	r^2	% outside data quality objectives	Number of sites
National Network	28.15	26.84	0.63	0	6
Verification Sites	27.60	25.39	-----	0	1

Table 4.3 Summary statistics for comparison between gravimetric modelled and measured concentrations of PM$_{10}$ at roadside sites

	Mean of measurements (µg m^{-3}, grav)	Mean of model estimates (µg m^{-3}, grav)	r^2	% outside data quality objectives	Number of sites
National Network	27.59	26.77	0.95	0	5
Verification Sites	39.80	44.62	-----	0	1

4.11 Comparison of gravimetric model against gravimetric equivalent TEOM data

Additional PM$_{10}$ modelling was undertaken in TEOM units in 2005 (as in 2004) to provide additional checks on and confidence in the gravimetric mapping. A detailed comparison between TEOM and gravimetric modelling results has not been presented in this report because the detailed comparison performed in 2004 was enough to provide confidence in the methodology used and the results (Stedman *et al.*, 2006a). The gravimetric results compared very favourably against the TEOM results. In 2005, TEOM mapping was used in the same capacity but detailed comparisons are not presented in this report. However, a verification of the gravimetric modelling against measured gravimetric equivalent TEOM concentrations (converted using the accepted factor of 1.3) is presented. Despite not using genuine gravimetric monitoring data, this verification does allow the gravimetric model to be tested against a greater number of monitoring sites, particularly important for the roadside model

which was only tested against a single independent genuine gravimetric site (Marylebone Road KFG). Figure 4.8 shows the verification plot for the gravimetric background model against measured TEOM concentrations *1.3 while Figure 4.9 shows the verification of the roadside model. The results are tabulated in Tables 4.4 and 4.5. These figures do not include the gravimetric data points shown in Figures 4.6 and 4.7.

Figure 4.8. Verification of background annual mean PM$_{10}$ (gravimetric) model 2005 vs. TEOM*1.3
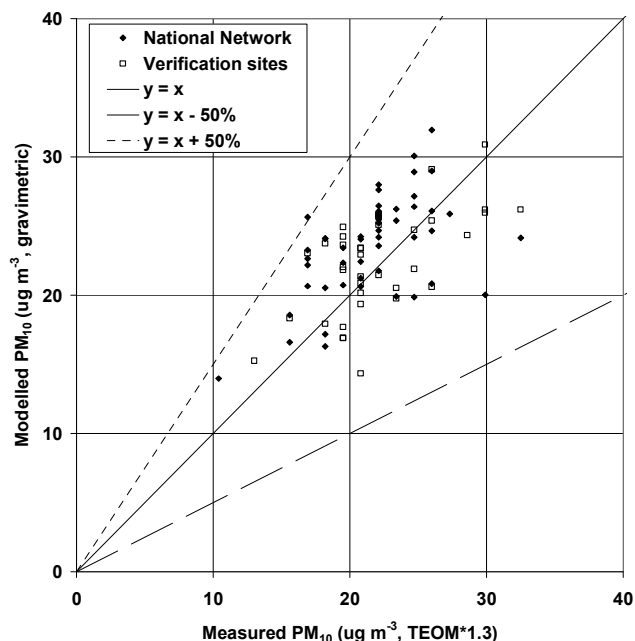
Figure 4.9. Verification of roadside annual mean PM$_{10}$ (gravimetric) model 2005 vs. TEOM*1.3
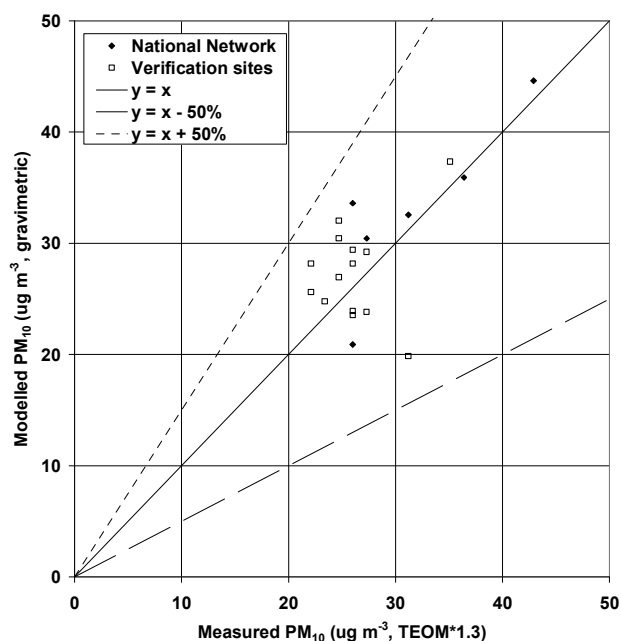
Table 4.4 Summary statistics for comparison between gravimetric modelled and measured TEOM*1.3 concentrations of PM$_{10}$ at background sites

	Mean of measurements (µg m^{-3}, TEOM*1.3)	Mean of model estimates (µg m^{-3}, grav)	r^2	% outside data quality objectives	Number of sites
National Network	21.66	23.61	0.28	2	50
Verification Sites	22.60	22.29	0.13	0	39

Table 4.5 Summary statistics for comparison between gravimetric modelled and measured TEOM*1.3 concentrations of PM$_{10}$ at roadside sites

	Mean of measurements (µg m^{-3}, TEOM*1.3)	Mean of model estimates (µg m^{-3}, grav)	r^2	% outside data quality objectives	Number of sites
National Network	31.63	33.01	0.71	0	6
Verification Sites	26.19	27.37	0.07	0	14

4.12 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 2 limit values by zone, are summarised in Tables 4.6 and 4.7 respectively. These data are also presented in Form 19c of the questionnaire. 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.

Estimates of area and population exposed have been derived from the background maps only. No attempt has been made to derive estimates using maps of roadside concentrations as these maps will only apply to within approximately 10 metres from the road kerb.

Table 4.6 Tabular results of and methods used for supplementary assessment (1999/30/EC Article 7(3) and Annex VIII(II), 2000/69/EC Article 5(3) and Annex VII(II) and 2002/3/EC Article 9(1) and Annex VII(II)) - Results of and methods used for supplementary assessment for PM10 (Stage 1)

Zone	Zone code	Above LV (24hr mean)						Above LV (annual mean)					
		Area		Road length		Population exposed		Area		Road length		Population exposed	
		km²	Method	km	Method	Number	Method	km²	Method	km	Method	Number	Method
Greater London Urban Area	UK0001	17	C	915.4	C	86643	C	0	A	155	A	0	A
West Midlands Urban Area	UK0002	2	C	178.0	C	3234	C	0	A	4	A	0	A
Greater Manchester Urban Area	UK0003	0	C	23.4	C	0	C	0	A	0	A	0	A
West Yorkshire Urban Area	UK0004	0	C	27.8	C	0	C	0	A	0	A	0	A
Tyneside	UK0005	0	C	7.8	C	0	C	0	A	0	A	0	A
Liverpool Urban Area	UK0006	0	C	0.7	C	0	C	0	A	0	A	0	A
Sheffield Urban Area	UK0007	1	C	33.2	C	284	C	0	A	0	A	0	A
Nottingham Urban Area	UK0008	0	C	18.8	C	0	C	0	A	0	A	0	A
Bristol Urban Area	UK0009	0	C	3.9	C	0	C	0	A	0	A	0	A
Brighton/Worthing/Littlehampton	UK0010	0	C	0.0	C	0	C	0	A	0	A	0	A
Leicester Urban Area	UK0011	0	C	16.6	C	0	C	0	A	0	A	0	A
Portsmouth Urban Area	UK0012	0	C	8.7	C	0	C	0	A	0	A	0	A
Teesside Urban Area	UK0013	0	C	4.2	C	0	C	0	A	0	A	0	A
The Potteries	UK0014	0	C	14.1	C	0	C	0	A	1	A	0	A
Bournemouth Urban Area	UK0015	0	C	0.0	C	0	C	0	A	0	A	0	A
Reading/Wokingham Urban Area	UK0016	0	C	0.6	C	0	C	0	A	0	A	0	A
Coventry/Bedworth	UK0017	0	C	11.4	C	0	C	0	A	0	A	0	A
Kingston upon Hull	UK0018	0	C	0.0	C	0	C	0	A	0	A	0	A
Southampton Urban Area	UK0019	0	C	4.3	C	0	C	0	A	0	A	0	A
Birkenhead Urban Area	UK0020	0	C	0.0	C	0	C	0	A	0	A	0	A
Southend Urban Area	UK0021	0	C	3.9	C	0	C	0	A	0	A	0	A
Blackpool Urban Area	UK0022	0	C	0.0	C	0	C	0	A	0	A	0	A
Preston Urban Area	UK0023	0	C	0.0	C	0	C	0	A	0	A	0	A
Glasgow Urban Area	UK0024	0	C	0.0	C	0	C	0	A	0	A	0	A
Edinburgh Urban Area	UK0025	0	C	0.0	C	0	C	0	A	0	A	0	A
Cardiff Urban Area	UK0026	0	C	0.0	C	0	C	0	A	0	A	0	A

Zone	Zone code	Above LV (24hr mean)						Above LV (annual mean)					
		Area		Road length		Population exposed		Area		Road length		Population exposed	
		km²	Method	km	Method	Number	Method	km²	Method	km	Method	Number	Method
Swansea Urban Area	UK0027	0	C	0.0	C	0	C	0	A	0	A	0	A
Belfast Urban Area	UK0028	0	C	3.9	C	0	C	0	A	0	A	0	A
Eastern	UK0029	0	C	44.1	C	0	C	0	A	1	A	0	A
South West	UK0030	0	C	3.4	C	0	C	0	A	0	A	0	A
South East	UK0031	0	C	38.9	C	0	C	0	A	0	A	0	A
East Midlands	UK0032	0	C	37.8	C	0	C	0	A	0	A	0	A
North West & Merseyside	UK0033	0	C	1.5	C	0	C	0	A	0	A	0	A
Yorkshire & Humberside	UK0034	0	C	25.4	C	0	C	0	A	0	A	0	A
West Midlands	UK0035	0	C	28.6	C	0	C	0	A	0	A	0	A
North East	UK0036	0	C	13.0	C	0	C	0	A	0	A	0	A
Central Scotland	UK0037	0	C	0.0	C	0	C	0	A	0	A	0	A
North East Scotland	UK0038	0	C	0.0	C	0	C	0	A	0	A	0	A
Highland	UK0039	0	C	0.0	C	0	C	0	A	0	A	0	A
Scottish Borders	UK0040	0	C	0.0	C	0	C	0	A	0	A	0	A
South Wales	UK0041	0	C	3.0	C	0	C	0	A	0	A	0	A
North Wales	UK0042	0	C	2.3	C	0	C	0	A	0	A	0	A
Northern Ireland	UK0043	0	C	0.0	C	0	C	0	A	0	A	0	A
Total		20		1474.7		90161		0		161		0	

Table 4.7 Tabular results of and methods used for supplementary assessment (1999/30/EC Article 7(3) and Annex VIII(II), 2000/69/EC Article 5(3) and Annex VI(II) and 2002/3/EC Article 9(1) and Annex VII(II)) - Results of and methods used for supplementary assessment for PM10 (Stage 2)

Zone	Zone code	Above LV (24hr mean)						Above LV (annual mean)					
		Area		Road length		Population exposed		Area		Road length		Population exposed	
		km²	Method	km	Method	Number	Method	km²	Method	km	Method	Number	Method
Greater London Urban Area	UK0001							1628	A	1889.0	A	7781081	A
West Midlands Urban Area	UK0002							594	A	560.8	A	2083891	A
Greater Manchester Urban Area	UK0003							547	A	663.7	A	1823138	A
West Yorkshire Urban Area	UK0004							334	A	425.1	A	1088097	A
Tyneside	UK0005							78	A	198.3	A	252546	A
Liverpool Urban Area	UK0006							167	A	224.2	A	639830	A
Sheffield Urban Area	UK0007							165	A	161.1	A	521984	A
Nottingham Urban Area	UK0008							169	A	136.3	A	558935	A
Bristol Urban Area	UK0009							137	A	118.7	A	485412	A
Brighton/Worthing/Littlehampton	UK0010							97	A	82.2	A	386373	A
Leicester Urban Area	UK0011							102	A	92.8	A	374314	A
Portsmouth Urban Area	UK0012							91	A	72.6	A	354964	A
Teesside Urban Area	UK0013							47	A	74.2	A	106884	A
The Potteries	UK0014							91	A	130.0	A	266188	A
Bournemouth Urban Area	UK0015							112	A	71.3	A	337446	A
Reading/Wokingham Urban Area	UK0016							97	A	84.4	A	305786	A
Coventry/Bedworth	UK0017							76	A	34.9	A	277475	A
Kingston upon Hull	UK0018							68	A	43.6	A	237656	A
Southampton Urban Area	UK0019							77	A	65.2	A	262379	A
Birkenhead Urban Area	UK0020							50	A	66.0	A	131840	A
Southend Urban Area	UK0021							64	A	49.8	A	217874	A
Blackpool Urban Area	UK0022							0	A	58.6	A	0	A
Preston Urban Area	UK0023							39	A	45.8	A	132034	A
Glasgow Urban Area	UK0024							7	A	218.3	A	17328	A
Edinburgh Urban Area	UK0025							0	A	58.4	A	0	A
Cardiff Urban Area	UK0026							51	A	52.0	A	200072	A

Zone	Zone code	Above LV (24hr mean)						Above LV (annual mean)					
		Area		Road length		Population exposed		Area		Road length		Population exposed	
		km²	Method	km	Method	Number	Method	km²	Method	km	Method	Number	Method
Swansea Urban Area	UK0027							16	A	64.3	A	29663	A
Belfast Urban Area	UK0028							62	A	174.1	A	223756	A
Eastern	UK0029							19113	A	870.1	A	4903503	A
South West	UK0030							3896	A	644.6	A	2099439	A
South East	UK0031							18362	A	1335.4	A	6145456	A
East Midlands	UK0032							13918	A	673.0	A	3210230	A
North West & Merseyside	UK0033							1893	A	901.5	A	1951996	A
Yorkshire & Humberside	UK0034							2727	A	744.7	A	1822507	A
West Midlands	UK0035							4818	A	547.5	A	2170374	A
North East	UK0036							110	A	223.1	A	147051	A
Central Scotland	UK0037							5	A	72.1	A	4310	A
North East Scotland	UK0038							0	A	38.6	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							292	A	306.6	A	338938	A
North Wales	UK0042							115	A	99.3	A	88768	A
Northern Ireland	UK0043							16	A	103.0	A	48506	A
Total								70231		12475.3		42028021	

5 Benzene

5.1 Introduction

Maps of annual mean benzene concentrations at background and roadside locations in 2005 are presented in Figures 5.1 and 5.2. Benzene concentrations have been calculated using a similar approach to that adopted for NO_x although a different approach has been adopted for the modelling of fugitive and process emissions from point sources.

Figure 5.1. Annual mean background benzene concentration, 2005 ($\mu g\ m^{-3}$)
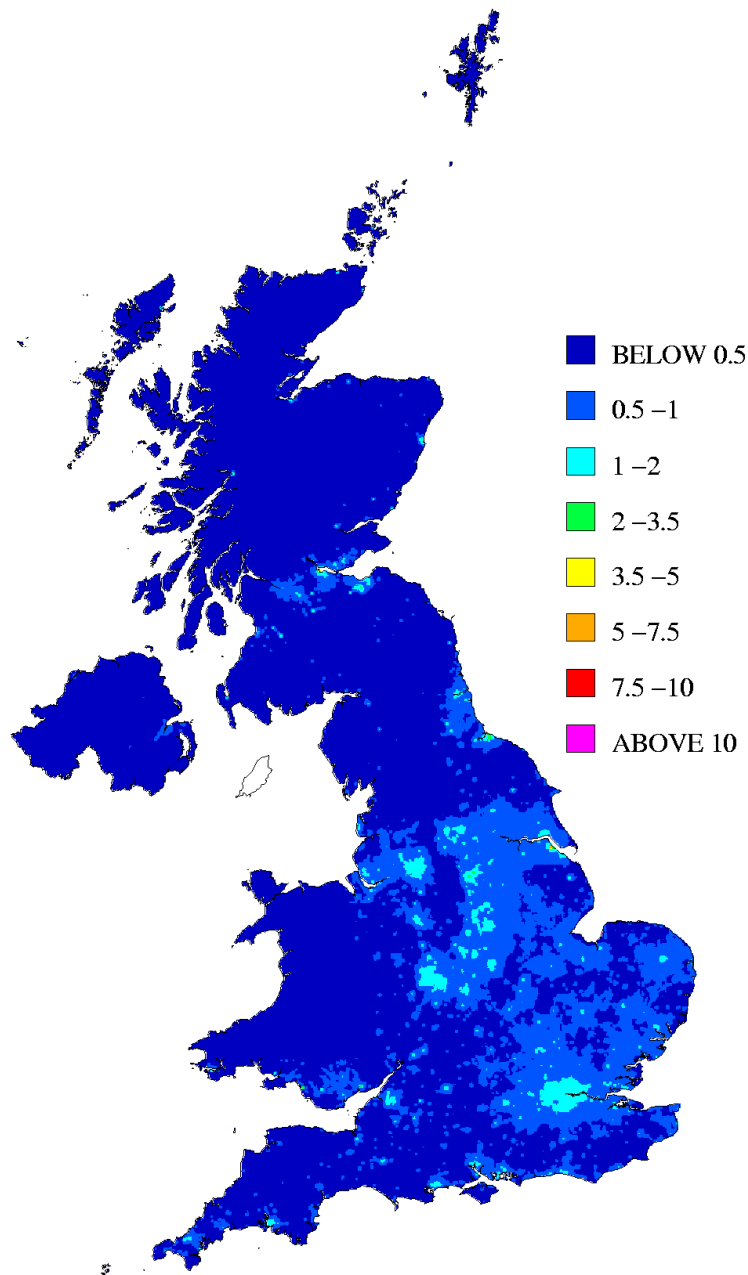
Figure 5.2. Urban major roads, annual mean roadside benzene concentration, 2005 (μg m^{-3})
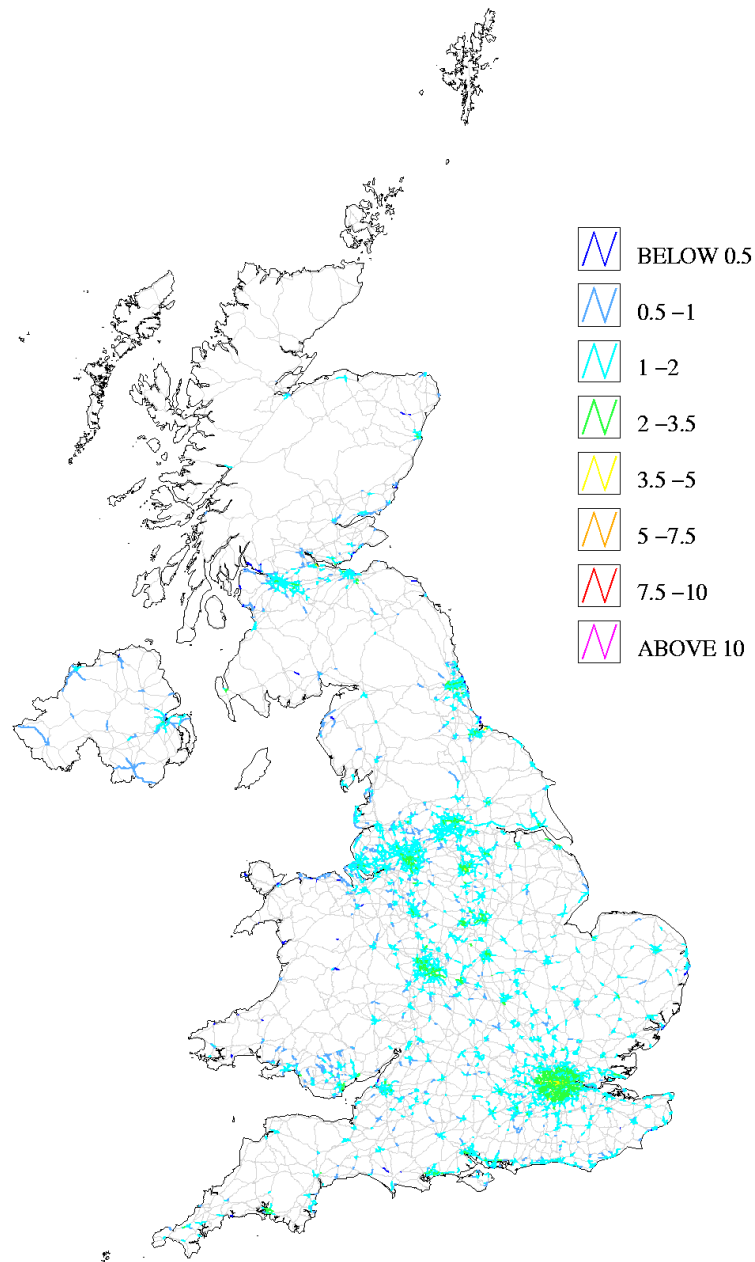
It has been considered that annual mean background benzene concentrations are made up of contributions from:

- Distant sources (characterised by an estimate of rural background concentration)

- Combustion point sources

- Fugitive and process point sources

- Local area sources.

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

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

5.2 Contributions from combustion point sources

Contributions to ground level annual mean benzene concentrations from large combustion-related point sources (those with annual emission greater than 5 tonnes) in the 2004 NAEI were estimated by modelling each source explicitly using an atmospheric dispersion model (ADMS 3.3) and sequential meteorological data for 2005 from Waddington. A total of 25 point sources were modelled. Surface roughness was assumed to be 0.1 metres. Concentrations were calculated for a 100km x 100km square composed of a regularly spaced 5km x 5km resolution receptor grid. Each receptor grid was centred on the point source.

5.3 Contributions from fugitive and process point sources

The contributions to ambient concentrations from fugitive and process emission point sources were modelled using a modified version of the small points model described in Appendix 3. The emissions from these sources are not generally as well characterised in terms of exact location and release parameters as emissions from combustion sources. Separate models are used for the 'in-square' concentration (the concentration in the 1km x 1km grid square that includes the source) and the concentration in surrounding grid squares ('the out-square concentration'). The method was revised in 2004 so that an in-square concentration has been estimated by assessing the concentration resulting from unit emissions released from a volume source of dimensions 200m by 200m and 30m high. The average concentration in the grid square has only been calculated for receptors outside an area 400m by 400m in the centre of the 1km x 1km square so that concentrations within the boundary fence of the process have been excluded. A dispersion kernel approach similar to that adopted for the area sources was used to calculate the out-square concentrations.

The results from this model were verified by comparison with benzene diffusion tube measurements made available by the process operator at Grangemouth and by the local authority at Killingholme. As expected, this generalised model was not able to provide a full description of the exact spatial pattern of measured concentrations close to each refinery but the overall patterns and, more importantly, the maximum modelled concentrations, were in good agreement.

5.4 Contributions from rural background concentrations

Regional rural benzene concentrations were estimated from the map of rural NO_x concentration described in Section 3.4. The rural NO_x map was scaled using the ratio of measured annual mean benzene and NO_x concentrations at the rural Harwell monitoring site in 2005.

5.5 Contributions from area sources

Figure 5.3 shows the calibration of the area source model. The modelled concentrations from point sources and estimated rural benzene concentrations have been subtracted from the measured annual mean concentration at automatic and pumped tube background measurement sites. This corrected background concentration is compared with the modelled area source contribution to annual mean benzene. An empirical method has been used to calculate the contribution to ambient concentrations from area sources. This approach applies an ADMS derived dispersion kernel to calculate the contribution to ambient concentrations at a central receptor location from area source emissions within a 33km x 33km square surrounding each monitoring site. Hourly sequential meteorological data from Waddington in 2005 has been used to construct the dispersion kernels, as described in Appendix 4. The calibration relationship used for large conurbations, for which there is only one point for benzene, was obtained by forcing the line through the origin.

Adjustment factors were applied to the emissions from selected transport sources to represent the diminishing influence of emissions on air quality at the UK land surface, as described in Section 3.5. A factor of 0.36 was applied to aircraft emissions and a factor of 0.25 was applied to 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 point source contributions and constant regional rural concentration were then added, resulting in a map of background annual mean benzene concentrations.

Figure 5.3. Calibration of area source benzene model 2005 (μg m^{-3})
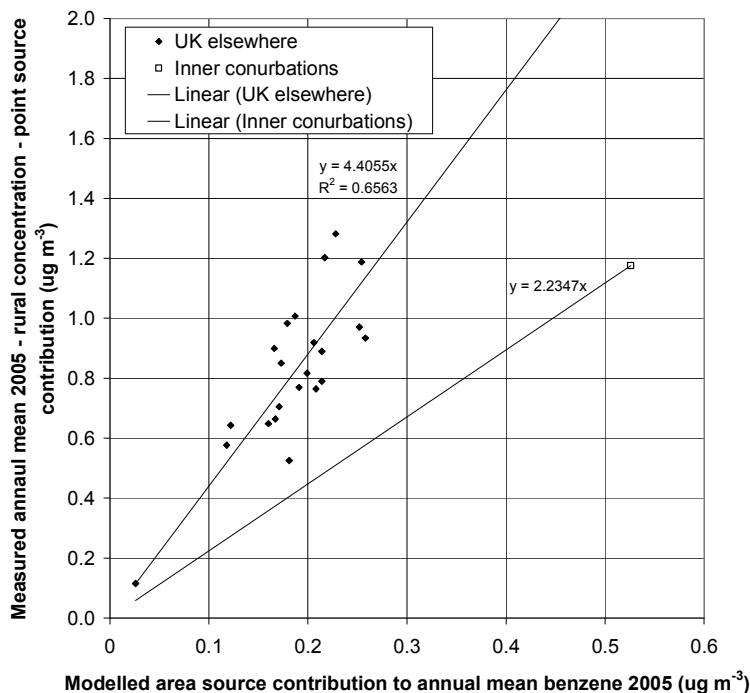
5.6 Roadside concentrations

Calibration of the benzene roadside increment model is shown in Figure 5.4. Roadside concentrations of annual mean benzene for 2005 have been modelled using a similar method to the NO$_x$ modelling described in Section 3.6.

The relationship on this calibration plot is poor and it was decided that there was not an adequately meaningful relationship to ensure the model was robust. As a result, a coefficient was chosen (coefficient = 0.000025) that provided a reasonable representation of the measured concentration - i.e. resulted in the most modelled concentrations being located within the data quality objective range on the verification plot (see Figure 5.6 and Table 5.2). Using this coefficient, only 2 sites (22%) fell outside the data quality objectives range, one being overestimated and the other underestimated.

Figure 5.4. Comparison of benzene roadside increment and road link emission 2005 (μg m^{-3})
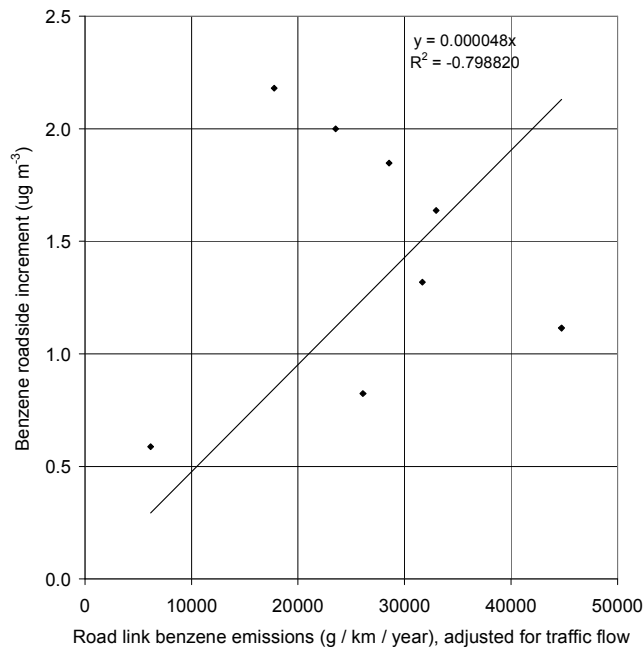
5.7 Verification of mapped values

Figures 5.5 and 5.6 show comparisons of the modelled and measured annual mean benzene concentrations for background and roadside locations. Lines showing
y = x – 50% and y = x + 50% are included in these charts. These represent the AQDD2 data quality objective for modelled benzene concentrations.

Figure 5.5. Verification of background annual mean benzene model 2005
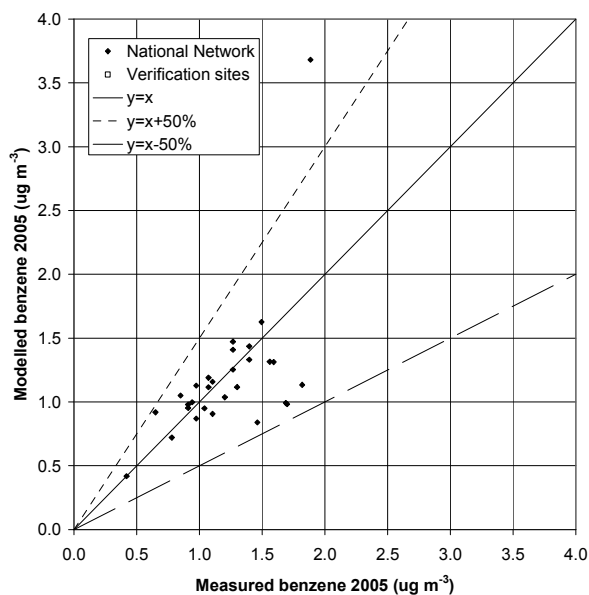
Figure 5.6. Verification of roadside annual mean benzene model 2005
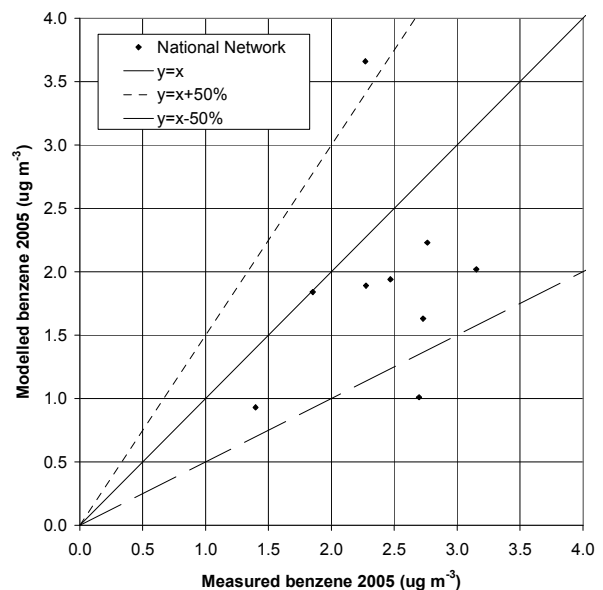
Summary statistics for the comparison between modelled and measured benzene concentrations are listed in Tables 5.1 and 5.2. No monitoring sites were available to provide an independent verification of the background or roadside models

Table 5.1 Summary statistics for comparison between modelled and measured benzene concentrations at background sites (µg m^{-3})

	Mean of measurements (µg m^{-3})	Mean of model estimates (µg m^{-3})	r^2	% outside data quality objectives	Number of sites
National Network	1.21	1.18	0.33	4%	29

Table 5.2 Summary statistics for comparison between modelled and measured benzene concentrations at roadside sites (µg m^{-3})

	Mean of measurements (µg m^{-3})	Mean of model estimates (µg m^{-3})	r^2	% outside data quality objectives	Number of sites
National Network	2.40	1.91	0.04	22%	9

5.8 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 5.3. These data have also been presented in Form 19e of the questionnaire. Method A in this table refers to the modelling method described in this report.

Estimates of area and population exposed have been derived from the background maps only. No attempt has been made to derive estimates using maps of roadside concentrations as these maps will only apply to within approximately 10 metres from the road kerb.

Table 5.3 Tabular results of and methods used for supplementary assessment (1999/30/EC Article 7(3) and Annex VIII(II), 2000/69/EC Article 5(3) and Annex VI(II) and 2002/3/EC Article 9(1) and Annex VII(II))

Zone	Zone code	Above LV					
		Area		Road length		Population exposed	
		km^2	Method	km	Method	Number	Method
Greater London Urban Area	UK0001	0	A	0	A	0	A
West Midlands Urban Area	UK0002	0	A	0	A	0	A
Greater Manchester Urban Area	UK0003	0	A	0	A	0	A
West Yorkshire Urban Area	UK0004	0	A	0	A	0	A
Tyneside	UK0005	0	A	0	A	0	A
Liverpool Urban Area	UK0006	0	A	0	A	0	A
Sheffield Urban Area	UK0007	0	A	0	A	0	A
Nottingham Urban Area	UK0008	0	A	0	A	0	A
Bristol Urban Area	UK0009	0	A	0	A	0	A
Brighton/Worthing/Littlehampton	UK0010	0	A	0	A	0	A
Leicester Urban Area	UK0011	0	A	0	A	0	A
Portsmouth Urban Area	UK0012	0	A	0	A	0	A
Teesside Urban Area	UK0013	0	A	0	A	0	A
The Potteries	UK0014	0	A	0	A	0	A
Bournemouth Urban Area	UK0015	0	A	0	A	0	A
Reading/Wokingham Urban Area	UK0016	0	A	0	A	0	A
Coventry/Bedworth	UK0017	0	A	0	A	0	A
Kingston upon Hull	UK0018	0	A	0	A	0	A
Southampton Urban Area	UK0019	0	A	0	A	0	A
Birkenhead Urban Area	UK0020	0	A	0	A	0	A

Zone	Zone code	Above LV					
		Area		Road length		Population exposed	
		km^2	Method	km	Method	Number	Method
Southend Urban Area	UK0021	0	A	0	A	0	A
Blackpool Urban Area	UK0022	0	A	0	A	0	A
Preston Urban Area	UK0023	0	A	0	A	0	A
Glasgow Urban Area	UK0024	0	A	0	A	0	A
Edinburgh Urban Area	UK0025	0	A	0	A	0	A
Cardiff Urban Area	UK0026	0	A	0	A	0	A
Swansea Urban Area	UK0027	0	A	0	A	0	A
Belfast Urban Area	UK0028	0	A	0	A	0	A
Eastern	UK0029	0	A	0	A	0	A
South West	UK0030	0	A	0	A	0	A
South East	UK0031	0	A	0	A	0	A
East Midlands	UK0032	0	A	0	A	0	A
North West & Merseyside	UK0033	0	A	0	A	0	A
Yorkshire & Humberside	UK0034	6	A	0	A	872	A
West Midlands	UK0035	0	A	0	A	0	A
North East	UK0036	0	A	0	A	0	A
Central Scotland	UK0037	2	A	0	A	79	A
North East Scotland	UK0038	0	A	0	A	0	A
Highland	UK0039	0	A	0	A	0	A
Scottish Borders	UK0040	0	A	0	A	0	A
South Wales	UK0041	0	A	0	A	0	A
North Wales	UK0042	0	A	0	A	0	A
Northern Ireland	UK0043	0	A	0	A	0	A
Total		8		0		950	

6   CO

6.1 Introduction

Maps of maximum 8-hour mean CO concentrations at background and roadside locations in 2005 are presented in Figures 6.1 and 6.2.

First background and roadside maps of annual mean CO were calculated. These maps were then scaled using the relationship between measured annual mean CO concentrations and measured maximum of 8-hour concentrations from the national network. Only the maximum 8-hour mean maps are required for comparison with the AQDD2 limit value but annual mean maps are prepared as an intermediate step within the modelling exercise. The annual mean maps are not presented in this report but details of the calibration and the verification of the annual mean background and roadside models are presented because they are directly relevant to the model output of the maximum 8-hour metric.

CO concentrations have been calculated using a similar approach to that adopted for NO_x but without the inclusion of a mapped regional rural component because regional rural CO concentrations in the UK are not well characterised within the monitoring networks.

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

- Large point sources
- Small point sources
- Local area sources
- Regional background

The area source model has been calibrated using data from the national monitoring networks. At locations close to busy roads an additional roadside contribution was added to account for contributions to total CO from road traffic sources.

Figure 6.1. Maximum 8-hour mean background CO concentration, 2005 (mg m^{-3})
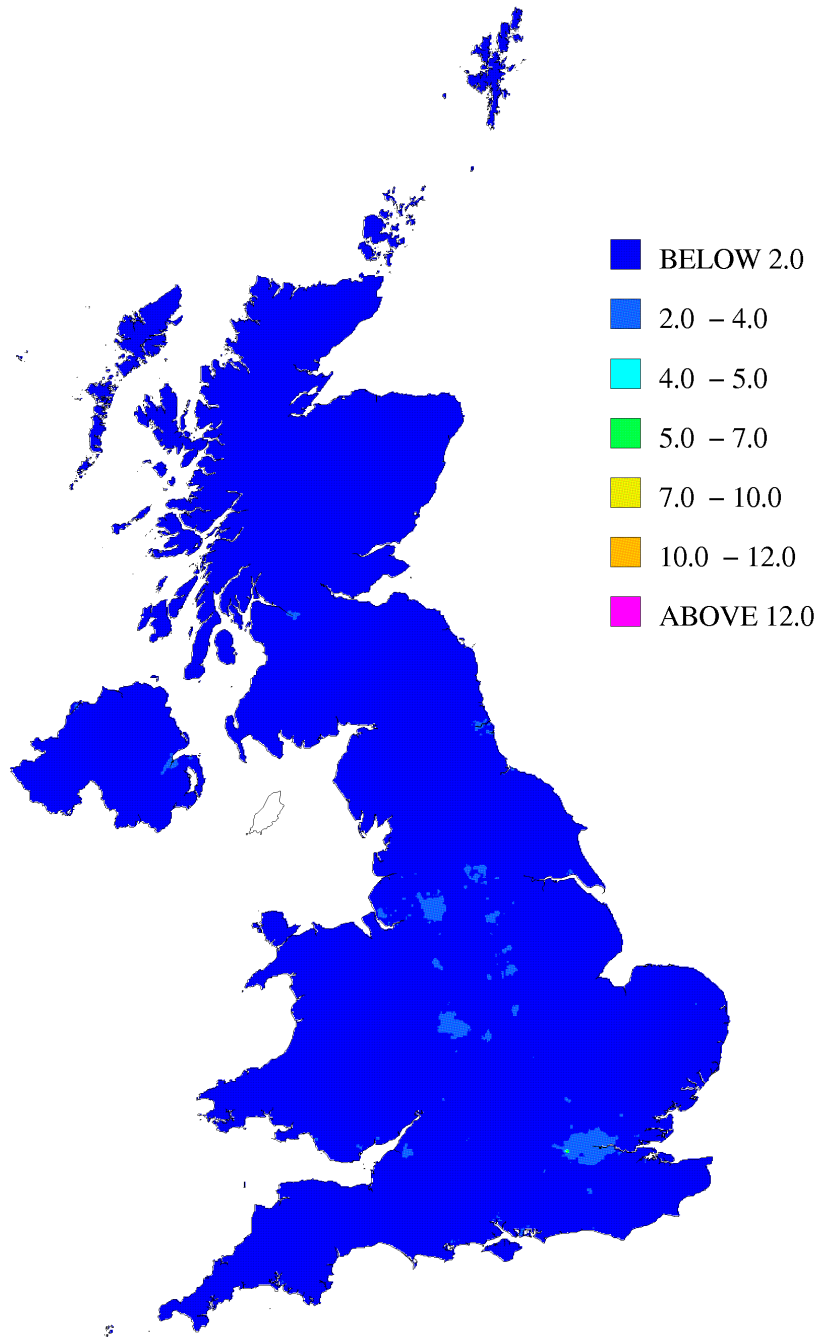
© Crown copyright. All rights reserved Defra, Licence number 100018880 [2006]

Figure 6.2. Urban major roads, maximum 8-hour mean roadside CO concentration, 2005 (mg m^{-3})
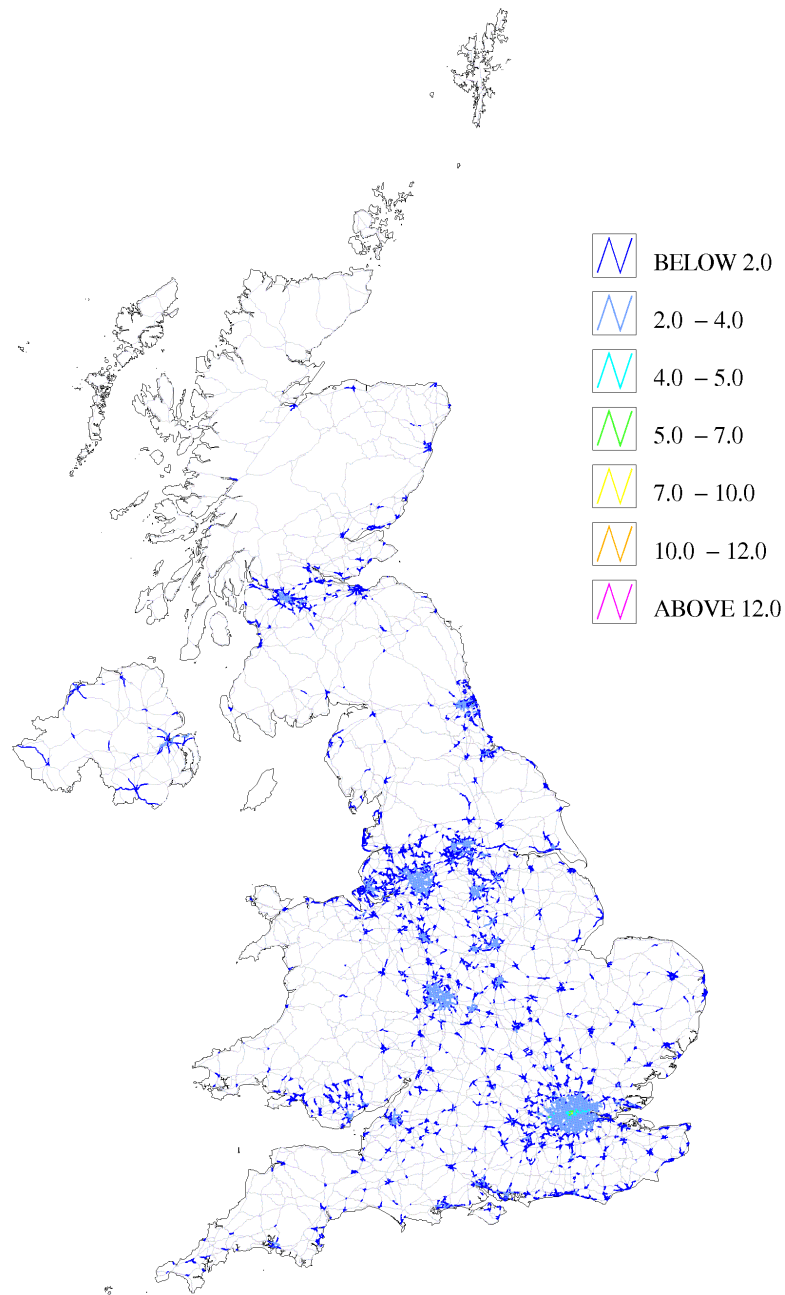
	BELOW 2.0
	2.0 – 4.0
	4.0 – 5.0
	5.0 – 7.0
	7.0 – 10.0
	10.0 – 12.0
	ABOVE 12.0

6.2 Contributions from large point sources

Contributions to ground level annual mean CO concentrations from large point sources (those with annual emission greater than 3000 tonnes) in the 2004 NAEI were estimated by modelling each source explicitly using an atmospheric dispersion model (ADMS 3.3) and sequential meteorological data for 2005 from Waddington. A total of 50 point sources were modelled. Surface roughness was assumed to be 0.1 metres. Concentrations were calculated for a 100km x 100km square composed of

a regularly spaced 5km x 5km resolution receptor grid. Each receptor grid was centred on the point source.

6.3 Contributions from small point sources

Contributions from CO point sources with less than 3000 tonnes per annum release were modelled using the small points model described in Appendix 3.

6.4 Contributions from area sources

Figure 6.3 shows the calibration of the annual mean area source CO model for background locations.

Figure 6.3. Calibration of 2005 background annual mean CO model (mg m^{-3})
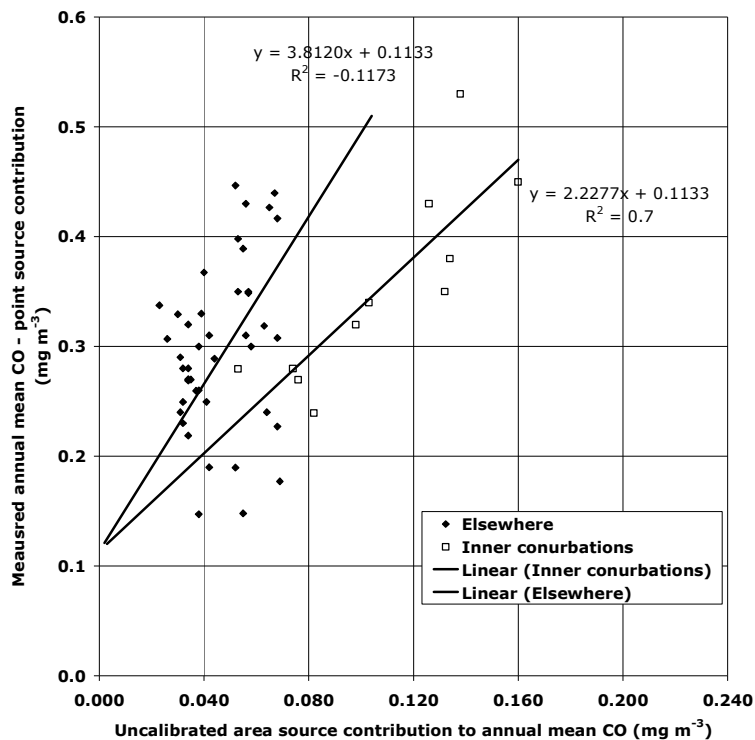
Measured annual mean CO concentrations at background sites have been corrected for contributions from modelled large and small point sources and compared with the modelled area source contribution to annual mean CO concentration. Calibration plots are shown in mg m^{-3}. An empirical method has been used to calculate the contribution to ambient concentrations from area sources. This approach applies an ADMS derived dispersion kernel to calculate the contribution to ambient concentrations at a central receptor location from area source emissions within a 33km x 33km square surrounding each monitoring site. Hourly sequential meteorological data from Waddington in 2005 has been used to construct the dispersion kernels, as described in Appendix 4.

Examination of Figure 6.3 shows that the monitoring sites fall into two groups:

• Inner conurbations

• Elsewhere

'Inner conurbations' includes Inner and Central London and central Birmingham. The intercept for the elsewhere relationship was taken to represent regional rural annual mean CO concentrations in the UK. The intercept of 0.1133 μg m^{-3} of the inner conurbations relationship was taken to represent the regional background CO concentrations across the UK.

Adjustment factors were applied to the emissions from selected transport sources to represent the diminishing influence of emissions on air quality at the UK land surface, as described in Section 3.5. A factor of 0.36 was applied to aircraft emissions and a factor of 0.25 was applied to 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 point source contributions and constant regional rural concentration were then added, resulting in a map of background annual mean CO concentrations.

6.5 Roadside annual mean CO concentrations

Calibration of the CO roadside increment model is shown in Figure 6.4. We have considered that the annual mean concentration of CO at a roadside location is made up of two parts: the background concentration (as described above) and a roadside increment:

roadside CO concentration = background CO concentration + CO roadside increment

The NAEI provides estimates of CO emissions for major road links in the UK for 2004 (Dore *et al.*, 2006) and these have been adjusted to provide estimates of emissions in 2005. The background CO component at these roadside monitoring sites was derived from the map described above. The roadside increment was calculated by multiplying an adjusted road link emission by the empirical dispersion coefficient determined from Figure 6.4. The traffic flow adjustment factors used were the same as those applied in the roadside NO$_x$ modelling (Section 3.6) and are presented in Figure 3.6. The relationship between the measured annual mean roadside CO concentration and road link emissions is clearly poor. This is due to a combination of the greater uncertainty associated with current low measured CO concentrations and road link emission inventories. Emissions of CO are highly dependent on local traffic conditions, particularly at low speeds and detailed information on speeds and congestion are not available from national inventories.

Figure 6.4. Calibration of 2005 roadside annual mean CO model (mg m^{-3})
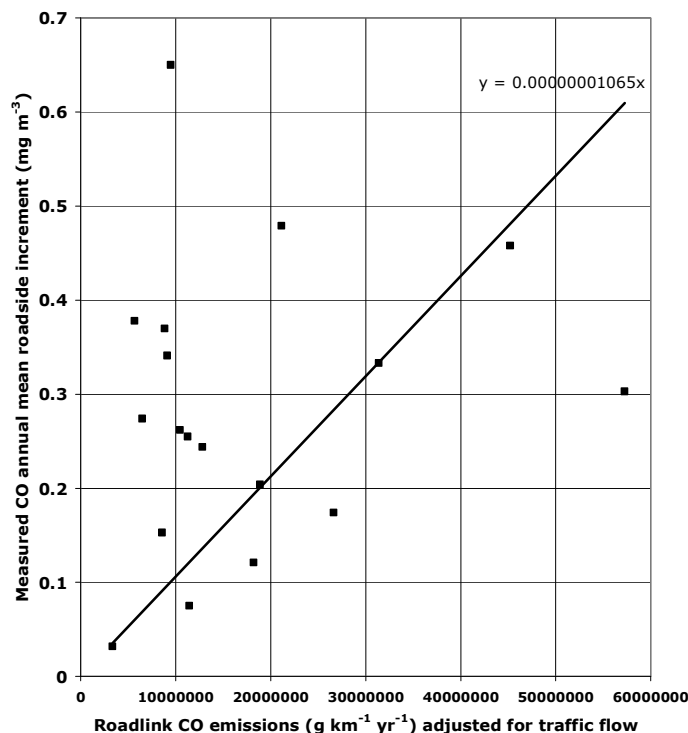
6.6 Modelling the maximum 8-hour mean CO concentration

The map of maximum 8-hour mean CO concentrations at background locations shown in Figure 6.1 was calculated from the map of background annual mean CO concentrations by scaling annual mean map with the relationship between measured annual mean concentrations and the measured maximum 8-hour concentrations from the national network. Figure 6.5 shows this relationship.

Figure 6.5 Calibration of 2005 background maximum 8-hour mean CO model (mg m^{-3})
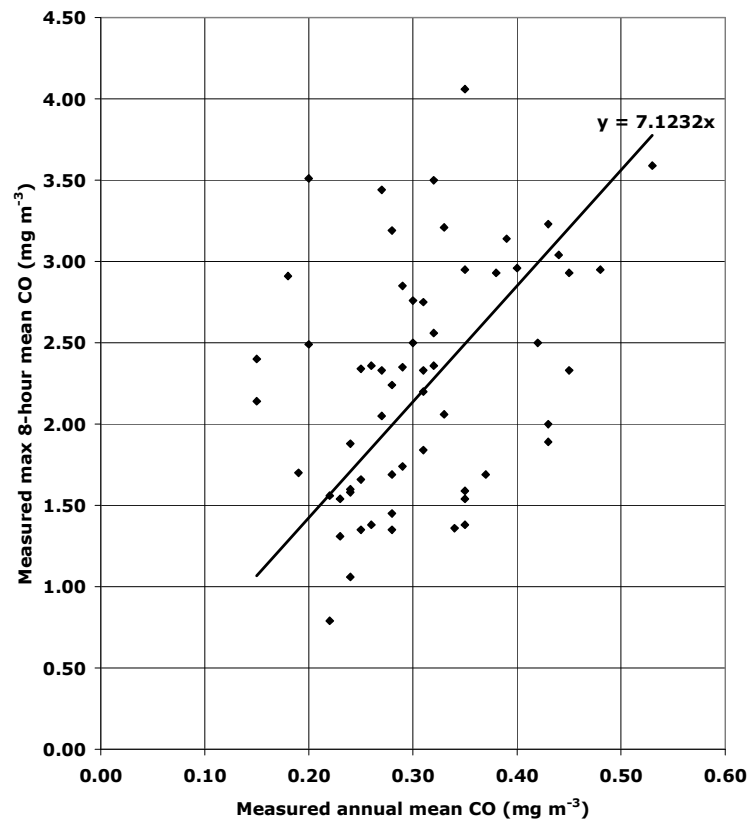
The map of maximum 8-hour mean CO concentrations at roadside locations shown in Figure 6.2 was calculated from map of annual mean concentrations at roadside locations. The empirical relationship used to scale the annual mean roadside map to derive the maximum 8-hour mean map is presented in Figure 6.6. Roadside concentrations for urban roads only are reported to the EU and included in this report.

Figure 6.6. Calibration of 2005 roadside maximum 8-hour CO model (mg m^{-3})
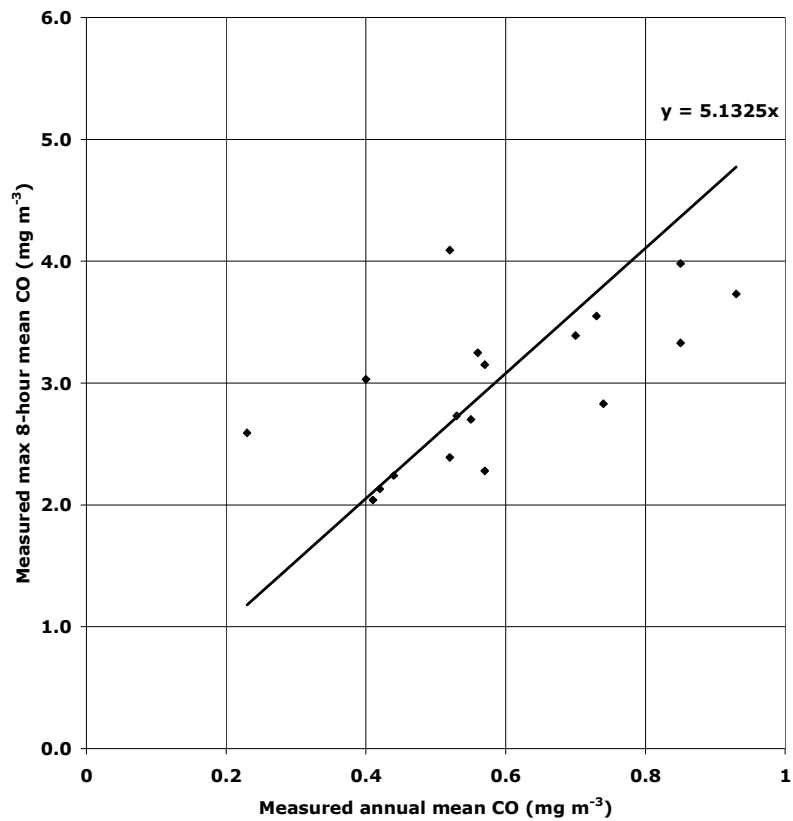
6.7 Verification of mapped values

Figures 6.7 to 6.10 show comparisons of the modelled and measured annual mean and maximum 8-hour CO concentrations for background and roadside locations. The national network sites used to calibrate the models are shown in addition to the verification sites. Lines showing y = x – 50% and y = x + 50% are included in these charts – these represent the AQDD2 data quality objective for modelled carbon monoxide concentrations. Summary statistics for the comparison between modelled and measured carbon monoxide concentrations are listed in Tables 6.1 to 6.4.

Figure 6.7. Verification of background annual mean CO model 2005
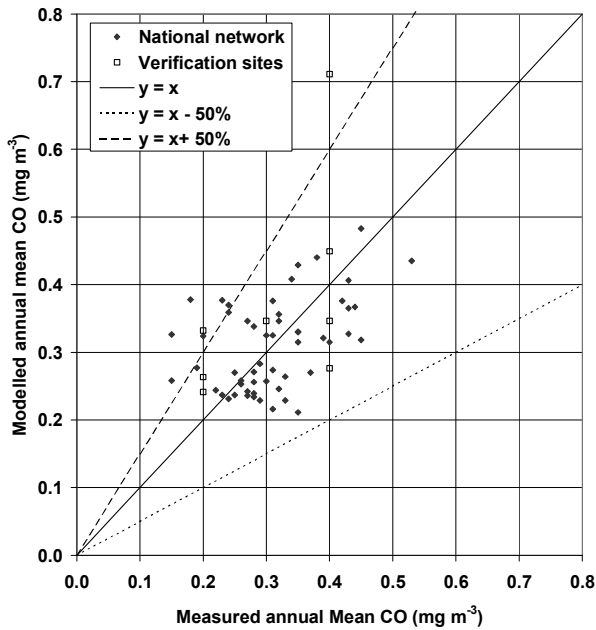
Figure 6.8. Verification of background maximum 8-hour mean CO model 2005
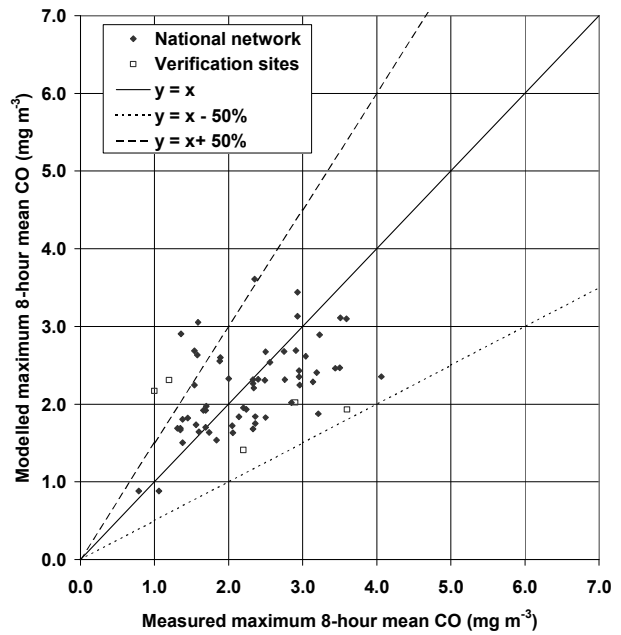
Figure 6.9. Verification of roadside annual mean CO model 2005
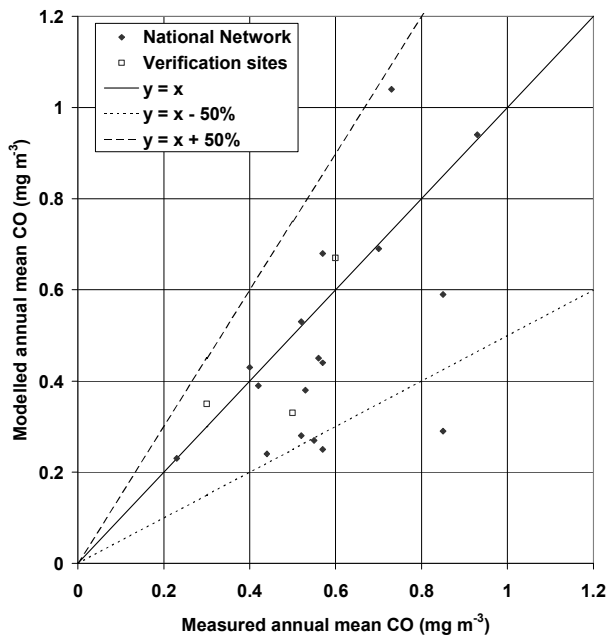
Figure 6.10. Verification of roadside maximum 8-hour mean CO model 2005
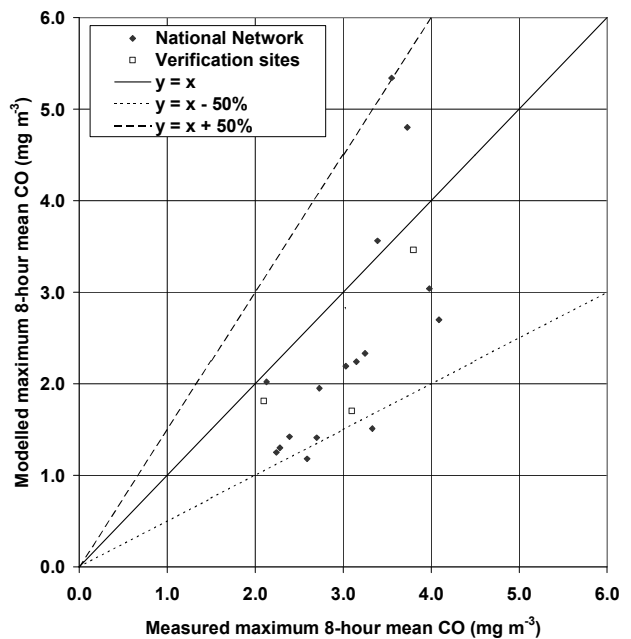
Table 6.1. Summary statistics for comparison between modelled and measured annual mean CO concentrations at background sites (mg m^{-3})

	Mean of measurements (mg m^{-3})	Mean of model estimates (mg m^{-3})	r^2	% outside data quality objectives	Number of sites
National Network	0.31	0.31	0.20	5.9	54
Verification Sites	0.31	0.37	0.30	25	8

Table 6.2. Summary statistics for comparison between modelled and measured maximum 8-hour mean CO concentrations at background sites (mg m^{-3})

	Mean of measurements (mg m^{-3})	Mean of model estimates (mg m^{-3})	r^2	% outside data quality objectives	Number of sites
National Network	2.29	2.21	0.29	0.0	54
Verification Sites	2.29	2.64	0.15	25	8

Table 6.3. Summary statistics for comparison between modelled and measured annual mean CO concentrations at roadside sites (mg m^{-3})

	Mean of measurements (mg m^{-3})	Mean of model estimates (mg m^{-3})	r^2	% outside data quality objectives	Number of sites
National Network	0.58	0.48	0.35	17.6	17
Verification Sites	0.47	0.45	0.30	0	3

Table 6.4. Summary statistics for comparison between modelled and measured maximum 8-hour mean CO concentrations at roadside sites (mg m^{-3})

	Mean of measurements (mg m^{-3})	Mean of model estimates (mg m^{-3})	r^2	% outside data quality objectives	Number of sites
National Network	3.24	2.45	0.32	17.6	17
Verification Sites	3.00	2.32	0.15	0	3

6.8 Detailed comparison of modelling results with limit values

Modelling results for CO have not been tabulated here because the modelled and measured CO concentrations for 2005 are below the limit value for all zones.

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

7.1 Results for 2005

The tables included in this section are from Form 8 of the questionnaire. Exceedence (or otherwise) of the limit value (LV) and limit value plus margin of tolerance (LV + MOT) where this exists are indicated by a 'y' for measured exceedences and with an 'm' for modelled exceedences. If both measurements and model estimates show that a threshold has been exceeded then the measurements are regarded as the primary basis for compliance status and 'y' 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 'n' indicates that the limit value is not applicable for that zone. The ecosystem and vegetation limit values, for example, do not apply in agglomeration zones.

The results of the air quality assessments for SO_2, NO_2 and NO_x, PM_{10}, lead, benzene and CO are listed in Tables 7.1 to 7.6. The relationship between the number of days with PM_{10} concentrations greater than $50 \mu g \ m^{-3}$ and annual means is less certain than the Stage 2 24-hour LV as discussed in Section 4.1. This is why we have not attempted to model exceedences of this LV. In Table 7.3, however we have assumed that a modelled exceedence of the Stage 1 24-hour LV implies an exceedence of the Stage 2 24-hour LV.

We have assessed that lead concentrations were below the LV in all zones where measurements have not been made on the basis of emission inventory results (objective estimation).

Table 7.1. List of zones and agglomerations where levels exceed or do not exceed limit values (LV) or limit values plus margin of tolerance (LV + MOT) for SO$_2$ (96/62/EC Articles 8, 9 and 11, 1999/30/EC Annexes I, II, III and IV, 2000/69/EC Annexes I and II)

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			y		y		n		n
West Midlands Urban Area	UK0002			y		y		n		n
Greater Manchester Urban Area	UK0003			y		y		n		n
West Yorkshire Urban Area	UK0004			y		y		n		n
Tyneside	UK0005			y		y		n		n
Liverpool Urban Area	UK0006			y		y		n		n
Sheffield Urban Area	UK0007			y		y		n		n
Nottingham Urban Area	UK0008			y		y		n		n
Bristol Urban Area	UK0009			m		m		n		n
Brighton/Worthing/Littlehampton	UK0010			y		y		n		n
Leicester Urban Area	UK0011			y		y		n		n
Portsmouth Urban Area	UK0012			y		y		n		n
Teesside Urban Area	UK0013			y		y		n		n
The Potteries	UK0014			m		m		n		n
Bournemouth Urban Area	UK0015			y		y		n		n
Reading/Wokingham Urban Area	UK0016			m		m		n		n
Coventry/Bedworth	UK0017			y		y		n		n
Kingston upon Hull	UK0018			y		y		n		n
Southampton Urban Area	UK0019			y		y		n		n
Birkenhead Urban Area	UK0020			m		m		n		n
Southend Urban Area	UK0021			y		y		n		n
Blackpool Urban Area	UK0022			m		m		n		n
Preston Urban Area	UK0023			y		y		n		n
Glasgow Urban Area	UK0024			y		y		n		n
Edinburgh Urban Area	UK0025			y		y		n		n
Cardiff Urban Area	UK0026			m		m		n		n
Swansea Urban Area	UK0027			y		y		n		n
Belfast Urban Area	UK0028			y		y		n		n
Eastern	UK0029	m			m			y		y
South West	UK0030			y		y		m		m

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
South East	UK0031			y			y		y		y
East Midlands	UK0032			y			y		y		y
North West & Merseyside	UK0033			y			y		m		m
Yorkshire & Humberside	UK0034			y			y		m		m
West Midlands	UK0035			m			m		m		m
North East	UK0036			y			y		m		m
Central Scotland	UK0037			y			y		m		m
North East Scotland	UK0038			y			y		m		m
Highland	UK0039			m			m		m		m
Scottish Borders	UK0040			m			m		m		m
South Wales	UK0041			y			y		y		y
North Wales	UK0042			y			y		m		m
Northern Ireland	UK0043			y			y		m		m

Table 7.2. List of zones and agglomerations where levels exceed or do not exceed limit values (LV) or limit values plus margin of tolerance (LV+MOT) for NO$_2$ and NO$_x$ (96/62/EC Articles 8, 9 and 11 and 1999/30/EC Annexes I, II, III and IV)

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	y			y				n
West Midlands Urban Area	UK0002			y	m				n
Greater Manchester Urban Area	UK0003			y	y				n
West Yorkshire Urban Area	UK0004			y	m				n
Tyneside	UK0005			y	m				n
Liverpool Urban Area	UK0006			y	m				n
Sheffield Urban Area	UK0007			y	m				n
Nottingham Urban Area	UK0008			y	m				n
Bristol Urban Area	UK0009		y		y				n
Brighton/Worthing/Littlehampton	UK0010			y	m				n
Leicester Urban Area	UK0011			y	m				n
Portsmouth Urban Area	UK0012			y	m				n

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
Teesside Urban Area	UK0013			y	m				n
The Potteries	UK0014			y	m				n
Bournemouth Urban Area	UK0015			y		m			n
Reading/Wokingham Urban Area	UK0016			y	m				n
Coventry/Bedworth	UK0017			y	m				n
Kingston upon Hull	UK0018				m				n
Southampton Urban Area	UK0019			y	m				n
Birkenhead Urban Area	UK0020					m			n
Southend Urban Area	UK0021			y	m				n
Blackpool Urban Area	UK0022						m		n
Preston Urban Area	UK0023					m			n
Glasgow Urban Area	UK0024			y	y				n
Edinburgh Urban Area	UK0025			y	m				n
Cardiff Urban Area	UK0026				m				n
Swansea Urban Area	UK0027			y			y		n
Belfast Urban Area	UK0028				m				n
Eastern	UK0029			y	m				y
South West	UK0030			y	y				y
South East	UK0031			y	y				y
East Midlands	UK0032			y	m				y
North West & Merseyside	UK0033			y	m				m
Yorkshire & Humberside	UK0034			y	m				y
West Midlands	UK0035				m				m
North East	UK0036			y	m				m
Central Scotland	UK0037			y	m				m
North East Scotland	UK0038			y	m				m
Highland	UK0039			y			y		m
Scottish Borders	UK0040			y			y		y
South Wales	UK0041			y	m				y
North Wales	UK0042			y	m				y
Northern Ireland	UK0043			y			y		m

Table 7.3. List of zones and agglomerations where levels exceed or do not exceed limit values (LV) or limit values plus margin of tolerance (LV+MOT) for PM$_{10}$ (96/62/EC Articles 8, 9 and 11 and 1999/30/EC Annexes I, II, III and IV)

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	≤LV	>LV+MOT	≤LV+MOT; >LV	≤LV
Greater London Urban Area	UK0001	y			y			y		y		
West Midlands Urban Area	UK0002	m			m			y		m		
Greater Manchester Urban Area	UK0003	m						y		m		
West Yorkshire Urban Area	UK0004	y						y		y		
Tyneside	UK0005	m						m		m		
Liverpool Urban Area	UK0006	m						m		m		
Sheffield Urban Area	UK0007	m						m		m		
Nottingham Urban Area	UK0008	m						m		m		
Bristol Urban Area	UK0009	m						m		m		
Brighton/Worthing/Littlehampton	UK0010	y						y		y		
Leicester Urban Area	UK0011	m						m		m		
Portsmouth Urban Area	UK0012	m						m		m		
Teesside Urban Area	UK0013	m						y		m		
The Potteries	UK0014	m			m			m		m		
Bournemouth Urban Area	UK0015			y				y		m		
Reading/Wokingham Urban Area	UK0016	m						m		m		
Coventry/Bedworth	UK0017	m						m		m		
Kingston upon Hull	UK0018			y					y	m		
Southampton Urban Area	UK0019	m						m		m		
Birkenhead Urban Area	UK0020			m							m	
Southend Urban Area	UK0021	m						m		m		
Blackpool Urban Area	UK0022			m					y		m	
Preston Urban Area	UK0023			y				y			m	
Glasgow Urban Area	UK0024			y					y	m		
Edinburgh Urban Area	UK0025			y				y			m	
Cardiff Urban Area	UK0026			m							m	
Swansea Urban Area	UK0027			y				y			y	
Belfast Urban Area	UK0028	m						m		m		
Eastern	UK0029	m			m			m		m		
South West	UK0030	m						m		m		
South East	UK0031	m						m		m		

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	≤LV	>LV+ MOT	≤LV+ MOT; >LV	≤LV
East Midlands	UK0032	m					y	y		m		
North West & Merseyside	UK0033	m					y	y		m		
Yorkshire & Humberside	UK0034	m					y	y		m		
West Midlands	UK0035	m					m	m		m		
North East	UK0036	m					y	m		m		
Central Scotland	UK0037			y			y		y		m	
North East Scotland	UK0038			y			y		y		m	
Highland	UK0039			y			y		y			y
Scottish Borders	UK0040			y			y		y			y
South Wales	UK0041	m					y	m		m		
North Wales	UK0042	m					y	y		m		
Northern Ireland	UK0043			y			y		y		y	

Table 7.4. List of zones and agglomerations where levels exceed or do not exceed limit values (LV) or limit values plus margin of tolerance (LV+MOT) for lead (96/62/EC Articles 8, 9 and 11 and 1999/30/EC Annexes I, II, III and IV)

Zone	Zone code	LV		
		>LV+MOT	≤LV+MOT; >LV	≤LV
Greater London Urban Area	UK0001			y
West Midlands Urban Area	UK0002			y
Greater Manchester Urban Area	UK0003			y
West Yorkshire Urban Area	UK0004			y
Tyneside	UK0005			y
Liverpool Urban Area	UK0006			m
Sheffield Urban Area	UK0007			y
Nottingham Urban Area	UK0008			m
Bristol Urban Area	UK0009			y
Brighton/Worthing/Littlehampton	UK0010			m
Leicester Urban Area	UK0011			m
Portsmouth Urban Area	UK0012			m
Teesside Urban Area	UK0013			m
The Potteries	UK0014			m
Bournemouth Urban Area	UK0015			m
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			m
Preston Urban Area	UK0023			m
Glasgow Urban Area	UK0024			y
Edinburgh Urban Area	UK0025			m
Cardiff Urban Area	UK0026			y
Swansea Urban Area	UK0027			y
Belfast Urban Area	UK0028			m
Eastern	UK0029			m
South West	UK0030			y
South East	UK0031			m
East Midlands	UK0032			m
North West & Merseyside	UK0033			y
Yorkshire & Humberside	UK0034			m
West Midlands	UK0035			m
North East	UK0036			m
Central Scotland	UK0037			y
North East Scotland	UK0038			y
Highland	UK0039			m
Scottish Borders	UK0040			y
South Wales	UK0041			y
North Wales	UK0042			m
Northern Ireland	UK0043			m

Table 7.5 List of zones and agglomerations where levels exceed or do not exceed limit values (LV) or limit values plus margin of tolerance (LV + MOT) for benzene (96/62/EC Articles 8, 9 and 11, 1999/30/EC Annexes I, II, III and IV, 2000/69/EC Annexes I and II)

Zone	Zone code	LV		
		>LV + MOT	≤LV+MOT; >LV	≤LV
Greater London Urban Area	UK0001			y
West Midlands Urban Area	UK0002			y
Greater Manchester Urban Area	UK0003			y
West Yorkshire Urban Area	UK0004			y
Tyneside	UK0005			y
Liverpool Urban Area	UK0006			y
Sheffield Urban Area	UK0007			y
Nottingham Urban Area	UK0008			y
Bristol Urban Area	UK0009			y
Brighton/Worthing/Littlehampton	UK0010			y
Leicester Urban Area	UK0011			y
Portsmouth Urban Area	UK0012			y
Teesside Urban Area	UK0013			y
The Potteries	UK0014			y
Bournemouth Urban Area	UK0015			y
Reading/Wokingham Urban Area	UK0016			y
Coventry/Bedworth	UK0017			y
Kingston upon Hull	UK0018			y
Southampton Urban Area	UK0019			y
Birkenhead Urban Area	UK0020			m
Southend Urban Area	UK0021			y
Blackpool Urban Area	UK0022			m
Preston Urban Area	UK0023			m
Glasgow Urban Area	UK0024			y
Edinburgh Urban Area	UK0025			y
Cardiff Urban Area	UK0026			m
Swansea Urban Area	UK0027			m
Belfast Urban Area	UK0028			y
Eastern	UK0029			y
South West	UK0030			y
South East	UK0031			y
East Midlands	UK0032			y
North West & Merseyside	UK0033			y
Yorkshire & Humberside	UK0034		m	
West Midlands	UK0035			y
North East	UK0036			y
Central Scotland	UK0037		m	
North East Scotland	UK0038			m
Highland	UK0039			m
Scottish Borders	UK0040			m
South Wales	UK0041			y
North Wales	UK0042			m
Northern Ireland	UK0043			m

Table 7.6 List of zones and agglomerations where levels exceed or do not exceed limit values (LV) or limit values plus margin of tolerance (LV + MOT) for CO (96/62/EC Articles 8, 9 and 11, 1999/30/EC Annexes I, II, III and IV, 2000/69/EC Annexes I and II)

Zone	Zone code	LV		
		>LV + MOT	≤LV + MOT; >LV	≤LV
Greater London Urban Area	UK0001			y
West Midlands Urban Area	UK0002			y
Greater Manchester Urban Area	UK0003			y
West Yorkshire Urban Area	UK0004			y
Tyneside	UK0005			y
Liverpool Urban Area	UK0006			y
Sheffield Urban Area	UK0007			y
Nottingham Urban Area	UK0008			y
Bristol Urban Area	UK0009			y
Brighton/Worthing/Littlehampton	UK0010			y
Leicester Urban Area	UK0011			y
Portsmouth Urban Area	UK0012			y
Teesside Urban Area	UK0013			y
The Potteries	UK0014			y
Bournemouth Urban Area	UK0015			y
Reading/Wokingham Urban Area	UK0016			y
Coventry/Bedworth	UK0017			y
Kingston upon Hull	UK0018			m
Southampton Urban Area	UK0019			y
Birkenhead Urban Area	UK0020			m
Southend Urban Area	UK0021			y
Blackpool Urban Area	UK0022			m
Preston Urban Area	UK0023			y
Glasgow Urban Area	UK0024			y
Edinburgh Urban Area	UK0025			y
Cardiff Urban Area	UK0026			m
Swansea Urban Area	UK0027			y
Belfast Urban Area	UK0028			y
Eastern	UK0029			y
South West	UK0030			y
South East	UK0031			y
East Midlands	UK0032			y
North West & Merseyside	UK0033			y
Yorkshire & Humberside	UK0034			m
West Midlands	UK0035			m
North East	UK0036			y
Central Scotland	UK0037			y
North East Scotland	UK0038			y
Highland	UK0039			y
Scottish Borders	UK0040			y
South Wales	UK0041			m
North Wales	UK0042			y
Northern Ireland	UK0043			y

7.2 Measured exceedences of Limit Values + Margins of Tolerance

Form 11 of the questionnaire requires reasons associated with the measured exceedences of the limit value and margin of tolerance to be documented. This information is summarised in Tables 7.7 to 7.9 for monitoring stations in the UK at which exceedences of the limit value and margin of tolerance were measured. Measured exceedences of the limit value and margin of tolerance for 1-hour mean NO_2 are listed in Table 7.7. Measured exceedences of the limit value and margin of tolerance for annual mean NO_2 are listed in Table 7.8. Measured exceedences of the limit value for 24-hour mean and annual mean PM_{10} are listed in Tables 7.9 and 7.10 (there is no margin of tolerance for PM_{10} in 2005 as the limit values are now in force).

Details of the reason codes and associated explanations used in the compilation of the 2005 questionnaire are presented in Appendix 5 of this report.

Table 7.7. Measured exceedences of the 1-hour mean NO_2 limit value plus margin of tolerance, 2005 (Form 11e). London Marylebone Road (Greater London Urban Area)

Month	Day of month	Hour	Level ($\mu g/m^3$)	Reason code(s) *
January	13	8	262	S2
January	13	9	298	S2
January	13	17	273	S2
January	13	18	277	S2
January	13	19	265	S2
January	19	14	260	S2
February	8	15	256	S2
February	8	18	258	S2
February	9	11	267	S2
February	9	17	254	S2
February	11	10	252	S2
February	17	11	256	S2
February	17	14	281	S2
March	1	8	252	S2
March	1	12	260	S2
March	1	13	252	S2
March	4	8	262	S2
March	4	9	252	S2
March	10	17	252	S2
March	14	7	277	S2
March	14	8	277	S2
March	15	8	260	S2
March	18	10	252	S2
April	11	6	260	S2
April	13	8	275	S2
April	13	9	285	S2
April	13	11	265	S2
April	13	16	279	S2
April	14	7	264	S2
April	14	11	275	S2
April	25	14	279	S2
April	25	15	262	S2
April	27	8	260	S2
April	28	14	260	S2
May	26	6	273	S2

Month	Day of month	Hour	Level (μg/m³)	Reason code(s) *
May	27	16	262	S2; S10
June	1	8	275	S2
June	14	8	262	S2
June	14	9	260	S2
June	22	6	254	S2; S10
June	22	13	267	S2; S10
June	22	16	260	S2; S10
June	22	18	279	S2; S10
June	23	7	300	S2; S10
June	23	8	279	S2; S10
June	23	9	323	S2; S10
June	23	10	336	S2; S10
June	23	13	277	S2; S10
June	23	14	300	S2; S10
June	23	15	287	S2; S10
June	23	16	273	S2; S10
June	23	17	308	S2; S10
June	23	18	309	S2; S10
June	23	19	256	S2; S10
June	29	8	269	S2
June	29	13	283	S2
June	29	14	273	S2
June	30	8	271	S2
June	30	13	262	S2
July	1	11	252	S2
July	14	12	256	S2; S10
July	14	13	256	S2; S10
July	14	14	281	S2; S10
July	14	15	330	S2; S10
July	29	12	277	S2
July	29	14	304	S2
August	2	12	260	S2
August	5	8	252	S2
August	11	15	256	S2
August	23	15	287	S2
August	25	13	264	S2
August	31	16	271	S2; S10
August	31	18	294	S2; S10
August	31	19	265	S2; S10
September	1	6	256	S2
September	1	11	308	S2
September	5	15	288	S2
September	6	15	275	S2
September	6	17	260	S2
September	6	18	258	S2
September	7	6	267	S2
September	7	7	260	S2
September	7	8	321	S2
September	7	9	267	S2
September	7	12	311	S2
September	7	13	277	S2
September	7	14	281	S2

Month	Day of month	Hour	Level (µg/m³)	Reason code(s) *
September	7	15	269	S2
September	7	16	262	S2
September	8	6	298	S2
September	8	9	277	S2
September	13	13	267	S2
September	13	15	287	S2
September	14	7	260	S2
September	14	8	267	S2
September	19	8	292	S2
September	19	11	252	S2
September	19	12	265	S2
September	20	7	279	S2
September	20	8	254	S2
September	20	12	260	S2
September	21	7	256	S2
September	21	14	281	S2
September	21	16	287	S2
September	22	10	277	S2
September	22	11	283	S2
September	22	12	256	S2
September	22	13	279	S2
September	22	15	306	S2
September	22	16	271	S2
September	22	17	271	S2
September	22	18	256	S2
September	23	7	256	S2
September	23	10	254	S2
September	23	12	288	S2
September	23	13	273	S2
September	26	8	300	S2
September	26	9	254	S2
September	27	7	279	S2
September	27	8	273	S2
September	27	9	285	S2
September	27	14	254	S2
September	28	7	311	S2
September	28	9	258	S2
September	28	11	275	S2
September	30	12	262	S2
September	30	14	256	S2
October	3	6	273	S2
October	6	15	265	S2
October	6	16	260	S2
October	10	13	277	S2
October	12	7	258	S2
October	12	13	269	S2
October	19	11	254	S2
October	19	16	264	S2
October	20	13	277	S2
October	20	14	256	S2
October	20	16	260	S2
October	21	9	281	S2

Month	Day of month	Hour	Level (µg/m³)	Reason code(s) *
October	28	16	256	S2
October	31	10	262	S2
November	1	8	264	S2
November	1	15	254	S2
November	1	16	252	S2
November	4	11	273	S2
November	7	7	281	S2
November	7	8	262	S2
November	7	9	256	S2
November	7	10	271	S2
November	7	11	254	S2
November	7	12	281	S2
November	10	15	273	S2
November	14	7	346	S2
November	14	8	279	S2
November	14	9	325	S2
November	14	11	256	S2
November	14	12	269	S2
November	14	14	252	S2
November	14	16	308	S2
November	14	17	292	S2
November	19	23	254	S2
November	20	0	304	S2
November	20	1	254	S2
November	20	3	262	S2
November	21	6	252	S2
November	21	7	277	S2
November	21	8	325	S2
November	24	7	260	S2
November	24	8	302	S2
November	24	9	285	S2
November	24	10	308	S2
November	24	11	308	S2
November	24	12	262	S2
November	30	6	271	S2
November	30	7	321	S2
November	30	8	363	S2
November	30	9	321	S2
November	30	10	277	S2
November	30	15	311	S2
November	30	16	275	S2
November	30	17	290	S2
December	5	8	262	S2
December	6	8	275	S2
December	7	7	338	S2
December	7	8	359	S2
December	7	9	302	S2
December	7	10	277	S2
December	7	11	323	S2
December	7	12	309	S2
December	7	13	260	S2
December	7	14	323	S2

Month	Day of month	Hour	Level (µg/m³)	Reason code(s) *
December	7	15	269	S2
December	7	16	267	S2
December	7	17	252	S2
December	9	12	340	S2
December	9	13	277	S2
December	9	14	258	S2
December	9	15	340	S2
December	9	16	292	S2
December	20	7	296	S2
December	20	8	348	S2
December	20	9	258	S2
December	20	10	281	S2
December	20	12	287	S2
December	20	13	294	S2
December	20	15	258	S2
December	21	8	267	S2
December	21	14	264	S2
December	21	15	256	S2
December	21	16	260	S2

* see Appendix 5 for details

Table 7.8. Measured exceedences of the annual mean NO$_2$ limit value plus margin of tolerance, 2005 (Form 11f)

Site	Zone	Level (µg m⁻³)	Reason code(s) *
Bath Roadside	UK0030	64	S2
Bristol Old Market	UK0009	60	S2
Bury Roadside	UK0003	64	S2
Camden Kerbside	UK0001	76	S2
Glasgow Kerbside	UK0024	62	S2
London A3 Roadside	UK0001	61	S2
London Bloomsbury	UK0001	57	S1
London Cromwell Road 2	UK0001	79	S2
London Lewisham	UK0001	51	S2
London Marylebone Road	UK0001	112	S2
London Wandsworth	UK0001	54	S2
Oxford Centre Roadside	UK0031	67	S2
Southwark Roadside	UK0001	60	S2
Tower Hamlets Roadside	UK0001	61	S2

* see Appendix 5 for details

Table 7.9. Measured exceedences of the 24-hour mean PM$_{10}$ limit value plus margin of tolerance, 2005 (Form 11h). London Marylebone Road (Greater London Urban Area)

Site	Zone	Month	Day of month	Level (μg m^{-3})	Reason code(s) *
Bradford Centre	UK0004	February	7	53	S14
Bradford Centre	UK0004	March	21	60	S14
Bradford Centre	UK0004	March	30	52	S14
Bradford Centre	UK0004	March	31	81	S14
Bradford Centre	UK0004	April	1	53	S14
Bradford Centre	UK0004	April	2	55	S14
Bradford Centre	UK0004	May	9	76	S14
Bradford Centre	UK0004	May	17	81	S14
Bradford Centre	UK0004	May	18	52	S14
Bradford Centre	UK0004	July	12	76	S14
Bradford Centre	UK0004	August	17	78	S14
Bradford Centre	UK0004	August	18	60	S14
Bradford Centre	UK0004	August	30	71	S14
Bradford Centre	UK0004	August	31	99	S14
Bradford Centre	UK0004	September	2	67	S14
Bradford Centre	UK0004	September	5	96	S14
Bradford Centre	UK0004	September	6	64	S14
Bradford Centre	UK0004	September	7	131	S14
Bradford Centre	UK0004	September	8	51	S14
Bradford Centre	UK0004	October	5	52	S14
Bradford Centre	UK0004	October	6	54	S14
Bradford Centre	UK0004	October	17	58	S14
Bradford Centre	UK0004	November	18	57	S14
Bradford Centre	UK0004	November	21	59	S14
Bradford Centre	UK0004	November	22	53	S14
Bradford Centre	UK0004	November	29	56	S14
Bradford Centre	UK0004	November	30	54	S14
Bradford Centre	UK0004	December	5	75	S14
Bradford Centre	UK0004	December	6	55	S14
Bradford Centre	UK0004	December	8	85	S14
Bradford Centre	UK0004	December	9	86	S14
Bradford Centre	UK0004	December	12	74	S14
Bradford Centre	UK0004	December	13	115	S14
Bradford Centre	UK0004	December	14	79	S14
Bradford Centre	UK0004	December	15	168	S14
Bradford Centre	UK0004	December	16	70	S14
Bradford Centre	UK0004	December	17	54	S14
Brighton Roadside PM10	UK0010	February	7	72	S2
Brighton Roadside PM10	UK0010	February	8	67	S2
Brighton Roadside PM10	UK0010	February	25	82	S2
Brighton Roadside PM10	UK0010	March	6	52	S2
Brighton Roadside PM10	UK0010	March	7	58	S2
Brighton Roadside PM10	UK0010	March	9	58	S2
Brighton Roadside PM10	UK0010	March	10	61	S2
Brighton Roadside PM10	UK0010	March	15	64	S2
Brighton Roadside PM10	UK0010	March	16	69	S2;S10
Brighton Roadside PM10	UK0010	March	20	80	S2

Site	Zone	Month	Day of month	Level (µg m^{-3})	Reason code(s) *
Brighton Roadside PM10	UK0010	March	21	57	S2
Brighton Roadside PM10	UK0010	March	22	60	S2
Brighton Roadside PM10	UK0010	March	23	53	S2;S10
Brighton Roadside PM10	UK0010	March	24	56	S2
Brighton Roadside PM10	UK0010	March	25	51	S2
Brighton Roadside PM10	UK0010	March	26	62	S2
Brighton Roadside PM10	UK0010	March	27	66	S2
Brighton Roadside PM10	UK0010	March	28	79	S2;S10
Brighton Roadside PM10	UK0010	March	29	100	S2;S10
Brighton Roadside PM10	UK0010	April	1	56	S2
Brighton Roadside PM10	UK0010	April	2	69	S2
Brighton Roadside PM10	UK0010	April	21	54	S2
Brighton Roadside PM10	UK0010	April	23	59	S2
Brighton Roadside PM10	UK0010	June	16	51	S2
Brighton Roadside PM10	UK0010	August	18	59	S2;S10
Brighton Roadside PM10	UK0010	September	22	74	S2
Brighton Roadside PM10	UK0010	October	6	76	S2;S10
Brighton Roadside PM10	UK0010	October	7	83	S2;S10
Brighton Roadside PM10	UK0010	October	8	57	S2;S10
Brighton Roadside PM10	UK0010	October	15	63	S2;S10
Brighton Roadside PM10	UK0010	October	16	52	S2;S10
Brighton Roadside PM10	UK0010	October	25	55	S2
Brighton Roadside PM10	UK0010	November	21	67	S2
Brighton Roadside PM10	UK0010	December	2	51	S2
Brighton Roadside PM10	UK0010	December	10	52	S2
Brighton Roadside PM10	UK0010	December	11	58	S2
Brighton Roadside PM10	UK0010	December	20	59	S2
Camden Kerbside	UK0001	January	14	52	S2
Camden Kerbside	UK0001	January	25	52	S2
Camden Kerbside	UK0001	January	26	67	S2
Camden Kerbside	UK0001	February	7	63	S2
Camden Kerbside	UK0001	February	8	67	S2
Camden Kerbside	UK0001	February	15	51	S2
Camden Kerbside	UK0001	February	16	54	S2
Camden Kerbside	UK0001	February	17	52	S2
Camden Kerbside	UK0001	February	19	52	S2
Camden Kerbside	UK0001	February	23	54	S2
Camden Kerbside	UK0001	February	25	56	S2
Camden Kerbside	UK0001	March	3	67	S2
Camden Kerbside	UK0001	March	5	51	S2
Camden Kerbside	UK0001	March	6	57	S2
Camden Kerbside	UK0001	March	7	57	S2
Camden Kerbside	UK0001	March	8	62	S2
Camden Kerbside	UK0001	March	19	55	S2
Camden Kerbside	UK0001	March	21	61	S2
Camden Kerbside	UK0001	March	23	51	S2;S10
Camden Kerbside	UK0001	March	24	52	S2
Camden Kerbside	UK0001	March	28	52	S2;S10
Camden Kerbside	UK0001	April	2	56	S2

Site	Zone	Month	Day of month	Level (μg m^{-3})	Reason code(s) *
Camden Kerbside	UK0001	April	22	57	S2
Camden Kerbside	UK0001	June	20	52	S2
Camden Kerbside	UK0001	June	24	52	S2;S10
Camden Kerbside	UK0001	July	13	53	S2
Camden Kerbside	UK0001	August	17	61	S2
Camden Kerbside	UK0001	August	18	59	S2;S10
Camden Kerbside	UK0001	August	30	54	S2;S10
Camden Kerbside	UK0001	September	9	63	S2
Camden Kerbside	UK0001	September	22	63	S2
Camden Kerbside	UK0001	October	6	60	S2;S10
Camden Kerbside	UK0001	October	7	71	S2;S10
Camden Kerbside	UK0001	October	10	56	S2
Camden Kerbside	UK0001	October	11	68	S2
Camden Kerbside	UK0001	October	15	57	S2;S10
Camden Kerbside	UK0001	October	16	56	S2;S10
Camden Kerbside	UK0001	October	17	55	S2
Camden Kerbside	UK0001	October	18	59	S2
Camden Kerbside	UK0001	October	27	51	S2
Camden Kerbside	UK0001	November	18	61	S2
Camden Kerbside	UK0001	November	20	87	S2
Camden Kerbside	UK0001	November	21	71	S2
Camden Kerbside	UK0001	November	29	51	S2
Camden Kerbside	UK0001	November	30	51	S2
Camden Kerbside	UK0001	December	9	59	S2
Camden Kerbside	UK0001	December	10	56	S2
Camden Kerbside	UK0001	December	11	55	S2
Camden Kerbside	UK0001	December	12	63	S2
Camden Kerbside	UK0001	December	13	70	S2
Camden Kerbside	UK0001	December	14	65	S2
Camden Kerbside	UK0001	December	20	69	S2
London Marylebone Road	UK0001	January	6	53	S2
London Marylebone Road	UK0001	January	12	54	S2
London Marylebone Road	UK0001	January	13	66	S2
London Marylebone Road	UK0001	January	14	59	S2
London Marylebone Road	UK0001	February	4	57	S2
London Marylebone Road	UK0001	February	7	73	S2
London Marylebone Road	UK0001	February	8	89	S2
London Marylebone Road	UK0001	February	9	57	S2
London Marylebone Road	UK0001	February	17	68	S2
London Marylebone Road	UK0001	February	28	59	S2
London Marylebone Road	UK0001	March	10	60	S2
London Marylebone Road	UK0001	March	14	65	S2
London Marylebone Road	UK0001	March	15	68	S2
London Marylebone Road	UK0001	March	17	61	S2
London Marylebone Road	UK0001	March	18	56	S2
London Marylebone Road	UK0001	March	19	55	S2
London Marylebone Road	UK0001	March	20	58	S2
London Marylebone Road	UK0001	March	21	62	S2
London Marylebone Road	UK0001	March	22	70	S2

Site	Zone	Month	Day of month	Level (μg m^{-3})	Reason code(s) *
London Marylebone Road	UK0001	March	23	63	S2;S10
London Marylebone Road	UK0001	March	24	74	S2
London Marylebone Road	UK0001	March	28	53	S2;S10
London Marylebone Road	UK0001	March	29	54	S2;S10
London Marylebone Road	UK0001	April	1	70	S2
London Marylebone Road	UK0001	April	2	62	S2
London Marylebone Road	UK0001	April	12	51	S2
London Marylebone Road	UK0001	April	13	52	S2
London Marylebone Road	UK0001	April	22	61	S2
London Marylebone Road	UK0001	April	23	54	S2
London Marylebone Road	UK0001	April	26	55	S2
London Marylebone Road	UK0001	April	27	51	S2
London Marylebone Road	UK0001	April	29	53	S2
London Marylebone Road	UK0001	May	3	52	S2
London Marylebone Road	UK0001	May	18	56	S2
London Marylebone Road	UK0001	May	19	68	S2
London Marylebone Road	UK0001	May	20	64	S2
London Marylebone Road	UK0001	May	23	51	S2
London Marylebone Road	UK0001	May	24	52	S2
London Marylebone Road	UK0001	May	25	51	S2
London Marylebone Road	UK0001	May	26	59	S2
London Marylebone Road	UK0001	May	27	60	S2
London Marylebone Road	UK0001	June	1	54	S2
London Marylebone Road	UK0001	June	9	54	S2
London Marylebone Road	UK0001	June	14	56	S2
London Marylebone Road	UK0001	June	15	54	S2
London Marylebone Road	UK0001	June	16	60	S2
London Marylebone Road	UK0001	June	22	51	S2
London Marylebone Road	UK0001	June	23	62	S2;S10
London Marylebone Road	UK0001	June	29	62	S2
London Marylebone Road	UK0001	June	30	60	S2
London Marylebone Road	UK0001	July	1	58	S2
London Marylebone Road	UK0001	July	5	54	S2
London Marylebone Road	UK0001	July	13	59	S2
London Marylebone Road	UK0001	July	14	68	S2
London Marylebone Road	UK0001	July	17	65	S2
London Marylebone Road	UK0001	July	18	59	S2
London Marylebone Road	UK0001	July	23	51	S2
London Marylebone Road	UK0001	July	28	52	S2
London Marylebone Road	UK0001	July	29	54	S2
London Marylebone Road	UK0001	August	2	60	S2
London Marylebone Road	UK0001	August	17	60	S2
London Marylebone Road	UK0001	August	18	61	S2;S10
London Marylebone Road	UK0001	August	30	55	S2;S10
London Marylebone Road	UK0001	August	31	66	S2
London Marylebone Road	UK0001	September	1	53	S2
London Marylebone Road	UK0001	September	3	53	S2;S10
London Marylebone Road	UK0001	September	4	60	S2;S10
London Marylebone Road	UK0001	September	5	57	S2

Site	Zone	Month	Day of month	Level (μg m^{-3})	Reason code(s) *
London Marylebone Road	UK0001	September	6	63	S2
London Marylebone Road	UK0001	September	7	61	S2
London Marylebone Road	UK0001	September	8	60	S2
London Marylebone Road	UK0001	September	9	56	S2
London Marylebone Road	UK0001	September	13	65	S2
London Marylebone Road	UK0001	September	14	54	S2
London Marylebone Road	UK0001	September	19	56	S2
London Marylebone Road	UK0001	September	20	63	S2
London Marylebone Road	UK0001	September	21	51	S2
London Marylebone Road	UK0001	September	22	78	S2
London Marylebone Road	UK0001	September	23	66	S2
London Marylebone Road	UK0001	September	26	51	S2
London Marylebone Road	UK0001	September	27	60	S2
London Marylebone Road	UK0001	September	30	56	S2
London Marylebone Road	UK0001	October	6	69	S2;S10
London Marylebone Road	UK0001	October	7	74	S2;S10
London Marylebone Road	UK0001	October	8	60	S2;S10
London Marylebone Road	UK0001	October	10	60	S2;S10
London Marylebone Road	UK0001	October	11	73	S2
London Marylebone Road	UK0001	October	12	63	S2
London Marylebone Road	UK0001	October	15	57	S2;S10
London Marylebone Road	UK0001	October	16	54	S2;S10
London Marylebone Road	UK0001	October	17	58	S2
London Marylebone Road	UK0001	October	18	61	S2
London Marylebone Road	UK0001	October	20	54	S2
London Marylebone Road	UK0001	October	21	51	S2
London Marylebone Road	UK0001	October	25	53	S2
London Marylebone Road	UK0001	October	26	63	S2
London Marylebone Road	UK0001	October	27	56	S2
London Marylebone Road	UK0001	October	28	53	S2
London Marylebone Road	UK0001	October	31	54	S2
London Marylebone Road	UK0001	November	3	57	S2
London Marylebone Road	UK0001	November	4	63	S2
London Marylebone Road	UK0001	November	7	58	S2
London Marylebone Road	UK0001	November	8	52	S2
London Marylebone Road	UK0001	November	10	55	S2
London Marylebone Road	UK0001	November	14	65	S2
London Marylebone Road	UK0001	November	20	88	S2
London Marylebone Road	UK0001	November	21	69	S2
London Marylebone Road	UK0001	November	30	74	S2
London Marylebone Road	UK0001	December	4	54	S2
London Marylebone Road	UK0001	December	7	63	S2
London Marylebone Road	UK0001	December	9	72	S2
London Marylebone Road	UK0001	December	10	79	S2
London Marylebone Road	UK0001	December	11	66	S2
London Marylebone Road	UK0001	December	20	111	S2
London Marylebone Road	UK0001	December	21	75	S2
London Marylebone Road	UK0001	December	22	69	S2
London Marylebone Road	UK0001	December	23	63	S2

Site	Zone	Month	Day of month	Level ($\mu g\ m^{-3}$)	Reason code(s) *
London Marylebone Road		December	29	58	S2

* see Appendix 5 for details

Table 7.10. Measured exceedences of the annual mean PM$_{10}$ limit value plus margin of tolerance (Stage 1), 2005 (Form 11i)

Site	Zone	Level ($\mu g\ m^{-3}$)	Reason code(s) *
London Marylebone Road	UK0001	43	S2

* see Appendix 5 for details

7.3 Comparison with previous years

Tables 7.11 and 7.12 provide a comparison of the monitoring and modelling results for 2005 with the results of the air quality assessments reported to the EU for 2001, 2002, 2003 and 2004 (Stedman, *et al.,* 2002, Stedman, *et al.,* 2003, Stedman, *et al.,* 2005, Stedman, *et al.,* 2006a). The listed numbers of zones exceeding the LV in Table 7.12 include the zones exceeding the LV + MOT. An exceedence of the LV can be determined by either measurements or modelling. Where an exceedence of the LV + MOT has been determined by modelling, the exceedence of the LV in this zone may still be determined by either measurements or modelling but this distinction is not shown in Tables 7.1 to 7.6.

Modelled exceedences of the 1-hour LV + MOT and 24-hour LV for SO$_2$ have been reported for 2005. As in 2004 these exceedences were limited to Stewartby in Eastern zone. The modelling analysis indicates that these exceedences were associated with emissions from a brick works. A plan or programme is now in place to address these exceedences. There were no reported exceedences of the annual or winter mean limit values for SO$_2$ in ecosystem areas.

An exceedence of the 1-hour LV + MOT for NO$_2$ has been reported for the first time in 2003 and was repeated in 2004 and 2005 in London. The reasons for this exceedence at the London Marylebone Road site remain under investigation and appear to be related to an increase in primary NO$_2$ emissions (Abbott, 2005). Reasons may include changes in traffic management and fleet emission characteristics. The number of zones in which there were modelled exceedences of the annual mean LV + MOT increased from 2004 to 2005 although the number of measured exceedences remained the same. Modelled exceedences of the annual mean LV remained the same in 2005 than in 2004 though the number of measured exceedences marginally increased. There were no reported exceedences of the annual mean LV for NO$_x$ in vegetation areas.

Exceedences of 'old' directives are listed in Table 7.13. Directive 85/203/EEC was exceeded at one monitoring site, Marylebone Road, in 2005 as in the previous 2 years.

There were more zones with reported modelled and measured exceedences of the Stage 1 LV for PM$_{10}$ in 2005 than in 2004 for both the annual mean and 24-hour metrics. However, the number of zones exceeding the Stage 2 LV for PM10 decreased from 2004 to 2005 for both annual and 24-hour metrics.

There were no exceedences for Lead in 2001, 2002, 2003, 2004 or 2005.

Two exceedences of the benzene LV were modelled in 2005 but there were no modelled exceedences of the LV + MOT. These exceedences were modelled in close proximity to large oil refineries at Grangemouth and Killingholme.

CO concentrations were below the LV in all zones in 2005.

Table 7.11 Exceedences of limit values plus margins of tolerance for 1st and 2nd Daughter Directives

Pollutant	Averaging time	2005	2004	2003	2002	2001
SO_2	1-hour[3]	n/a	1 zone modelled (Eastern)	1 zone modelled (Eastern)	none	none
SO_2	24-hour[2]	n/a	none	1 zone modelled (Eastern)	none	1 zone measured (Belfast Urban Area)
SO_2	annual[3]	n/a	n/a	n/a	n/a	n/a
SO_2	winter[3]	n/a	n/a	n/a	n/a	n/a
NO_2	1-hour[4]	1 zone measured (Greater London Urban Area)	1 zone measured (Greater London Urban Area)	1 zone measured (Greater London Urban Area)	none	none
NO_2	annual	35 zones (6 measured + 29 modelled)	34 zones (6 measured + 28 modelled)	35 zones (5 measured + 30 modelled)	19 Zones (5 measured + 14 modelled)	21 Zones (4 measured + 17 modelled)
NO_x	annual[3]	n/a	n/a	n/a	n/a	n/a
PM_{10}	24-hour (Stage 1)[3]	n/a	19 zones (1 measured + 18 modelled)	18 zones (2 measured + 16 modelled)	1 zone modelled (Greater London Urban Area)	1 zone modelled (Greater London Urban Area)
PM_{10}	annual (Stage 1)[3]	n/a	1 zone modelled (Greater London Urban Area)	10 zones (1 measured + 9 modelled)	1 zone modelled (Greater London Urban Area)	1 zone modelled (Greater London Urban Area)
PM_{10}	24-hour (Stage 2)[5]	n/a	n/a	n/a	n/a	n/a
PM_{10}	annual (Stage 2)[6]	32 zones (3 measured + 29 modelled)	32 zones (3 measured + 29 modelled)	36 zones (8 measured + 28 modelled)	22 zones (3 measured + 18 modelled)	not assessed
Lead	annual[3]	n/a	none	none	none	none
Benzene	annual	none	none	none	not assessed	not assessed
CO	8-hour[3]	n/a	none	none	not assessed	not assessed

1 Includes zones exceeding LV + MOT
2 No MOT defined, LV + MOT = LV
3 No MOT. LVs are already in force in 2005
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

Table 7.12 Exceedences of limit values for 1st and 2nd Daughter Directives

Pollutant	Averaging time	2005	2004	2003	2002	2001
SO_2	1-hour	1 zone modelled (Eastern)	1 zone modelled (Eastern)	1 zone modelled (Eastern)	none	none
SO_2	24-hour[1]	1 zone modelled (Eastern)	none	1 zone modelled (Eastern)	none	1 Zone measured (Belfast Urban Area)
SO_2	Annual[2]	none	none	none	none	none
SO_2	Winter[2]	none	none	none	none	not assessed
NO_2	1-hour[3]	2 zones measured (London, Bristol)	1 zone measured (Greater London Urban Area)	3 zones measured (London, Glasgow, South East)	1 zone measured (Glasgow Urban Area)	4 zones measured
NO_2	Annual	38 zones (8 measured + 30 modelled)	39 zones (9 measured + 30 modelled)	42 zones (10 measured + 32 modelled)	36 zones (6 measured + 30 modelled)	38 zones (6 measured + 32 modelled)
NO_x	Annual[2]	none	none	none	none	None
PM_{10}	24-hour[4] (Stage 1)	29 zones (3 measured + 26 modelled)	27 zones (2 measured + 25 modelled)	33 zones (10 measured + 23 modelled)	18 zones (1 measured + 17 modelled)	26 zones (5 measured + 21 modelled)
PM_{10}	annual (Stage 1)	4 zones (1 measured + 3 modelled)	2 zones (1 measured, London + 1 modelled, West Midlands Urban Area)	15 zones (1 measured + 14 modelled)	2 zones (Greater London Urban Area measured, Eastern modelled)	2 zones (London measured, Manchester modelled)
PM_{10}	24-hour[4] (Stage 2)	13 zones (13 measured)	15 zones (15 measured)	36 zones (36 measured)	21 zones (21 measured)	25 zones (25 measured)
PM_{10}	annual[5] (Stage 2)	40 zones (26 measured + 14 modelled)	41 zones (26 measured + 15 modelled)	43 zones (35 measured + 8 modelled)	42 zones (16 measured, 26 modelled)	43 zones (28 measured, 15 modelled)
Lead	Annual	none	none	none	none	none
Benzene	Annual	2 zones modelled (Yorkshire & Humberside, Central Scotland)	none	1 zone modelled (Greater London Urban Area)	not assessed	not assessed
CO	8-hour	none	none	none	not assessed	not assessed

1 No MOT defined, LV + MOT = LV
2 Applies to vegetation and ecosystem areas only. No MOT defined, LVs are already in force
3 No modelling for 1-hour LV
4 Stage 2 indicative LV, no modelling for 24-hour Stage 2 LV
5 Stage 2 indicative LV

Table 7.13 Exceedences of old Directives

Pollutant	Directive	Averaging time	2005 concentration ($\mu g\ m^{-3}$)	2004 concentration ($\mu g\ m^{-3}$)	2003 concentration ($\mu g\ m^{-3}$)	2002 concentration ($\mu g\ m^{-3}$)	2001 concentration ($\mu g\ m^{-3}$)
NO_2	85/203/EEC	1-hour 98%ile	256 (measured at London Marylebone Road)	233 (measured at London Marylebone Road)	235 (measured at London Marylebone Road)	No exceedences	No exceedences

8 Acknowledgements

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Appendices

Appendix 1: Monitoring sites used to verify the mapped estimates

Appendix 2: Particulate matter mass closure research

Appendix 3: Small point source model

Appendix 4: Dispersion kernels for area source model

Appendix 5: Reason codes for reporting of EC air quality questionnaire

Appendix 1 Monitoring sites used to verify the mapped estimates

Table A1.1. Monitoring sites used to verify the mapped estimates (PM₁₀ measurements by gravimetric and TEOM instruments were used in the verification)

Site	Site type	Local Authority	SO$_2$	NO$_2$	PM$_{10}$	CO
Abingdon	URBAN BACKGROUND	Vale of White Horse DC	y	y	y	
Antrim Greystone Estate	URBAN BACKGROUND	Antrim BC	y			
Ards	URBAN BACKGROUND	Ards BC	y		y	
Armagh Lonsdale Road	KERBSIDE	Armagh City DC		y	y	
Ballymena Ballykeel	URBAN BACKGROUND	Ballymena BC	y		y	
Ballymena North Road	KERBSIDE	Ballymena BC		y		
Ballymoney	URBAN BACKGROUND	Ballymoney BC			y	
Barnsley A628 Roadside	ROADSIDE	Barnsley MBC		y	y	
Barnsley Cudworth	URBAN BACKGROUND	Barnsley MBC	y	y	y	
Barnsley Old Mill Lane Roadside	ROADSIDE	Barnsley MBC		y	y	
Barnsley Royston	ROADSIDE	Barnsley MBC	y	y	y	
Basingstoke Eastrop	URBAN BACKGROUND	Basingstoke & Deane DC		y	y	
Belfast Roadside	ROADSIDE	Belfast City Council		y		
Belfast Westlink	KERBSIDE	Belfast City Council		y	y	
Birmingham Airport	AIRPORT	Birmingham International Airport	y	y	y	y
Boston Haven Bridge Road	ROADSIDE	Boston BC		y		
Bracknell Foxhill	URBAN BACKGROUND	Bracknell Forest BC		y	y	
Bracknell Yorktown Road Sandhurst	ROADSIDE	Bracknell Forest BC		y	y	
Caerphilly Ton-y-Felin Roadside	ROADSIDE	Caerphilly County BC		y	y	
Cambridge Gonville Place	ROADSIDE	Cambridge City Council		y	y	
Cambridge Newmarket Road	URBAN BACKGROUND	Cambridge City Council		y	y	
Cambridge Parker Street	ROADSIDE	Cambridge City Council		y	y	
Cambridge Silver Street	ROADSIDE	Cambridge City Council		y	y	
Cardiff Briardene	URBAN BACKGROUND	Cardiff City Council	y	y	y	y
Carrickfergus Rosebrook Avenue	URBAN BACKGROUND	Carrickfergus BC	y		y	
Castlereagh Espie Way	URBAN BACKGROUND	Castlereagh BC	y		y	
Castlereagh Lough View Drive	ROADSIDE	Castlereagh BC		y	y	
Chepstow	ROADSIDE	Monthmouthshire CC		y	y	

Site	Site type	Local Authority	SO$_2$	NO$_2$	PM$_{10}$	CO
Chesterfield Birdholme School	URBAN BACKGROUND	Chesterfield BC	y	y	y	
Chesterfield Whittington Roadside	ROADSIDE	Chesterfield BC	y	y	y	
Craigavon Castle Lane	ROADSIDE	Craigavon BC		y		
Craigavon Lord Lurgan Park	URBAN BACKGROUND	Craigavon BC	y		y	
Derry Brandywell	URBAN BACKGROUND	Derry City Council	y		y	
Derry Claudy	URBAN BACKGROUND	Derry City Council			y	
Derry Dale's Corner	KERBSIDE	Derry City Council		y		
Glasgow Anderston	URBAN BACKGROUND	Glasgow City Council	y	y	y	
Glasgow Battlefield Road	ROADSIDE	Glasgow City Council		y	y	
Glasgow Byres Road	ROADSIDE	Glasgow City Council		y	y	
Glasgow Waulkmillglen Reservoir	RURAL	Glasgow City Council		y	y	
Guildford Gyratory	ROADSIDE	Guildford BC		y	y	
Heathrow Bedfont Court	AIRPORT	BAA			y	
Heathrow Green Gates	AIRPORT	BAA		y	y	
Heathrow LHR2	AIRPORT	BAA		y	y	y
Heathrow Main Road	AIRPORT	BAA	y	y	y	y
Heathrow Mondial Way	AIRPORT	BAA		y		
Heathrow Moorbridge	AIRPORT	BAA			y	
Heathrow Oaks Road	AIRPORT	BAA		y	y	
Heathrow West End Lane	AIRPORT	BAA		y		
Ipswich Piper's Court	ROADSIDE	Ipswich BC		y		
King's Lynn Railway Road	ROADSIDE	Kings Lynn & West Norfolk BC		y	y	
King's Lynn South Quay	URBAN BACKGROUND	Kings Lynn & West Norfolk BC			y	
Larne	URBAN BACKGROUND	Larne BC	y		y	
Larne Craigyhill	URBAN BACKGROUND	Larne BC			y	
Lisburn Dunmurry High School	URBAN BACKGROUND	Lisburn City Council			y	
Lisburn Island Civic Centre	URBAN BACKGROUND	Lisburn City Council	y		y	
Lisburn Lagan Valley Hospital	ROADSIDE	Lisburn City Council		y	y	
Liverpool Islington	ROADSIDE	Liverpool City Council	y	y	y	
Macclesfield Disley	ROADSIDE	Macclesfield BC		y	y	
Marchlyn Mawr	REMOTE	Gwyneth Council		y		

AEA Energy & Environment

Site	Site type	Local Authority	SO$_2$	NO$_2$	PM$_{10}$	CO
Newham Cam Road	ROADSIDE	London Borough of Newham	y	y	y	y
Newham Wren Close	URBAN BACKGROUND	London Borough of Newham	y	y	y	y
Newport Malpas Depot	URBAN BACKGROUND	Newport County BC		y	y	
Newport St Julians Comp School	URBAN BACKGROUND	Newport County BC		y	y	
Newry Kilkeel	URBAN BACKGROUND	Newry and Mourne DC			y	
Newry Monaghan Row	URBAN BACKGROUND	Newry and Mourne DC	y	y	y	
Newry Trevor Hill	KERBSIDE	Newry and Mourne DC	y	y	y	
Newtownabbey Ballyclare	URBAN BACKGROUND	Newtownabbey BC			y	
Newtownabbey Shore Road	ROADSIDE	Newtownabbey BC		y		
North Down Bangor	URBAN BACKGROUND	North Down BC	y		y	
North Down Holywood A2	ROADSIDE	North Down BC		y	y	
North Lincs Killingholme	URBAN INDUSTRIAL	North Lincolnshire Council	y	y	y	
North Lincs Santon	URBAN INDUSTRIAL	North Lincolnshire Council	y	y	y	
Norwich Airport 2	AIRPORT	BAA	y	y	y	y
Oldham West End House	URBAN BACKGROUND	Oldham MBC	y	y	y	y
Oxford High St	ROADSIDE	Oxford City Council		y	y	
Oxford St Ebbes	URBAN BACKGROUND	Oxford City Council		y	y	
Rhondda-Cynon-Taf Nantgarw	ROADSIDE	Rhondda-Cynon-Taf CBC			y	
Ribble Valley Chatburn	URBAN INDUSTRIAL	Ribble Valey BC	y	y	y	
Ribble Valley Lillands	URBAN BACKGROUND	Ribble Valey BC	y	y	y	
S Cambs Bar Hill	ROADSIDE	South Cambridgeshire DC		y	y	
S Cambs Barrington Fruit Farm	RURAL	South Cambridgeshire DC	y			
S Cambs Impington	ROADSIDE	South Cambridgeshire DC		y	y	
Salford M60	ROADSIDE	Salford MBC	y	y	y	y
Scunthorpe Town NOx and CO	URBAN INDUSTRIAL	North Lincolnshire Council		y		
Slough Chalvey	ROADSIDE	Slough BC		y		
Slough Colnbrook	URBAN BACKGROUND	Slough BC		y	y	
Slough Town Centre A4	ROADSIDE	Slough BC		y	y	
South Bucks Gerrards Cross	ROADSIDE	South Bucks DC		y	y	
South Holland	RURAL	South Holland DC		y	y	
Spalding Monkhouse School	URBAN BACKGROUND	South Holland DC		y	y	

Site	Site type	Local Authority	SO$_2$	NO$_2$	PM$_{10}$	CO
Stansted 3	AIRPORT	BAA		y	y	y
Stockport Bredbury	URBAN BACKGROUND	Stockport MBC		y	y	
Stockport Hazel Grove	ROADSIDE	Stockport MBC		y	y	
Strabane Springhill Park	URBAN BACKGROUND	Strabane DC	y		y	
Swansea Morfa Roadside	ROADSIDE	Swansea CC	y	y	y	y
Swansea Morriston Roadside	ROADSIDE	Swansea CC	y	y	y	y
Tameside Two Trees School	URBAN BACKGROUND	Tameside MBC	y	y	y	y
Trafford	URBAN BACKGROUND	Trafford MBC	y	y	y	
Trafford A56	ROADSIDE	Trafford MBC		y	y	
V Glamorgan Fonmon	RURAL	Vale of Glamorgan Council	y	y	y	
V Glamorgan Penarth	ROADSIDE	Vale of Glamorgan Council		y		
Wigan Leigh 2	URBAN BACKGROUND	Wigan Metropolitan Borough Council		y	y	
Wokingham Winnersh	URBAN BACKGROUND	Wokingham DC		y	y	
Wokingham Woodward Close	ROADSIDE	Wokingham DC		y	y	

Data were collected from the following sources: AEA Energy & Environment's Calibration Club, the Welsh Air Quality Forum

AEA Energy & Environment

Table A1.2. Additional monitoring sites maintained by the electricity generating companies used calibrate the SO$_2$ models.

Site	Company
Bentley Hall Farm	EON
Bexleyheath	RWE
Blair Mains	RWE
Bottesford	EON
Carr Lane (Drax)	RWE
Didcot South	RWE
Downes Ground Farm	RWE
East Tilbury	RWE
Font-y-gary	RWE
Gainsborough Cemetery	EON
Gillingham	EON
Grove Reservoir	EON
Hemingbrough	RWE
Longniddry West	RWE
Marton School	EON
North Featherstone	RWE
Northfleet	RWE
Rosehurst Farm	RWE
Ruddington Field	EON
Smeathalls Fm	RWE
Stile Cop Cemetery	EON
Telford Aqueduct	EON
Telford School	EON
Thorney	EON
West Bank	RWE
West Thurrock	RWE
Weston On Trent	EON

Appendix 2 Particulate matter mass closure research

PARTICULATE MATTER MASS CLOSURE RESEARCH

PROFESSOR R. DERWENT (May 2005)

Introduction

1. The aim of this paper is to provide some underpinning for the regression methods used in the NETCEN PM_{10} Receptor Model and to understand how to handle particulate ammonium in the PM_{10} maps.

2. The methodology employed is based on particulate matter data collected in two intensive campaigns:

- PUMA Campaign, University of Birmingham campus, June-July 1999,

- EC/OC Campaign, Bush Estate, July 2002 – June 2003.

These campaign data have been used to construct an approximate mass closure for PM_{10} and $PM_{2.5}$ for a central England location.

PUMA Campaign Data

3. Professor Harrison conducted some detailed particulate sampling during the PUMA Campaign at the University of Birmingham urban background site. The data from this campaign can be used to provide speciated composition data for both the fine and coarse particulate fractions.

4. In interpreting these data, it has been assumed that aerosol bound water accounts for 28% of the mass of sulphate, nitrate and ammonium. Significant amounts of sulphate and ammonium were detected in the coarse fraction in a molar ratio of 1.4 x NH_4 to SO_4. This corresponds well with ammonium to sulphate ratio of 1.5 to 1, associated with the mixture of ammonium sulphate and sulphuric acid produced by cloud-processing, an important component of the background aerosol. The origins of this material may well be of long-range or intercontinental origins.

5. A significant amount of total carbon was also reported in the coarse fraction. Again, this may reflect cloud-processing of a combustion derived aerosol. Alternatively, it may represent the take-up of semi-volatile organic compounds on to coarse particles. Nitrate appeared to be distributed in both the fine and the coarse fractions. The fine particle nitrate is presumably ammonium nitrate and the coarse,

a mixture of sodium and calcium nitrates formed by displacement reactions on sea-salts and wind-blown dusts.

EC/OC Campaign Data

6.   The EMEP/CCC operated an EC/OC site at Bush Estate, Midlothian from July 2002 to June 2003 and measurements were reported of elemental carbon EC and organic carbon OC, together with $PM_{2.5}$ and PM_{10}. The measurement campaign encompassed the period during the spring of 2003 that were associated with the intense pollution episodes. Outside of this period, elemental carbon showed a pronounced seasonal variation with low summer values and high winter values. Organic carbon showed a much less pronounced seasonal cycle which reflects a significant contribution from secondary organic matter of photochemical origin.

7.   By assuming that there is no secondary organic matter present during winter and that primary organic matter and elemental carbon have the same seasonal cycles, then it is possible to quantify the three components: elemental carbon EC, primary organic particulate matter POM and secondary organic particulate matter, SOM. Furthermore, in converting from $\mu g\ C\ m^{-3}$ to $\mu g\ PM\ m^{-3}$, conversion factors of 1.0, 1.4 and 1.4, respectively, were used for the three components. The three-way split between the three components was therefore found to be 0.2, 0.56 and 0.24, respectively. This same split was applied to both fine and coarse fractions and universally across rural areas of the UK.

Mass Closure for a Central England Location

8.   The results of the mass closure analysis are given in Table 1 below. The total $PM_{2.5}$ and PM_{10} concentrations are found to be 11.1 and 16.1 $\mu g\ m^{-3}$, of which the non-volatile components are 6.2 and 9.9 $\mu g\ m^{-3}$, respectively. This would imply TEOM to gravimetric factors of 1.79 and 1.62, respectively, for $PM_{2.5}$ and PM_{10}. These factors are somewhat higher than typical values observed for a rural location in central England. The primary, secondary and coarse splits for total PM_{10} are 3.89, 7.94 and 4.30 $\mu g\ m^{-3}$ whilst those for the non-volatile PM_{10} are 1.02, 4.55 and 4.30 $\mu g\ m^{-3}$.

Table 1. Mass closure at a rural central England location for the fine and coarse fractions and for total and non-volatile species. [PM$_{2.5}$ = fine fraction, PM$_{10}$ = fine fraction + coarse fraction]

Component		Fine fraction, $\mu g\ m^{-3}$		Coarse fraction, $\mu g\ m^{-3}$	
		Total	Non-volatile	Total	Non-volatile
sulphate	dry	2.40	2.40	0.15	0.15
bound water		0.67		0.04	
ammonium	dry	1.13	1.13	0.04	0.04
bound water		0.31		0.01	
nitrate	dry	0.68		0.83	0.83
bound water		0.19		0.23	
NaCl		0.20	0.20	0.56	0.56
EC		0.76	0.76	0.26	0.26
POM		2.14		0.73	
SOM		0.94		0.32	
resuspended		1.70	1.70	1.84	1.84
Total		11.12	6.19	5.01	3.69

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 are 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 3.3 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 flow rate 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 than 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:

$$U = 1.36Q^{0.6}\left(1 - 4.7 \times 10^{-5} Q^{1.69}\right)$$

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 ADMS 3.3 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 A4.1 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 A4.1 does not include results for the 1 km source square.
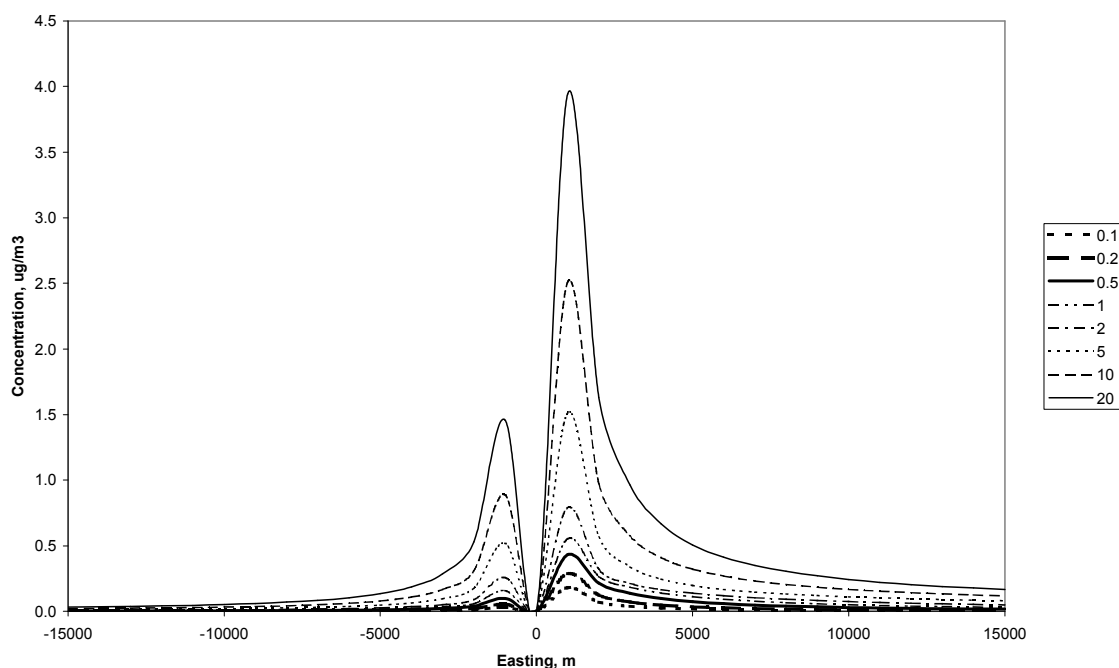

Figure A4.1 Sulphur dioxide concentration on east-west axis, 2000 meteorological data

Figure A4.2 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.
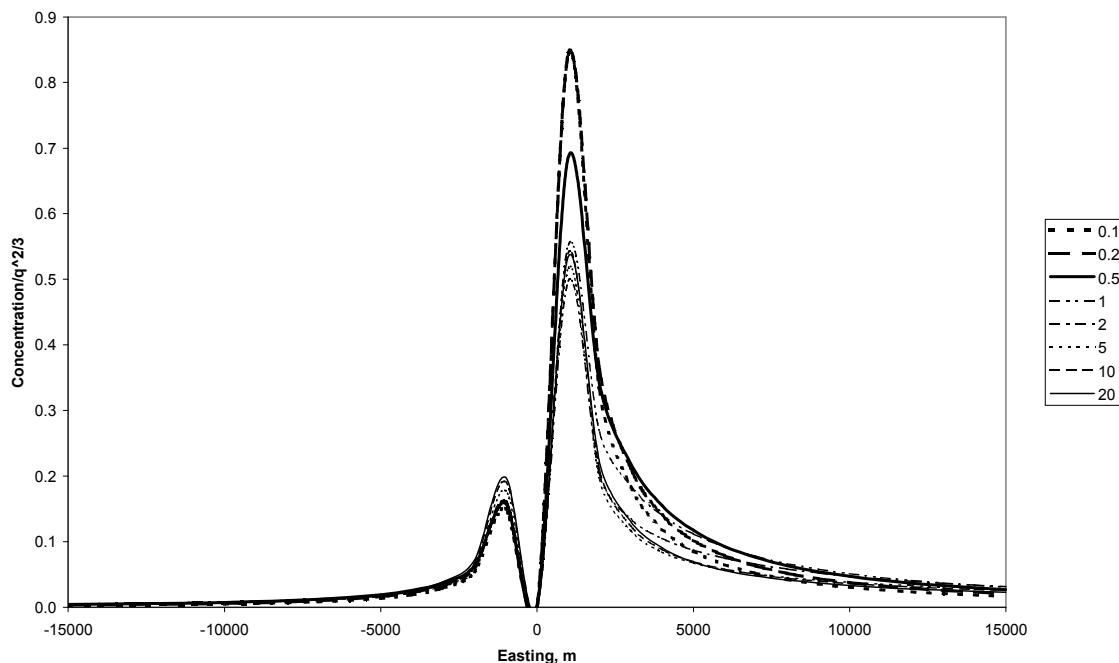
Figure A4.2 Reduced sulphur dioxide concentrations on the east-west axis, 2000 meteorological data

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 A3.5 In-square oxides of nitrogen concentrations, 2000

Emission rate, g/s	In square concentration, $\mu g\ m^{-3}$
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, $\mu g\ m^{-3}$ 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).
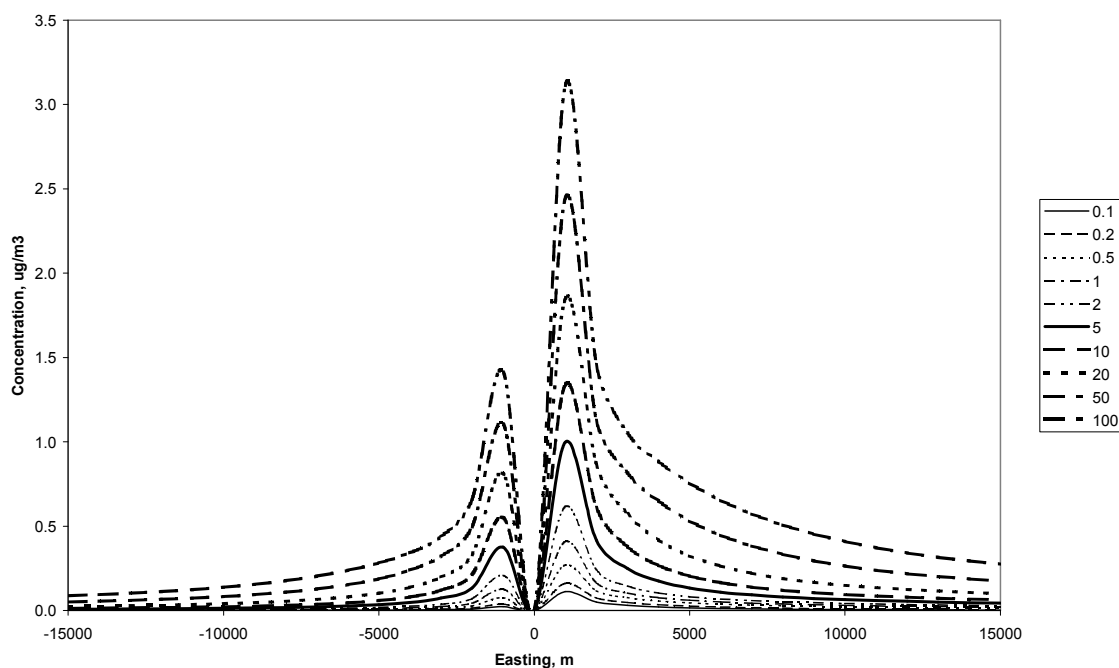

Figure A3.3 Oxides of nitrogen concentration on east-west axis, 2000 meteorological data

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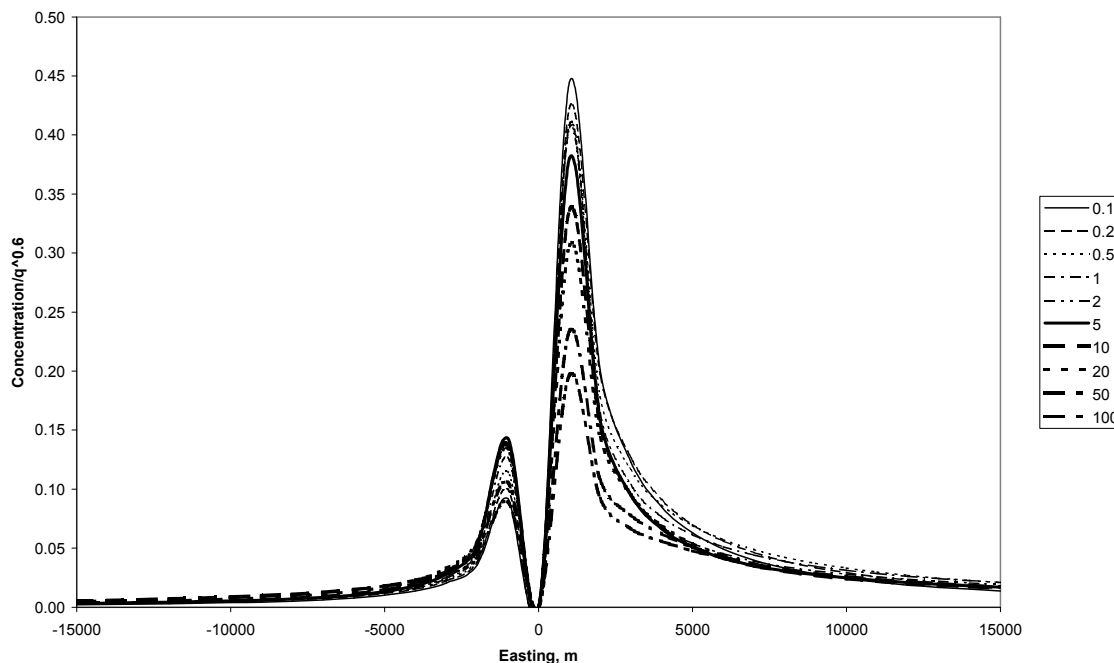
Figure A3.4 Reduced oxides of nitrogen concentrations on the east-west axis, 2000 meteorological data

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, $\mu g\ m^{-3}$ 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.

CO

The method for CO was the same as for NO_x, except that point sources with emissions greater than or equal to 3000 tonnes per year (95.1 g/s) have been modelled explicitly using ADMS. Point sources with emissions less than 3000 tonnes per year have been modelled using the small points model.

Benzene

The method for benzene was the different. Point sources with combustions emissions greater than or equal to 5 tonnes per year (0.16 g/s) have been modelled explicitly using ADMS. Fugitive and process point sources have been modelled using a different small points model, as described in Section 5.3.

# Appendix 4 Dispersion kernels for area source model

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 2005 using sequential meteorological data from Waddington. 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 emissions
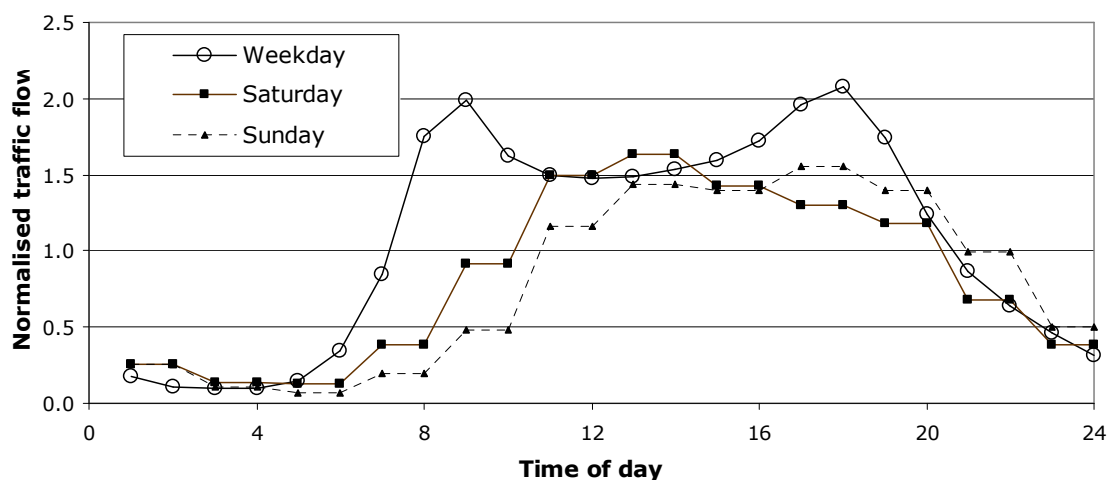
Dispersion kernels were calculated at spatial resolutions of 1 km x 1 km, 3 x 3 km and 5 x 5 km, representing the size of emission and receptor squares modelled. Previous modelling studies (Stedman *et al.*, 2002) used kernels at a resolution of 5 km x 5 km for NO_x and PM_{10}. A comparison of the fit 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}, benzene and CO. 1 km x 1 km kernels were used for SO_2.

Appendix 5 Reason codes for reporting of EC air quality questionnaire

Explanation of EC air quality questionnaire reason codes

The questionnaire submitted to the Commission summarises the results of national monitoring and modelling campaigns. Where exceedences of legislative objectives established by European air quality Directives are reported there is an obligation to supply information on the reason for these exceedences. In most cases the reason is prescribed by the guidance documents for the questionnaire but there is scope to introduce bespoke reason for unique situations. Table A5.1 below presents the reason codes and associated explanations that were used in the compilation of the 2005 questionnaire.

Table A5.1

Code	Explanation
S1	Heavily trafficked urban centre
S2	Proximity to a major road
S3	Local industry including power production
S4	Quarrying or mining activities
S5	Domestic heating
S6	Accidental emission from an industrial source
S7	Accidental emission from a non-industrial source
S8	Natural source(s) or natural event(s)
S9	Winter sanding of roads
S10	Transport of air pollution from sources outside the Member State
S11	Local petrol station
S12	Parking facility
S13	Benzene storage
S14	Local building or demolition work