UK air quality modelling for annual reporting 2008 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 Government and the Department of the Environment for Northern Ireland

Susannah E Grice
Justin JN Lingard
John R Stedman
Sally L Cooke
Fee Wen Yap
Andrew J Kent
Tony J Bush
Keith J Vincent
John Abbott

ED 48208
AEAT/ENV/R/2859 Issue 1
July 2010

Title	UK air quality modelling for annual reporting 2008 on ambient air quality assessment under Council Directives 96/62/EC, 1999/30/EC and 2000/69/EC
Customer	The Department for Environment, Food and Rural Affairs, Welsh Assembly Government, the Scottish Government and the Department of the Environment for Northern Ireland
Customer reference	CPEA 15
Confidentiality, copyright and reproduction	This report is the Copyright of AEA Technology and has been prepared by AEA Technology plc under contract to Defra. The contents of this report may not be reproduced in whole or in part, nor passed to any organisation or person without the specific prior written permission of the Commercial Manager, AEA Technology plc. AEA Technology plc accepts no liability whatsoever to any third party for any loss or damage arising from any interpretation or use of the information contained in this report, or reliance on any views expressed therein.
File reference	w:/dd2008/reporting/1_dd12mappingreport/dd122008mapsrep.doc
Reference number	AEAT/ENV/R/2859 Issue 1

AEA
The Gemini Building
Fermi Avenue
Harwell International Business Centre
Didcot
OX11 0QR

t: 0870 190 6573
f: 0870 190 6318

john.stedman@aeat.co.uk

AEA is a business name of
AEA Technology plc

AEA is certificated to ISO9001
and ISO14001

Author	Name	Susannah E Grice Justin J N Lingard John R Stedman Sally L Cooke Fee Wen Yap Andrew J Kent Tony J Bush Keith J Vincent John Abbott
Approved by	Name	John Stedman
	Signature	John Stedman.
	Date	2 July 2010

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. Directive 2004/107/EC (the fourth Daughter Directive) sets target values to be achieved for arsenic, cadmium, nickel and polycyclic aromatic hydrocarbons with benzo(a)pyrene (BaP) as an indicator species.

Directive 2008/50/EC on ambient air quality and clean air for Europe entered into force in June 2008. This directive replaced the framework and first three daughter directives and has been transposed into UK law two years after entering into force (June 2010). The air quality assessments for 2008 were carried out under the provisions of the Framework and daughter directives. One important change between the Framework and Daughter Directives and Directive 2008/50/EC is that the new directive includes a requirement to deduct the contribution to ambient PM from a wider range of natural sources prior to the comparison with limit values than specified in the previous directives. Since this is mandatory under the new directive we have included this in our assessment of concentrations in 2008.

2008 is the eighth year for which an annual air quality assessment for the first Daughter Directive pollutants is required and the sixth year for which an annual air quality assessment has been undertaken for the second Daughter Directive pollutants. 2008 is the fifth year for which an annual air quality assessment has been undertaken for the third Daughter Directive and the first year an annual air quality assessment has been undertaken for the fourth 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 and target 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.

This report does not contain any supplementary modelling information on ozone or lead. The accompanying report (Kent and Stedman, 2009) contains a summary of the key results of 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. Yap et al. (2009) contains a summary of key results from the questionnaire from the annual air quality assessment for the fourth Daughter Directive pollutants and contains additional technical information on the modelling methods that have been used to assess arsenic, cadmium, lead, nickel and benzo(a)pyrene (BaP) 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, except lead, 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 2008 on a 1 km x 1 km grid have been prepared. Maps of roadside concentrations of NO_2, PM_{10}, benzene and CO have been prepared for a total of 9,553 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 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) (where applicable) and limit values (LV). Table E2 contains details of exceedences of old directives.

Table E1. Summary results of air quality assessment for 2008

Pollutant	Averaging time	Number of zones exceeding limit value + margin of tolerance	Number of zones exceeding limit value
SO_2	1-hour	n/a	none
SO_2	24-hour[1]	n/a	none
SO_2	Annual[2]	n/a	none
SO_2	Winter[2]	n/a	none
NO_2	1-hour[3]	2 zones measured (Greater London Urban Area & Glasgow Urban Area)	3 zones measured
NO_2	Annual	40 zones (7 measured + 33 modelled)	40 zones (7 measured + 33 modelled)
NO_x	Annual[2]	n/a	none
PM_{10}	24-hour (Stage 1)	n/a	2 zones (1 measured + 1 modelled)
PM_{10}	Annual (Stage 1)	n/a	none
Lead	Annual	n/a	none
Benzene	Annual	none	none
CO	8-hour	n/a	none

[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

Table E2. Exceedences of old Directives

Pollutant	Directive	Averaging time	Concentration ($\mu g\ m^{-3}$)
NO_2	85/203/EEC	1-hour 98%ile	252 (measured at London Marylebone Road)

Table of contents

1 Introduction 7

- 1.1 The Framework and first and second Daughter Directives 7
- 1.2 This report 7
- 1.3 Preliminary assessments and definition of zones 8
- 1.4 Monitoring sites 11
- 1.5 Limit Values and Margins of Tolerance 11
- 1.6 Data quality objectives for modelling results and model verification 13
- 1.7 Air quality modelling 13
- 1.8 Air quality in Gibraltar in 2008 14

2 SO_2 15

- 2.1 Introduction 15
- 2.2 SO_2 emissions 15
- 2.3 Maps of winter and annual mean concentrations 16
- 2.4 Maps of percentile concentrations for comparison with the 1-hour and 24-hour limit values 20
- 2.5 Verification of mapped values 24
- 2.6 Source apportionment 26
- 2.7 Comparison of modelling results with limit values 28

3 NO_2/NO_X 29

- 3.1 Introduction 29
- 3.2 NO_x modelling 35
- 3.3 NO_2 Modelling 41
- 3.4 Results 51

4 PM_{10} 57

- 4.1 Introduction 57
- 4.2 Contributions from secondary inorganic aerosol 62
- 4.3 Contributions from secondary organic aerosol 62
- 4.4 Contributions from large and small point sources 63
- 4.5 Contributions from distant sources of primary particles 63
- 4.6 Iron and calcium rich dusts 63
- 4.7 Sea salt 67
- 4.8 Contributions from area sources 68
- 4.9 Roadside concentrations 69
- 4.10 Verification of mapped values 70
- 4.11 PM_{10} source apportionment at monitoring sites 72
- 4.12 Detailed comparison of modelling results with limit values 72
- 4.13 Subtraction of sea salt component 77

5 Benzene 79
5.1 Introduction 79
5.2 Contributions from combustion point sources 82
5.3 Contributions from fugitive and process point sources 82
5.4 Contributions from rural background concentrations 82
5.5 Contributions from area sources 82
5.6 Roadside concentrations 83
5.7 Verification of mapped values 84
5.8 Benzene source apportionment at monitoring sites 86
5.9 Detailed comparison of modelling results with limit values 86
6 CO 89
6.1 Introduction 89
6.2 Contributions from large point sources 92
6.3 Contributions from small point sources 92
6.4 Contributions from area sources 92
6.5 Roadside annual mean CO concentrations 92
6.6 Modelling the maximum 8-hour mean CO concentration 93
6.7 Verification of mapped values 95
6.8 CO source apportionment at monitoring sites 96
6.9 Detailed comparison of modelling results with limit values 96
7 Lists of zones in relation to Limit Values and Margins of Tolerance 99
7.1 Results for 2008 99
7.2 Measured exceedences of Limit Values + Margins of Tolerance 108
7.3 Comparison with previous years 108
8 Acknowledgements 113
9 References 114

Appendices

Appendix 1 Monitoring sites used to verify the mapped estimates
Appendix 2 Small point source model
Appendix 3 Dispersion kernels for area source model
Appendix 4 Revised method for calculating and mapping emissions from aircraft and shipping
Appendix 5 Application of the Volatile Correction Model (VCM) to TEOM data
Appendix 6 Air Quality monitoring data from Gibraltar in 2008

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. Directive 2004/107/EC (the fourth Daughter Directive, AQDD4) sets target values to be achieved for arsenic, cadmium, nickel and polycyclic aromatic hydrocarbons with benzo(a)pyrene (BaP) as an indicator species.

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.

Directive 2008/50/EC on ambient air quality and clean air for Europe entered into force in June 2008. This directive replaced the framework and first three daughter directives and has been transposed into UK law two years after entering into force (June 2010). The air quality assessments for 2008 were carried out under the provisions of the Framework and daughter directives. One important change between the Framework and Daughter Directives and Directive 2008/50/EC is that the new directive includes a requirement to deduct the contribution to ambient PM from a wider range of natural sources prior to the comparison with limit values than specified in the previous directives. Since this is mandatory under the new directive we have included this in our assessment of concentrations in 2008.

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}, lead, 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, 2009). 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. Full details of the assessment carried out for lead are included in the accompanying report (Yap et al., 2009), which includes assessments for the heavy metals covered by AQDD4. Summary results for lead are included in Section 7 of this report for easy reference.

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 (Kent and Stedman, 2009).

Sections 2 to 6 describe the Pollution Climate Mapping (PCM) 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

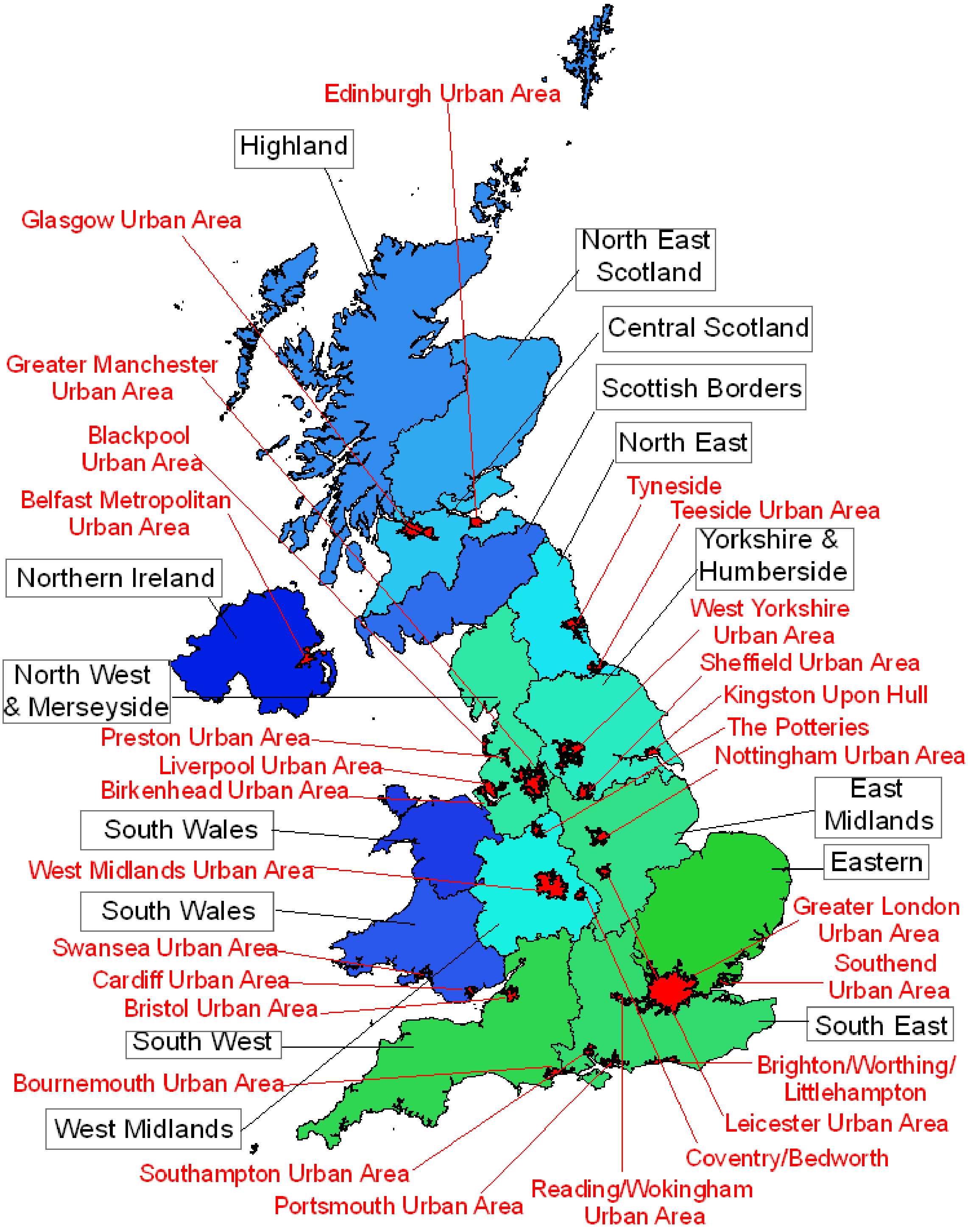
- Detailed modelling results.

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, 2009) 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 previous years (Stedman et al., 2002; Stedman et al., 2003; Stedman et al., 2005; Stedman et al., 2006a; Kent et al., 2007a; Kent et al., 2007b; Grice et al., 2009).

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 2008



Agglomeration zones (red)
Non-agglomeration zones (blue/green)
© Crown copyright. All rights reserved Defra, Licence number 100022861 [2009]

Table 1.1. Zones for AQDD reporting

Zone	Zone code	Ag or non-ag*	Population	Area (km^2)	Number of urban road links	Length of urban road links (km)
Greater London Urban Area	UK0001	ag	8278251	1629.9	1934	1890.4
West Midlands Urban Area	UK0002	ag	2284093	599.7	393	552.2
Greater Manchester Urban Area	UK0003	ag	2244931	556.5	550	661.0
West Yorkshire Urban Area	UK0004	ag	1499465	370.0	282	423.9
Tyneside	UK0005	ag	879996	210.7	171	206.0
Liverpool Urban Area	UK0006	ag	816216	186.1	254	216.7
Sheffield Urban Area	UK0007	ag	640720	162.2	110	160.3
Nottingham Urban Area	UK0008	ag	666358	158.4	123	134.0
Bristol Urban Area	UK0009	ag	551066	139.8	113	116.2
Brighton/Worthing/Littlehampton	UK0010	ag	461181	94.1	61	88.9
Leicester Urban Area	UK0011	ag	441213	101.6	66	81.3
Portsmouth Urban Area	UK0012	ag	442252	94.4	55	75.3
Teesside Urban Area	UK0013	ag	365323	114.3	63	73.6
The Potteries	UK0014	ag	362403	96.6	112	129.0
Bournemouth Urban Area	UK0015	ag	383713	108.1	48	72.1
Reading/Wokingham Urban Area	UK0016	ag	369804	93.2	65	76.8
Coventry/Bedworth	UK0017	ag	336452	75.5	29	36.0
Kingston upon Hull	UK0018	ag	301416	80.4	40	60.1
Southampton Urban Area	UK0019	ag	304400	72.8	53	63.7
Birkenhead Urban Area	UK0020	ag	319675	89.1	65	73.4
Southend Urban Area	UK0021	ag	269415	66.8	31	50.6
Blackpool Urban Area	UK0022	ag	261088	65.8	48	64.8
Preston Urban Area	UK0023	ag	264601	60.4	35	47.4
Glasgow Urban Area	UK0024	ag	1168270	368.7	201	300.6
Edinburgh Urban Area	UK0025	ag	452194	120.1	60	102.3
Cardiff Urban Area	UK0026	ag	327706	75.6	38	59.1
Swansea Urban Area	UK0027	ag	270506	79.7	29	65.1
Belfast Metropolitan Urban Area	UK0028	ag	515484	198.1	29	158.4
Eastern	UK0029	non-ag	4909880	19133.7	603	866.0
South West	UK0030	non-ag	4039460	23562.6	439	648.9
South East	UK0031	non-ag	6160630	18672.6	808	1303.0
East Midlands	UK0032	non-ag	3261330	15495.9	418	696.3
North West & Merseyside	UK0033	non-ag	3470620	13722.9	578	970.7
Yorkshire & Humberside	UK0034	non-ag	3003870	14796.6	365	754.8
West Midlands	UK0035	non-ag	2624020	12186.3	351	544.4
North East	UK0036	non-ag	1443910	8291.4	199	289.3
Central Scotland	UK0037	non-ag	1883010	9347.6	222	360.9
North East Scotland	UK0038	non-ag	976022	18631.4	130	230.4
Highland	UK0039	non-ag	341329	39134.5	9	32.4
Scottish Borders	UK0040	non-ag	250529	11184.1	35	47.3
South Wales	UK0041	non-ag	1698080	12228.4	167	321.1
North Wales	UK0042	non-ag	702506	8382.6	86	156.0
Northern Ireland	UK0043	non-ag	1149150	13974.1	85	348.9
Total			61392538	244813.3	9553	13609.8

ag = agglomeration zone
non-ag = non-agglomeration zone

1.4 Monitoring sites

The monitoring stations operating during 2008 for the purpose of AQDD1 and AQDD2 are listed in Form 3 of the questionnaire which can be found on the CDR (2009). Not all sites had sufficient data capture during 2008 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 for the entire year in the analysis in order to ensure that we can make maximum use of data from the monitoring sites operational for the whole of 2008 for reporting purposes. Data capture statistics for sites operational during 2008 are also presented in Form 3 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 were included in AQDD1 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 2008 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 came into force in 2001. 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. Member states are no longer required to report with respect to the Stage 2 indicative limit values for PM_{10}. Details of the assessment carried out for lead are provided in the accompanying report (Yap et al., 2009).

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. A reported exceedence of the limit value + margin of tolerance also means that 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’ must be prepared.

Table 1.2. Limit values for SO_2

	Averaging period	LV	LV + MOT 2008	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 2008	Date by which LV is to be met
1. Hourly LV for the protection of human health	1 hour	200 $\mu g\ m^{-3}$ NO_2 not to be exceeded more than 18 times a calendar year	220 $\mu g\ m^{-3}$, 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 $\mu g\ m^{-3}$ NO_2	44 $\mu g\ m^{-3}$, NO_2	1 January 2010
3. LV for the protection of vegetation	Calendar year	30 $\mu g\ m^{-3}$ 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 2008	Date by which LV is to be met
1. 24-hour LV for the protection of human health	24 hour	50 $\mu g\ m^{-3}$ 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 $\mu g\ m^{-3}$	N/A	1 January 2005

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

	Averaging period	LV	LV + MOT 2008	Date by which LV is to be met
1. 24-hour LV for the protection of human health	24 hour	50 $\mu g\ m^{-3}$ 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 $\mu g\ m^{-3}$	24 $\mu g\ m^{-3}$	1 January 2010

Table 1.5. Limit values for lead

	Averaging period	LV	LV + MOT 2008	Date by which LV is to be met
Annual LV for the protection of human health	Calendar year	0.5 $\mu g\ m^{-3}$	N/A	1 January 2005

Table 1.6. Limit values for benzene

	Averaging period	LV	LV + MOT 2008	Date by which LV is to be met
Annual LV for the protection of human health	Calendar year	5 $\mu g\ m^{-3}$	7 $\mu g\ m^{-3}$	1 January 2010

Table 1.7. Limit values for CO

	Averaging period	LV	LV + MOT 2008	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 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 under contract and not part of the national network, including Local Authority sites in the AEA Calibration Club, Scottish Air Quality Archive monitoring sites, Welsh Air Quality Forum monitoring sites and sites from the Kent and Medway Air Quality Monitoring Network, 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, are formally members of the Calibration Club. For 2008 we have also obtained monitoring data from the London Air Quality Network (LAQN) and Hertfordshire and Bedfordshire Air Quality Monitoring Network, courtesy of ERG. 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. 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 1 km x 1 km grid for the 2008 calendar year. Emissions estimates used in calculating pollutant concentrations have been taken from the National Atmospheric Emissions Inventory (Murrells et al., 2009). Maps of roadside concentrations of NO_2, PM_{10} and benzene and CO have also been prepared for 9,553 urban major road links (A-roads and motorways). Emissions maps utilised in this modelling work are presented in the NAEI report (Murrells et al., 2009).

The dominant contributions to ambient SO_2 concentrations in the UK are from power stations and refineries. Emissions of SO_2 from point sources were therefore modelled explicitly, whereas, the more diffuse area sources were 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 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_X 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 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) (Murrells et al., 2009). Emission maps from the 2007 NAEI have been used for the modelling work described here. Emission estimates for area sources have been scaled to values appropriate to 2008, using UK sector total emissions from 2007 and 2008.

The methods used to calculate the dispersion kernels for 2008 are described in Appendix 3.

The work carried out to check that the revised aircraft and shipping emissions were suitable for use in the PCM model for 2008 is described in Appendix 4.

1.8 Air quality in Gibraltar in 2008

Air quality monitoring is undertaken in Gibraltar and these data are submitted to the Commission each year via a separate questionnaire to that compiled for the UK (CDR, 2009). Three continuous automatic monitoring stations were in operation in 2008 – Bleak House (background site), Rosia Road (roadside site) and Witham’s Road (roadside site). The results of the air quality assessment are presented in Appendix 6, including tables of the relevant forms from the questionnaire and details of the monitoring sites.

2 SO_2

2.1 Introduction

Maps of annual mean, winter mean, 99.73 percentile of hourly mean and 99.18 percentile of daily mean SO_2 concentrations have been calculated for 2008. The percentile concentrations presented here correspond to the number of allowed exceedences of the 1-hour and 24-hour limit values for SO_2. The modelling methods were developed by Abbott and Vincent (1999, 2006). Emissions from point and area sources were modelled separately and the results combined within a geographical information system to produce the respective concentration maps.

Emissions from larger point sources (sources with emissions ≥ 500 tonnes per year) were modelled using the dispersion model ADMS 4.1 (CERC, 2008). Hourly emissions profiles for the power stations in England and Wales for 2008 were provided by the Environment Agency. Emissions from power stations in Northern Ireland were modelled using emissions profiles typical of electricity generation in summer and winter. Emissions from non-power station point sources were based upon data obtained from the Environment Agency’s Pollution Inventory. Emissions from smaller point sources (< 500 tonnes) were modelled using the “small point source model”. This model is described in more detail in Appendix 2. The emissions for both the non-power station large and small point sources are for 2007; 2008 emissions for these types of sources were not available when the modelling work was conducted.

For the large point emission sources, concentrations are predicted for 5 km x 5 km receptors within a number of receptor areas (or tiles), which together covered the UK. The size of the receptor areas was typically 100 km x 100 km, extending out to 150 km where appropriate. All sources within the receptor area and extending out 100 km from the square’s border were assumed to influence concentrations within the receptor area. Emissions were modelled using sequential meteorological data for Waddington in Lincolnshire. This site was chosen as the most representative of meteorology in the vicinity of the largest point sources in the UK. This approach ensures that the combined impact of several sources on ambient high percentile concentrations is estimated correctly.

The contribution to ambient SO_2 concentrations from area sources was calculated using a dispersion kernel approach. Emission estimates for area sources have been scaled to values appropriate to 2008, using UK sector total emissions for 2007 and 2008. Concentrations are predicted for 1 km x 1 km receptors. Dispersion kernels were calculated using ADMS 4.1 and hourly sequential meteorological data for 2008 from Waddington. Modelling of the area sources is described in more detail in Appendix 3.

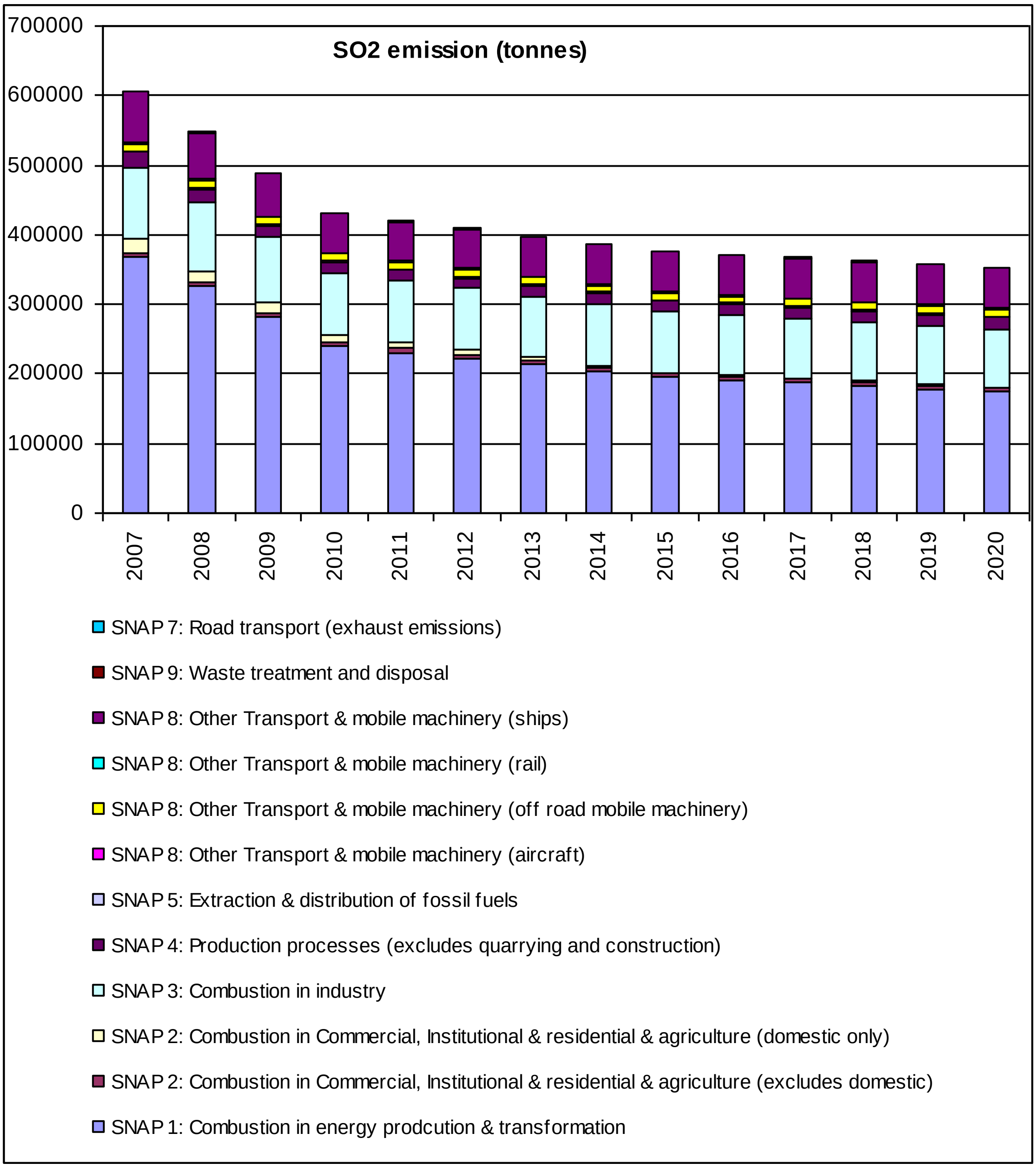
Details of the method to combine the component parts are described in the following sections. The map of winter mean SO_2 concentrations was derived from the annual mean map using a factor of 1.30, which is the ratio between the average concentration measured at rural SO_2 monitoring sites during the 2007-2008 winter period and annual concentration for during 2008, 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 2.4).

2.2 SO_2 emissions

Figure 2.1 shows the total UK SO_2 emissions for each year from 2007 to 2020 and the emissions broken down by SNAP code. The emissions are dominated by combustion in energy production & transformation and the total emissions are predicted to decrease into the future.

Figure 2.1. Total UK SO_2 emissions for 2007 and emissions projections up to 2020 by SNAP code from NAEI 2007

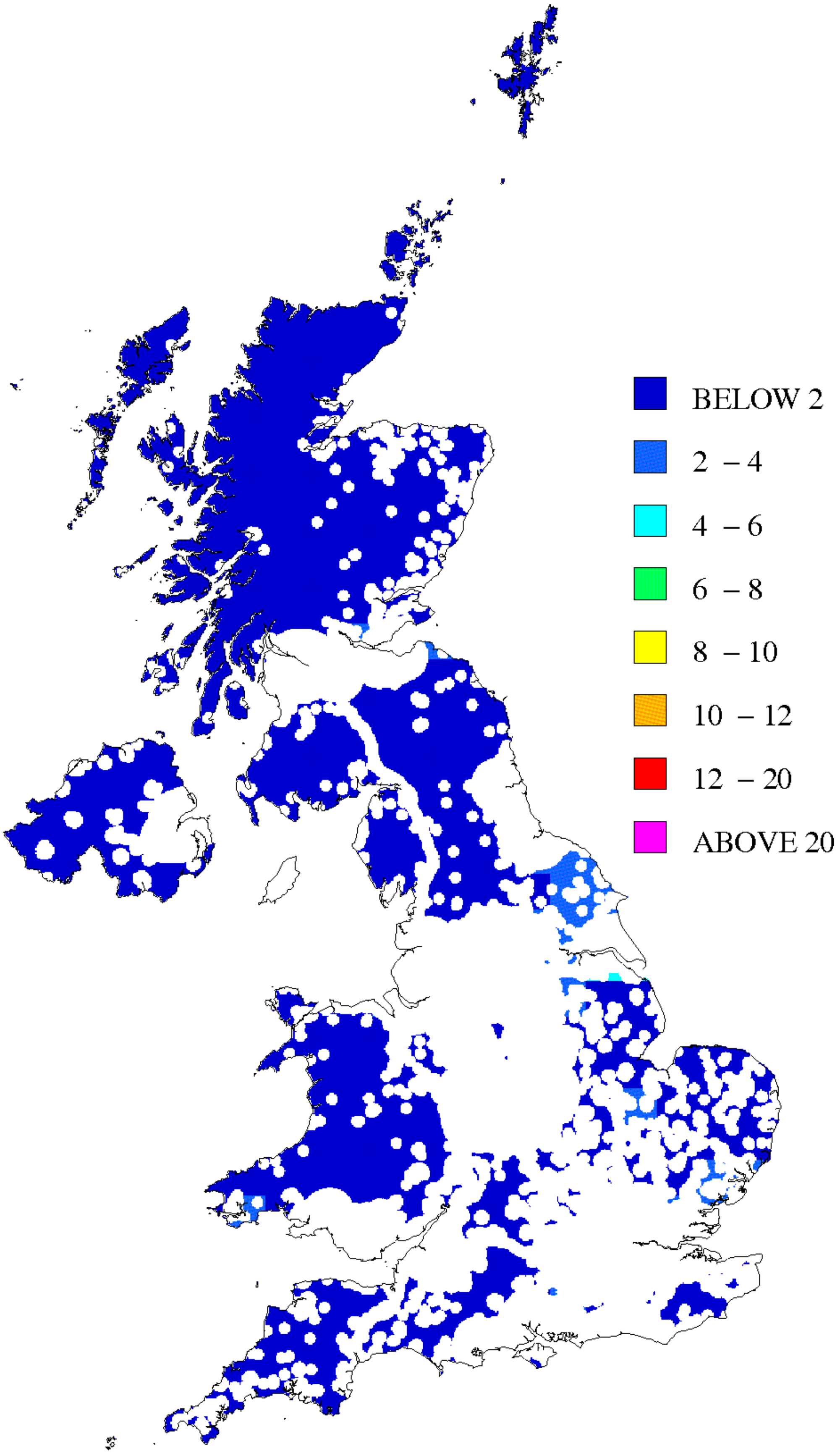


2.3 Maps of winter and annual mean concentrations

A map of annual mean SO_2 concentration for 2008 in ecosystem areas is shown in Figure 2.2. This map has been calculated by removing non-ecosystem areas from the background SO_2 map and calculating the zonal mean of the 1 km^2 grid squares for a 30 km^2 grid.

Mean concentrations on a 30 km^2 grid have been used to prevent the influence of any urban area appearing unrealistically large on adjacent ecosystem areas. Thus the modelled concentrations in ecosystem areas should be representative of approximately 1000 km^2 as specified in Directive 1999/30/EC for monitoring sites used to assess concentrations for the ecosystem limit value.

Figure 2.2. Annual mean SO_2 concentration, 2008 (μg m^{-3}) in ecosystem areas



© Crown copyright. All rights reserved Defra, Licence number 100022861 [2009]

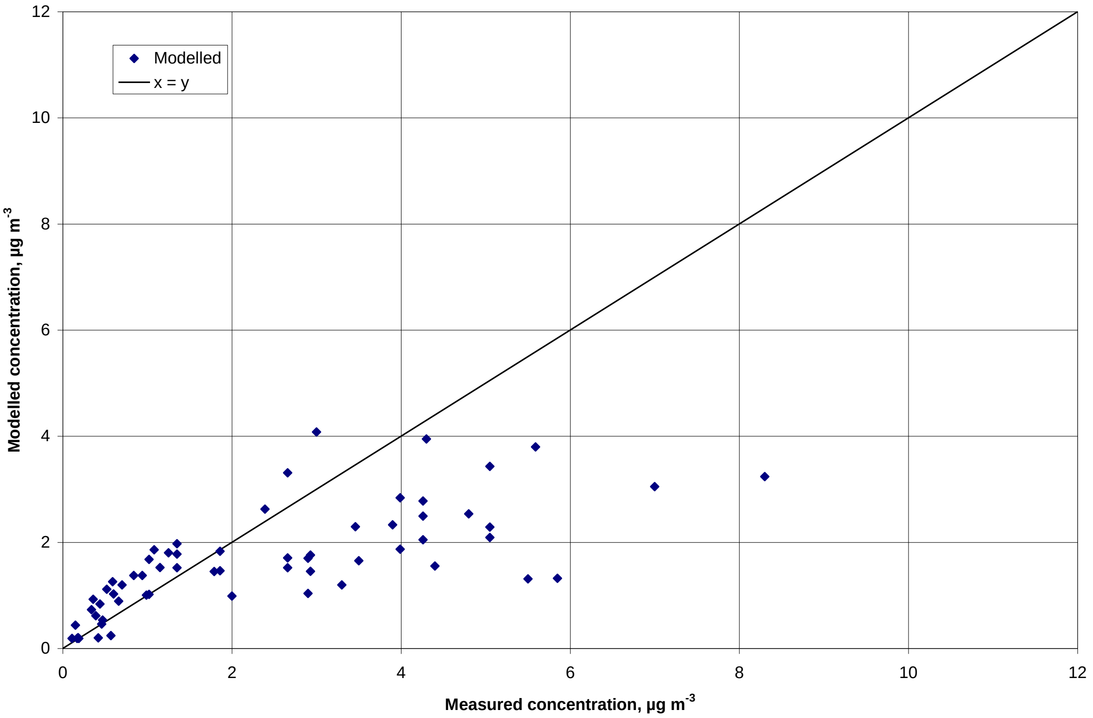
The factors used to combine the point source and area source contributions are shown in Table 2.1. A residual concentration of 0.19 µg m^{-3} was added. This residual was derived by a linear least squares fit between the measured and modelled concentrations. The residual is associated with contributions from more distant sources, for example, from continental European sources that are not explicitly modelled. The area coefficient was derived from the NO_x calibration with measured data. The local contribution to ambient NO_X concentrations is dominated by area sources. The calibration of the area source model for NO_X should therefore provide a robust coefficient for the area sources of other pollutants.

Table 2.1. Coefficients for annual mean model

	Points coefficient	Area coefficient	Constant (µg m^{-3})
Annual mean	1	2.4547	0.19

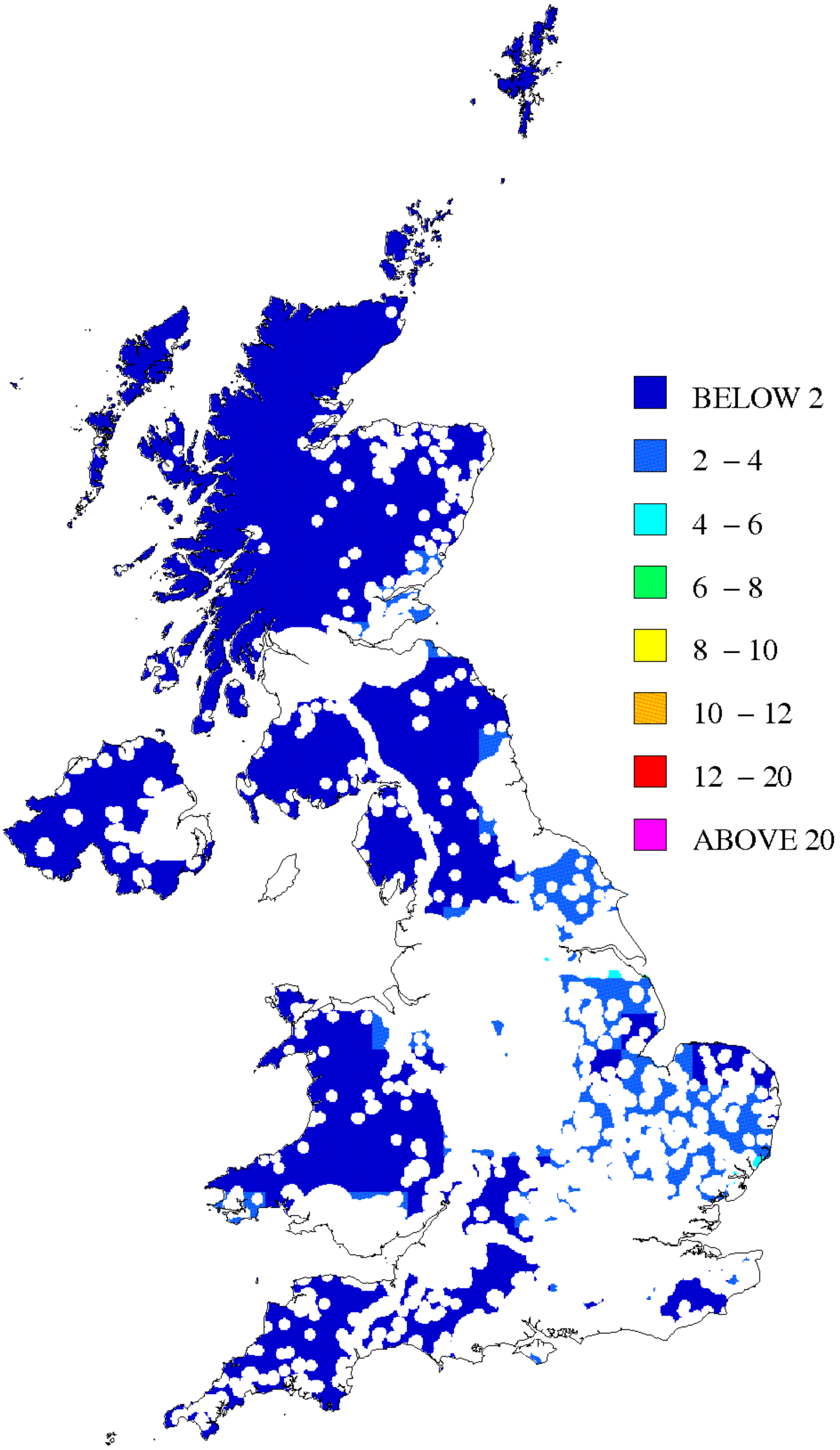
Measured concentrations from Rural SO_2 Monitoring Network sites (Tang, 2009), rural, suburban and industrial sites in the national automatic monitoring networks and rural automatic monitoring sites maintained by the electricity generating companies were used to check the method used to combine the modelled components. A list of the sites maintained by the electricity generating companies is included in Appendix 1. The comparison plot for 2008 is shown in Figure 2.3.

Figure 2.3. Comparison plot for 2008 annual mean SO_2 concentration



A map of winter mean SO_2 concentrations for the period October 2007 to March 2008 has also been calculated and is shown in Figure 2.4. This map was calculated by multiplying the annual mean map for 2008 by 1.30, which is the ratio between the average concentration measured at rural SO_2 monitoring sites during the 2007-2008 winter period and annual concentration for during 2008.

Figure 2.4. Winter mean SO_2 concentration, 2007-2008 ($\mu g\ m^{-3}$) in ecosystem areas



© Crown copyright. All rights reserved Defra, Licence number 100022861 [2009]

2.4 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 2008 are shown in Figures 2.5 and 2.6 and were calculated for comparison with the 1-hour and 24-hour limit values for SO_2.

The methodology to produce the maps is based on research on combining concentrations arising from area and industrial sources undertaken for the Environment Agency (Abbott and Vincent, 2006). This 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 by Abbott and Vincent assuming that the variance of the residuals was proportional to the modelled concentration. The regression model was of the form:

$$c_{measured} = \max \begin{bmatrix} A c_{modelled\_industrial,\%ile} + 2(c_{modelled\_area} + c_{long\_range})_{annual} \\ 2A c_{modelled\_industrial,annual} + k(c_{modelled\_area} + c_{long\_range})_{annual} \end{bmatrix} .$$

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. The k factors include the calibration factor of 2.4547 derived for NO_X.

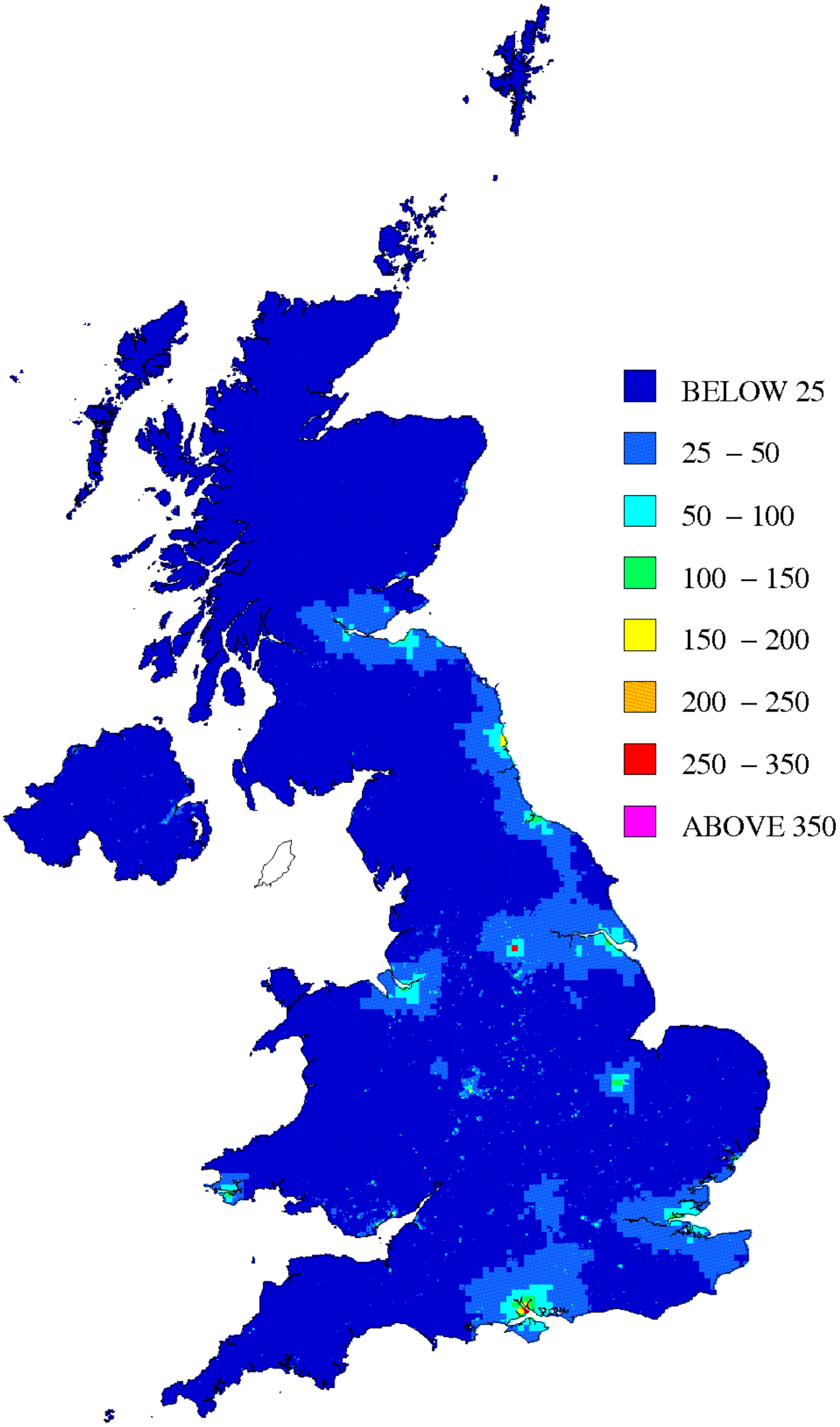
Table 2.2. Factors for percentile models

Metric	Constant (A)	Background multiplier factor (k)	c_{long_range}
99.73 percentile of 1-hour values	1.09	24.79	0.19
99.18 percentile of 24-hour values	1.23	8.10	0.19

The justification for treating industrial sources and area emissions separately 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.

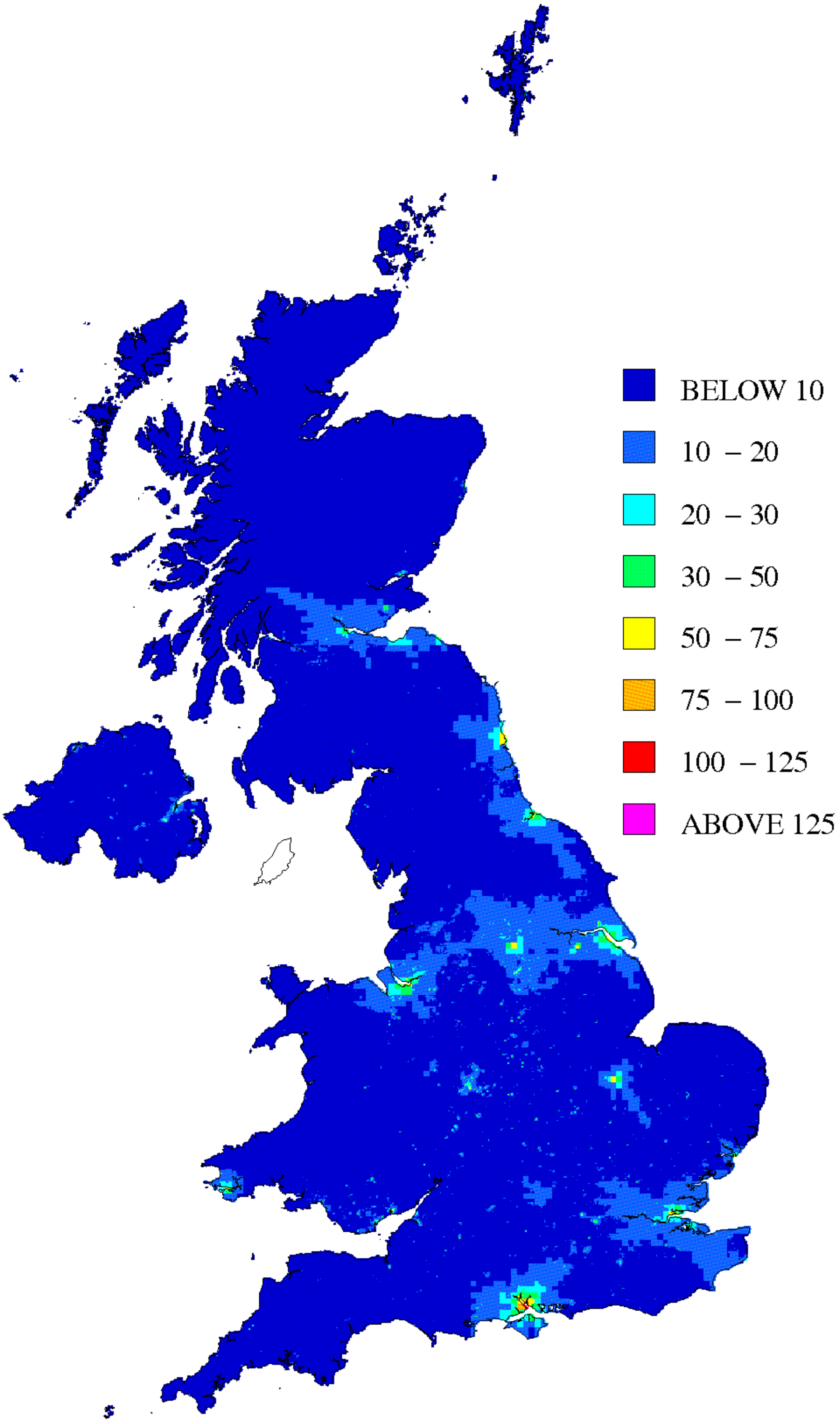
Figures 2.7 and 2.8 provide an intermediate quality check at rural and suburban sites which form part of the national network and at sampling sites operated by the electricity supply companies.

Figure 2.5. 99.73 percentile of 1-hour mean SO_2 concentration, 2008 ($\mu g\ m^{-3}$)



© Crown copyright. All rights reserved Defra, Licence number 100022861 [2009]

Figure 2.6. 99.18 percentile of 24-hour mean SO_2 concentration, 2008 ($\mu g\ m^{-3}$)



Crown copyright. All rights reserved Defra, Licence number 100022861 [2009]

Figure 2.7. Comparison plot for 2008 99.73 percentile of 1-hour mean SO_2 concentrations

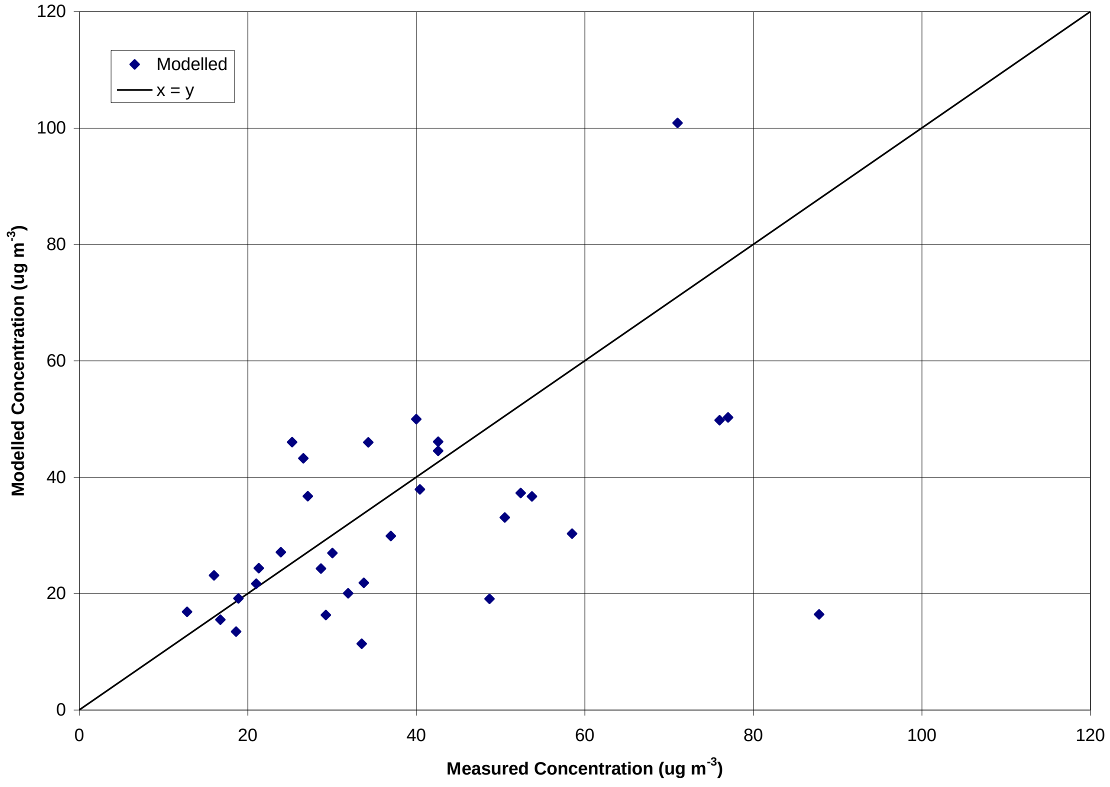
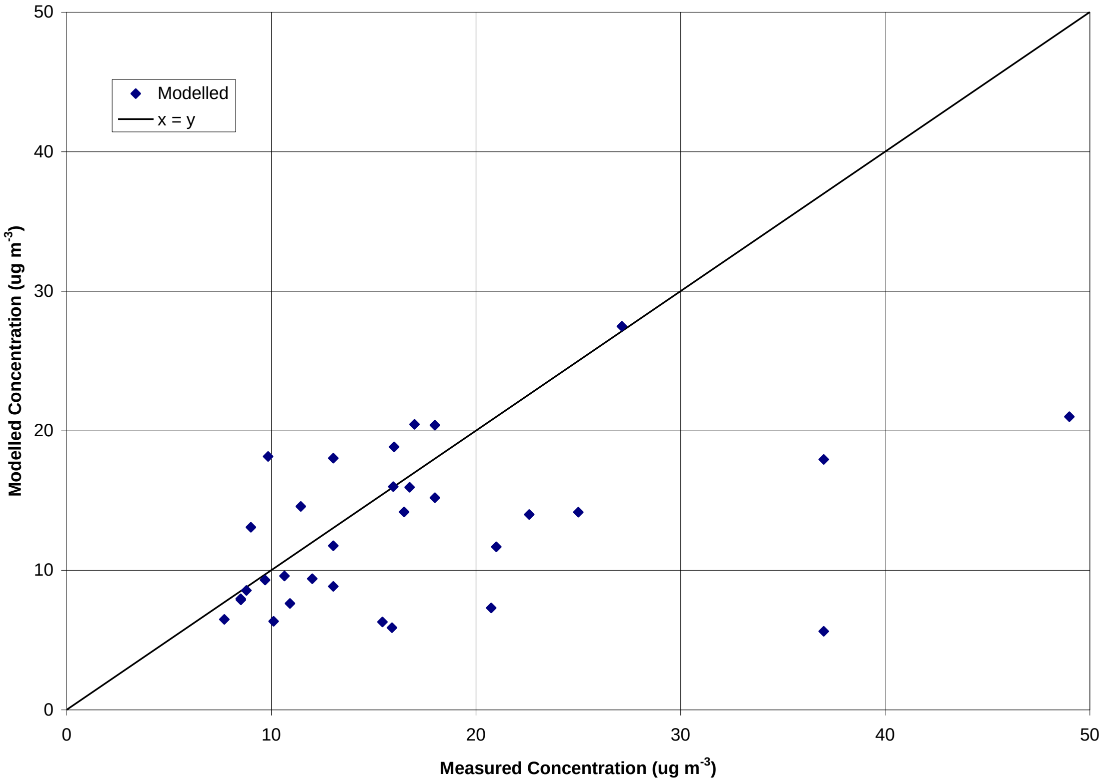


Figure 2.8. Comparison plot for 2008 99.18 percentile of 24-hour mean SO_2 concentrations



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 2008 at national network and AEA Calibration Club monitoring sites. Figures 2.9a and 2.9b show the relationship between the annual mean and the 99.73 percentile of 1-hour mean values and the 99.18 percentile of 24-hour 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 = 7.99 × *Modelled Annual Mean* + 2.38

Predicted 99.18 %ile in Northern Ireland = 4.18 × *Modelled Annual Mean* - 0.026.

Figure 2.9a. Relationship between mean concentration and 99.73 percentile of 1-hour concentrations at sampling sites in Northern Ireland

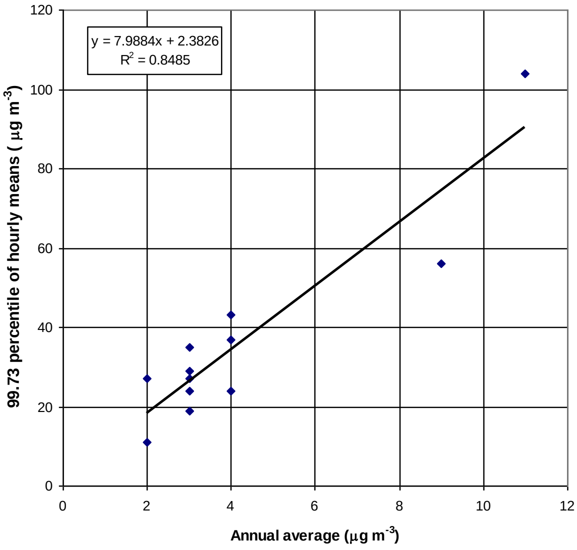
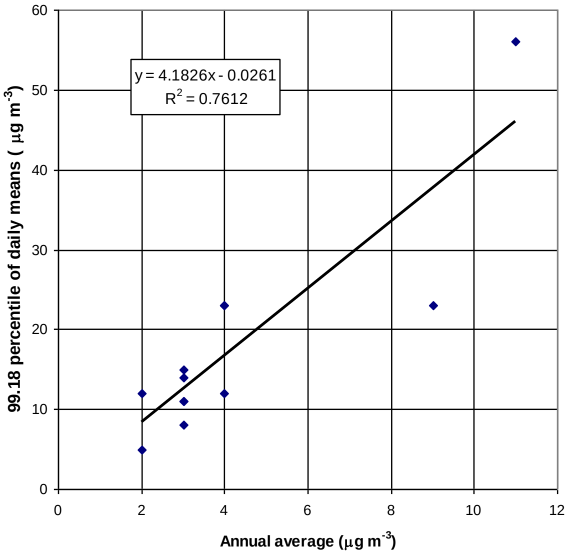


Figure 2.9b. Relationship between mean concentration and 99.18 percentile of 24-hour concentrations at sampling sites in Northern Ireland



2.5 Verification of mapped values

Figures 2.10, 2.11 and 2.12 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 2008 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'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% or 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 2.10. Verification of annual mean SO_2 model 2008

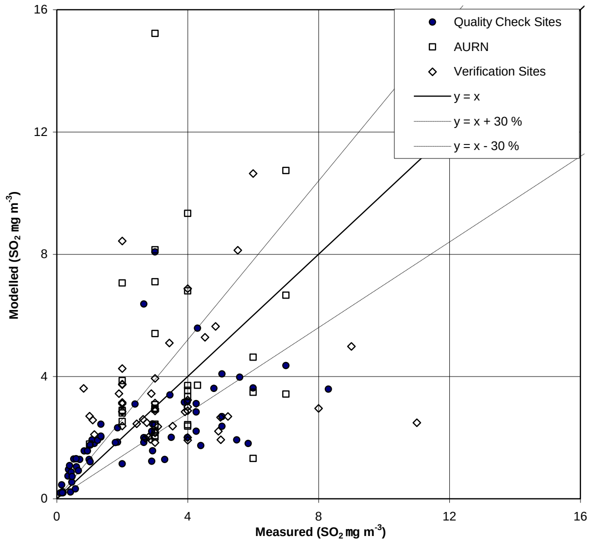


Figure 2.11. Verification of 99.73 percentile of 1-hour mean SO_2 model 2008

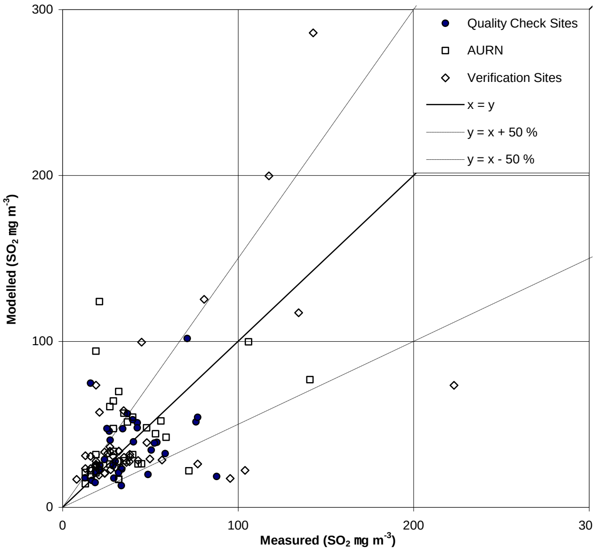
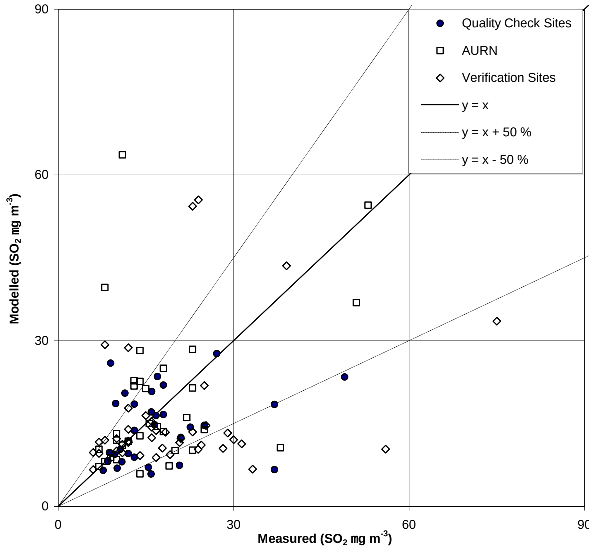


Figure 2.12. Verification of 99.18 percentile of 24-hour mean SO_2 model 2008



Summary statistics for modelled and measured SO_2 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 concentration for each averaging time agrees reasonably well, with some outliers. The agreement between measured and modelled concentrations on a site-by-site basis (quantified using R^2) has historically been poor for all metrics both for sites in the national network and the verification sites. Note that the 1 km^2 grid annual mean map is not compared directly with the annual mean limit value; the zonal mean of the 1 km^2 grid squares in ecosystem areas has been calculated for a 30 km^2 grid, as discussed above.

Reasons for the poor agreement 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 for point sources (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.

The R^2 values in Tables 2.3 to 2.5 for national network sites were comparable to those reported in previous years. The R^2 values for the verification sites were far smaller than in previous years.

Methods to improve the prediction could include:

- Improving emission characteristics for smaller emission sources;
- Increasing the resolution of the receptor area (5 km to 1 km or 2 km);
- Considering using region specific meteorological data;
- Using 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	2.42	2.88	0.30	70	70[a]
Verification sites	3.53	3.45	0.04	62	47

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	17.56	18.22	0.11	33	39[b]
Verification sites	21.69	19.33	0.09	38	45

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

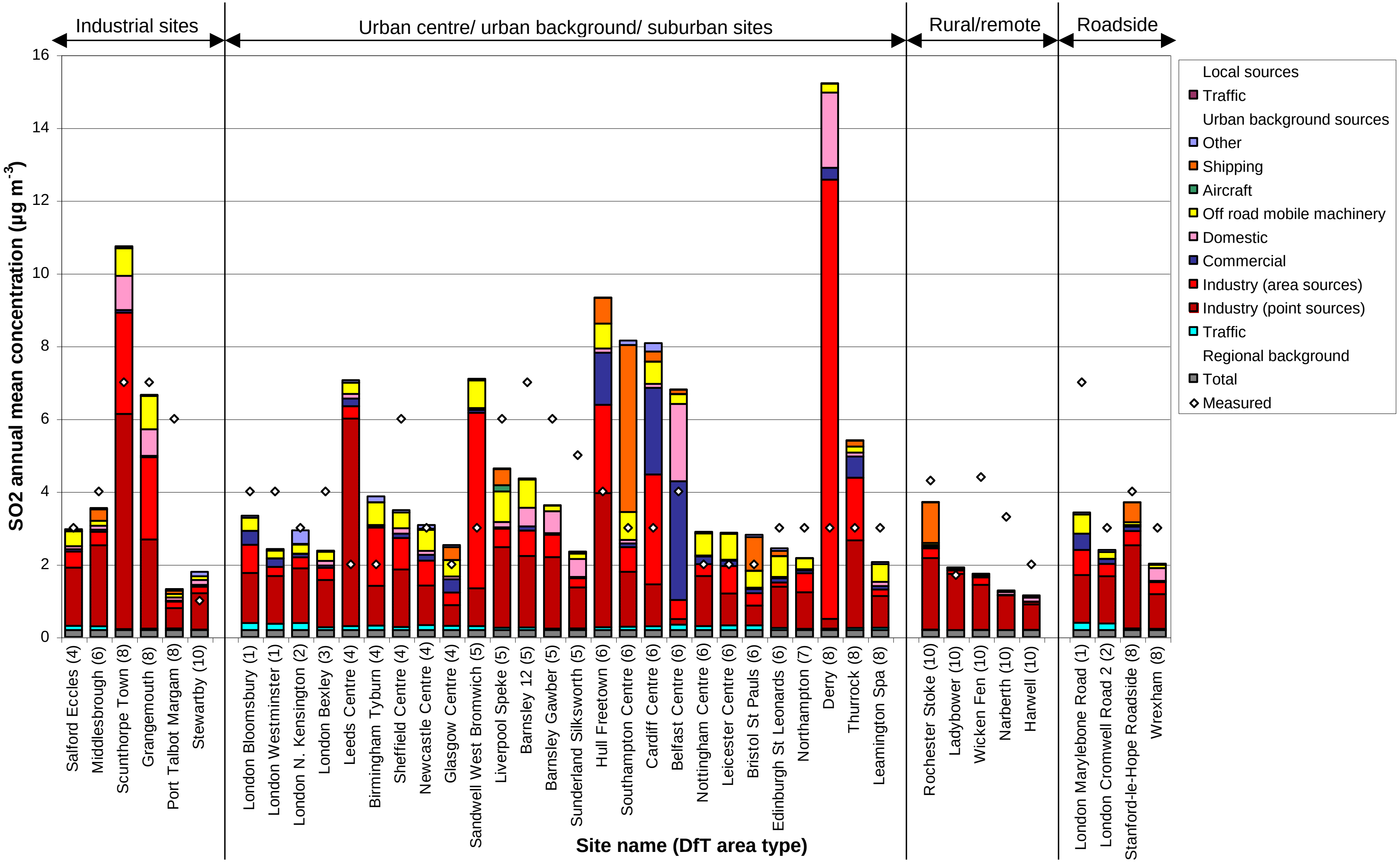
	Mean of measurements ($\mu g\ m^{-3}$)	**Mean of model estimates ($\mu g\ m^{-3}$)**	**R^2**	**% of sites outside DQO of ±50%**	**Number of sites in assessment**
National Network	37.57	42.55	0.15	31	39[c]
Verification sites	45.11	45.41	0.37	33	45

c includes measurement data from sites in Defra’s AURN only

2.6 Source apportionment

Figure 2.13 shows the source apportionment for modelled annual mean concentrations of SO_2 at AURN monitoring sites for 2008. Measured annual mean concentrations at each site are shown for reference. This figure shows that annual mean SO_2 concentrations at most sites are dominated by contributions from industrial sources. Some sites also have significant contributions from shipping, commercial and domestic sources. It appears that the contribution from industrialised sources has been over-estimated at the Derry site, where the measured concentration is considerably lower than the model estimate.

Figure 2.13. The source apportionment for modelled annual mean concentrations of SO_2 at AURN monitoring sites for 2008 (area type of each site is shown in parenthesis after its name – see Table 3.2)



2.7 Comparison of modelling results with limit values

Modelling results for SO_2 have not been tabulated here because the modelled and measured SO_2 concentrations for 2008 are below the limit values for all zones. In contrast to some previous years there were no modelled exceedences in the Eastern Zone associated with industrial emissions at the brickworks at Stewartby. This was to be expected as the brickworks have now closed.

3 NO_2/NO_X

3.1 Introduction

Limit values

Two limit values for ambient NO_2 concentrations are set out in the First Daughter Directive. These have been specified for the protection of human health and will come into force on 01/01/2010. These limit values are:

- An annual mean concentration of 40 µg m^{-3}.
- An hourly concentration of 200 µg m^{-3}, with 18 permitted exceedences each year

An annual mean limit value for NO_X has also been specified in the directive:

- An annual mean concentration 30 µg m^{-3} (NO_X as NO_2).

This limit value is designed to protect vegetation and as such only applies in vegetation areas defined in the directive. This limit value came into force 19/07/2001.

Annual mean modelling

Annual mean concentrations of NO_X and NO_2 have been modelled for the UK for 2008 at background and roadside locations. Figures 3.1 and 3.2 present maps of annual mean NO_2 concentrations for these locations in 2008. These maps have been used for comparison with the NO_2 limit values described above.

To calculate NO_2 annual mean maps, we have first calculated NO_X annual mean concentration maps at background and roadside locations. The background NO_X map has also been used to generate a map of annual mean NO_X concentrations in vegetation areas for comparison with the NO_X limit value described above. This map is shown in Figure 3.3. This map has been calculated by removing non-vegetation areas from the background NO_X map and calculating the zonal mean of the 1 km^2 grid squares for a 30 km^2 grid so that it complies with the criteria set out in the Directive. Mean concentrations on a 30 km^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 1000 km^2 as specified in Directive 1999/30/EC for monitoring sites used to assess concentrations for the vegetation limit value.

The modelling methods for annual mean NO_X 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, Kent et al., 2007, Kent et al., 2008, Grice et al., 2009).

Outline of the annual mean model

The 1 km x 1 km annual mean background NO_X concentration map has been calculated by summing the contributions from:

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

The area source model has been calibrated using data from the national automatic monitoring networks (AURN) for 2008. At locations close to busy roads an additional roadside contribution has been added to account for contributions to total NO_X from road traffic sources. The contributions from each of these components are described in Section 3.2

In order to estimate the NO_2 concentrations, modelled NO_X concentrations derived from the approach outlined above are converted to NO_2 using a calibrated version of the updated oxidant-partitioning model. This model describes the complex inter-relationships between NO, NO_2 and ozone as a set of chemically coupled species (Jenkin, 2004; Murrells et al., 2008). This approach provides additional insights into the factors controlling ambient levels of NO_2 (and O_3), and how they may vary with NO_X concentration.

Hourly modelling

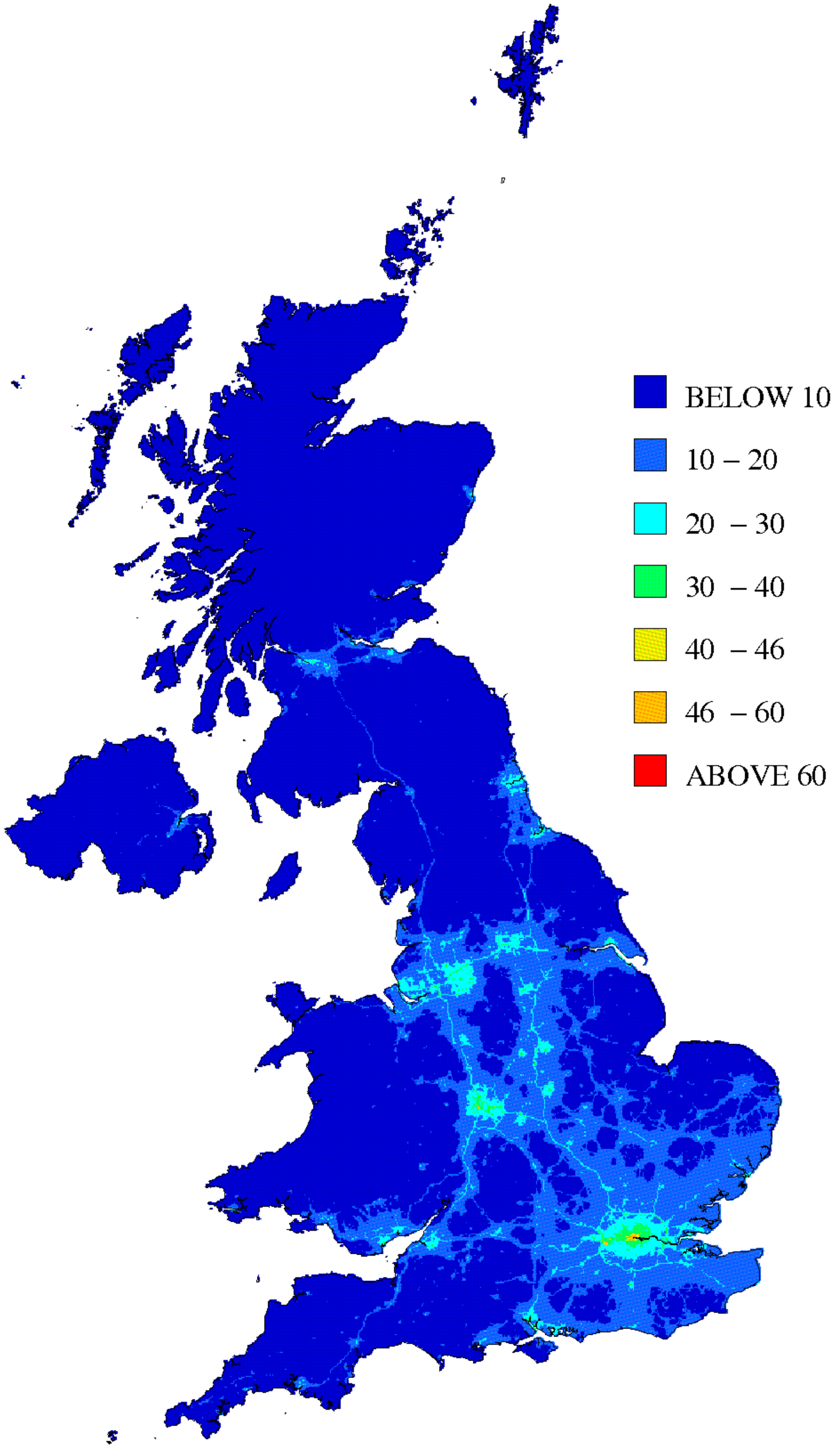
No attempt has been made to model hourly concentrations for comparison with the 1-hour limit value in this report. This is due to the considerable uncertainties involved in modelling at such a fine temporal scale.

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 3.4, which is a scatter plot of the annual mean metric in 2008 against the 99.8th percentile (equivalent to 18 exceedences) hourly mean concentration in the same year. This plot shows a significantly higher number of sites exceeding the annual mean limit value of 40 $\mu g\ m^{-3}$ than the 200 $\mu g\ m^{-3}$ hourly limit value.

Chapter structure

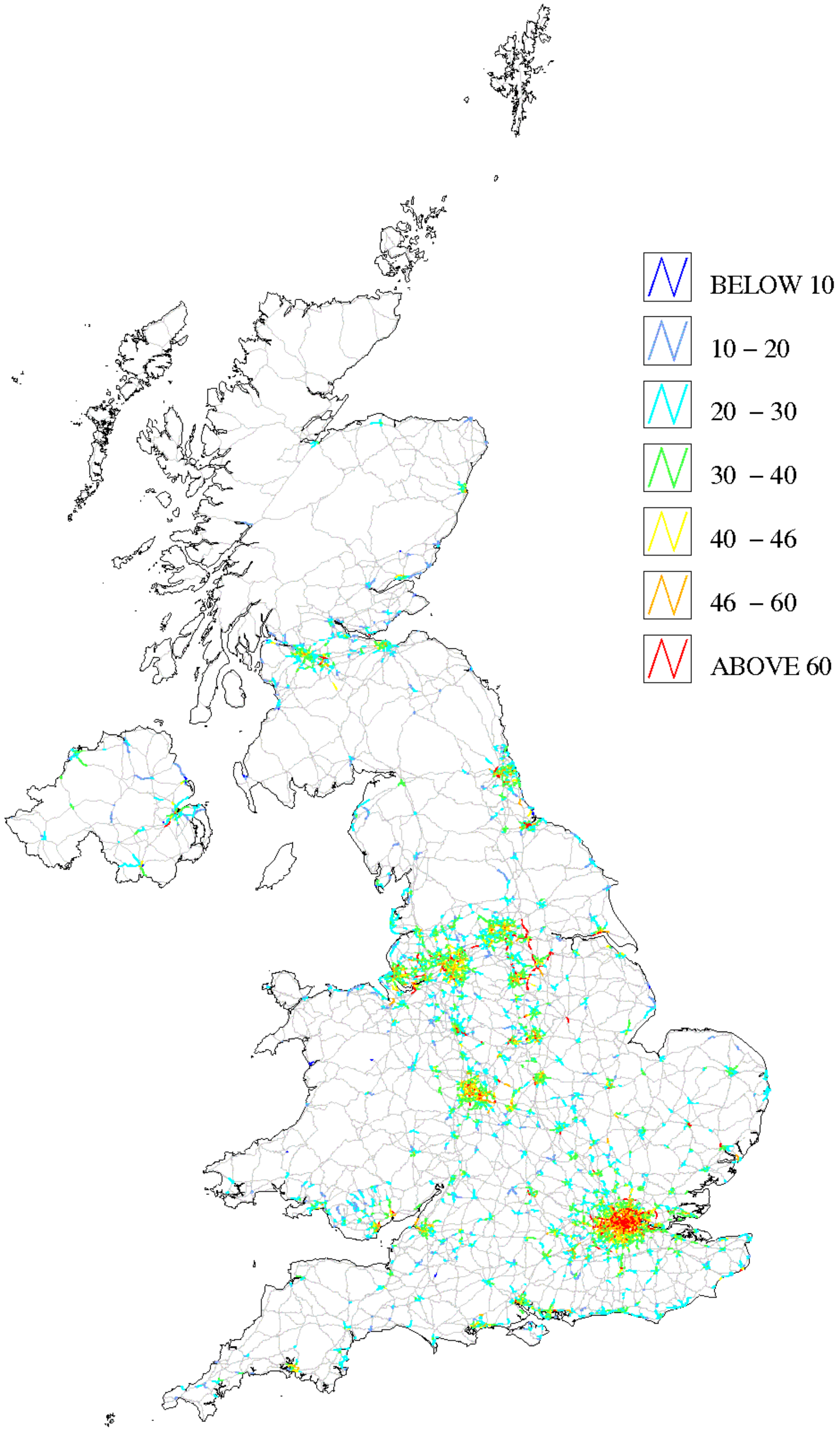
This chapter describes modelling work carried out for 2008 to assess compliance with the NO_X and NO_2 limit values described above. Section 3.2 describes the NO_X modelling methods. Details of the methods used to estimate ambient NO_2 from NO_X are presented in Section 3.3. The modelling results are presented in Section 3.4.

Figure 3.1. Annual mean background NO_2 concentration, 2008 ($\mu g\ m^{-3}$)



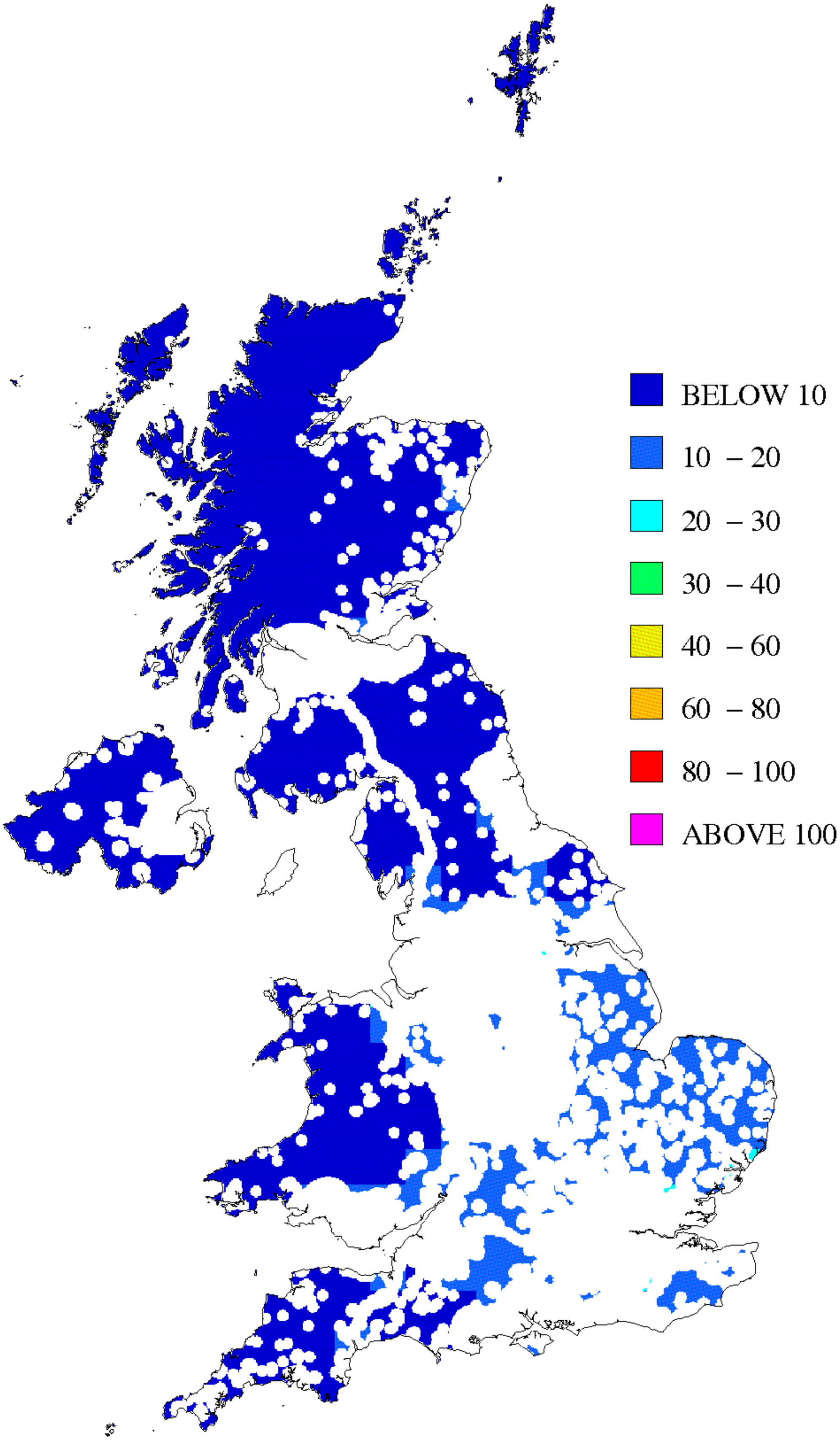
© Crown copyright. All rights reserved Defra, Licence number 100022861 [2009]

Figure 3.2. Urban major roads, annual mean roadside NO_2 concentration, 2008 ($\mu g\ m^{-3}$)



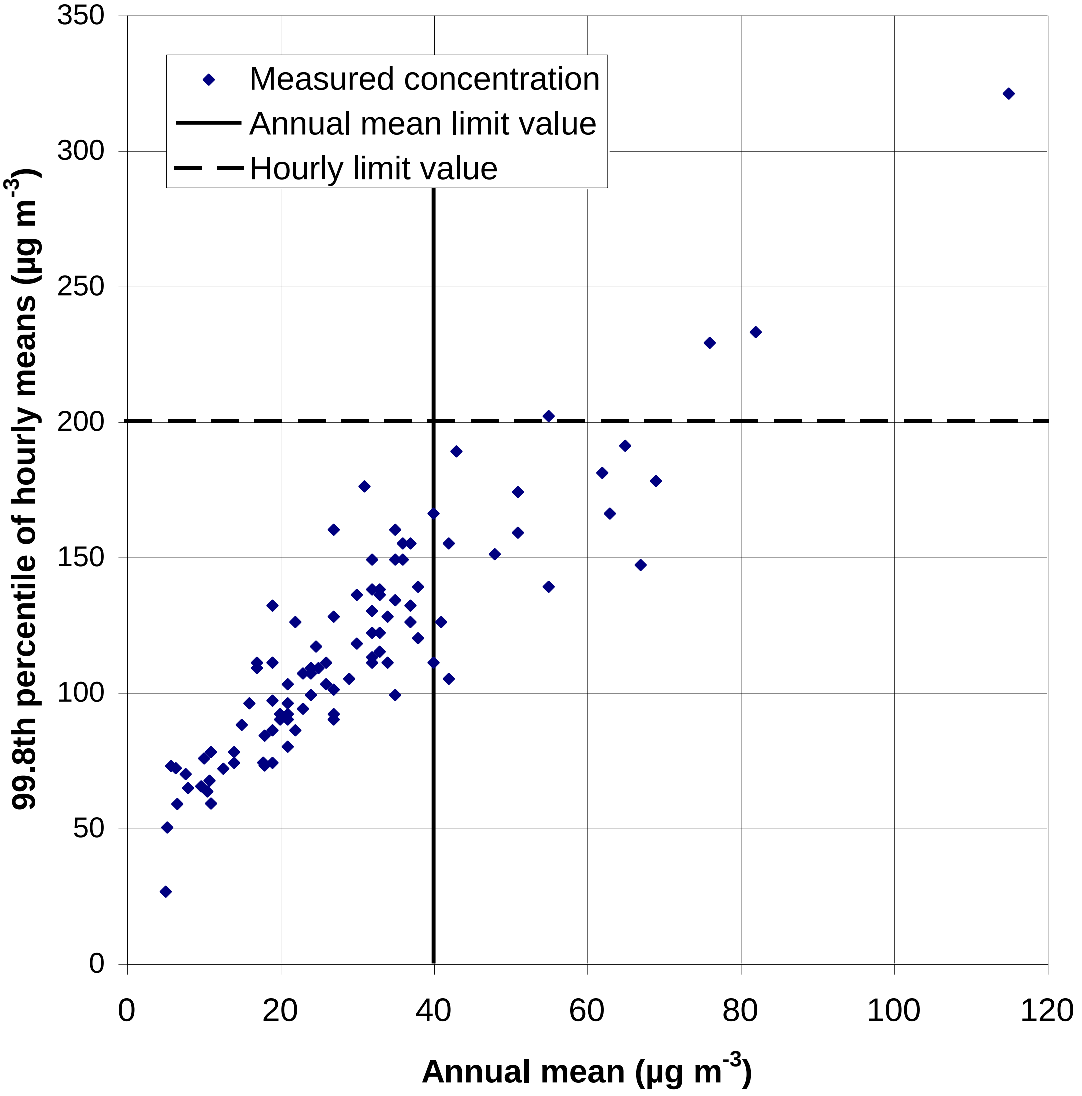
© Crown copyright. All rights reserved Defra, Licence number 100022861 [2009]

Figure 3.3. Annual mean map of NO_X concentrations for comparison with the NO_X vegetation limit value, 2008 ($\mu g\ m^{-3}$, as NO_2)



© Crown copyright. All rights reserved Defra, Licence number 100022861 [2009]

Figure 3.4. Plot of annual mean against 99.8th percentile hourly NO_2 concentrations in 2008



3.2 NO_x modelling

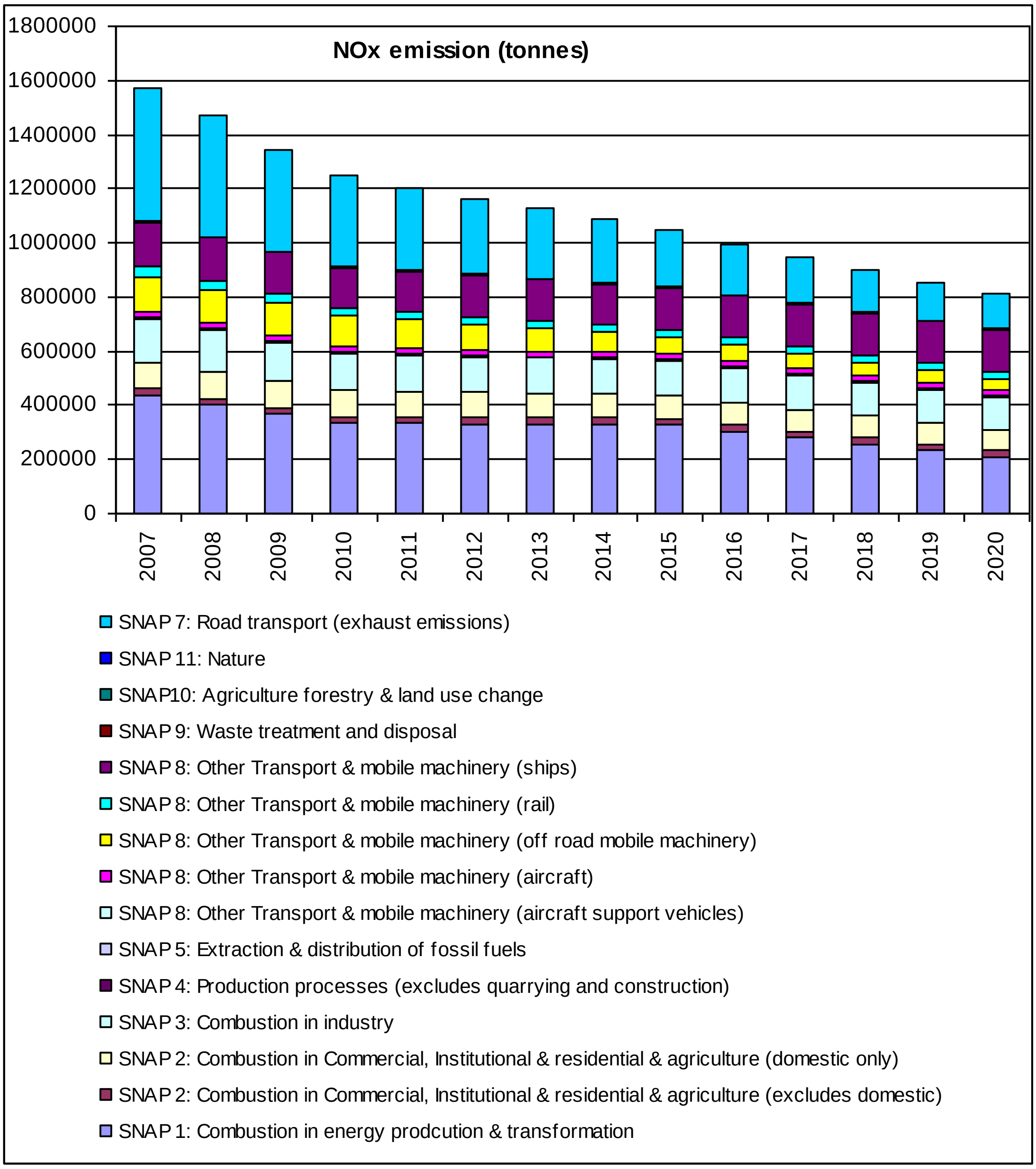
3.2.1 NO_x emissions

The NO_X modelling is underpinned by the NAEI 2007 NO_X emissions estimates. Figure 3.5 shows UK total UK NO_X emissions for 2007 and emissions projections up to 2020 split by SNAP code. This shows that NO_X emissions in 2007 are dominated by two main sources:

- SNAP 7: road transport (exhaust emissions)
- SNAP 1: combustion in energy production & transformation

NO_X emissions are predicted nearly halve between 2007 and 2020, with a particularly steep decline from road transport exhaust emissions over this period.

Figure 3.5. UK total UK NO_X emissions for 2007 and emissions projections up to 2020 by SNAP code from NAEI 2007



3.2.2 NO_X 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 2007 NAEI were estimated by modelling each source explicitly using an atmospheric dispersion model (ADMS 4.1) and sequential meteorological data for 2008 from Waddington. A total of 168 large point sources were modelled for NO_X. Surface roughness was assumed to be 0.1 m. Concentrations were calculated for a 99 km x 99 km square composed of a regularly spaced 1 km x 1 km resolution receptor grid. Each receptor grid was centred on the point source. For each large point source information was retrieved from our stack parameters database. This database has been developed over a period of time under the PCM contract and is updated annually as required. Data sources for this database include a survey of Part A authorisation notices held by the Environment agency and previously collated datasets on emission release parameters from large SO_2 point sources (Abbott and Vincent, 1999). Parameters used in the modelling from the stack parameters database include:

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

Where release parameters were unavailable, engineering assumptions were applied.

3.2.3 NO_X contributions from small point sources

Contributions from NO_X point sources with less than 500 tonnes per annum emissions in the 2007 NAEI were modelled using the small points model described in Appendix 2.

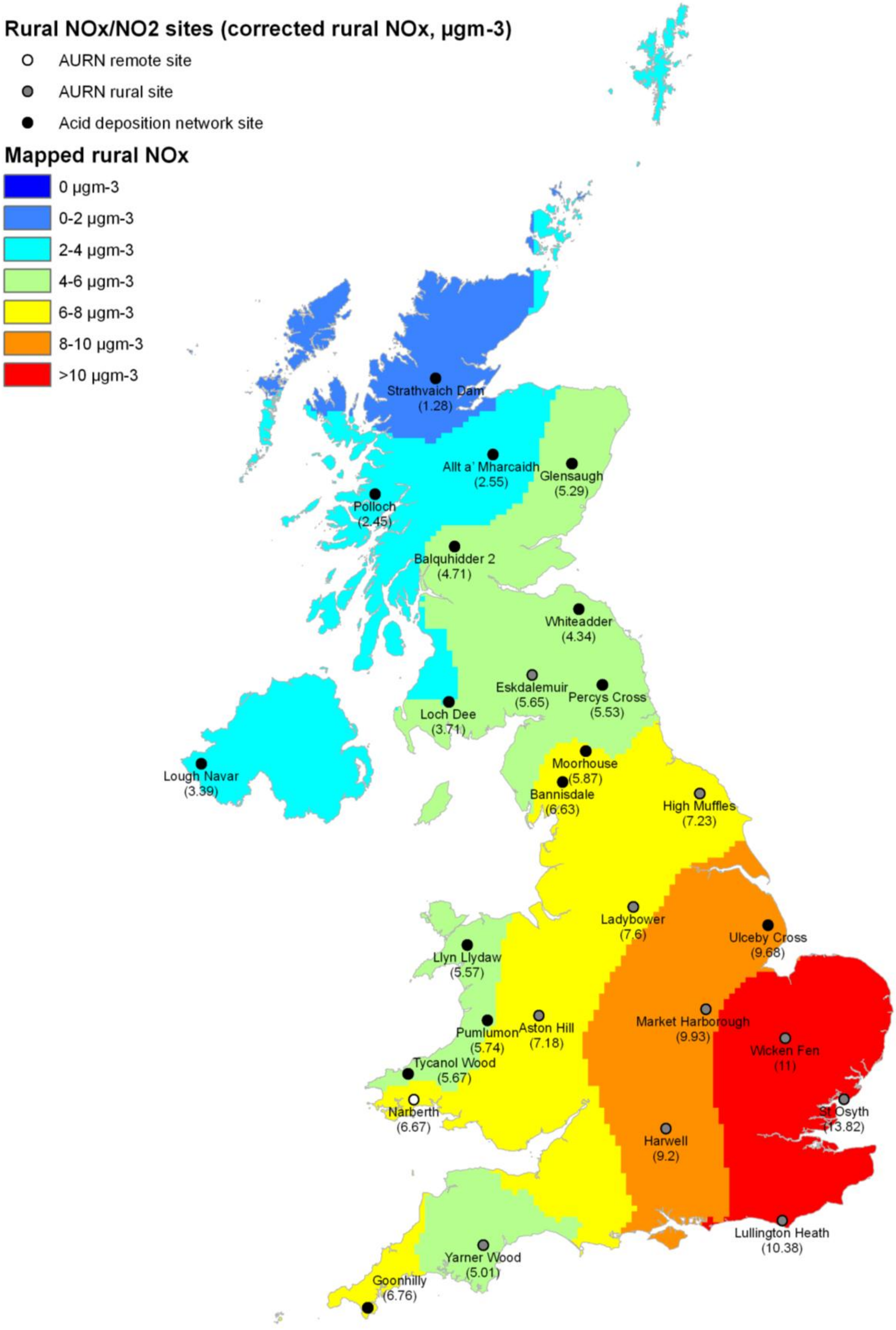
3.2.4 NO_X contribution from rural background concentrations

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 16 rural NO_2 diffusion tube sites from the Acid Deposition Monitoring Network (Lawrence, 2009)

Figure 3.6 shows the locations of these monitoring sites and the interpolated rural map.

Figure 3.6. Rural background NO$_X$ concentrations map with monitoring sites in the interpolation (annual mean NO$_X$ concentrations for 2008 (µg m^{-3}, as NO$_2$) are shown below the site name)



© Crown copyright. All rights reserved Defra, Licence number 100022861 [2009]

Rural NO_x was estimated from rural NO_2 at diffusion tube sites by dividing by 0.7835. This factor, which is a typical NO_X/NO_2 ratio measured at rural automatic monitoring sites (Stedman et al., 2003), does not vary significantly between years or 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 ($\mu g\ m^{-3}$) *= Uncorrected rural background* ($\mu g\ m^{-3}$) *– (A + B + C)*,

where: A is an estimate of the contribution from area source components, derived using the area source model empirical coefficients from the 2007 modelling,

B is the sum of contributions from large point sources in 2008 modelling,

C is the sum of contributions from small point sources in 2008 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.

3.2.5 NO_X contributions from local area sources

The modelled uncalibrated area source contribution has been calculated by applying an ADMS 4.1 derived dispersion kernel to calculate the contribution to ambient concentrations at a central receptor location from area source emissions within a 33 km x 33 km square surrounding each monitoring site. Hourly sequential meteorological data from Waddington in 2008 has been used to construct the dispersion kernels, as described in Appendix 3.

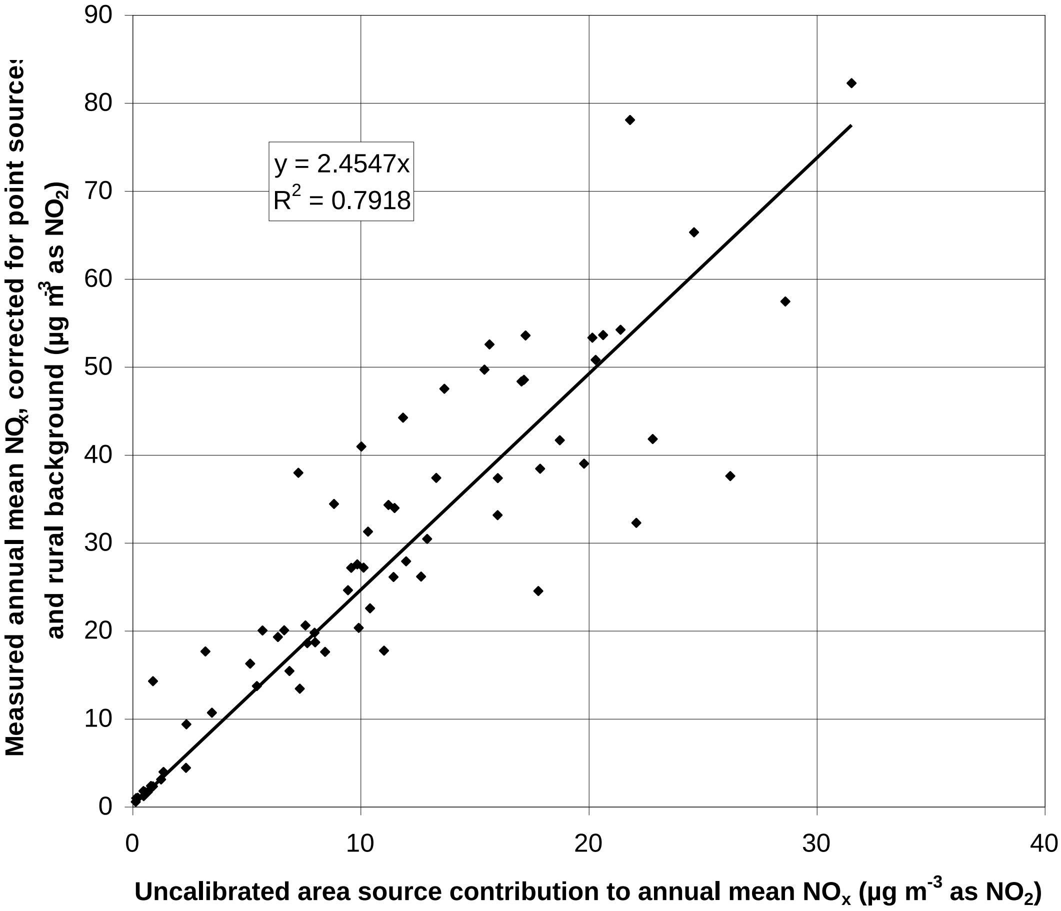
The NAEI aircraft emissions total for NO_X includes all emissions up to 1000m above ground level. To avoid over estimating area source contributions from aircraft to ground level NO_X concentrations, we have applied a factor of 0.5 to take off and landing emissions and have excluded all other non-ground level aircraft emissions. The factor of 0.5 has been chosen on the basis of findings from detailed studies (Underwood, 2009). All ground level aircraft emissions have been included as given in the NAEI 2007. Appendix 5 describes the methodology used to estimate the contribution of aircraft emission to ground-level NO_X emissions. Figure A.5.1 shows good agreement between measured and modelled ground-level NO_X concentrations at Gatwick and Heathrow airports using the revised methodology for estimating ground-level NOx emissions from aircraft.

A new method for calculating shipping emissions has been used in the NAEI 2007. In our area source model, we have applied a cap of 90 tonnes to the total emissions from any given grid square to avoid calculating the equivalent of dock side concentrations in grid squares which are meant to be representative of the entire 1 km x 1 km square. Details of how this cap has been selected are given in Appendix 5.

Figure 3.7 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 to calculate the calibration coefficients used in the area source modelling.

The modelled area source contribution was multiplied by the coefficient to calculate the calibrated area source contribution for each grid square in the country. The point source contributions and regional rural concentrations were then added, resulting in a map of background annual mean NO_X concentrations.

Figure 3.7. Calibration of area source NO_x model, 2008 (µg m^{-3}, as NO_2)



3.2.6 NO_X Roadside concentrations

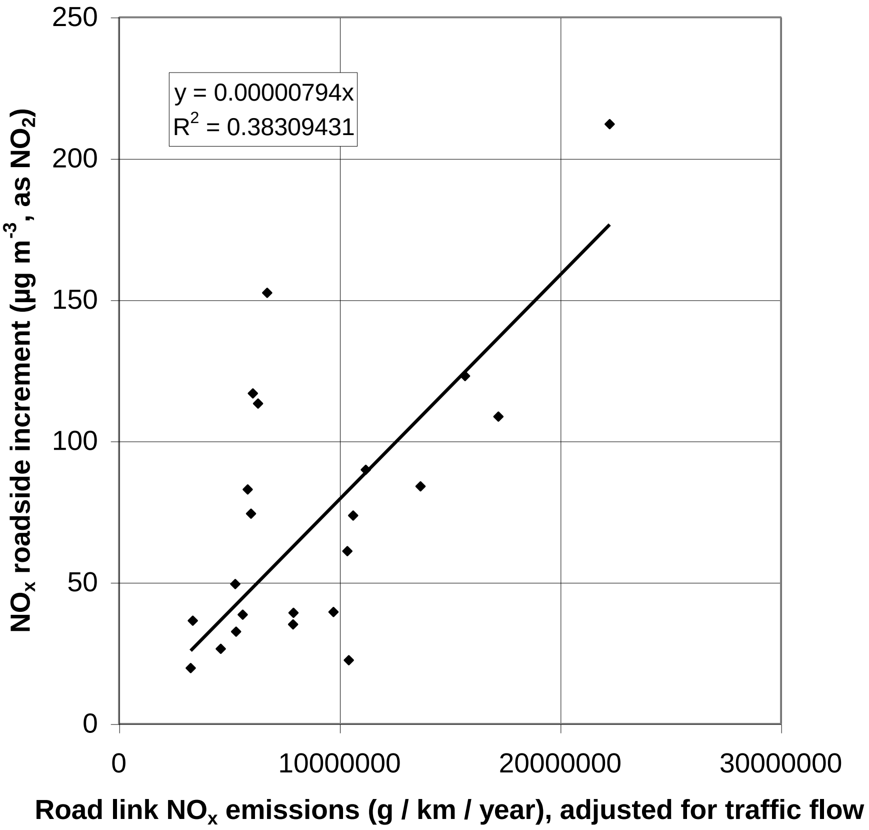
We have assumed that the annual mean concentration of NO_X at roadside locations is made up of two parts: the background concentration (as described above) and a roadside increment:

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 2007 (Murrells et al., 2009) and these have been adjusted to provide estimates of emissions in 2008. Figure 3.8 shows the roadside increment of annual mean NO_X concentrations (i.e. measured roadside NO_X concentration – modelled background NO_X concentration) at roadside or kerbside AURN monitoring sites plotted against NO_X emission estimates adjusted for traffic flow for the individual road links alongside which these sites are located. The background NO_X component at these roadside monitoring sites is taken from the background map described in Section 3.2.4 above.

The calibration coefficient derived is then used to calculate the roadside increment on each road link by multiplying it by an adjusted road link emission (see Figure 3.8). Roadside concentrations for urban major road links (A-roads and motorways) only are reported to the EU and included in this report.

Figure 3.8. Calibration of NO_X roadside increment model, 2008 (µg m^{-3}, as NO_2)



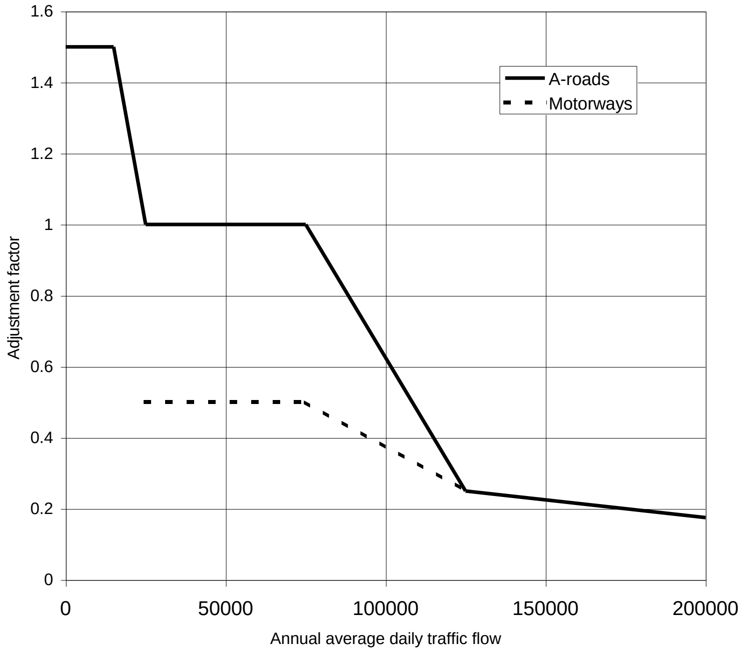
The dispersion of emissions from vehicles travelling along an urban road is influenced by a number of factors. These factors generally contribute to make the dispersion of emissions less efficient on urban roads with lower flows. Factors include:

- Traffic speed (urban roads with lower flows are more likely to have slower moving traffic and thus cause less initial dispersion due to mechanical and thermal turbulence)
- Road width (dispersion will tend to be more efficient on wider roads, such as motorways than on smaller roads in town centres)
- Proximity of buildings to the kerbside (urban roads with lower flows are more likely to have with buildings close to the road, giving a more confined setting and reduced dispersion)

We are only considering urban roads here because the model does not cover rural roads.

Detailed information on the dispersion characteristics of each urban major road link within the NAEI is not available. We have therefore adopted an approach similar to that used within the DMRB Screening Model (Boulter et al., 2003) and applied adjustment factors to the estimated emissions. These adjustment factors are illustrated in Figure 3.9 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 3.9.

Figure 3.9. The adjustment factors applied to road link emissions



3.3 NO_2 Modelling

3.3.1 Introduction

Maps of estimated annual mean NO_2 concentrations (Figure 3.1 and 3.2) have been calculated from our modelled NO_X concentrations using a calibrated version of the updated oxidant-partitioning model (Jenkins, 2004; Murrells et al., 2008). This model uses representative equations to account for the chemical coupling of O_3, NO and NO_2 within the atmosphere. A key advantage of this approach for modelling NO_2 concentrations is that we can directly address emission scenarios by varying regional oxidant levels and/or primary NO_2 emissions.

3.3.2 The updated oxidant-partitioning model

The oxidant-partitioning model, developed by Jenkins (2004), enables NO_2 concentrations to be calculated using the following equations (concentrations in ppb[1]):

$$[NO_2] = [OX].([NO_2]/[OX]) \qquad (i)$$

$$[OX] = f\text{-}NO_2.[NO_X] + [OX]_B \qquad (ii)$$

$$[NO_2]/[OX] = f(NO_X) \qquad (iii)$$

Where OX is the total oxidant (the sum of NO_2 and O_3), f-NO_2 is the primary NO_2 emission fraction (defined as the proportion of NO_X emitted directly as NO_2) and B is the regional oxidant.

In Jenkin (2004) $[NO_2]/[OX]$ was calculated using two equations, one of which represented background locations and the other roadside locations. However, updated equations for $[NO_2]/[OX]$ have subsequently been developed in Murrells et al. (2008), which we have used in the modelling here. These are better than the original equations presented in Jenkin (2004) because they account

---

[1] 1 ppb of NO_2 = 1.91 μg m^{-3} of NO_2, NO_X concentrations are expressed as NO_2, so the conversion factor is the same. 1 ppb of O_3 = 2 μg m^{-3} of O_3.

for the under-prediction of the annual mean metric caused by averaging points along an idealised curve (Murrells et al., 2008) rather than being based on an empirical fit to monitoring data.

Murrells et al. (2008) present five equations for calculating $[NO_2]/[OX]$ as a function of $[NO_X]$. These are:

- An idealized relationship, which has been generated by solving the analytical chemistry for an idealised site with a constant NO_X concentration throughout the year.
- Four relationships for realistic cases. These are four further analytical solutions derived for sites where the NO_X concentration varies from hour to hour. The different relationships represent different levels of hourly variation.

The four relationships for realistic cases are presented in Table 3.1 below. They have been derived to apply at sites with different levels of inter-hourly variability in NO_X concentrations. Murrells et al. (2008) have used NO_X quartile ratios to represent this variability, where the NO_X quartile ratio is the ratio of the 75th percentile to 25th percentile of measured NO_X.

Table 3.1. The four 'realistic case' relationships in the updated oxidant-partitioning model (Murrells et al., 2008)

PCM Category (Category in Murrells et al. (2008) shown in brackets)	Derived for site with a NO_X quartile ratio of:	Relationship (where y = [NO2]/[OX] and x = [NOx], in ppb)
1 (I)	<2.5	y = 4.856E-14x^6 - 3.290E-13x^5 - 9.371E-09x^4 + 2.824E-06x^3 - 3.684E-04x^2 + 2.582E-02x
2 (II)	2.5-3.5	y = -1.673E-13x^6 + 1.195E-10x^5 - 3.469E-08x^4 + 5.305E-06x^3 - 4.692E-04x^2 + 2.595E-02x
4 (IIIa)	3.5	y = -2.423E-13x^6 + 1.607E-10x^5 - 4.329E-08x^4 + 6.132E-06x^3 - 5.020E-04x^2 + 2.593E-02x
3 (III)	>3.5	y = -2.881E-13x^6 + 1.857E-10x^5 - 4.843E-08x^4 + 6.620E-06x^3 - 5.211E-04x^2 + 2.591E-02x

The following sections describe the method for calculating a map of regional oxidant in the UK (Section 3.3.3), local oxidant calculations for background and roadside locations (Section 3.3.4), Calculating $[NO_2]/[OX]$ in the PCM model (Section 3.3.5) and how we have applied the updated oxidant-partitioning model in the UK in background and roadside locations (Section 3.3.6).

3.3.3 UK regional oxidant map

A map of UK regional oxidant for 2008 ($[OX]_B$ in equation ii above) has been calculated using the method outlined in Murrells et al. (2008). Assessments made prior to the assessment for 2007 used of estimates of regional oxidant published by Jenkin (2004). The revised method proposed by Murrells et al. (2008) has the benefit of incorporating an understanding of the drivers influencing the spatial pattern of regional oxidant concentrations and how these vary from year to year.

The regional oxidant concentration is considered to consist of two components:

$$[OX]_B = [OX]_H + [OX]_R \,, \qquad (iv)$$

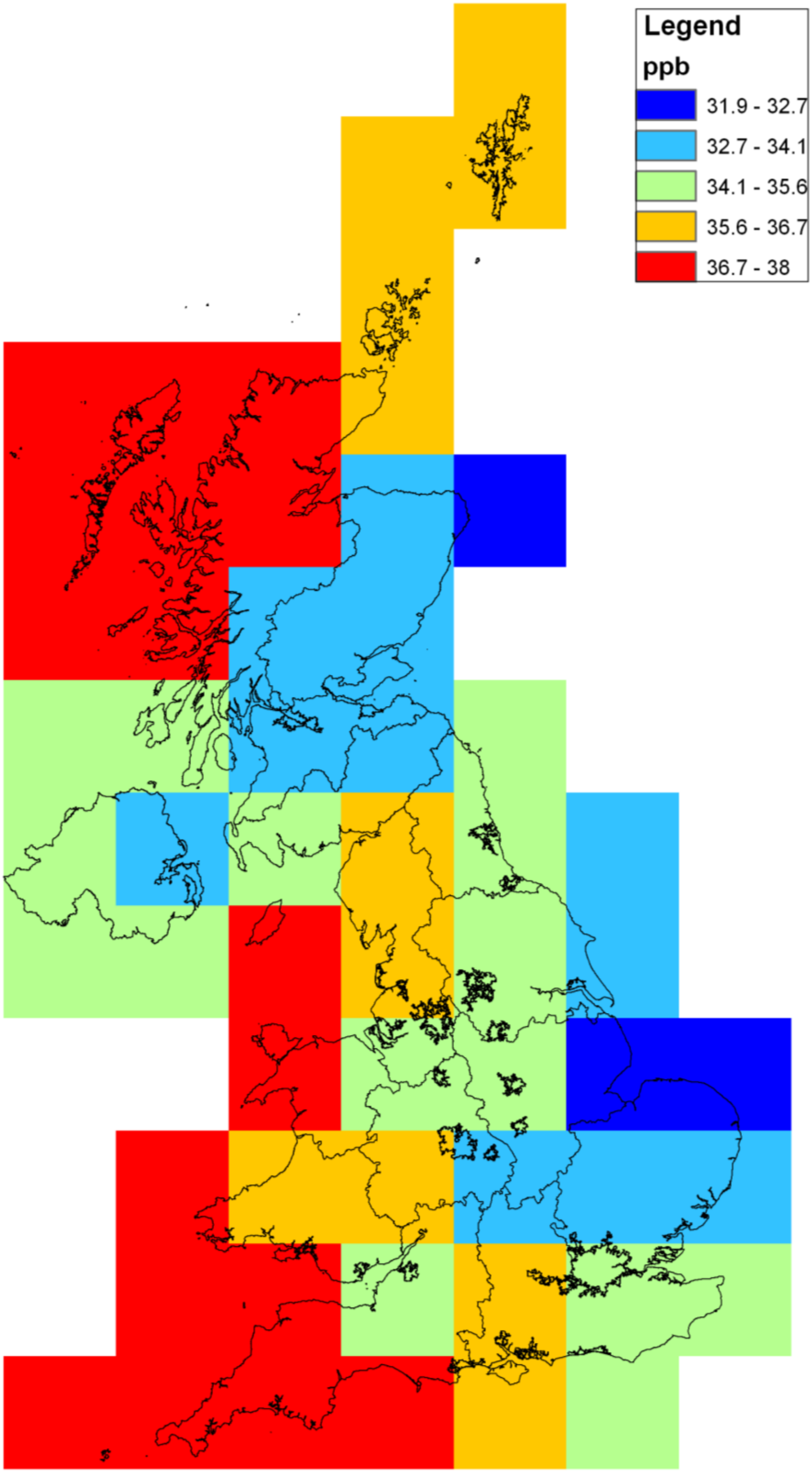
where: $[OX]_H$ is the hemispheric background concentration and $[OX]_R$ is a regional modification. An analysis of monitoring data from the AURN presented by Murrells et al. (2008) has shown that both of these components vary across the UK.

The value of $[OX]_H$ has been found to decrease in a north-easterly direction across the UK with distance from the coast as a result of losses due to dry deposition. The regional modification $[OX]_R$ has been found to have two components. A positive regional modification due to the photochemical generation of oxidant in the summer shows a decrease in a north-westerly direction from the south east of England, as the distance from the major source regions for ozone precursors in continental

Europe increases. A negative regional modification due to dry deposition in the winter has been found to show an increase in a south-westerly direction from the north east coast.

The regional variation in these different components has been described by Murrells et al. (2008) using a model for which the year specific parameters can be derived from an analysis of monitoring data. Figure 3.9 shows the map of regional oxidant for 2008. Values have been calculated on a 100 km x 100 km grid.

Figure 3.9. Regional oxidant $[OX]_B$ for 2008 (ppb)



© Crown copyright. All rights reserved Defra, Licence number 100022861 [2009]

3.3.4 Local oxidant calculations

Local oxidant is calculated in the updated oxidant-partitioning model as:

$$\text{Local oxidant} = f\text{-}NO_2.[NO_X]. \qquad (iv)$$

Therefore to calculate local oxidant levels, we need to know f-NO_2 levels from different local sources. In general it is possible to make a distinction between f-NO_2 from road traffic sources and f-NO_2 from non-road traffic sources. f-NO_2 from road traffic sources is thought to be generally rising, although this trend displays considerable variation with location (AQEG, 2007). By comparison, f-NO2 from non-traffic sources has remained relatively constant with time.

f-NO_2 for road traffic sources on individual road links

Figure 3.10 shows fleet average f-NO_2 projections by vehicle type for London and the rest of the UK from the NAEI 2007.

This shows that London buses in 2008 had a much higher f-NO_2 (up to 30%) than buses outside of London (approximately 13%). A rapid decline in f-NO_2 from London buses is expected so that by 2020 they are expected reach a similar level to buses outside London at approximately 10%.

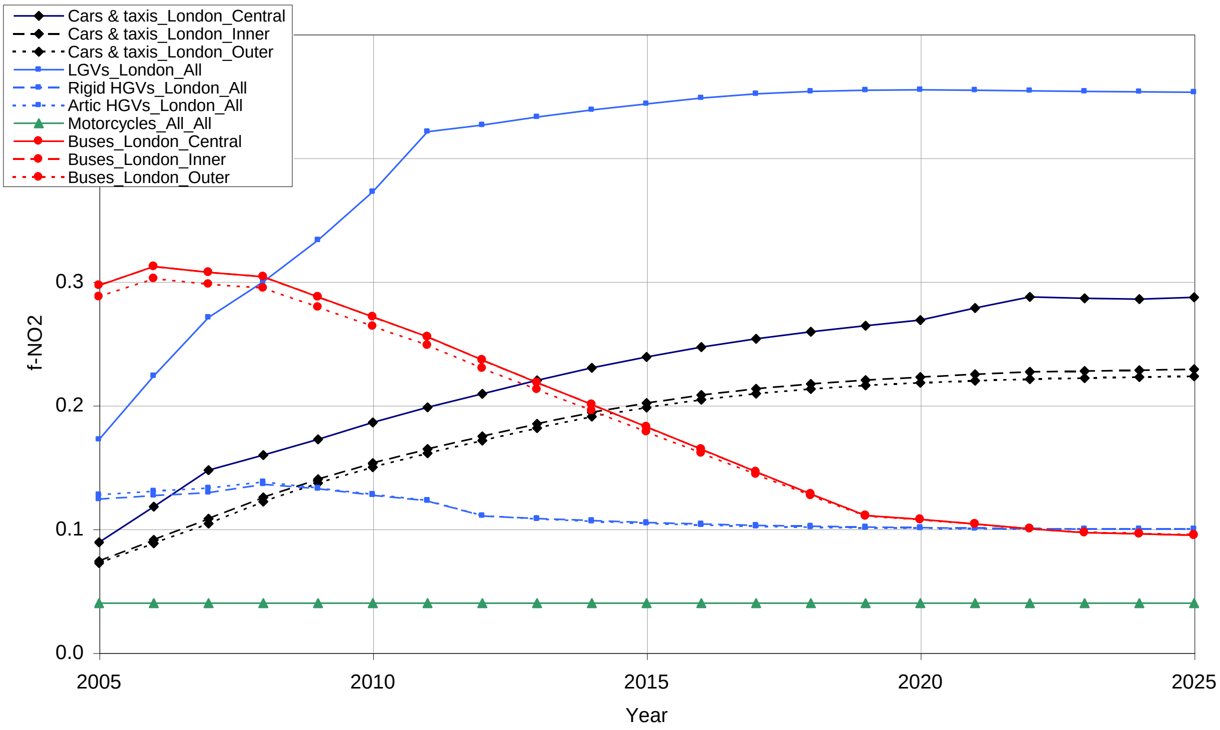
Cars and taxis are lumped together in these fleet average f-NO_2 projections. Three distinct geographical areas are picked out: London, Northern Ireland and the rest of the UK. For all three locations, f-NO_2 from cars and taxis is expected to rise significantly between 2005 and 2020. Variation between the three geographical areas reflects variations in the proportion of diesel cars found in these areas. The proportion of diesel cars is higher in Northern Ireland and diesel cars have higher f-NO_2 than petrol cars.

Fleet average f-NO_2 from LGVs is set to rise significantly from approximately 17% in 2005 to over 40% by 2015 in all locations. However, the rise is initially stepper in London because of the impact of the Low Emission Zone (LEZ) on LGV fleet make up in London.

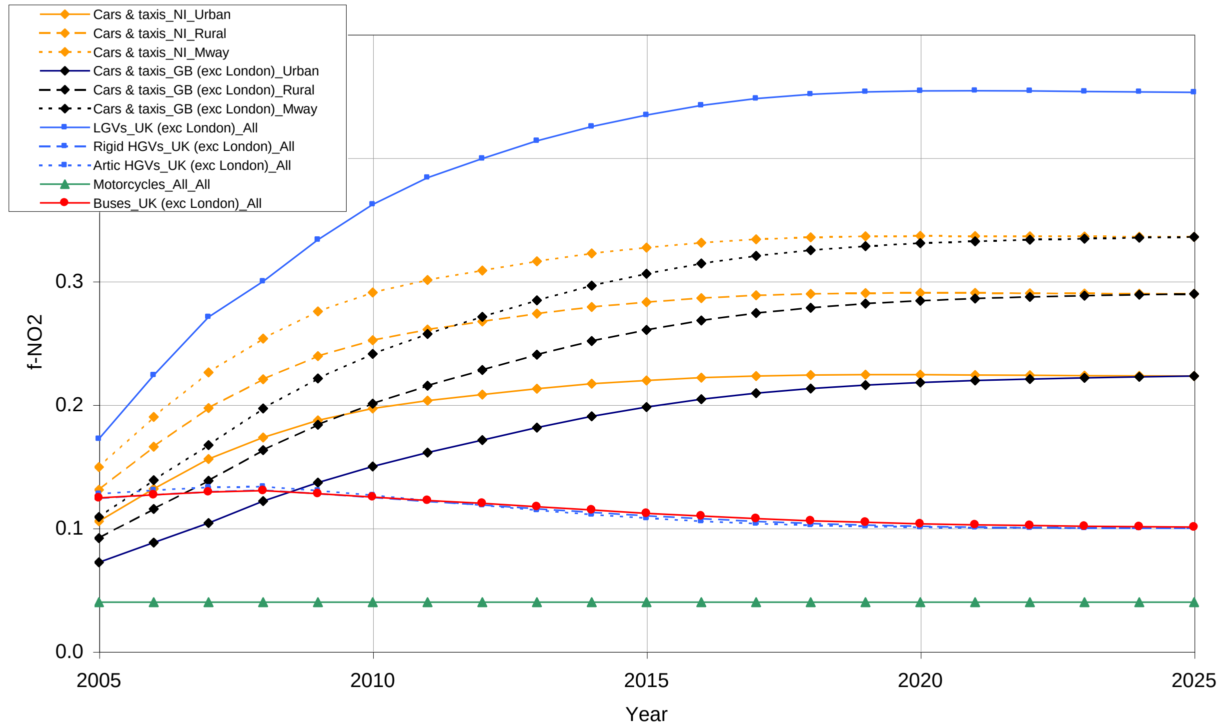
For each road link, these vehicle specific f-NO_2 factors have been applied to NO_X road link emissions for each vehicle class to calculate a road link specific f-NO_2 from traffic sources. This method therefore takes into account the vehicle split on each road link, but assumes that each road link has the fleet average make up of the specific vehicle types.

Figure 3.10. Fleet average f-NO_2 projections by vehicle type for a) London and b) rest of the UK from NAEI 2007

a) London



b) Rest of the UK



f-NO_2 for background sources

Table 3.2 shows the f-NO_2 values used for background sources in 2008.

The non-road f-NO_2 values used for background calculations in Table 3.2 have been taken directly from Jenkin (2004), as there is little evidence that this has changed significantly over the past few years.

The road traffic f-NO_2 values for background calculations have been calculated using the average of the major road link f-NO_2 values for each area type.

Table 3.2. Local oxidant coefficients (*f*-NO_2) for background concentrations in 2008

DfT Area type[1]	Region	Non-road *f*-NO_2 for background calculations	Road *f*-NO_2 for background calculations
1	Central London	0.140	0.233
2	Inner London	0.128	0.208
3	Outer London	0.093	0.185
4	Inner Conurbations	0.093	0.151
5	Outer Conurbations	0.093	0.157
6	Urban (population > 250,000)	0.093	0.154
7	Urban (population > 100,000)	0.093	0.153
8	Urban (population > 25,000)	0.093	0.155
9	Urban (population > 10,000)	0.093	0.158
10	Rural	0.093	0.165

[1] Locations in Northern Ireland have been assigned area types on the basis of how built up they are. This is because the DfT area types map does not cover Northern Ireland.

Local oxidant calculations

A map of local oxidant for the background NO_2 calculations was generated by splitting the background annual mean NO_X map into its two constituent components:

- NO_X from background non-road traffic emissions (includes rural background component)
- NO_X from background road-traffic emissions

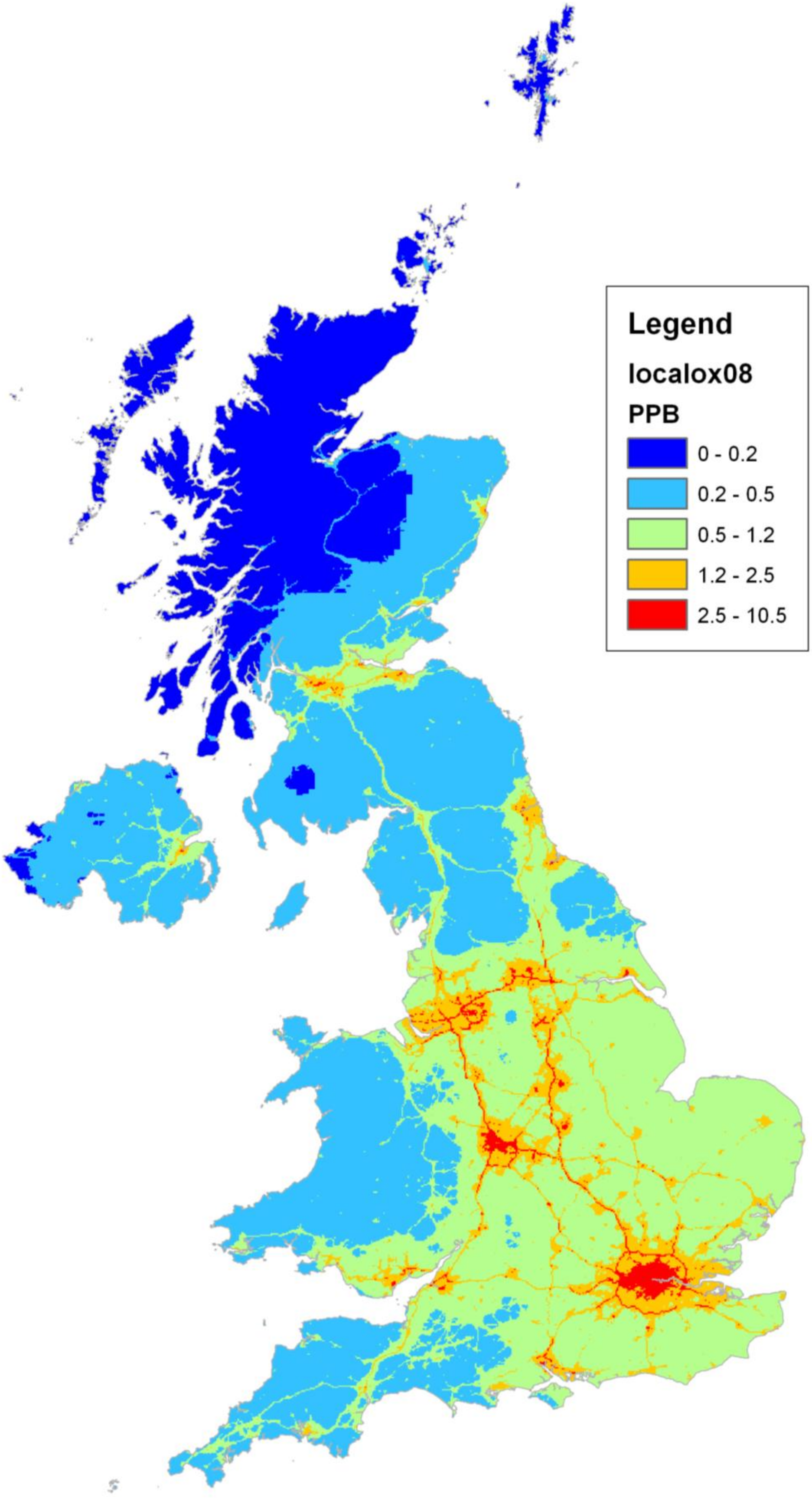
These components were multiplied by the relevant *f*-NO_2 value from Table 3.2 and then added together to give a total local oxidant. Figure 3.11 shows the UK background local oxidant map for 2008

Local oxidant on individual road links was calculated by splitting the total annual mean NO_X for the road link into its three constituent components:

- NO_X from background non-road traffic emissions (includes rural background component)
- NO_X from background road-traffic emissions
- Roadside increment NO_X concentrations from emissions on the specific road link under consideration

The background components were then multiplied by the relevant f-NO_2 value from Table 3.2 and the roadside increment NO_X was multiplied by the specific f-NO_2 calculated for that road link. These local oxidant values were then added together to give a total local oxidant for the road.

Figure 3.11. Background local oxidant map for 2008 (ppb)



© Crown copyright. All rights reserved Defra, Licence number 100022861 [2009]

3.3.5 Calculating $[NO_2]/[OX]$ in the PCM model

As described in Section 3.3.2, four ‘realistic case’ relationships for calculating $[NO_2]/[OX]$ have been derived in Murrells et al. (2008). The ratio of $[NO_2]/[OX]$ has been considered separately for background and roadside locations in this analysis because background and roadside sites tend to behave differently because of differences in the ‘age’ of the NO_X at these locations.

Roadside

For roadside locations, we have selected to use the category 4 (IIIa) relationship and have applied an additional calibration using data from AURN roadside and kerbside sites for 2008. The reason for selecting the category 4 (IIIa) relationship is that, of the four relationships available, this one typically performed best when calculating NO_2 from measured NO_X for each AURN roadside and kerbside sites for 2008 and comparing with the measured NO_2 at these sites. We chose to calibrate the model because the category 4 (IIIa) relationship was not the right shape and therefore tended to over predict NO_2 concentrations close to the limit value. The calibration was performed by plotting the ratio of measured NO_2 to modelled NO_2 as a function of NO_X for each AURN roadside and kerbside sites for 2008 and then fitting a curve through these points. Figure 3.12 shows this ratio for each site and also the curve that we have fitted though the data. The verification sites are also shown on this plot for reference although they were not used to calibrate the model.

Figure 3.13 shows a verification plot of measured NO_2 against modelled NO_2 calculated from measure NO_X using the uncalibrated category 4 (IIIa) relationship. Figure 3.14 shows the same information, but using the calibrated category 4 (IIIa) relationship. It is clear that the model provides a better fit to the monitoring data in the vicinity of the limit value of 40 $\mu g\ m^{-3}$. The model prediction for the highest measured annual mean of over 200 $\mu g\ m^{-3}$ is an under-prediction. This is because the oxidant partitioning curves are only valid for annual mean NO_X concentrations up to 350 $\mu g\ m^{-3}$, and NO_X concentrations above this value have been set to 350 $\mu g\ m^{-3}$. The measured annual mean NO_X concentration at this site in 2008 was about 500 $\mu g\ m^{-3}$.

Figure 3.12. Roadside NO_2 calibration curve (NB verification sites are shown for reference here, but were not used in calculating the calibration)

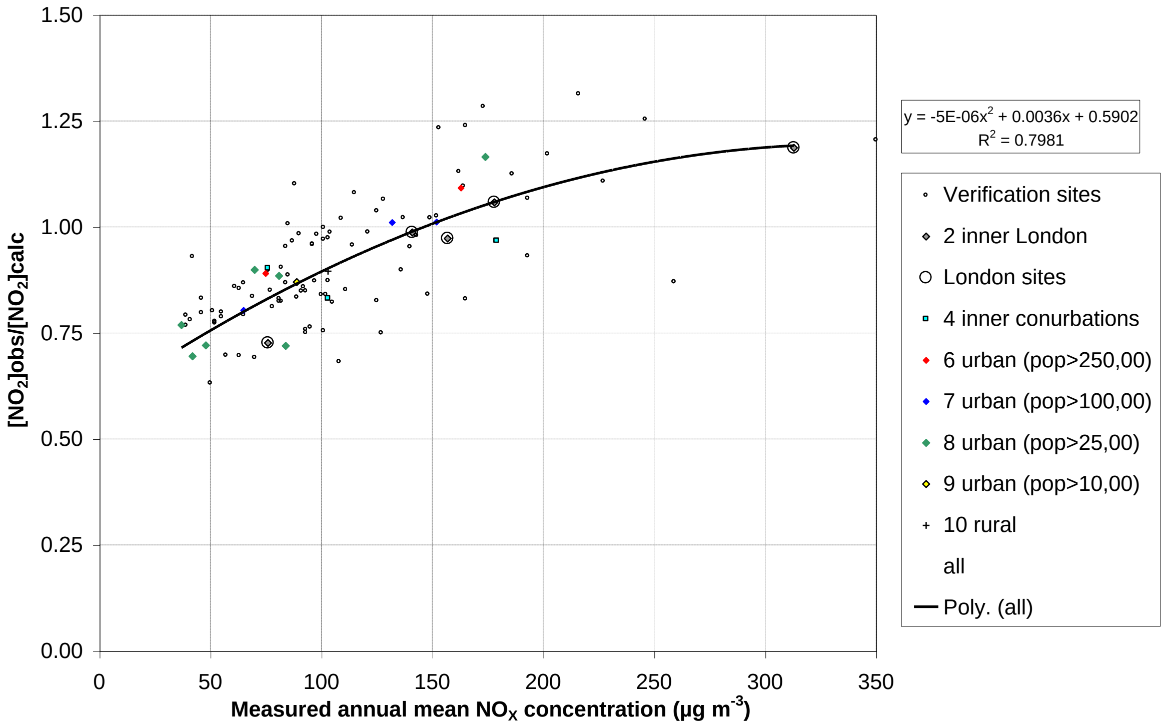


Figure 3.13. Verification of uncalibrated category 4 (IIIa) relationship at roadside locations in 2008

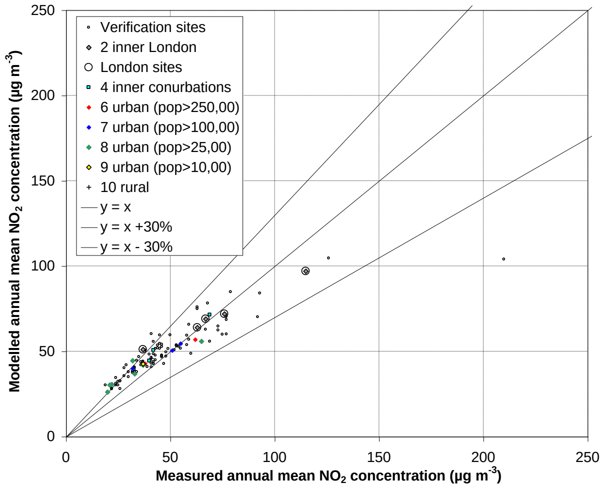
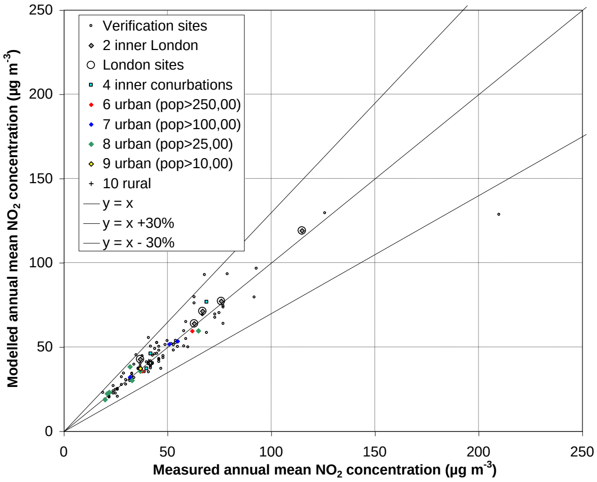


Figure 3.14. Verification of calibrated category 4 (IIIa) relationship at roadside locations in 2008



Background

For background locations, we have chosen to use the category 4 (IIIa) relationship calibrated using data from AURN background sites for 2008. The reason for selecting the category 4 (IIIa) relationship at background locations is to be as consistent as possible with the roadside model. The calibration plot for background sites is shown in Figure 3.15. Figures 3.16 and 3.17 show verification plots of measured NO_2 against modelled NO_2 calculated from measure NO_X using the uncalibrated category 4 (IIIa) relationship and calibrated category 4 (IIIa) relationship respectively. The agreement is better for the calibrated model, particularly for annual mean f-NO_2 concentration in the range from 20-40 µg m^{-3}.

The results for this modelling are presented in Section 3.4 below.

Figure 3.15. Roadside NO_2 calibration curve (NB verification sites are shown for reference here, but were not used in calculating the calibration)

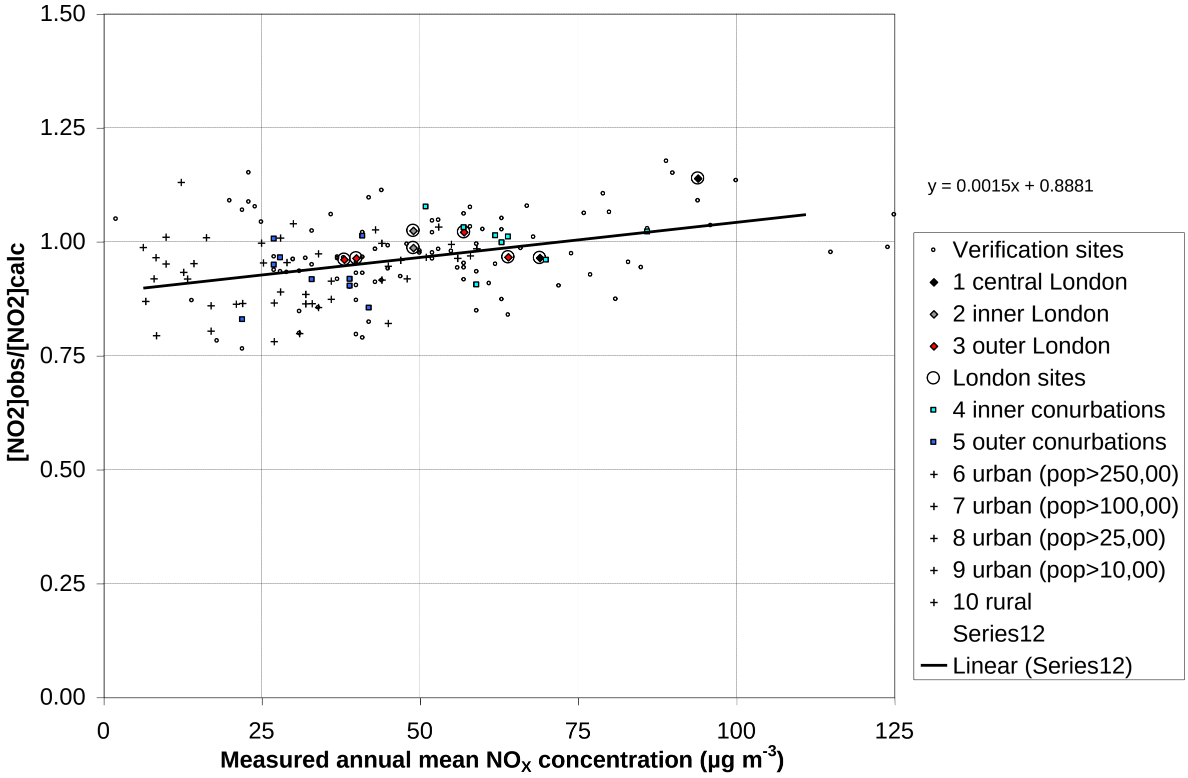


Figure 3.16. Verification of uncalibrated category 4 (IIIa) relationship at background locations in 2008

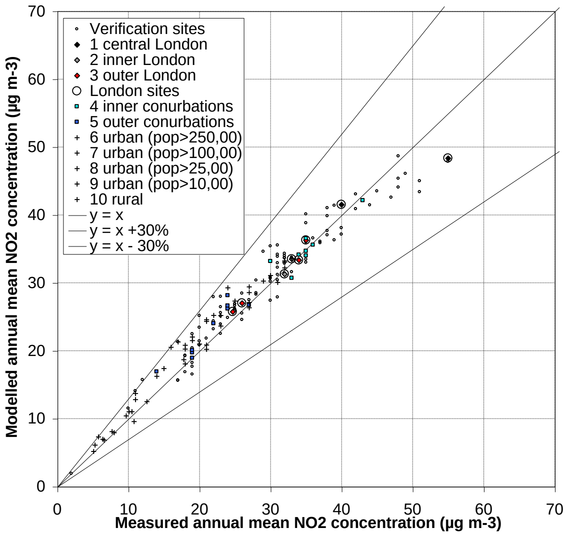
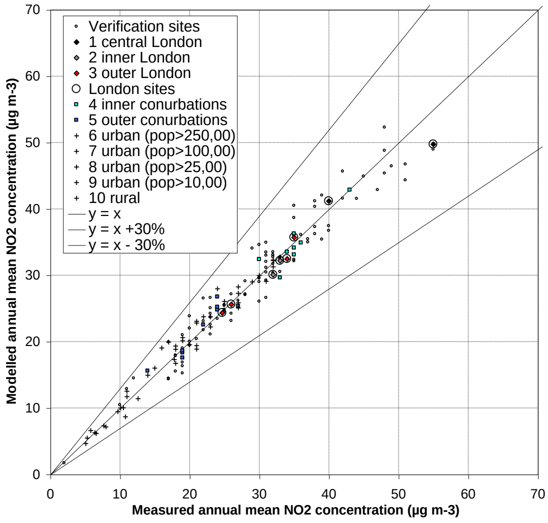


Figure 3.17. Verification of calibrated category 4 (IIIa) relationship at background locations in 2008



3.4 Results

3.4.1 Verification of mapped values

Figures 3.18 and 3.19 show comparisons of modelled and measured annual mean NO_X and NO_2 concentration in 2008 at background monitoring site locations. Figure 3.20 and 3.21 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.

Summary statistics for the comparison between modelled and measured NO_X and NO_2 concentrations are listed in Tables 3.3 and 3.4. 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.

Figure 3.18. Verification of background annual mean NO_X model 2008

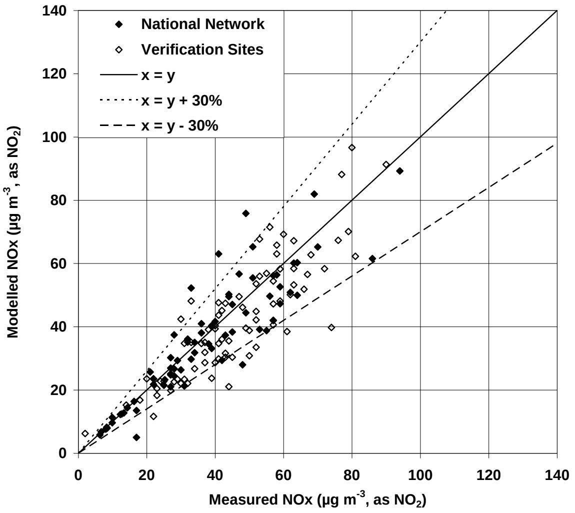


Figure 3.19. Verification of background annual mean NO_2 model 2008

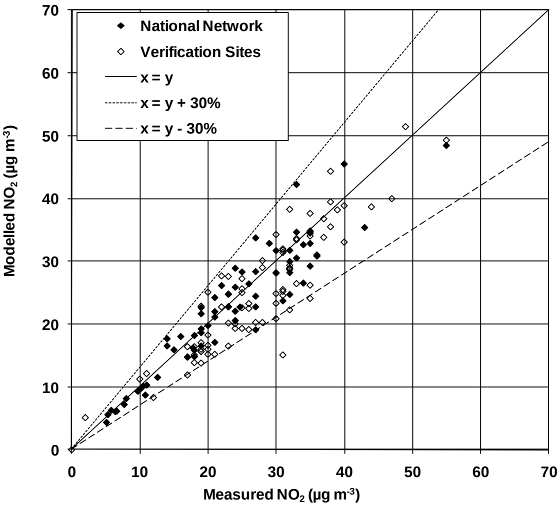


Figure 3.20. Verification of roadside annual mean NO_X model 2008

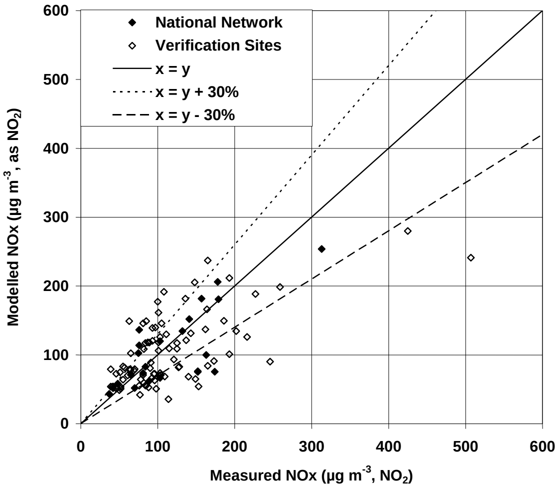


Figure 3.21. Verification of roadside annual mean NO_2 model 2008

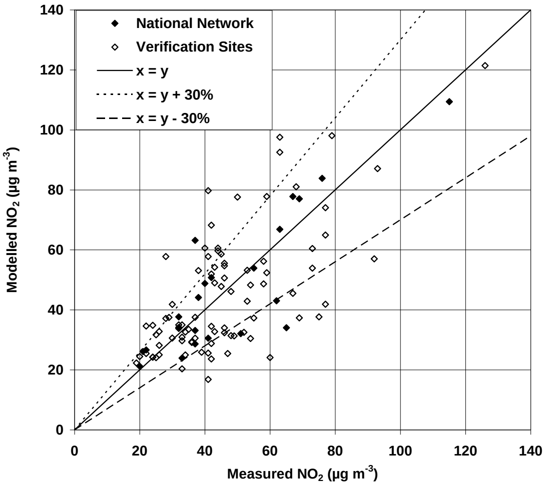


Table 3.3. Summary statistics for comparison between modelled and measured NO_x and NO_2 concentrations at background sites (µg m^{-3}, as NO_2)

		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
NO_X	National Network	37.3	36.0	0.81	11.4%	70
	Verification Sites	46.7	41.6	0.75	15.7%	82
NO_2	National Network	22.8	22.2	0.87	2.9%	70
	Verification Sites	27.6	25.0	0.81	7.3%	82

Table 3.4. 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
NO_X	National Network	115.4	108.7	0.63	36.4%	22
	Verification Sites	114.1	103.0	0.44	55.8%	86
NO_2	National Network	48.0	47.6	0.73	18.2%	22
	Verification Sites	48.1	45.8	0.48	41.9%	86

3.4.2 Source apportionment

Figures 3.22 and 3.23 shows the modelled NO_X source apportionment at AURN background and roadside sites respectively for 2008. This shows that while road transport is the dominant source in the majority of locations (background and roadside), contributions from other sectors such as domestic, commercial, off road mobile machinery and industry are also significant at many sites. Contributions from aircraft and shipping are evident at some sites.

No source apportionment is given for NO_2 because this is not a physically meaningful concept because of the non-linear relationship between NO_X and NO_2.

Figure 3.22. Annual mean NO_X source apportionment at background AURN monitoring sites (area type of each site is shown in parenthesis after its name – see Table 3.2)

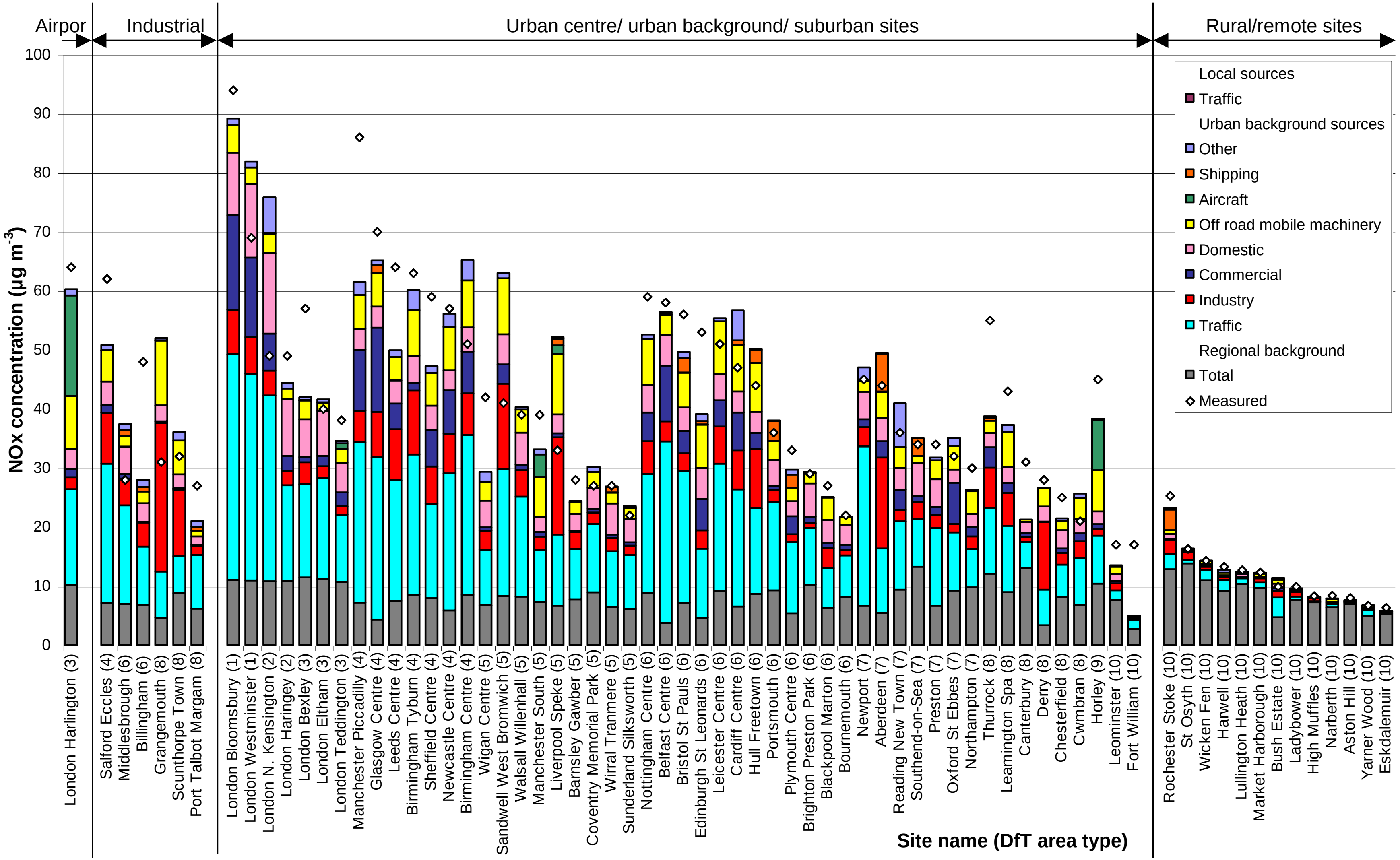
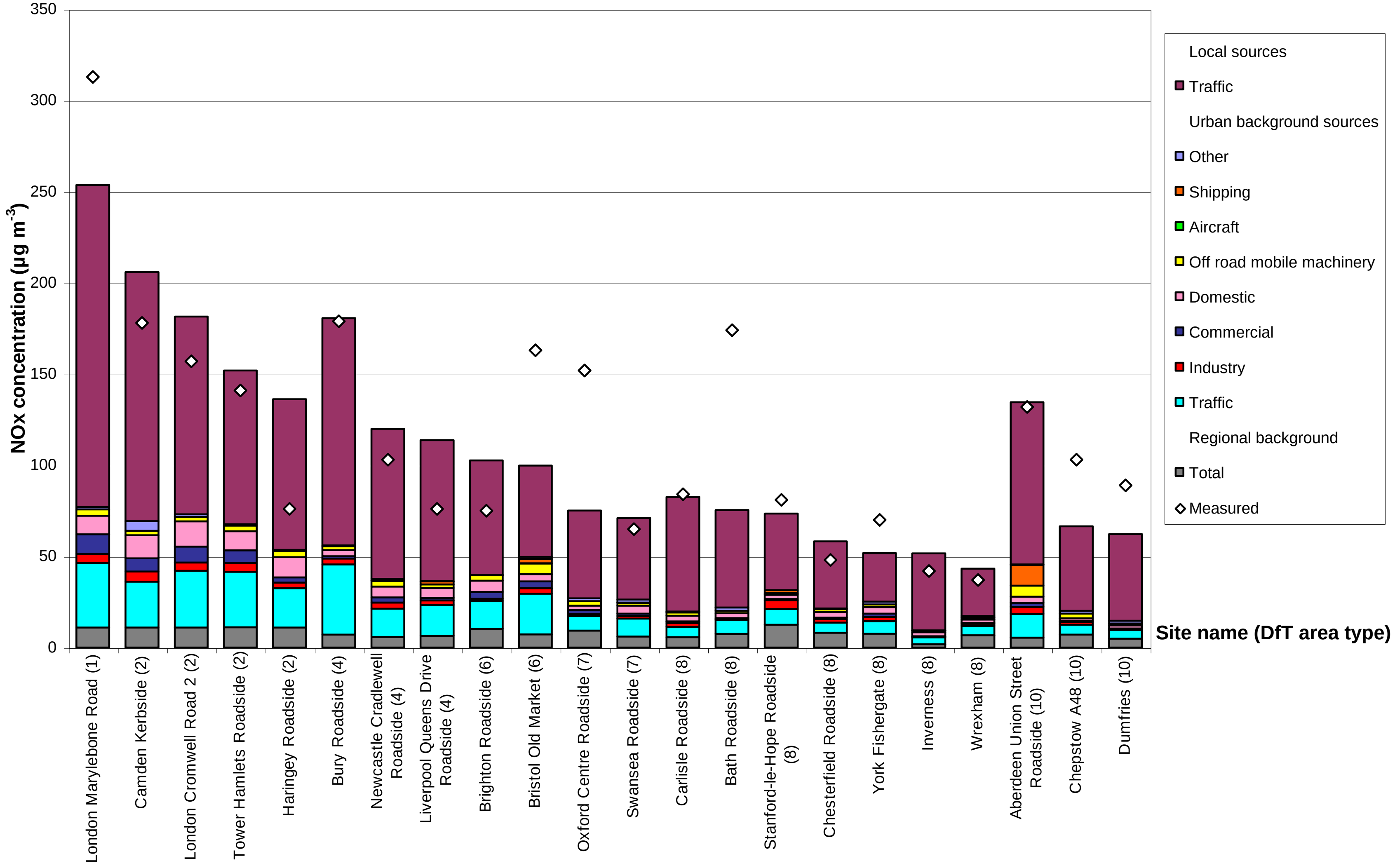


Figure 3.23. Annual mean NO_X source apportionment at roadside AURN monitoring sites (area type of each site is shown in parenthesis after its

name)


NOx concentration (µg m-3)
350
300
250
200
150
100
50
0
Local sources
Traffic
Urban background sources
Other
Shipping
Aircraft
Off road mobile machinery
Domestic
Commercial
Industry
Traffic
Regional background
Total
Measured
Site name (DfT area type)
London Marylebone Road (1)
Camden Kerbside (2)
London Cromwell Road 2 (2)
Tower Hamlets Roadside (2)
Haringey Roadside (2)
Bury Roadside (4)
Newcastle Cradlewell Roadside (4)
Liverpool Queens Drive Roadside (4)
Brighton Roadside (6)
Bristol Old Market (6)
Oxford Centre Roadside (7)
Swansea Roadside (7)
Carlisle Roadside (8)
Bath Roadside (8)
Stanford-le-Hope Roadside (8)
Chesterfield Roadside (8)
York Fishergate (8)
Inverness (8)
Wrexham (8)
Aberdeen Union Street Roadside (10)
Chepstow A48 (10)
Dumfries (10)

3.4.3 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 3.5. 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 2008. 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 m from the road kerb.

Table 3.5. 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	64	A	1286.7	A	487293	A
West Midlands Urban Area	UK0002	7	A	265.3	A	10900	A
Greater Manchester Urban Area	UK0003	0	A	260.5	A	0	A
West Yorkshire Urban Area	UK0004	0	A	109.9	A	0	A
Tyneside	UK0005	0	A	55.7	A	0	A
Liverpool Urban Area	UK0006	0	A	72.3	A	0	A
Sheffield Urban Area	UK0007	0	A	58.2	A	0	A
Nottingham Urban Area	UK0008	0	A	45.1	A	0	A
Bristol Urban Area	UK0009	0	A	31.8	A	0	A
Brighton/Worthing/Littlehampton	UK0010	0	A	3.2	A	0	A
Leicester Urban Area	UK0011	0	A	24.1	A	0	A
Portsmouth Urban Area	UK0012	0	A	13.6	A	0	A
Teesside Urban Area	UK0013	0	A	15.7	A	0	A
The Potteries	UK0014	0	A	23.0	A	0	A
Bournemouth Urban Area	UK0015	0	A	12.0	A	0	A
Reading/Wokingham Urban Area	UK0016	0	A	9.0	A	0	A
Coventry/Bedworth	UK0017	0	A	10.6	A	0	A
Kingston upon Hull	UK0018	0	A	31.7	A	0	A
Southampton Urban Area	UK0019	1	A	21.5	A	680	A
Birkenhead Urban Area	UK0020	0	A	13.0	A	0	A
Southend Urban Area	UK0021	0	A	8.7	A	0	A
Blackpool Urban Area	UK0022	0	A	0.0	A	0	A
Preston Urban Area	UK0023	0	A	3.5	A	0	A
Glasgow Urban Area	UK0024	0	A	75.9	A	0	A
Edinburgh Urban Area	UK0025	0	A	13.9	A	0	A
Cardiff Urban Area	UK0026	0	A	18.4	A	0	A
Swansea Urban Area	UK0027	0	A	2.5	A	0	A
Belfast Metropolitan Urban Area	UK0028	0	A	36.4	A	0	A
Eastern	UK0029	0	A	110.8	A	0	A
South West	UK0030	0	A	62.4	A	0	A
South East	UK0031	2	A	163.1	A	372	A
East Midlands	UK0032	0	A	82.5	A	0	A
North West & Merseyside	UK0033	0	A	209.7	A	0	A
Yorkshire & Humberside	UK0034	0	A	230.5	A	0	A
West Midlands	UK0035	0	A	76.3	A	0	A
North East	UK0036	0	A	52.7	A	0	A
Central Scotland	UK0037	0	A	24.1	A	0	A
North East Scotland	UK0038	0	A	18.4	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	32.4	A	0	A
North Wales	UK0042	0	A	11.0	A	0	A
Northern Ireland	UK0043	0	A	26.7	A	0	A
Total		74		3622.7		499244	

4 PM_{10}

4.1 Introduction

4.1.1 Maps of PM_{10} concentrations for 2008

Maps of annual mean PM_{10} in 2008 at background and roadside locations are shown in Figures 4.1 and 4.2. These maps have been calibrated using measurements from TEOM FDMS instruments only. Measurements from gravimetric instruments, TEOM monitors and TEOM monitors adjusted using the VCM model have been used to verify the mapped estimates by applying the appropriate scaling factors prior to comparison.

A detailed description of the Pollution Climate Mapping (PCM) models for PM in 2004 is provided by Stedman et al. (2006b). The methods used to derive the maps for 2008 are largely the same as was adopted for the 2007 maps as described Grice et al. (2009). The main revisions to the method for 2008 are the application of revised models for:

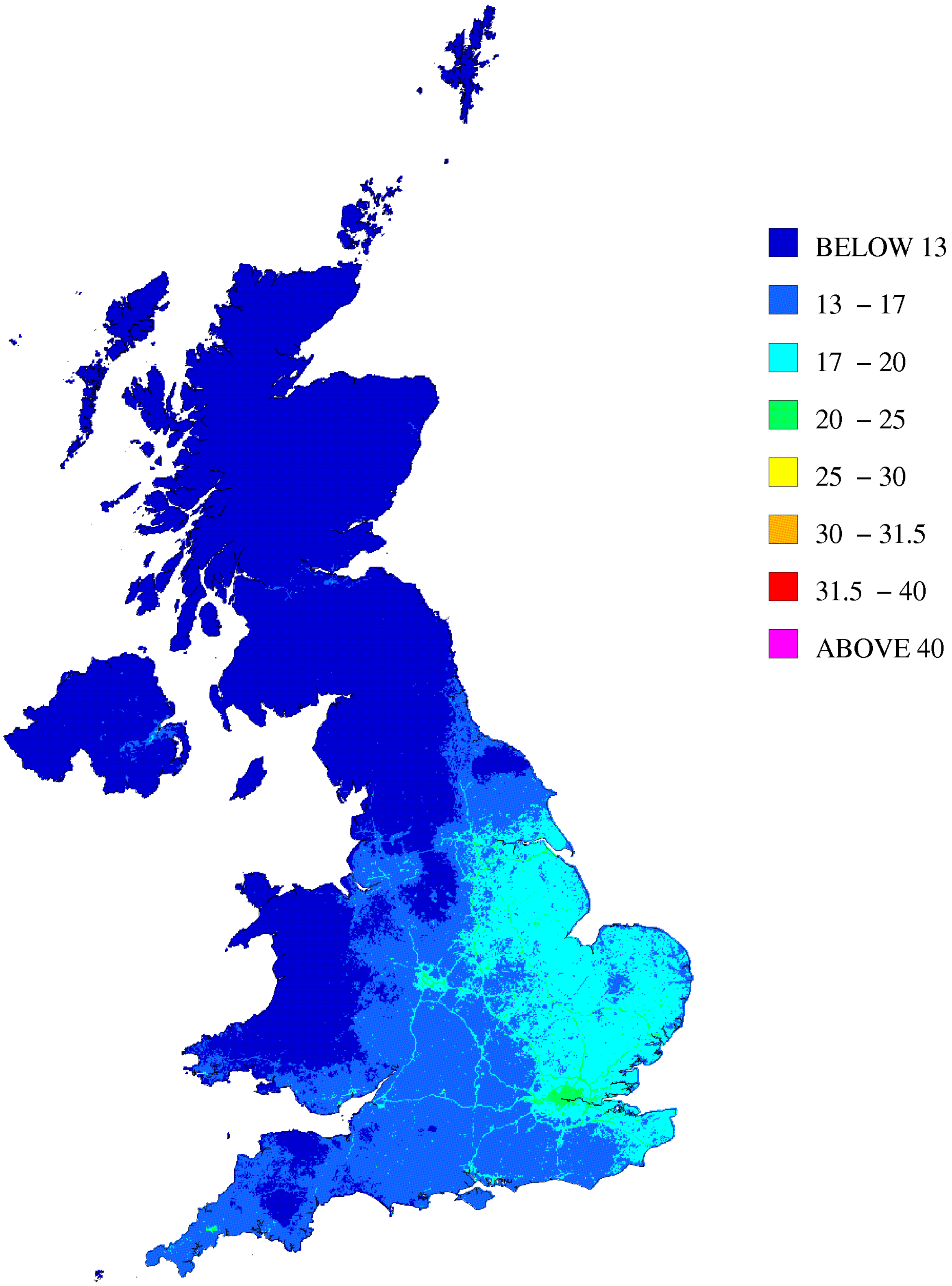
- Rural concentrations of calcium rich dusts
- Concentrations of iron rich dusts associated with vehicle movements

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

- Secondary inorganic aerosol (derived by interpolation and scaling of measurements of SO_4, NO_3 and NH_4 at rural sites)
- 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)
- Rural calcium rich dusts from re-suspension of soils (modelled using a dispersion kernel and information on land use)
- Urban calcium rich dusts from re-suspension of soils due to urban activity (estimated from a combination of measurements made in Birmingham and population density)
- Regional iron rich dusts from re-suspension (assumed to be a constant value, estimated measurements made in the vicinity of Birmingham)
- Iron rich dusts from re-suspension due to vehicle activity (modelled using a dispersion kernel land and vehicle activity data for heavy duty vehicles)
- Sea salt (derived by interpolation and scaling of measurements of chloride at rural sites)
- Residual (assumed to be a constant value)

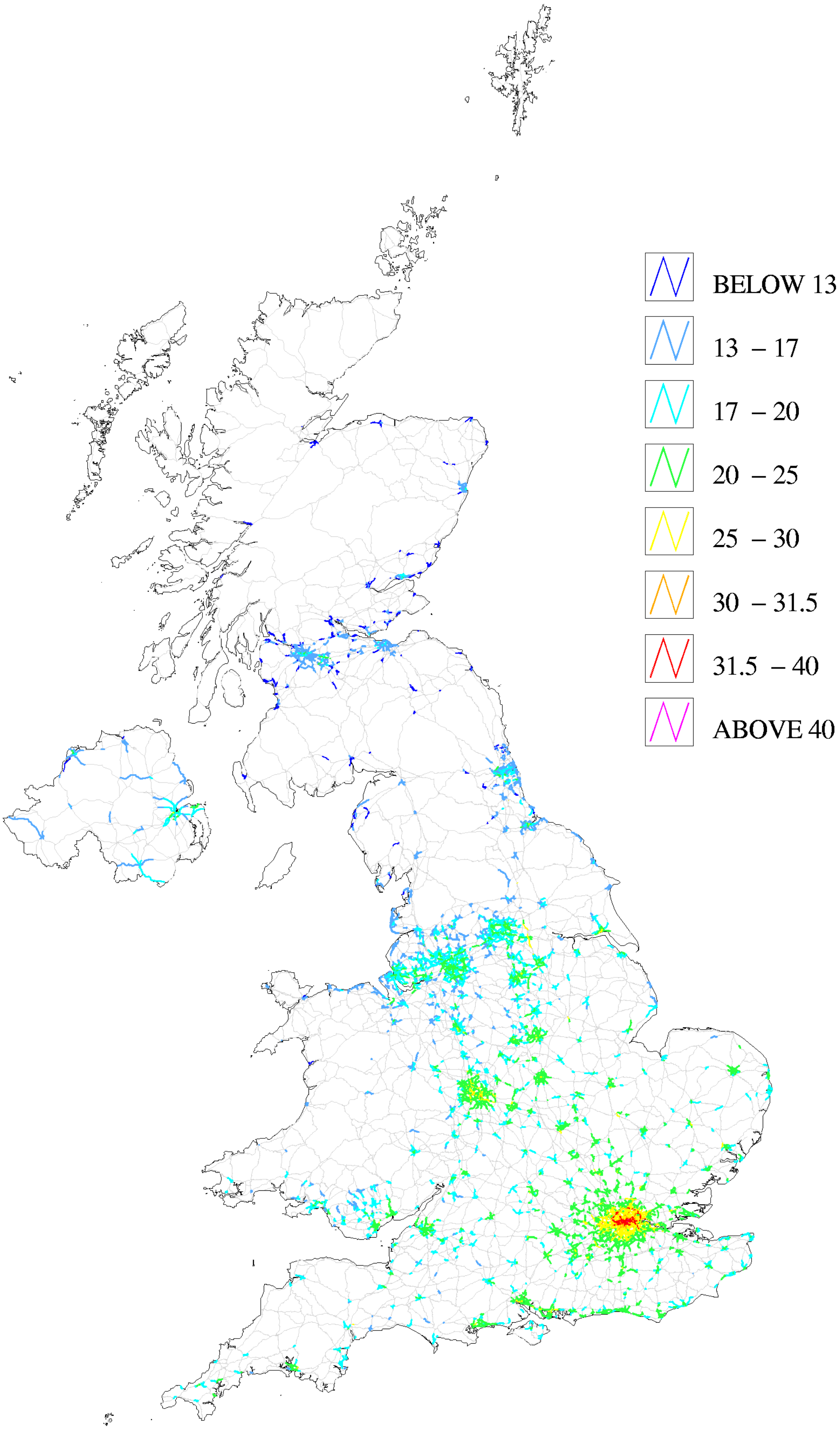
The concentrations of many of these components have been estimated separately for the fine and coarse fraction. This enables a consistent method to be adopted for estimation of PM_{10} (the sum of the fine and coarse fractions) and $PM_{2.5}$ (fine fractions only). These component pieces are then aggregated to a single 1 km x 1 km background PM_{10} grid. An additional roadside increment is added for roadside locations.

Figure 4.1. Annual mean background PM$_{10}$ concentration, 2008 (μg m^{-3}, gravimetric)



Crown copyright. All rights reserved Defra, Licence number 100022861 [2009]

Figure 4.2. Urban major roads, annual mean roadside PM_{10} concentration, 2008 ($\mu g\ m^{-3}$, gravimetric)



Crown copyright. All rights reserved Defra, Licence number 100022861 [2009]

4.1.2 Annual mean equivalent of the 24-hour limit value

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. An analysis of more recent monitoring data is shown in Figure 4.4 and shows that the value of 31.5 µg m^{-3} is still valid, since a 90th percentile of 24-hour mean values of greater than 50 µg m^{-3} is equivalent to more than 35 days with concentration greater than 50 µg m^{-3}.

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)

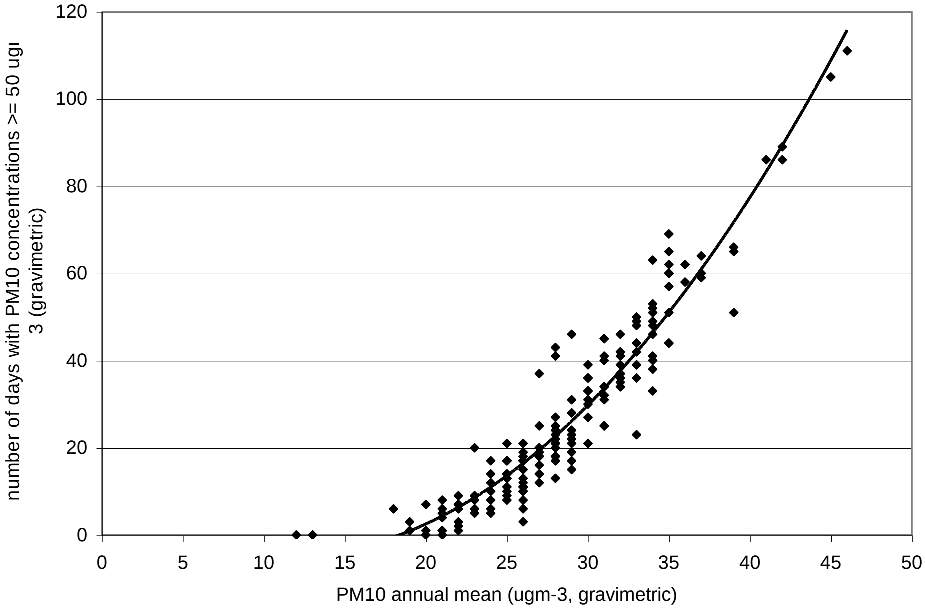
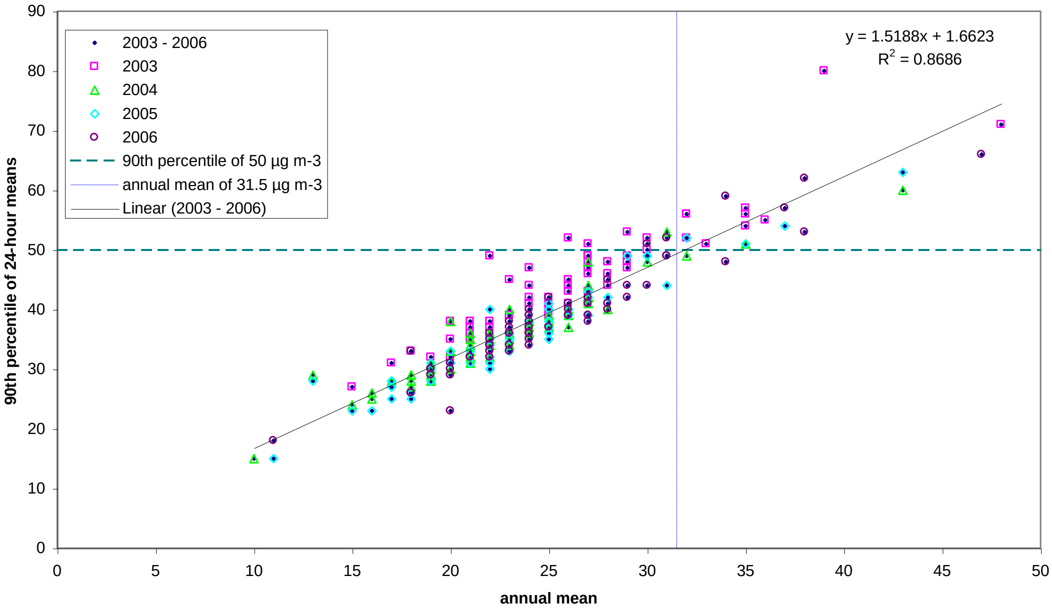


Figure 4.4. The relationship between the 90th percentile of 24-hour mean PM10 concentration and annual mean concentration (µg m^{-3})(2003 –2006)

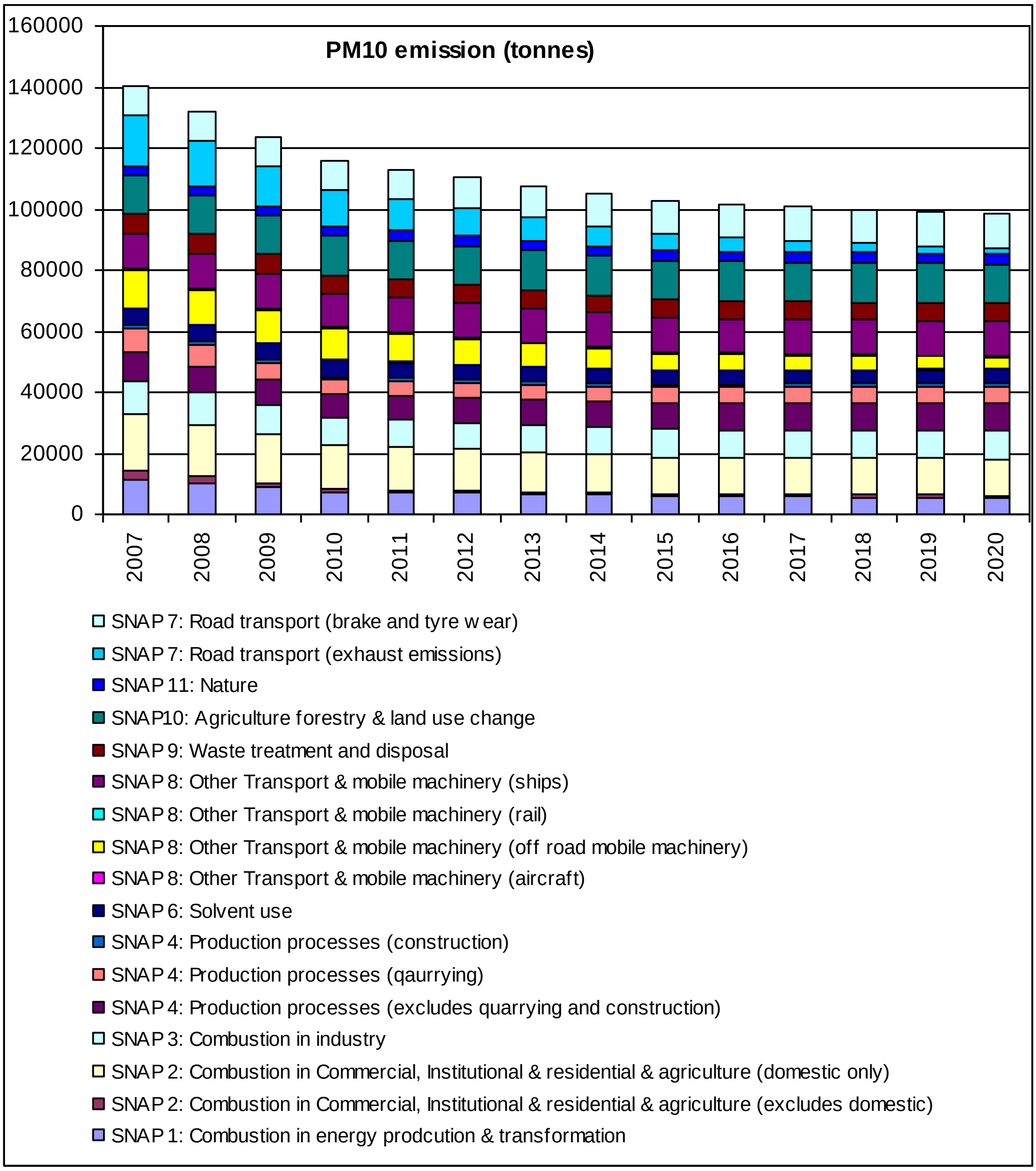


4.1.3 PM_{10} emissions

Estimates of the emissions of primary PM from the 2007 UK National Atmospheric Emission Inventory (NAEI) have been used in this study (Murrells et al., 2009). Figure 4.5 shows UK total UK PM_{10} emissions for 2007 and emissions projections up to 2020 split by SNAP code. This shows that PM_{10} emissions in 2007 include contributions from a wide range of different source sectors. Some of the sectors with the largest contribution to the total in 2007 include road traffic exhaust, off-road mobile machinery and domestic combustion.

Sector specific scaling factors have been used to scale the emissions to provide estimates for 2008. 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 2007 and for the projection year (2008 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.

Figure 4.5. UK total UK PM_{10} emissions for 2007 and emissions projections up to 2020 by SNAP code from NAEI 2007



4.2 Contributions from secondary inorganic aerosol

Maps of secondary inorganic aerosol (SIA) concentrations across the UK have been calculated from rural measurements of sulphate, nitrate and ammonium concentrations by interpolation, followed by the application of scaling factors derived from mass closure modelling. Measurements on a monthly basis are available for 28 rural monitoring sites for 2008 (Tang, 2009). Concentration surfaces on a 5 km x 5 km grid were calculated from the measurement data using Krigging.

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 and summarised by Kent et al., 2007a). 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 scaling factors for bound water and counter ions (non-volatile) have not been used in this study but would be appropriate for mapping TEOM concentrations. The factor for coarse mode nitrate is higher as this includes the mass of the counter-ion (sodium or calcium).

The split between coarse and fine nitrate was revised for the 2006 modelling assessment with reference to measurement data from the TRAMAQ (Abdalmogith et al., 2006) and Birmingham (Harrison and Yin, 2006) studies. This revised method has also been used in this 2008 assessment. Fine PM is used to describe $PM_{2.5}$ and coarse PM is used to describe $PM_{2.5-10}$ in this report. The split between fine and coarse PM is simple to interpret for most PM constituents but is more complex for nitrate PM because there are two modes. The fine nitrate mode consists of ammonium nitrate, which is volatile, and is all in the fine $PM_{2.5}$ fraction. The coarse mode consists of sodium nitrate, which is split roughly half and half between fine $PM_{2.5}$ and coarse $PM_{2.5-10}$ fractions (Abdalmogith et al., 2006). Measurement data from the Birmingham study (Harrison and Yin, 2006) shows that the fine $PM_{2.5}$ nitrate to coarse $PM_{2.5-10}$ ratio was 3.5. Thus the fine mode nitrate to coarse mode nitrate ratio was 1.25. The factors for nitrate in Table 4.1 has been derived from a combination of this factor of 1.25 and the half and half split of the coarse mode nitrate into the fine $PM_{2.5}$ and coarse $PM_{2.5-10}$ fractions.

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	0.556	1.279	0.00
	Coarse	0.222	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 10 km x 10 km grid have been taken from the HARM/ELMO model (Whyatt et al., 2007). 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 μg m^{-3} and the model predicted peak summer time monthly concentrations of 0.4-0.5 μg 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 4.1). Hourly sequential meteorological data for 2008 from Waddington was applied. Surface roughness was assumed to be 0.1 m. Concentrations were calculated for a 100 km x 100 km square composed of a regularly spaced 1 km x 1 km resolution receptor grid. Each receptor grid was centred on the point source. A total of 55 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 2. 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 to model the dispersion of unit emissions from a central source to a grid of receptors at a spatial resolution of 1 km x 1 km squares.

4.5 Contributions from distant sources of primary particles

Contributions from long-range transport of primary particles on a 10 km x 10 km 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 10 km 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 Iron and calcium rich dusts

4.6.1 Introduction

The NAEI does not include estimates of the emissions of iron or calcium rich dusts. We have therefore applied various process-based or more empirically based models to estimate the contribution of these dusts to ambient PM_{10} concentrations across the UK. We have chosen to split the contributions into four categories:

- Rural calcium rich dusts from re-suspension of soils
- Urban calcium rich dusts from re-suspension of soils due to urban activity
- Regional iron rich dusts from re-suspension

- Iron rich dusts from re-suspension due to vehicle activity

A method for estimating the mass of iron (Fe) and calcium (Ca) rich dusts was included in the modelling method for PM_{10} for the first time in 2006 and the same method was used for 2007. The PCM model has been revised for 2008 to incorporate a more process-based modelling approach for rural calcium rich dusts from re-suspension of soils and iron rich dusts from re-suspension due to vehicle activity. These revised models have been developed from those proposed by Abbott (2008). The models for urban calcium rich dusts and regional iron rich dusts remain largely unchanged and are based on a more empirical approach.

The starting point for the assessment of iron and calcium rich dusts is the measurements of a range of PM components including Fe and Ca reported by Harrison and Yin (2006) for three monitoring sites in the Birmingham area. Measurements were made and urban background site (BCCS) from May 2004 to May 2005, an urban roadside site (BROS) from May 2005 to November 2005 and at a rural site about 20 km from the city (CPSS) from November 2005 to May 2006. Measurements were not made at the different sites simultaneously but the measurement periods were sufficiently long that they can be use to provide reasonable estimates of the urban and roadside increments of various PM components. The measurement data for Fe and Ca are summarised in Table 4.2

Table 4.2. Measured concentration of iron and calcium and derived estimates of iron and calcium rich dusts (μg m^{-3})

	CPSS (rural)	BCCS (urban)	conversion factor	rural x factor	Urban increment x factor
Fe fine	0.06	0.10	9.0	0.54	0.36
Fe coarse	0.14	0.24	9.0	1.26	0.89
Ca fine	0.03	0.09	4.3	0.13	0.26
Ca coarse	0.12	0.30	4.3	0.52	0.77

Table 4.2 also includes the conversion factors suggested by Harrison et al. (2006) for use within their pragmatic mass closure model. This factor converts to mass of elemental Fe to iron related dusts and the mass of elemental Ca to calcium related dusts. The urban increment in the table has been calculated by subtracting the data for CPSS from that for the urban BCCS site. It is clear that there is an urban increment for both fine and coarse iron and calcium rich dusts. Measurement data for the BROS roadside site indicates that there is a roadside increment on top of the urban increment for Fe but not for Ca. Thus it is reasonable to assume that the urban increment for iron rich dusts is associated with emissions generated by road traffic but that the urban increment for calcium rich dusts is associated with urban emissions that are not related to traffic activity.

4.6.2 Rural calcium rich dusts

The regional concentration of Ca rich dusts was assumed to be a constant value across the UK in our 2006 and 2007 assessments (Grice et al., 2009). Abbott (2008) has developed a method to estimate the ambient concentration of Ca rich PM_{10} dusts resulting from the re-suspension of soils in rural areas. The starting points for this method are the proportion of bare soil, root crops and cereal crops in 1 km x 1 km grid squares across the UK within the Land Cover Map 2000 (2009). The concentration of Ca rich dusts cannot be calculated using the standard approach of using an estimate of the annual emissions and an air dispersion model. This is because the rate of re-suspension and the atmospheric dispersion of these emissions are both dependant on the meteorological conditions. The emission rate will be higher when the wind is stronger but the dispersion of these emissions will also be more efficient under these conditions.

The method presented by Abbott (2008) makes use of combined emission and dispersion kernels for cereal and root crop fields and for bare soils. Concentrations were calculated for each hour of the year based on hourly sequential meteorological data from twelve sites throughout the UK for 1999. This year was selected because the data were readily available.

We have adapted this method for use within the PCM models by using an inverse distance weighted average of the results from the different kernels for each receptor location. This revised method avoids the discontinuities caused by the use of a simpler nearest met site to the receptor method used in the original work.

Figure 4.6a shows the results for rural Ca rich dusts. The highest concentrations are predicted to be in eastern areas where bare soils, root and arable crops are more common and there is less rainfall. A maximum value for this component has been set as 5 μg m^{-3} within the map. This value has been chosen as our estimate of the maximum likely concentration for a grid square average based on a comparison of this map with available PM_{10} measurements in the locations with the highest predicted contributions.

4.6.3 Urban calcium rich dusts

A more empirical method has been used to estimate the urban increment for Ca rich dusts. We have used the normalized distribution grid of resident population on a 1 km x 1 km grid as a surrogate for urban emissions within our area source model. We have calibrated this model to provide good agreement with the urban increment for Ca rich dusts found by Harrison and Yin (2006) and listed in Table 4.2.

Figure 4.6b shows the results for urban Ca rich dusts. The highest concentrations are in the major urban areas since this is a re-scaled population density map. A maximum value for this component has been set as 2 μg m^{-3} within the map. This value has been chosen as our estimate of the maximum likely concentration for a grid square average based on a comparison of this map with available PM_{10} measurements in the locations with the highest predicted contributions.

4.6.4 Regional iron rich dusts

A constant value for the regional contribution to Fe rich dusts of 1 μg m^{-3} has been applied across the UK. This residual value has been chosen to provide the best fit to the measurements from the Birmingham study (Harrison and Yin, 2006) and available urban background particulate Fe measurements once the estimated contribution from re-suspension due to vehicle movements has been taken into account. Figure 4.6c shows this constant contribution across the UK.

4.6.5 Iron rich dusts from re-suspension associated with vehicle movements

Our assessments for 2006 and 2007 used an empirical method for the Fe rich dusts associated with re-suspension from vehicle movements based on the use of vehicle km statistics for 1 km x 1 km squares (Grice et al., 2009). Abbott (2008) has developed a more process-based approach to estimating this contribution, which takes vehicle km statistics for heavy-duty vehicles (heavy good vehicles and buses) as its starting point. These estimates are likely to be subject to greater uncertainty than the estimates for re-suspension from rural soils because there is little information on the availability of material on road surfaces to be re-suspended.

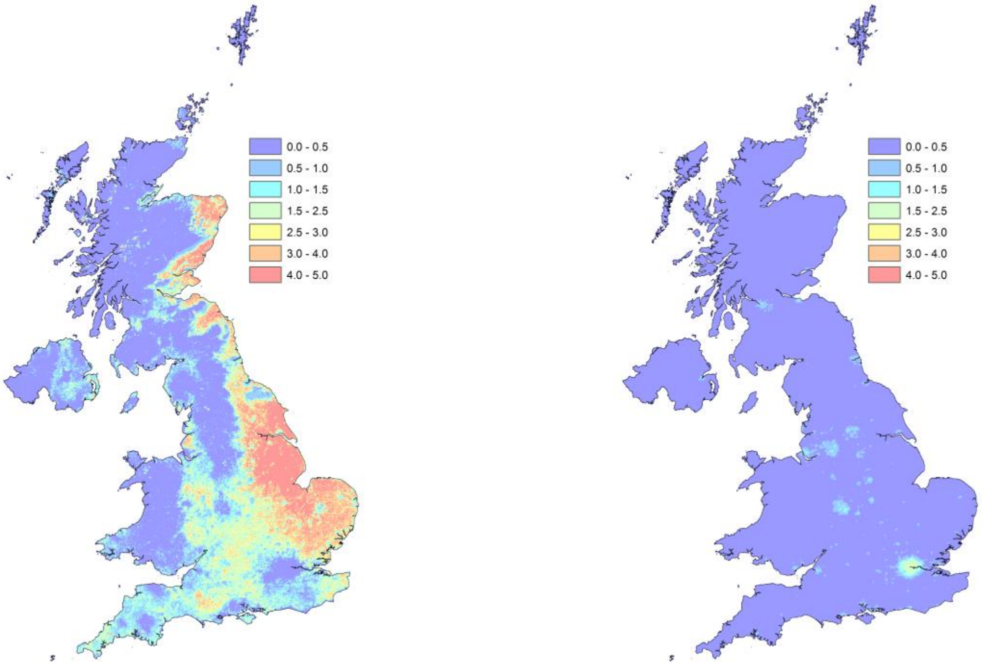
Abbott (2008) calculated two sets of combined emission and dispersion kernels for each of the 12 meteorological stations for 1999: one to represent rural conditions and one to represent urban conditions. The estimated re-suspension rate was considerably higher for rural conditions due to the higher speeds assumed. These two sets of kernels were then used to calculate the contribution to PM_{10} concentrations according to the proportion of urban and rural land cover in each 1 km x 1 km grid square. A detailed examination of the results from this assessment has shown that the concentrations in urban areas were largely driven by the small proportion of rural land cover in these urban areas. We have therefore chosen to apply the urban kernels for all roads within our PCM model.

Figure 4.6d shows the results for Fe rich dusts from vehicle movements. The highest concentrations are associated with the roads with the highest flows of heavy-duty vehicles. A maximum value for this component has been set as 2.5 μg m^{-3} within the map. This value has been chosen as our estimate of the maximum likely concentration for a grid square average based on a comparison of this map with available PM_{10} measurements in the locations with the highest predicted contributions.

Figure 4.6.

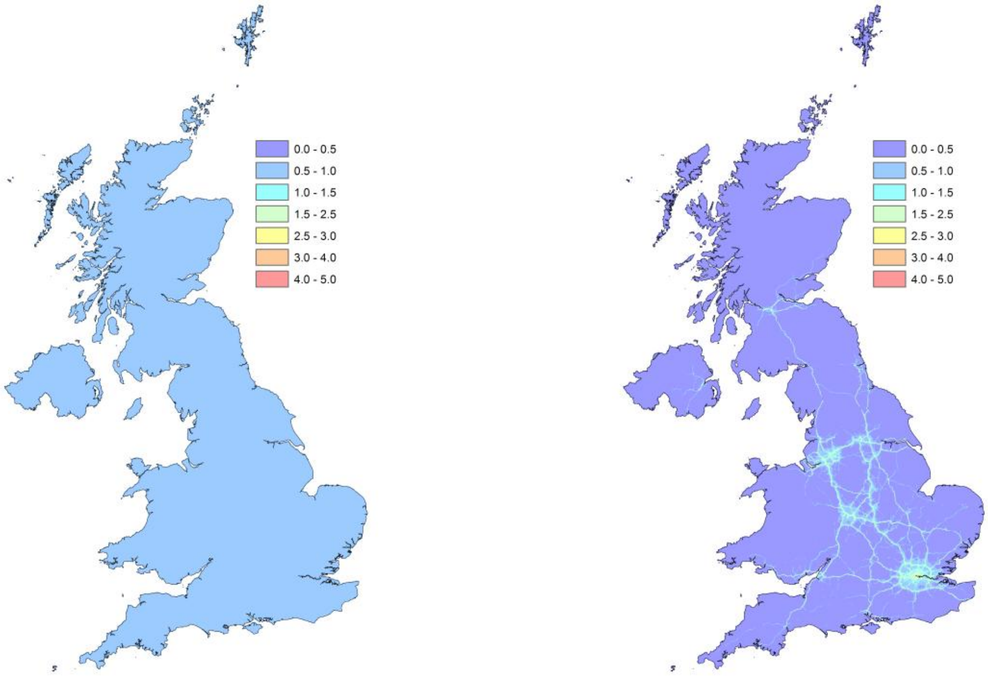
a) Contribution to PM_{10} from rural Ca rich dusts associated with re-suspension from soils ($\mu g\ m^{-3}$)

b) Contribution to PM_{10} from urban Ca rich dusts associated with urban activities ($\mu g\ m^{-3}$)



c) Contribution to PM_{10} from regional Fe rich dusts ($\mu g\ m^{-3}$)

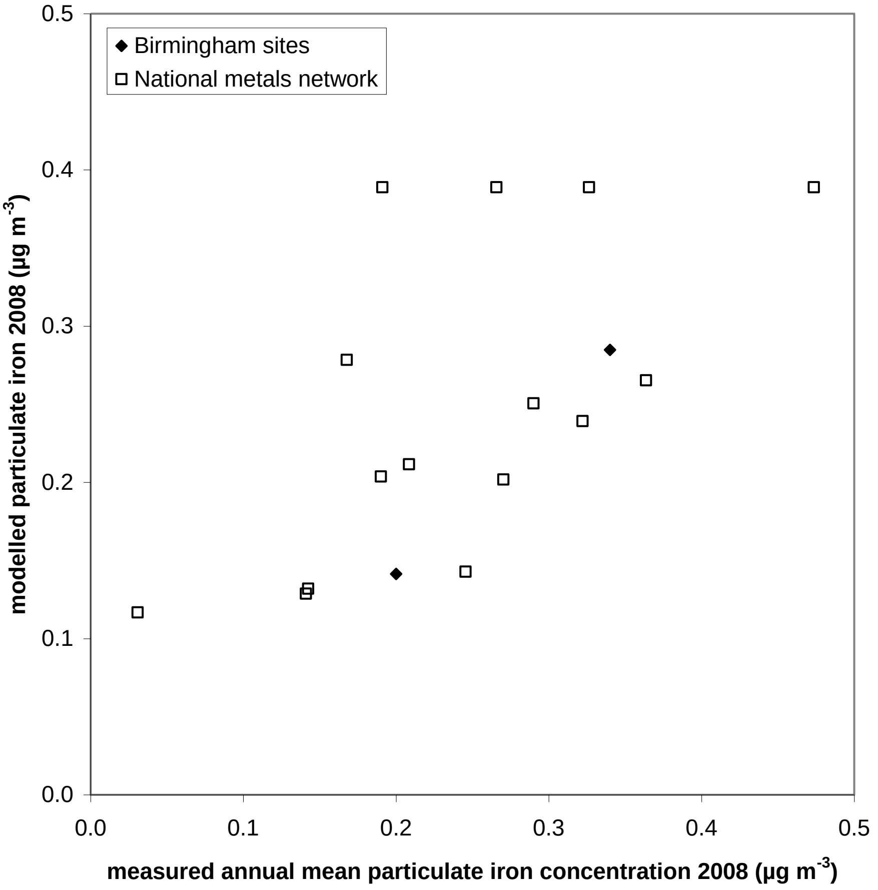
d) Contribution to PM_{10} from Fe rich dusts associated with vehicle movements ($\mu g\ m^{-3}$)



© Crown copyright. All rights reserved Defra, Licence number 100022861 [2009]

An indication that the method is providing reasonable estimates the total of Fe rich dusts is provided by Figure 4.7, which shows a comparison of modelled annual mean Fe (the sum of regional and vehicle related Fe) with ambient Fe measurements at non-industrial and non-roadside sites for 2008 from the national metals monitoring network. The modelled estimates are clearly of the correct magnitude and provide a reasonable description of the rural to urban gradients.

Figure 4.7. Comparison of modelled and measured annual mean elemental Fe concentrations 2008 (μg m^{-3})



4.6.6 Application to the mapping of heavy metal concentrations

Abbott (2008) also suggested a method for estimating the contributions to the ambient concentrations of heavy metals from soil and vehicle related re-suspension processes. The accompanying report (Yap et al., 2009) describes how the maps of PM mass from rural re-suspension of soils and re-suspension associated with vehicle movements have been used to estimate the contributions to the ambient concentration of heavy metals using a combination of information on the heavy metal content of soils and enhancement factors.

4.7 Sea salt

The contribution to ambient PM from sea salt has been derived directly from measurements of particulate chloride (Tang, 2009). Data from 28 rural sites were interpolated by Krigging onto a 5 km x 5 km grid. A scaling factor of 1.648 was applied to convert elemental chloride mass to sodium chloride mass. 73% of the sea salt mass was assumed to be in the coarse fraction and 27% in the fine fraction. This split was derived from measurement data presented by APEG (1999) and Harrison and Yin (2006).

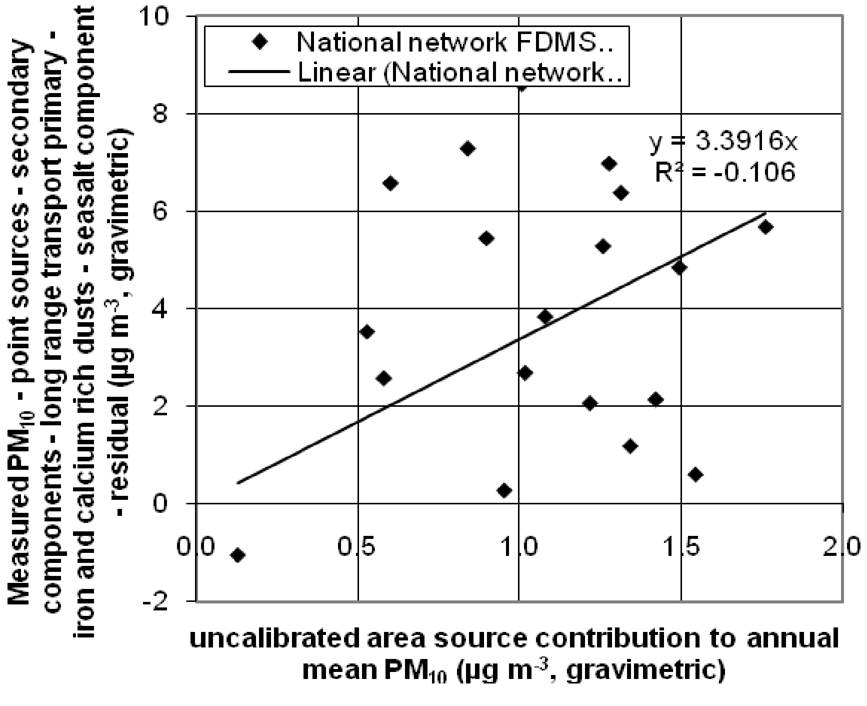
The use of chloride is potentially subject to both positive and negative artefacts. Sea salt is not the only source of particulate chloride in the atmosphere. HCl is emitted from coal burning but reductions in coal use and flue gas abatement are likely to have reduced atmospheric HCl and ammonium chloride concentrations considerably. There will also be loss of chloride from marine aerosol due to reactions with nitric acid. We consider the resulting sodium nitrate PM to be of anthropogenic origin and the contribution to PM mass from this sodium nitrate is explicitly included in our modelled concentrations. If sodium were used as our marker for sea salt then this sodium nitrate would tend to be included in the natural component.

In addition to selecting chloride as the marker for sea salt, we have also decided to simplify the analysis by assuming that the sea salt consists of sodium chloride only. Thus we have scaled the measured chloride concentration by a factor of 1.648. An alternative approach would be to scale by 1.809 to take account of the full composition of sea salt. The composition of sea salt is dominated by chloride and sodium. Other components contributing more than 1% by mass are sulphate, magnesium, calcium and potassium. Sulphate is already explicitly included in our modelled concentrations and we have not applied a sea salt correction to the measured concentrations used in the PCM model. Adding a further sea salt sulphate component would lead to double counting. The other components (magnesium, calcium and potassium) have, in effect, been treated as sodium by our use of a scaling factor of 1.648. The ratio of (chloride + sodium) to chloride in sea salt is 1.552, while the ratio of (chloride + sodium + magnesium + calcium + potassium) to chloride is 1.658. Thus our simplification of sea salt as pure sodium chloride has not had a large impact on the total mass assumed apart from the contribution from sea salt sulphate, which, as a simplification, we have included with the rest of the sulphate as anthropogenic.

4.8 Contributions from area sources

Figure 4.8 shows the calibration of the area source model. The modelling method utilises 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 33 km x 33 km square surrounding each monitoring site. Hourly sequential meteorological data from Waddington in 2008 was used to construct the dispersion kernels, as described in Appendix 3. A total of 19 background FDMS monitoring sites within the national network had sufficient data capture for PM_{10} in 2008 to be used to calibrate the model.

Figure 4.8. Calibration of PM_{10} area source model 2008 ($\mu g\ m^{-3}$, gravimetric)



The area source model has been calibrated using FDMS ambient PM monitoring data from the UK national networks. The modelled large point and small point source, SIA, SOA, iron and calcium rich dust, long range transport primary PM, sea salt and the residual 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. A residual concentration of 1 μg m^{-3} was found to provide the best fit to the monitoring data.

The modelled area source contribution was multiplied by the relevant empirical coefficient to calculate the calibrated area source contribution for each grid square in the country. The 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, from calcium and iron rich dusts and the residual, resulting in a map of background annual mean gravimetric PM_{10} concentrations.

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:

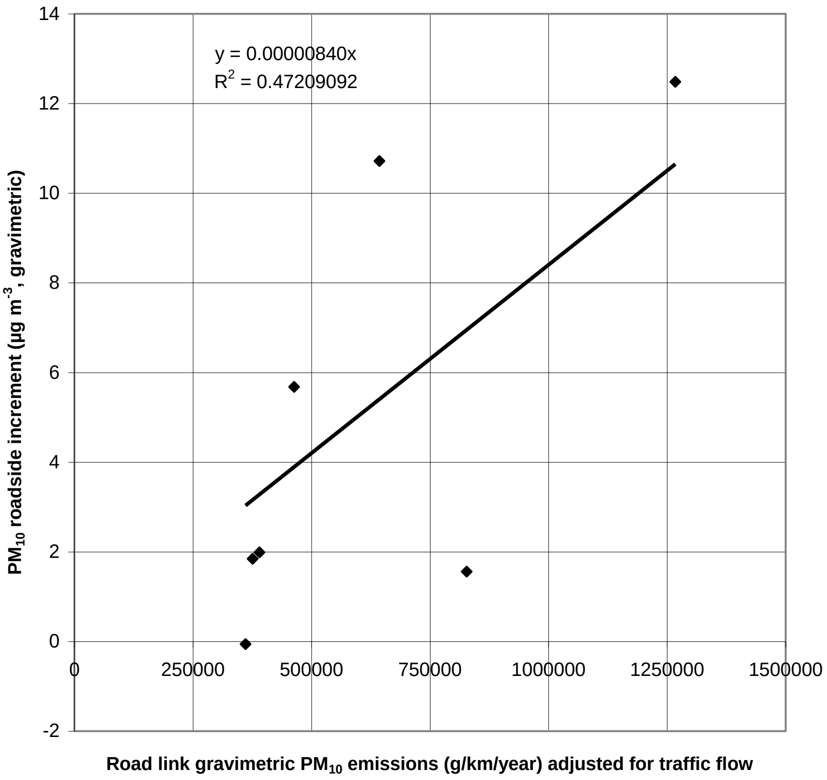
roadside concentration = background concentration + roadside increment.

The NAEI provides estimates of PM_{10} emissions for major road links in the UK for 2007 (Murrells et al., 2009) and these have been adjusted to provide estimates of emissions in 2008. Figure 4.9 shows a comparison of the roadside increment of annual mean PM_{10} concentrations at roadside or kerbside FDMS monitoring sites with PM_{10} emission estimates for the individual road links alongside which these sites are located. Data from the one national network roadside site with FDMS measurements has been supplemented with data for an additional six sites. The sites used to calibrate this model are listed in Table 4.3. The regression line has been forced through zero to provide a reasonable model output without imposing an unrealistic high residual to the roadside increment. Emissions were adjusted for annual average daily traffic flow using the method described in Section 3.2.6. Roadside concentrations for urban major road links (A-roads and motorways) only are reported to the EU and included in this report.

Table 4.3. The roadside and kerbside FDMS monitoring sites used calibrate the roadside increment model for 2008.

Site	Network
Swansea Roadside	National network
Ealing 2 (FDMS) - Acton Town Hall	London Air Quality Network
Tower Hamlets 4 - Blackwall	London Air Quality Network
Chichester Roadside FDMS	Sussex Air Quality Partnership
Bexley 7 (FDMS) - Thames Rd North	London Air Quality Network
Greenwich 13 - Plumstead High Street	London Air Quality Network
Greenwich 9 - Westhorne Ave	London Air Quality Network

Figure 4.9. Calibration of PM_{10} roadside increment model 2008 ($\mu g\ m^{-3}$, gravimetric)



4.10 Verification of mapped values

Figures 4.10 and 4.11 show comparisons of gravimetric PM_{10} modelled and measured annual mean PM_{10} concentration in 2008 at background and roadside monitoring site locations. 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 4.4 and 4.5.

The agreement between the FDMS measurement data used to calibrate the models is good, but this is to be expected. There are limited data available for FDMS verification sites. The comparison with TEOM data corrected using the VCM model (as described in Appendix 6) shows generally good agreement. The comparison with corrected national network Partisol gravimetric measurements shows generally good agreement. There is some indication that the model predicts higher concentrations than are measured at background locations. TEOM x 1.3 measurement data for both national network and verification sites are higher than the modelled estimates, as expected.

Figure 4.10. Verification of background annual mean PM_{10} (gravimetric) model 2008

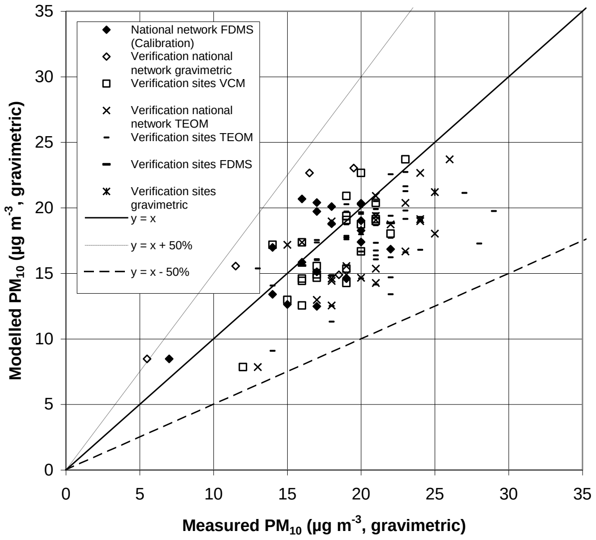


Figure 4.11. Verification of roadside annual mean PM_{10} (gravimetric) model 20079

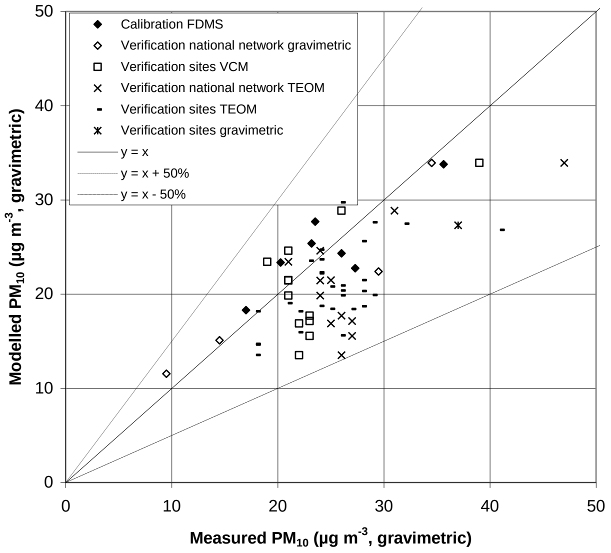


Table 4.4. Summary statistics for comparison between gravimetric modelled and measured concentrations of PM_{10} at background sites

	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 FDMS (Calibration)	17.2	16.9	0.42	0	19
Verification sites FDMS	19.0	17.2	-	0	2
Verification sites VCM	18.2	16.9	0.62	0	23
Verification national network gravimetric	14.3	16.9	0.65	20	5
Verification sites gravimetric	25.0	21.2	-	0	1
Verification national network TEOM	20.3	17.0	0.52	0	24
Verification sites TEOM	20.5	17.5	0.26	0	56

Table 4.5. Summary statistics for comparison between gravimetric modelled and measured concentrations of PM_{10} at roadside sites

	Mean of measurements ($\mu g\ m^{-3}$, grav)	Mean of model estimates ($\mu g\ m^{-3}$, grav)	R^2	% outside data quality objectives	Number of sites
Calibration FDMS	24.7	25.1	0.72	0	7
Verification sites VCM	23.4	21.2	0.45	0	4
Verification national network gravimetric	22.0	20.7	0.90	0	4
Verification sites gravimetric	37.0	27.3	-	0	1
Verification national network TEOM	27.3	21.2	0.44	0	12
Verification sites TEOM	25.1	20.8	0.39	0	30
Calibration FDMS	24.7	25.1	0.72	0	7

4.11 PM_{10} source apportionment at monitoring sites

Figures 4.11 and 4.12 show the modelled annual mean PM_{10} source apportionment for 2008 at AURN background and roadside monitoring sites respectively. The measured concentration at each site is also shown for reference.

At background locations, the contributions from non-emissions inventory sources (i.e. regional background sources and urban dusts), which are shown in grey on the figures, dominate with a particularly large contribution from secondary aerosols. The smaller contribution from urban background emissions sources, shown in colour on the figures, are dominated in most locations by traffic (exhaust emissions and brake and tyre wear), industry and off road mobile machinery.

At roadside locations the source apportionments follow a very similar pattern to background locations, except that there is an extra local road traffic component composed of local exhaust emissions and local brake and tyre wear emissions. Depending on the magnitude of the local traffic emissions, local traffic emissions can contribute up to 10 μgm^{-3} of PM_{10} at the roadside monitoring sites.

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 limit values by zone, are summarised in Table 4.6 These data are also presented in Form 19c of the questionnaire. Method A in these tables refers to the annual mean modelling methods described in this report. The European Commission have advised that comparisons with the indicative Stage 2 limit values for PM_{10} are no longer required.

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 kerbside.

Figure 4.11. Annual mean PM_{10} source apportionment at background AURN monitoring sites (the area type of each site is shown in parenthesis after its name)

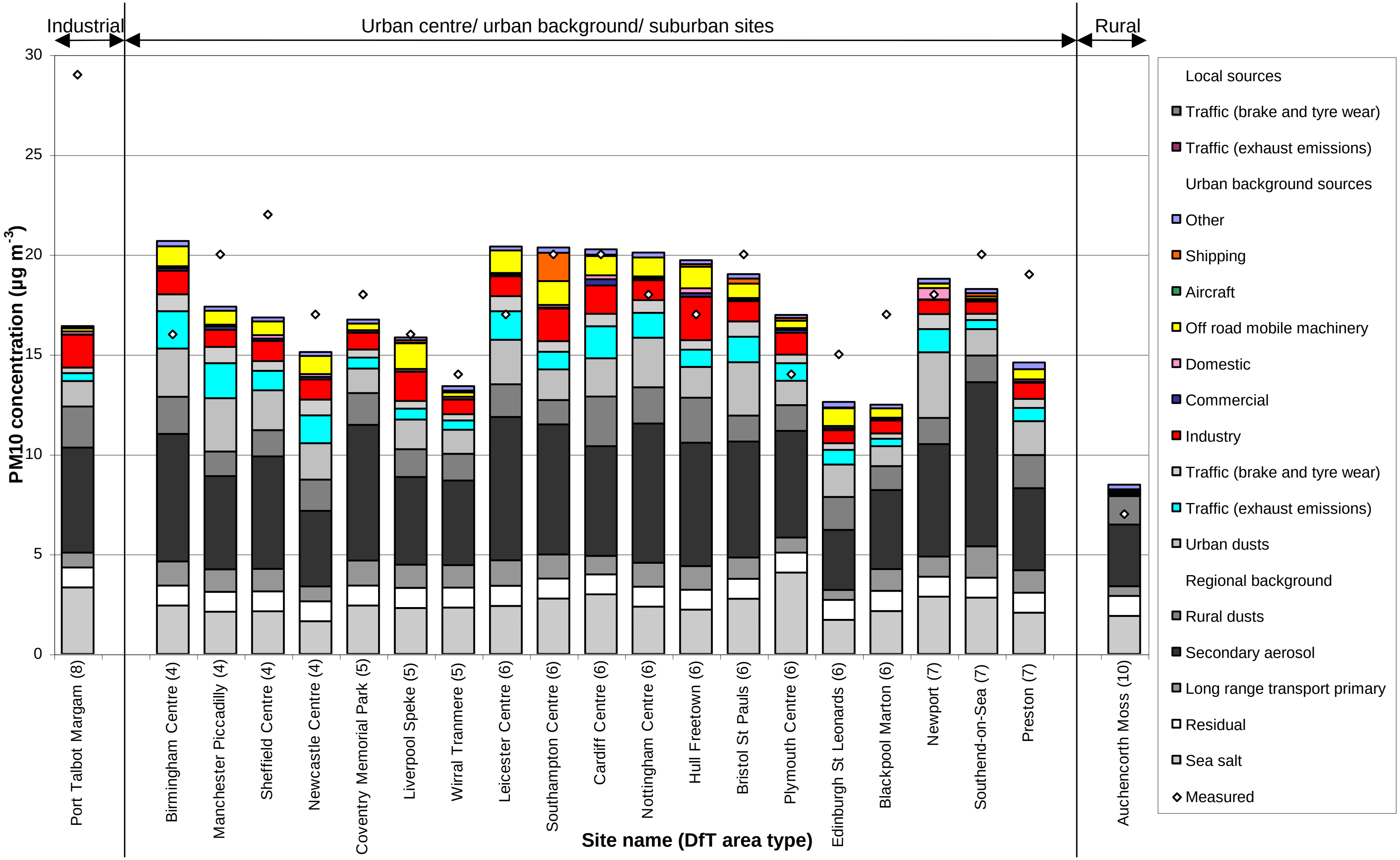


Figure 4.12. Annual mean PM_{10} source apportionment at roadside monitoring sites (the area type of each site is shown in parenthesis after its name)

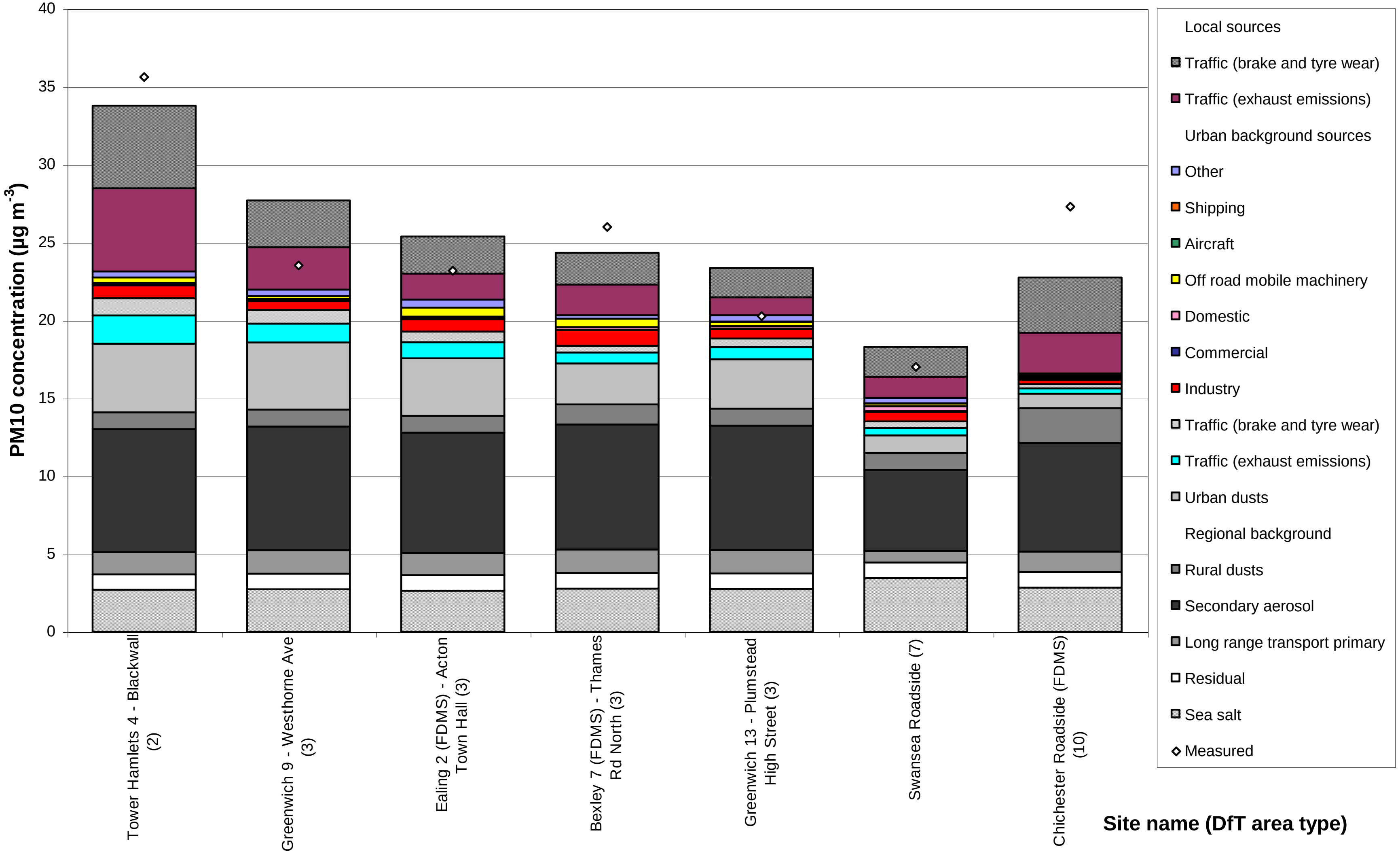


Table 4.6. Tabular results of and methods used for supplementary assessment (1999/30/EC Article 7(3) and Annex VIII(II), 2000/69/EC Article 5(3) and Annex VI(II) and 2002/3/EC Article 9(1) and Annex VII(II)) - Results of and methods used for supplementary assessment for PM10 (Stage 1) Questionnaire Form 19c.1

Zone	*Zone code*	*Above LV (24hr mean)*						*Above LV (annual mean)*					
		Area		*Road length*		*Population exposed*		*Area*		*Road length*		*Population exposed*	
		km^2	*Method*	*km*	*Method*	*Number*	*Method*	*km^2*	*Method*	*km*	*Method*	*Number*	*Method*
Greater London Urban Area	UK0001	0	A	71.5	A	0	A	0	A	0	A	0	A
West Midlands Urban Area	UK0002	0	A	0.0	A	0	A	0	A	0	A	0	A
Greater Manchester Urban Area	UK0003	0	A	0.0	A	0	A	0	A	0	A	0	A
West Yorkshire Urban Area	UK0004	0	A	0.0	A	0	A	0	A	0	A	0	A
Tyneside	UK0005	0	A	0.0	A	0	A	0	A	0	A	0	A
Liverpool Urban Area	UK0006	0	A	0.0	A	0	A	0	A	0	A	0	A
Sheffield Urban Area	UK0007	0	A	0.0	A	0	A	0	A	0	A	0	A
Nottingham Urban Area	UK0008	0	A	0.0	A	0	A	0	A	0	A	0	A
Bristol Urban Area	UK0009	0	A	0.0	A	0	A	0	A	0	A	0	A
Brighton/Worthing/Littlehampton	UK0010	0	A	0.0	A	0	A	0	A	0	A	0	A
Leicester Urban Area	UK0011	0	A	0.0	A	0	A	0	A	0	A	0	A
Portsmouth Urban Area	UK0012	0	A	0.0	A	0	A	0	A	0	A	0	A
Teesside Urban Area	UK0013	0	A	0.0	A	0	A	0	A	0	A	0	A
The Potteries	UK0014	0	A	0.0	A	0	A	0	A	0	A	0	A
Bournemouth Urban Area	UK0015	0	A	0.0	A	0	A	0	A	0	A	0	A
Reading/Wokingham Urban Area	UK0016	0	A	0.0	A	0	A	0	A	0	A	0	A
Coventry/Bedworth	UK0017	0	A	0.0	A	0	A	0	A	0	A	0	A
Kingston upon Hull	UK0018	0	A	0.0	A	0	A	0	A	0	A	0	A
Southampton Urban Area	UK0019	0	A	0.0	A	0	A	0	A	0	A	0	A
Birkenhead Urban Area	UK0020	0	A	0.0	A	0	A	0	A	0	A	0	A
Southend Urban Area	UK0021	0	A	0.0	A	0	A	0	A	0	A	0	A
Blackpool Urban Area	UK0022	0	A	0.0	A	0	A	0	A	0	A	0	A
Preston Urban Area	UK0023	0	A	0.0	A	0	A	0	A	0	A	0	A
Glasgow Urban Area	UK0024	0	A	0.0	A	0	A	0	A	0	A	0	A
Edinburgh Urban Area	UK0025	0	A	0.0	A	0	A	0	A	0	A	0	A
Cardiff Urban Area	UK0026	0	A	0.0	A	0	A	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	A	0.0	A	0	A	0	A	0	A	0	A
Belfast Urban Area	UK0028	0	A	0.0	A	0	A	0	A	0	A	0	A
Eastern	UK0029	0	A	1.4	A	0	A	0	A	0	A	0	A
South West	UK0030	0	A	0.0	A	0	A	0	A	0	A	0	A
South East	UK0031	0	A	0.0	A	0	A	0	A	0	A	0	A
East Midlands	UK0032	0	A	0.0	A	0	A	0	A	0	A	0	A
North West & Merseyside	UK0033	0	A	0.0	A	0	A	0	A	0	A	0	A
Yorkshire & Humberside	UK0034	0	A	0.0	A	0	A	0	A	0	A	0	A
West Midlands	UK0035	0	A	0.0	A	0	A	0	A	0	A	0	A
North East	UK0036	0	A	0.0	A	0	A	0	A	0	A	0	A
Central Scotland	UK0037	0	A	0.0	A	0	A	0	A	0	A	0	A
North East Scotland	UK0038	0	A	0.0	A	0	A	0	A	0	A	0	A
Highland	UK0039	0	A	0.0	A	0	A	0	A	0	A	0	A
Scottish Borders	UK0040	0	A	0.0	A	0	A	0	A	0	A	0	A
South Wales	UK0041	0	A	0.0	A	0	A	0	A	0	A	0	A
North Wales	UK0042	0	A	0.0	A	0	A	0	A	0	A	0	A
Northern Ireland	UK0043	0	A	0.0	A	0	A	0	A	0	A	0	A

4.13 Subtraction of sea salt component

4.13.1 Introduction

The directive on ambient air quality and cleaner air for Europe (2008/50/EC) requires member states to discount exceedences of limit values due to natural sources when reporting the results of air quality assessments. The definition of natural sources in this Directive includes sea spray. The monitoring data and model results presented in the reporting questionnaire (CDR, 2008) for PM_{10} in forms 8, 11 and 19 are the total concentrations. An assessment of the concentrations with the contribution from natural sources subtracted is provided in Form 23 for locations with measured or modelled exceedences of the limit values. 2008 is the first year for which we have subtracted the contribution from natural sources. We have done this because this is a transitional assessment, carried out under the Framework and daughter directives but meeting this key requirement of the new directive.

4.13.2 Map of annual mean sea salt PM_{10}

The method used to estimate the sea salt contribution to annual mean PM_{10} concentrations across the UK has been described in Section 4.7. The map of annual mean sea salt PM_{10} can be used to subtract this contribution directly from measured or modelled annual mean concentrations. The uncertainties associated with estimating the sea salt contribution to annual mean PM_{10} from measurements of particulate chloride have been discussed in Section 4.7. We recognise that our interpolated map of sea salt concentrations will not capture the steep gradients in sea salt concentration very close to the coast. Thus our analysis may underestimate the sea salt contribution to exceedences at the seaside.

4.13.3 Method for the 24-hour limit value

We have also developed a method for estimating the contribution from sea salt to exceedences of the 24-hour limit value for PM_{10} of no more than 35 days with concentration greater than 50 $\mu g\ m^{-3}$. This method has been described in detail by Defra (2009). This method makes use of the relationship between the number of days with concentrations greater than 50 $\mu g\ m^{-3}$ and annual mean concentrations described in Section 4.1.2 above. There is some scatter around the best-fit line of the relationship shown in Figure 4.3. We consider that it is appropriate to use the best-fit line relationship within our annual method for subtracting sea salt since this should give the best central estimate of the sea salt contribution.

An estimate of the number of days with a PM_{10} concentration greater than 50 $\mu g\ m^{-3}$ associated with the contribution to annual mean concentration from sea salt has been calculated by applying the relationship shown in Figure 4.3 in the vicinity of the limit value. This has been done by calculating the difference between the number of days corresponding to 31.5 $\mu g\ m^{-3}$ minus half the sea salt concentration and the number of days corresponding to 31.5 $\mu g\ m^{-3}$ plus half the sea salt concentration.

Daily chloride measurements are available for three sites in the south east of the UK. These measurements can be used to calculate a daily sea salt subtraction for PM_{10} monitoring data. This method is not applicable to model results and will be less reliable for sites not in the south east of the UK. For these reasons we have used the method based on annual mean sea salt concentrations across the UK as described above. Defra (2009) have provided a comparison of the annual and daily methods for the years 2005, 2006 and 2007 which shows that the agreement between the methods is reasonably good.

4.13.4 Results

The results of our assessment of number of days with a PM_{10} concentration greater than 50 $\mu g\ m^{-3}$ with the contribution from sea salt subtracted in zones with measured or modelled exceedences of the 24-hour limit value are shown in Table 4.7. This is a copy of from 23a of the reporting questionnaire. The exceedence in the Greater London Urban Area remains after the subtraction of the contribution from sea salt. The exceedence in the Eastern Zone is removed by the subtraction of the contribution from sea salt. S8 in this table refers to natural sources, sea salt in this instance.

There were no reported exceedences of the annual mean limit value for PM_{10} in 2008.

Table 4.7. Exceedence of limit values of PM_{10} due to natural events (1999/30/EC Article 5(4)) or natural contributions (2008/50/EC Article 20) - Contribution of natural events to exceedence of the PM10 limit value (stage 1; 24hr mean)

Zone code	Zone	EoI station code	Number of exceedences measured	Natural event code(s)	Estimated number of exceedences after subtraction of natural contribution
UK0001	Greater London Urban Area	GB0682A	57	S8	46
UK0029	Eastern	n/a	42	S8	31

5 Benzene

5.1 Introduction

Maps of annual mean benzene concentrations at background and roadside locations in 2008 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.

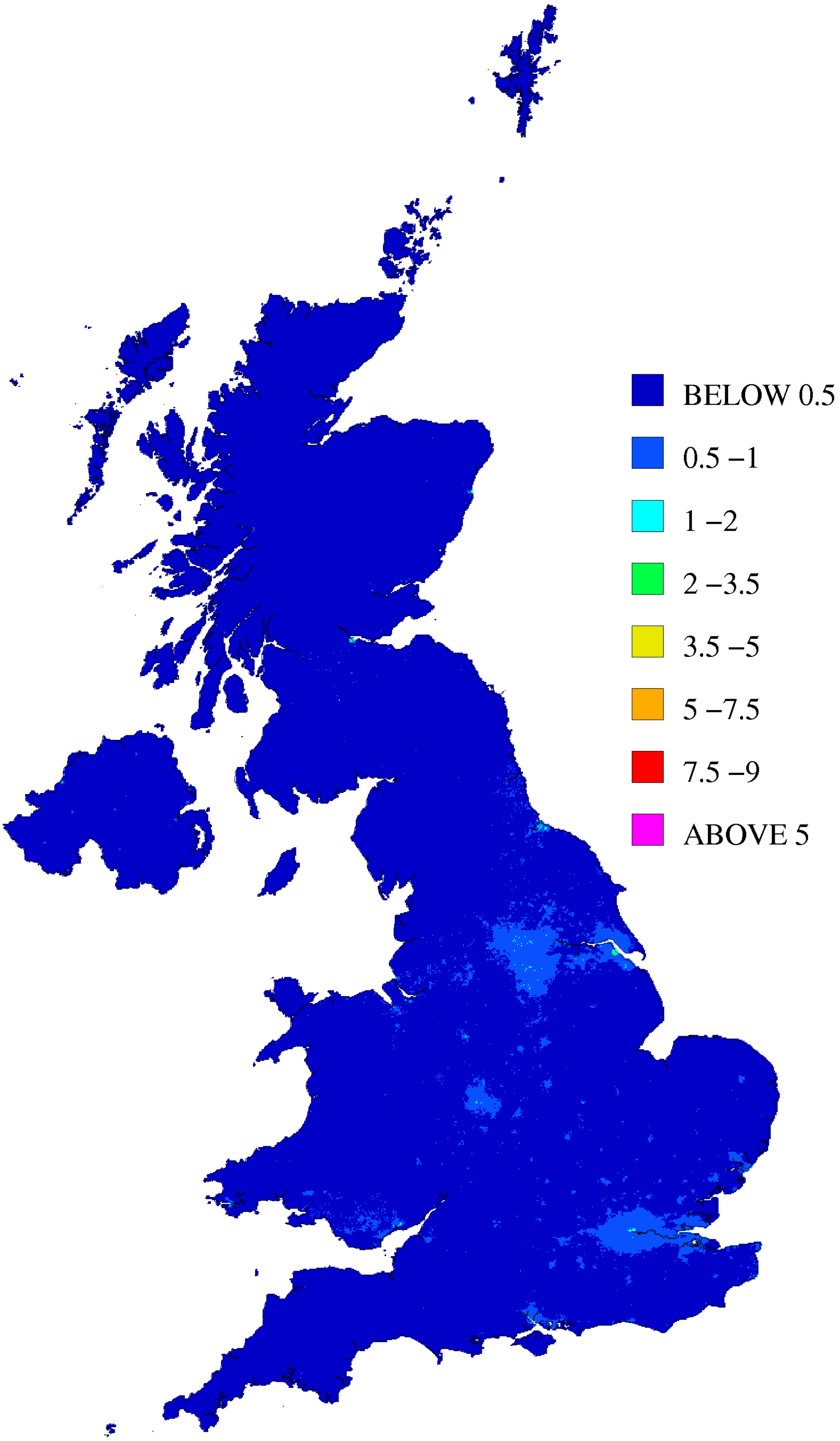
It has been considered that annual mean background benzene concentrations are made up of contributions from:

- 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.

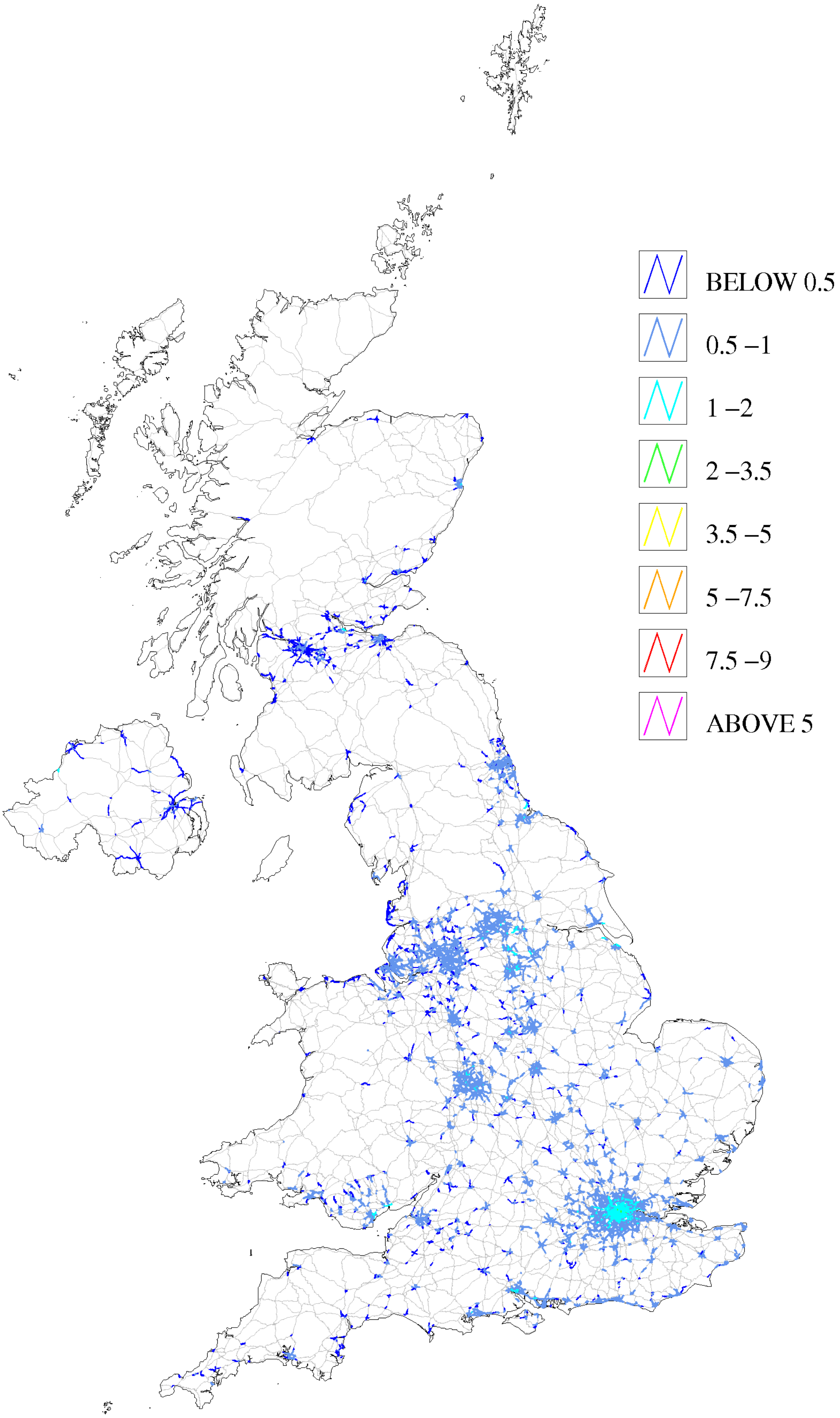
At locations close to busy roads an additional roadside contribution was added to account for contributions to total benzene from road traffic sources.

Figure 5.1. Annual mean background benzene concentration, 2008 ($\mu g\ m^{-3}$)



© Crown copyright. All rights reserved Defra, Licence number 100022861 [2009]

Figure 5.2. Urban major roads, annual mean roadside benzene concentration, 2008 (μg m^{-3})



Crown copyright. All rights reserved Defra, Licence number 100022861 [2009]

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 2007 NAEI were estimated by modelling each source explicitly using an atmospheric dispersion model (ADMS 4.1) and sequential meteorological data for 2008 from Waddington. A total of 29 point sources were modelled. Surface roughness was assumed to be 0.1 m. Concentrations were calculated for a 99 km x 99 km square composed of a regularly spaced 1 km x 1 km 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 small points model similar to the model described in Appendix 2, but adapted specifically for fugitive and process point sources of benzene. 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 1 km x 1 km grid square that includes the source) and the concentration in surrounding grid squares (the ‘out-square’ concentration). The ‘out-square’ concentration has been estimated using a dispersion kernel similar to the one used for area sources of benzene. The ‘in square’ concentration has been estimated by assuming a volume source of dimensions 200 m x 200 m x 30 m in the centre of the square with the concentration estimated as the average across receptors excluding those inside the central 800 m x 800 m of the 1000 m x 1000 m grid square. These parameters have been chosen to provide the best fit to the range and maximum of available monitoring data in the vicinity of refineries (Grice et al., 2009).

5.4 Contributions from rural background concentrations

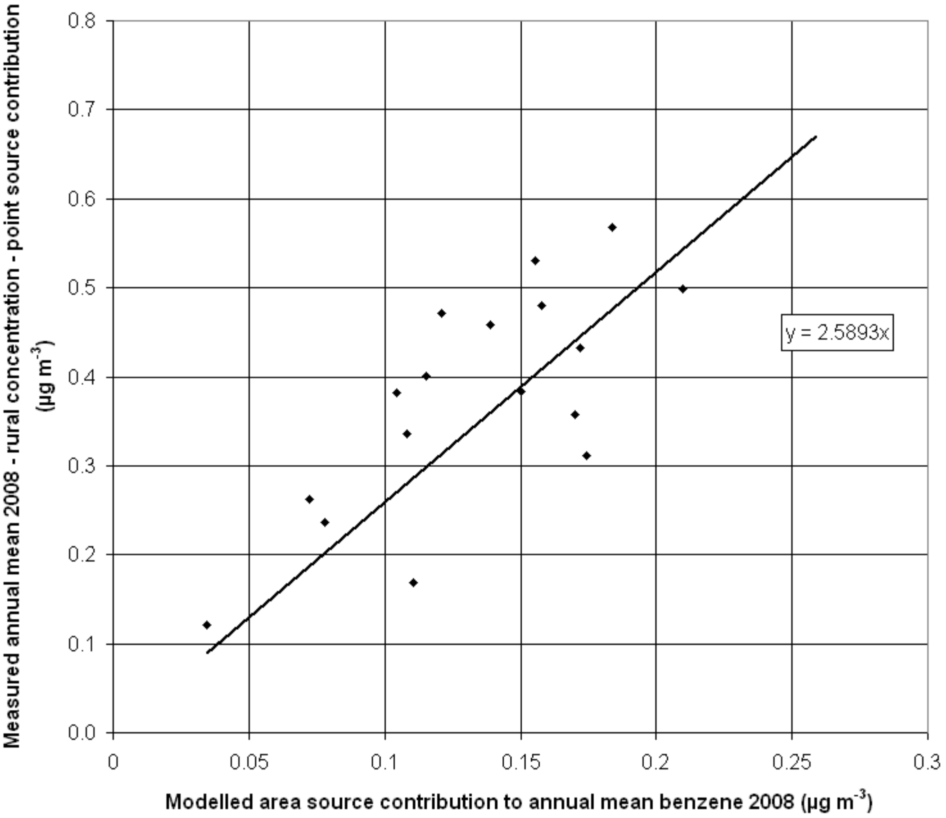
Regional rural benzene concentrations were estimated from the map of rural NO_X concentration described in Section 3.2. The rural NO_X map was scaled using the ratio of measured annual mean benzene and NO_X concentrations at the rural Harwell monitoring site in 2008.

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 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 33 km x 33 km square surrounding each monitoring site. Hourly sequential meteorological data from Waddington in 2008 has been used to construct the dispersion kernels, as described in Appendix 3.

The modelled area source contribution was multiplied by the 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 2008 (μg m^{-3})



5.6 Roadside concentrations

Calibration of the benzene roadside increment model is shown in Figure 5.4. Benzene concentrations have been measured at the London Marylebone Road monitoring station using two different methods. The automatic monitor measured a much lower benzene annual mean concentration than the pumped tube monitor.

An alternative calibration of the benzene roadside increment model was considered and is presented in Figure 5.5. The alternative calibration was plotted with the exclusion of the lower measurement at London Marylebone Road. This relationship gives a better agreement with the roadside calibration for NO_X (as shown as a dashed line in the figures). As a result, the roadside calibration coefficient of 0.00000818 was used.

Roadside concentrations of annual mean benzene for 2008 have been modelled using a similar method to the NO_X modelling described in Section 3.2.

Figure 5.4. Comparison of benzene roadside increment and road link emission 2008 (µg m^{-3}) (coefficient for NO_X shown as a dashed line)

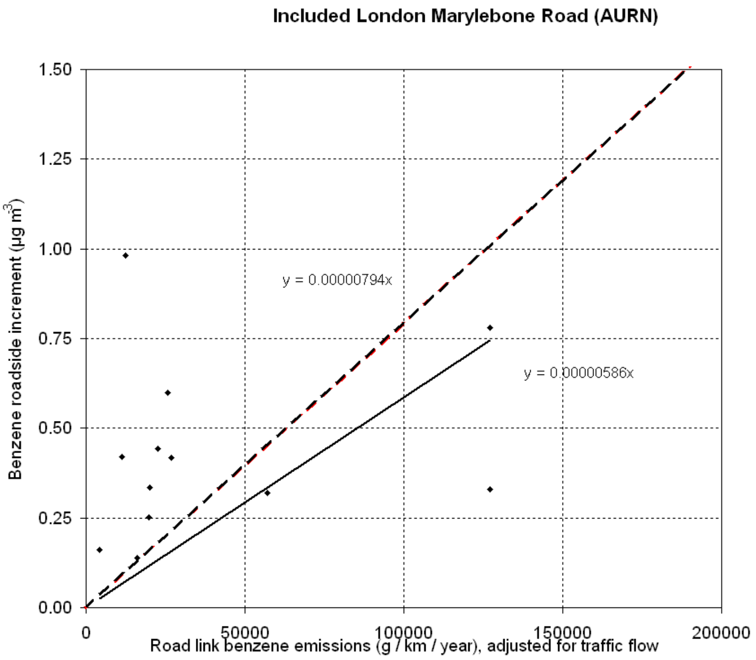
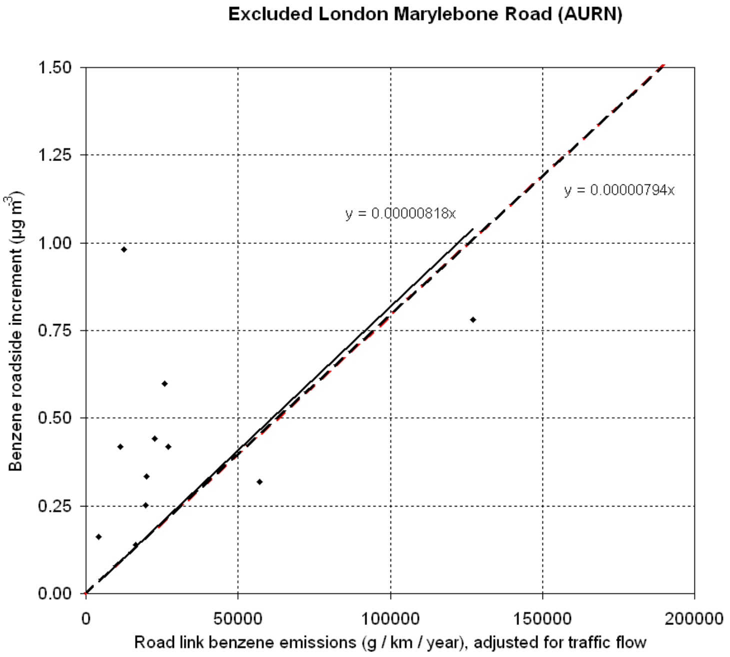


Figure 5.5. Comparison of benzene roadside increment and road link emission 2008 (µg m^{-3}) (coefficient for NO_X shown as a dashed line)



5.7 Verification of mapped values

Figures 5.6 and 5.7 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 5.6. Verification of background annual mean benzene model 2008

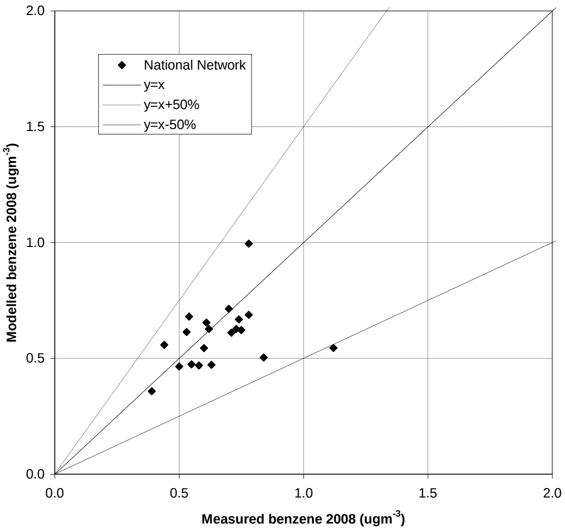
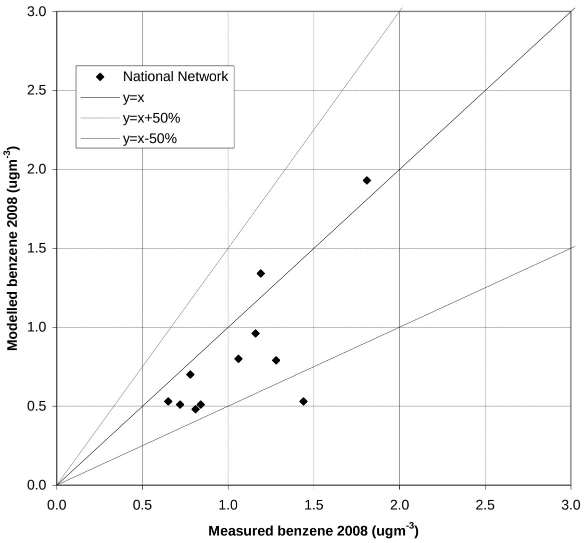


Figure 5.7. Verification of roadside annual mean benzene model 2008



Summary statistics for the comparison between modelled and measured benzene concentrations are listed in Tables 5.1 and 5.2. Urban background and rural AURN sites not been used in the calibration process are presented along with 'verification sites' and the details of verification sites are presented in Table A1.1 of Appendix 1. Lines representing y = x – 50 % and y = x + 50% are shown (the AQDD1 data quality objective for modelled annual mean and percentile benzene concentrations respectively).

No monitoring sites were available to provide an independent verification of the 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 modelled (µg m^{-3})**	**R^2**	**%outside data quality objectives**	**Number of sites**
National Network Sites	0.68	0.67	0.44	9	22

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 modelled (µg m^{-3})**	**R^2**	**%outside data quality objectives**	**Number of sites**
National Network Sites	1.05	0.72	0.19	8	12

5.8 Benzene source apportionment at monitoring sites

Figures 5.7 and 5.8 show the modelled annual mean benzene source apportionment for 2008 at AURN background and roadside monitoring sites, respectively. The measured concentration at each site is also shown for reference. Figure 5.7 shows that regional background, road transport, off road mobile machinery and domestic sources dominate the background source apportionment for the majority of background monitoring sites. Concentrations at Middlesbrough and Liverpool Speke monitoring sites are under predicted in the model by up to 0.5 µg m^{-3}. This is believed to be due to a failure to characterise emissions from industrial sources correctly. At Grangemouth the model also does not closely reflect measured concentrations. However, detailed analysis of monitoring data collected by the site operator at Grangemouth show that there are no exceedences of the benzene limit value in the area around Grangemouth. The roadside source apportionment in Figure 5.8 shows that local traffic sources can contribute up to 1.0 µg m^{-3} of benzene at roadside sites.

5.9 Detailed comparison of modelling results with limit values

Modelling results for benzene have not been tabulated here because the modelled and measured benzene concentrations for 2008 are below the limit value for all zones.

Figure 5.7. Annual mean benzene source apportionment at background AURN monitoring sites (the area type of each site is shown in parenthesis after its name)

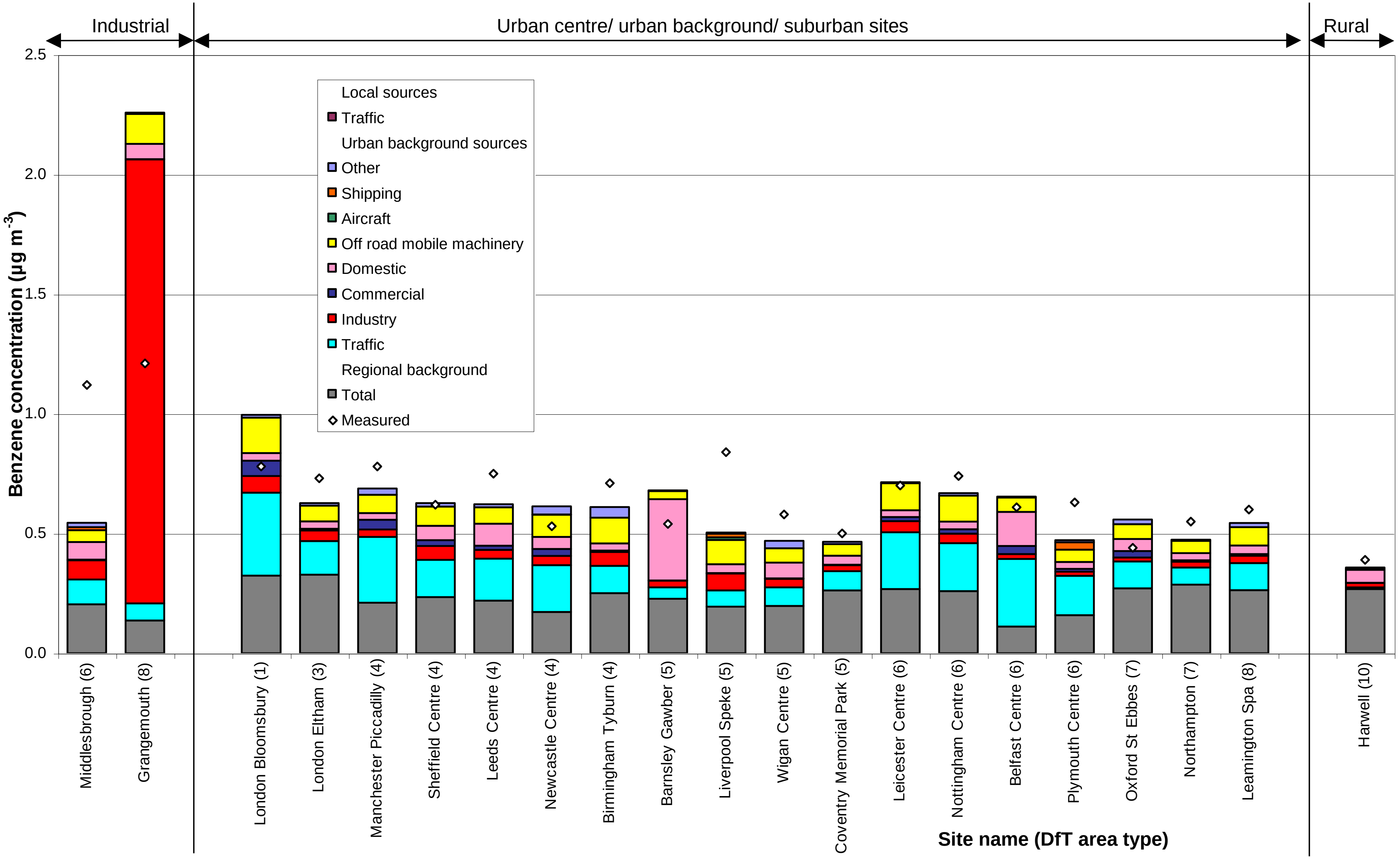
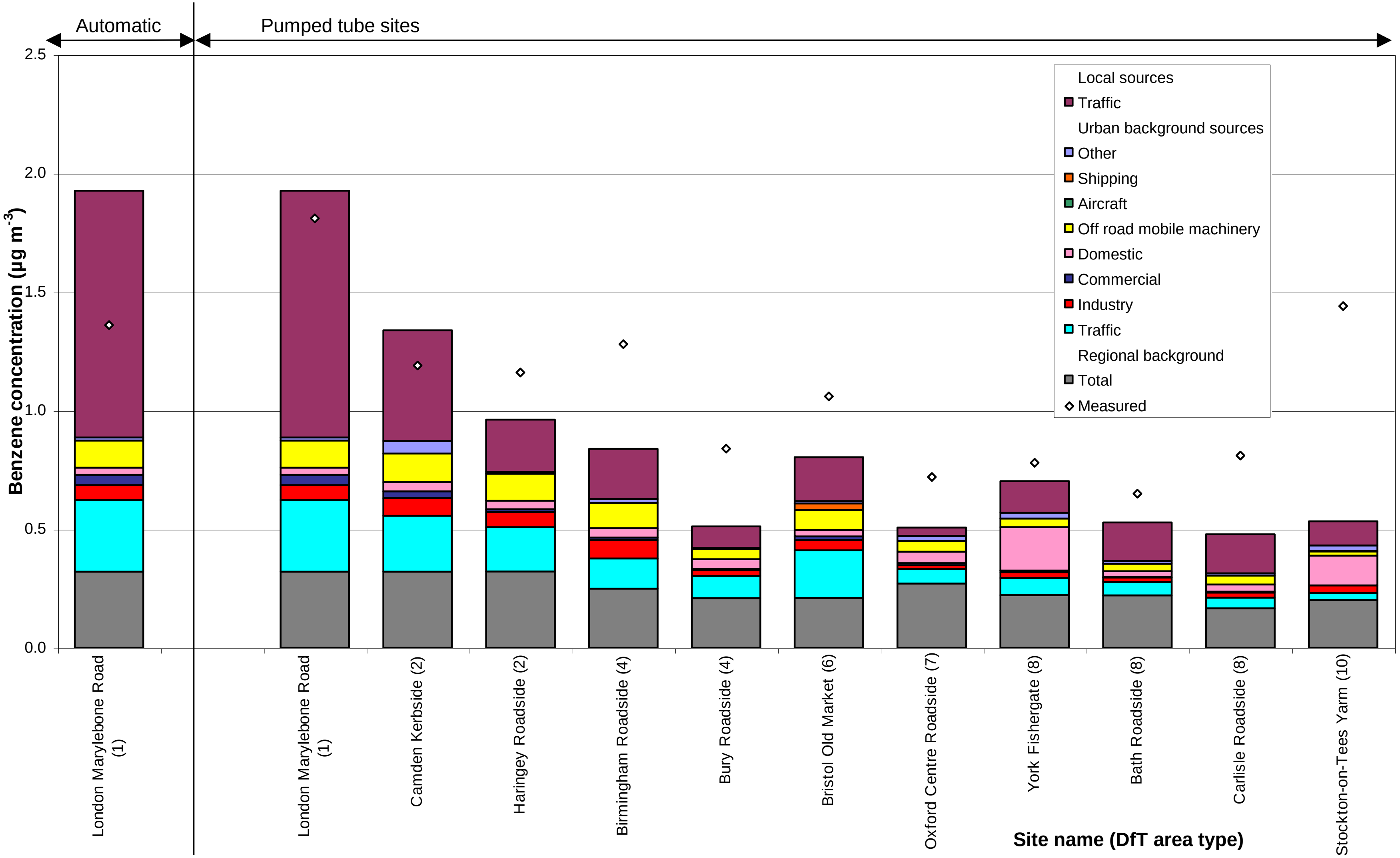


Figure 5.8. Annual mean benzene source apportionment at roadside AURN monitoring sites (the area type of each site is shown in parenthesis after its name)



6 CO

6.1 Introduction

Maps of maximum 8-hour mean CO concentrations at background and roadside locations in 2008 are presented in Figures 6.1 and 6.2.

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.

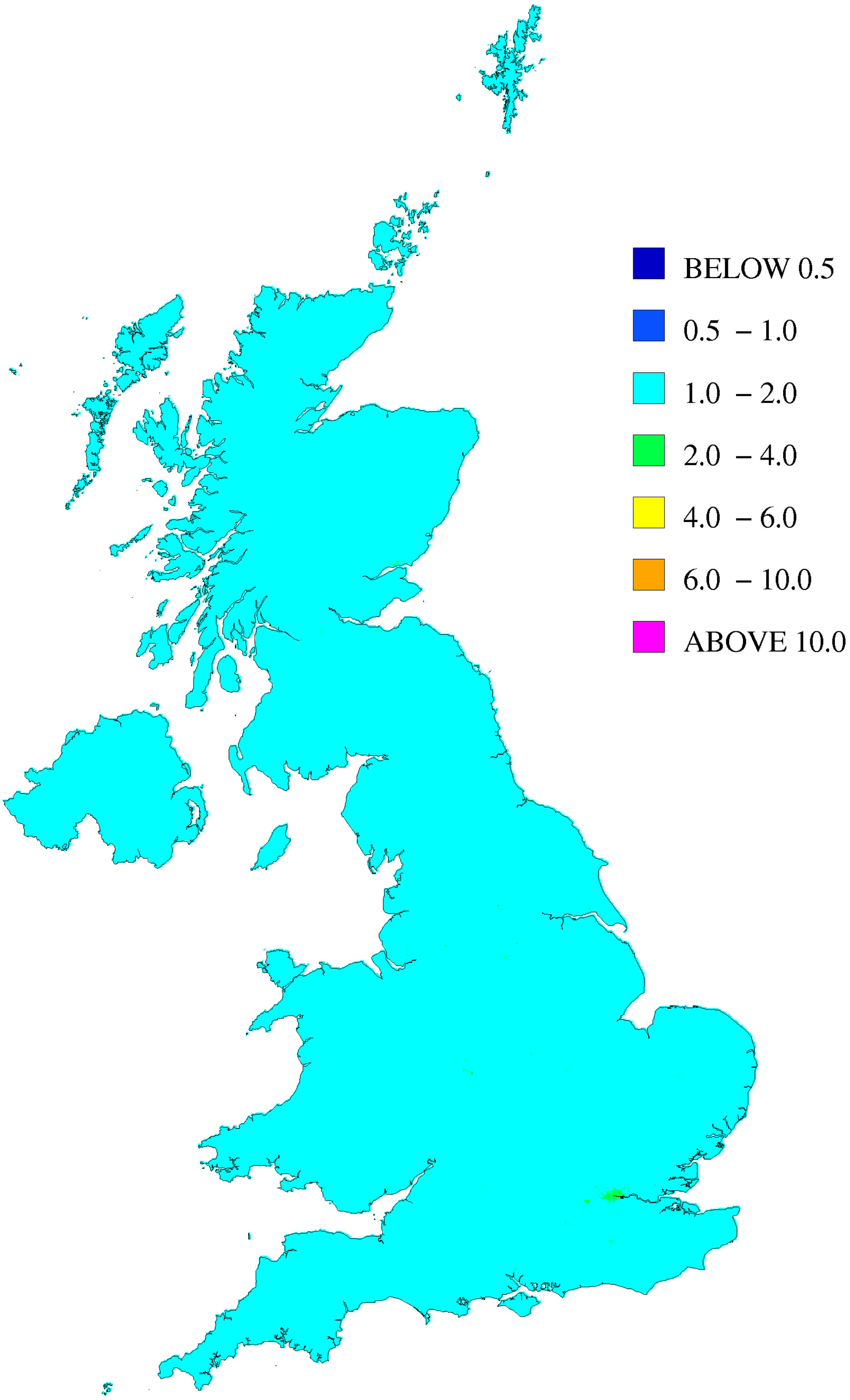
CO concentrations have been calculated using a similar approach to that adopted for NO_X but without the inclusion of a mapped regional rural component because regional rural CO concentrations in the UK are not well characterised within the monitoring networks.

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

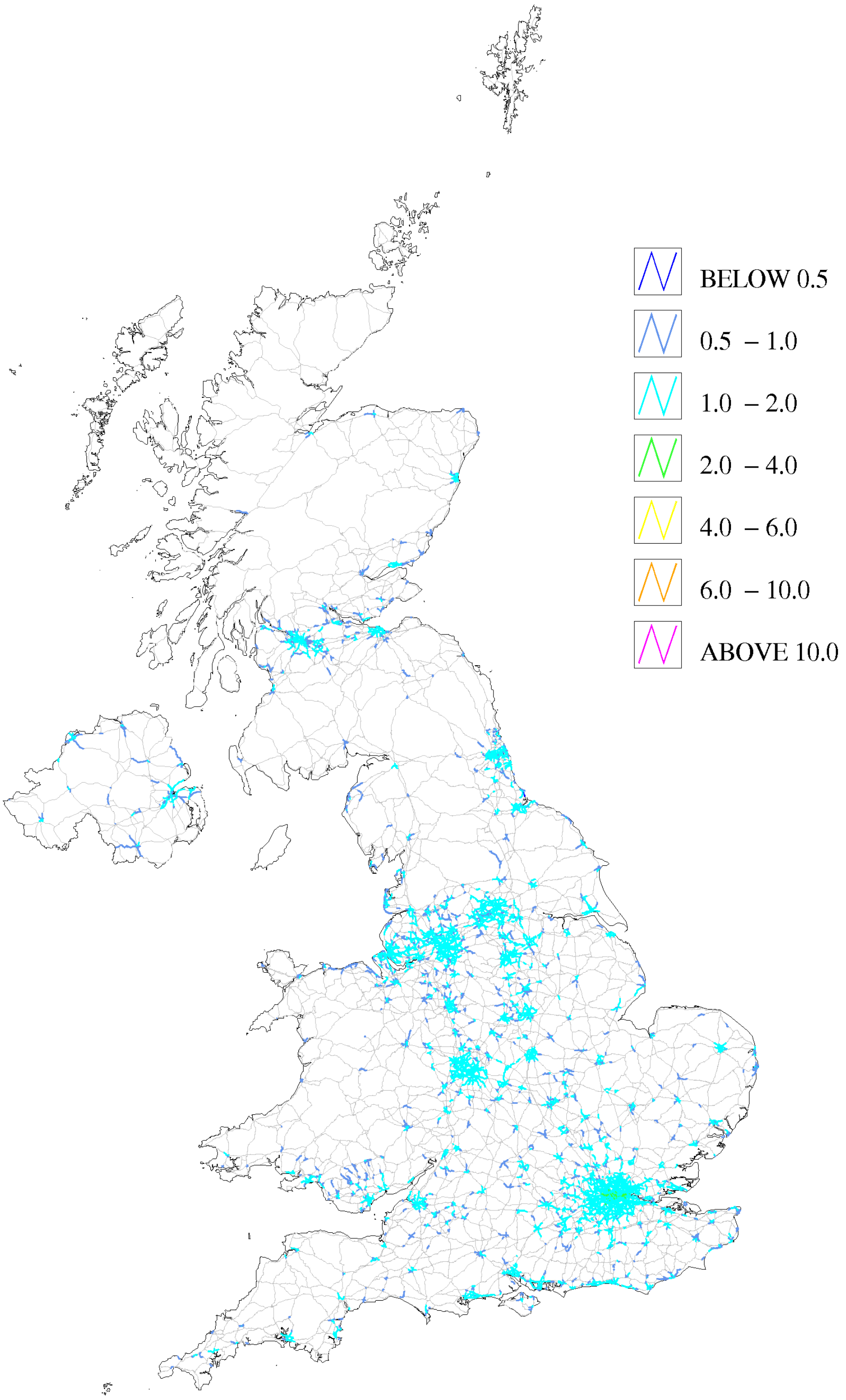
The area source model has been calibrated using data from the national monitoring networks. At locations close to busy roads an additional roadside contribution was added to account for contributions to total CO from road traffic sources.

Figure 6.1. Maximum 8-hour mean background CO concentration, 2008 (mg m^{-3})



© Crown copyright. All rights reserved Defra, Licence number 100022861 [2009]

Figure 6.2. Urban major roads, maximum 8-hour mean roadside CO concentration, 2008 (mg m^{-3})



© Crown copyright. All rights reserved Defra, Licence number 100022861 [2009]

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 3 ktonnes) in the 2007 NAEI were estimated by modelling each source explicitly using an atmospheric dispersion model (ADMS 4.1) and sequential meteorological data for 2008 from Waddington. A total of 96 large point sources were modelled. Surface roughness was assumed to be 0.1 metres. Concentrations were calculated for a 100 km x 100 km square composed of a regularly spaced 1 km x 1 km 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 3 ktonnes per annum release were modelled using the small points model described in Appendix 2.

6.4 Contributions from area sources

Figure 6.3 shows the calibration of the annual mean area source CO model for background locations. 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. 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 33 km x 33 km square surrounding each monitoring site. Hourly sequential meteorological data from Waddington in 2008 has been used to construct the dispersion kernels, as described in Appendix 3.

The modelled area source contribution was multiplied by the 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 annual mean 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 2007 (Murrells et al., 2009) and these have been adjusted to provide estimates of emissions in 2008. 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 NOx modelling (Section 3.2.5) 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 6.3. Calibration of 2008 background annual mean CO model (mg m^{-3})

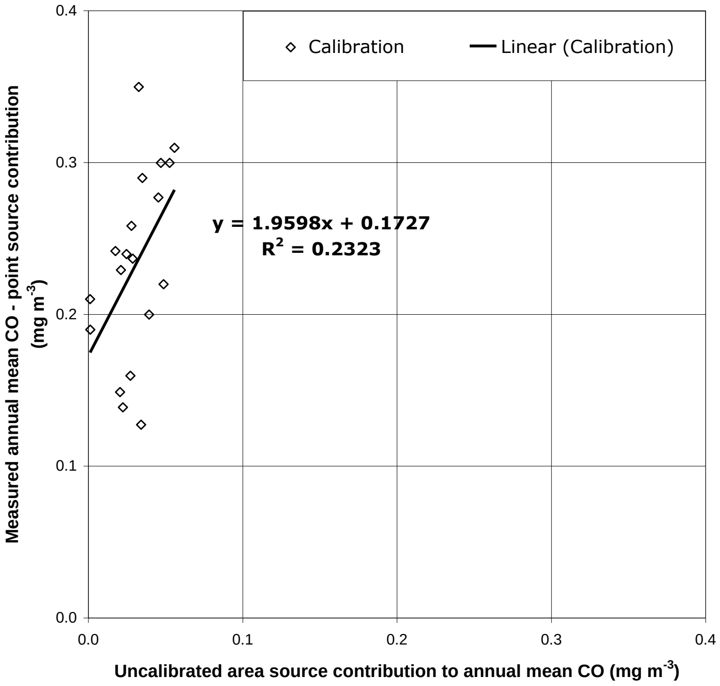
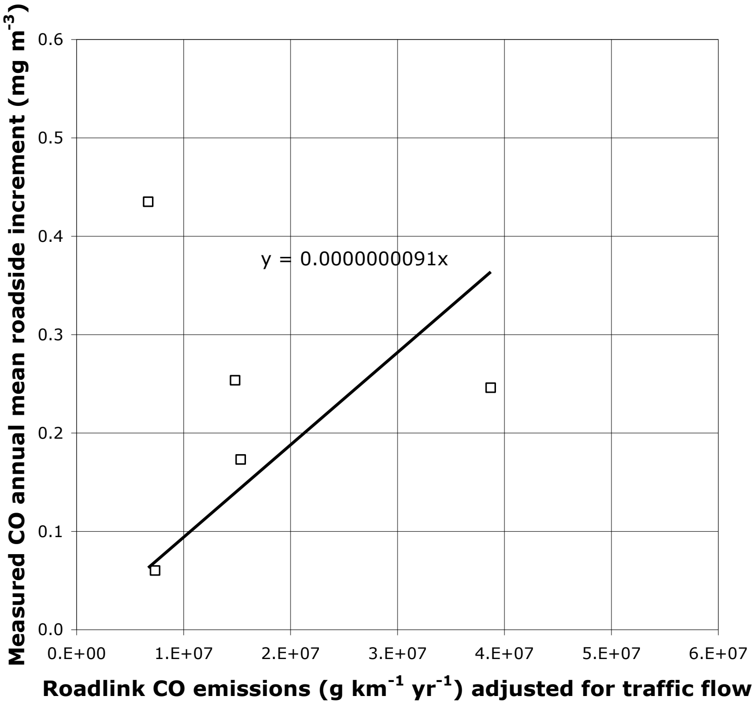


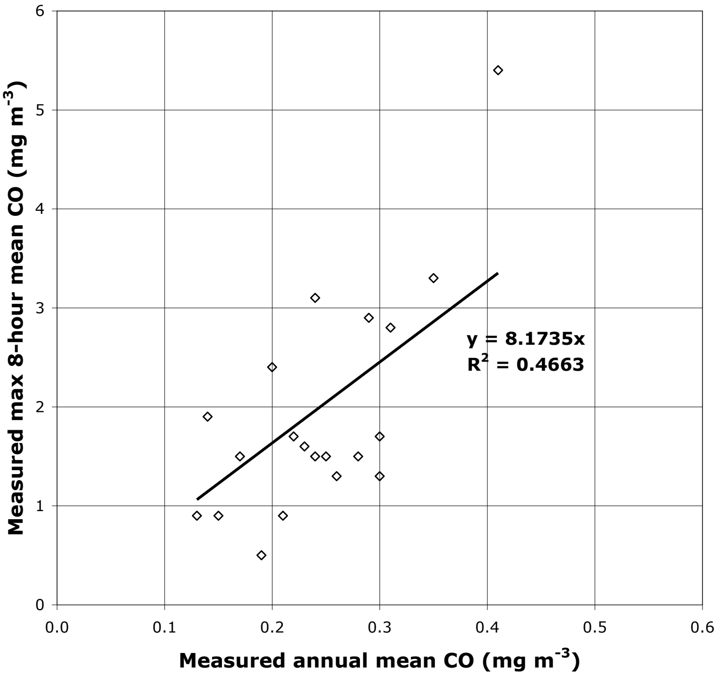
Figure 6.4. Calibration of 2008 roadside annual mean CO model (mg m^{-3})



6.6 Modelling the maximum 8-hour mean CO concentration

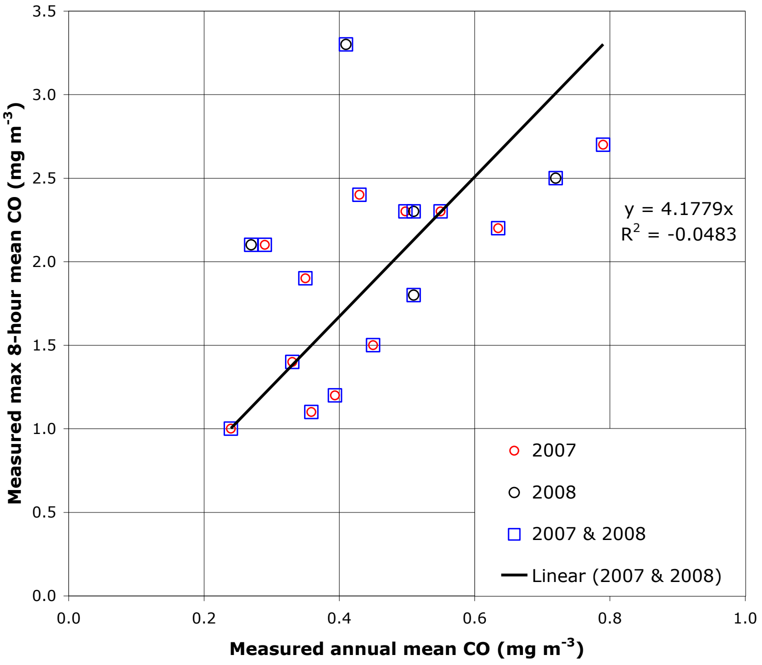
The map of maximum 8-hour mean CO concentrations at background locations shown in Figure 6.1 was calculated from the map of background annual mean CO concentrations by scaling annual mean map with the relationship between measured annual mean concentrations and the measured maximum 8-hour concentrations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

Figure 6.5. Calibration of 2008 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. This graph shows a composite of data from 2007 and 2008. This was due to a reduction in the number of roadside monitoring sites where CO concentrations were measured from twelve in 2007 to five in 2008. While few data points are available for 2008 it is clear that they are consistent with the relationship determined by the composite relationship. Roadside concentrations for urban roads only are reported to the EU and included in this report.

Figure 6.6. Calibration of 2008 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 2007

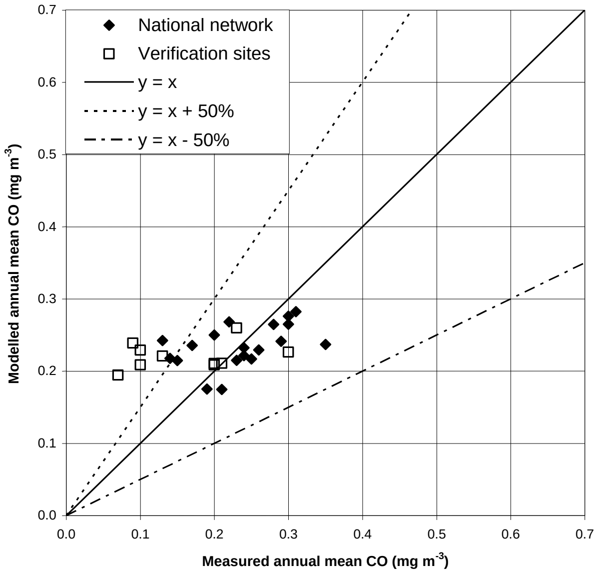


Figure 6.8. Verification of background maximum 8-hour mean CO model 2007

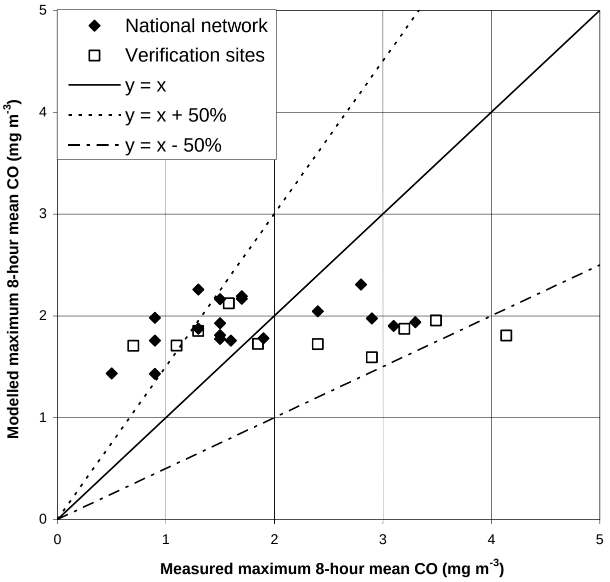


Figure 6.9. Verification of roadside annual mean CO model 2007

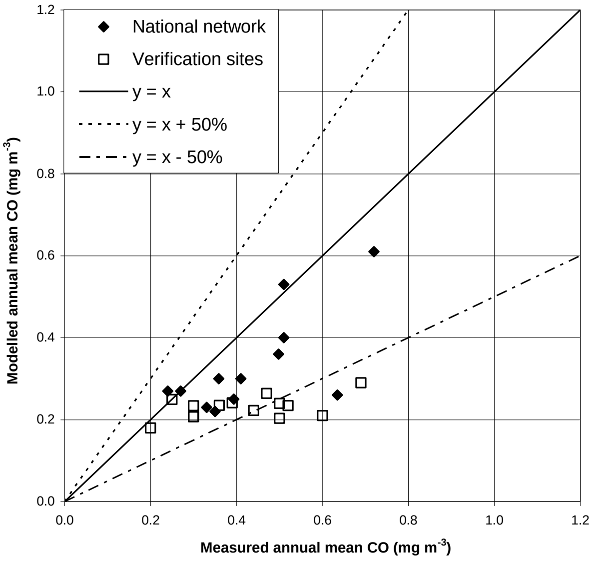


Figure 6.10. Verification of roadside maximum 8-hour mean CO model 2007

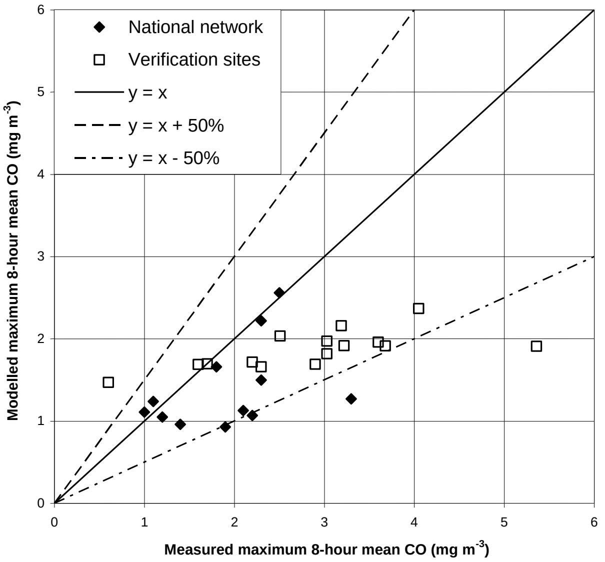


Table 6.1. Summary statistics for comparison between modelled and measured annual mean CO concentrations at background sites (mg m^{-3})

	Mean of measurements (mg m^{-3})	Mean of model estimates (mg m^{-3})	R^2	% outside data quality objectives	Number of sites
National Network	0.24	0.23	0.22	10.5	19
Verification Sites	0.16	0.22	0.07	50.0	10

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	1.93	1.91	0.19	26.3	19
Verification Sites	2.27	1.81	0.01	30.0	10

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	0.44	0.33	0.48	8.3	12
Verification Sites	0.40	0.23	0.28	33.3	15

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	1.93	1.39	0.17	25.0	12
Verification Sites	2.86	1.86	0.45	13.3	15

6.8 CO source apportionment at monitoring sites

Figures 6.10 and 6.11 show the modelled annual mean CO source apportionment for 2008 at AURN background and roadside monitoring sites, respectively. The measured concentration at each site is also shown for reference. Both plots show that road transport is modelled as the dominant emissions source. However, there is also a significant CO residual, which has not been assigned to a specific source. The residual is poorly defined. There are few rural sites with CO measurements in the UK and the annual mean concentrations for some of the sites are higher than those measured at some urban sites. This is due to the large uncertainties in the measurements of the low concentrations currently experienced. Thus the modelled CO concentrations are also subject to considerable uncertainty but it is clear that concentrations elsewhere are well below the limit values.

6.9 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 2008 are below the limit value for all zones.

Figure 6.10. Annual mean CO source apportionment at roadside AURN monitoring sites (the area type of each site is shown in parenthesis after its name)

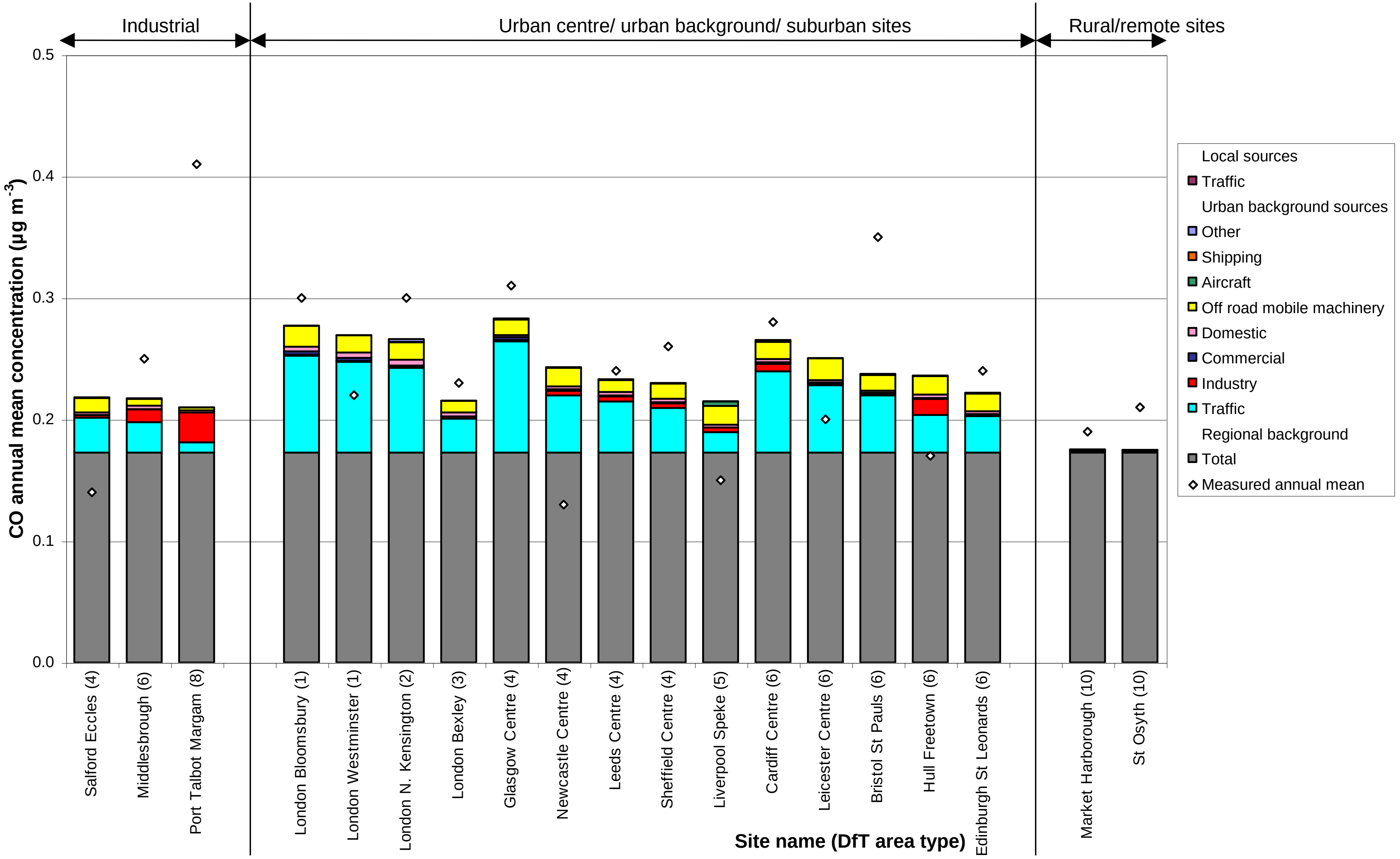
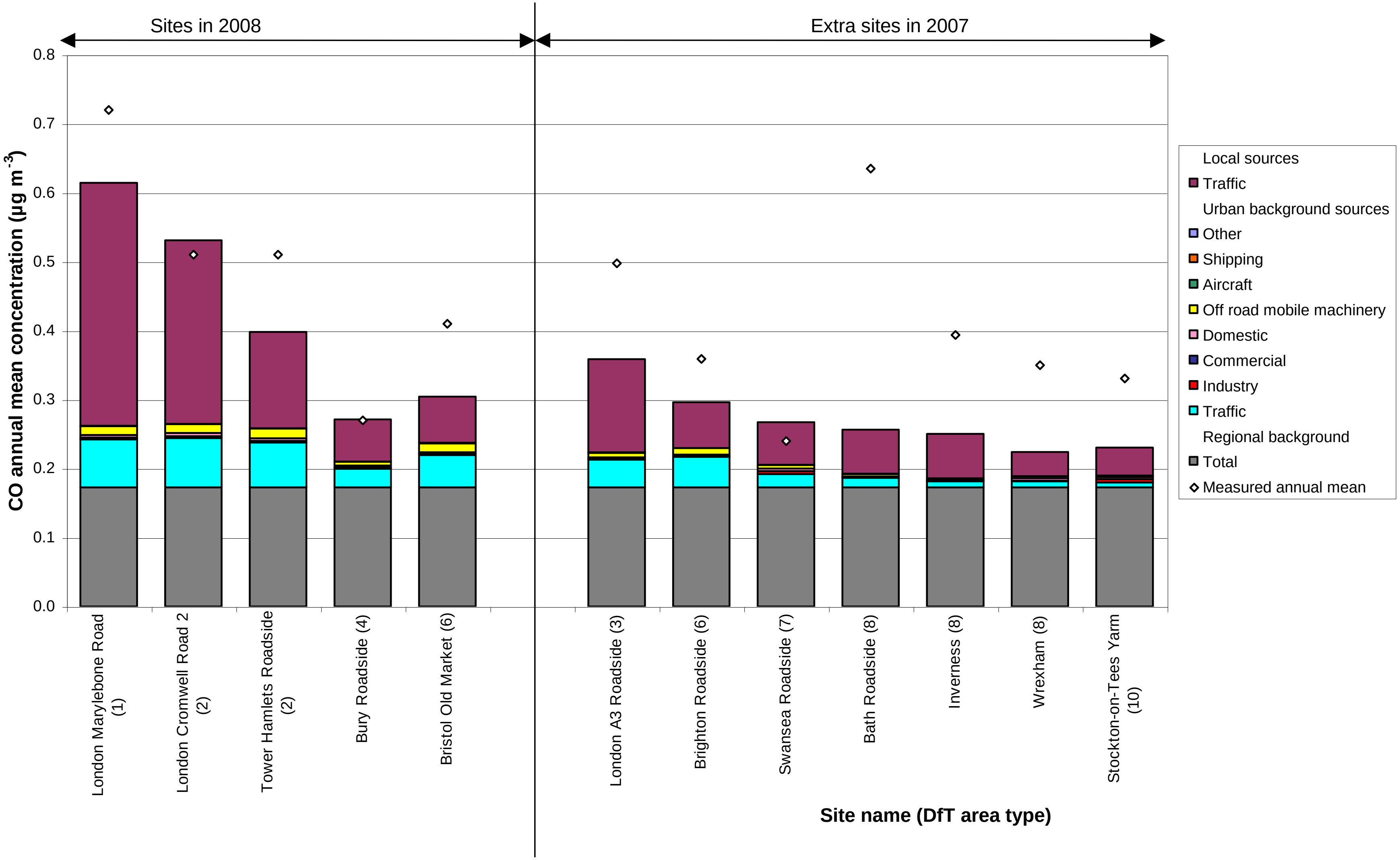


Figure 6.11. Annual mean CO source apportionment at roadside AURN monitoring sites (the area type of each site is shown in parenthesis after its name)



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

7.1 Results for 2008

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 or not required for that zone (where the Article 5 Assessment illustrates that concentrations are lower than the Lower Assessment Threshold) 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. An ‘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. Details of the assessment carried out for lead have been provided by Yap et al. (2009).

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			y		y		n		n
Brighton/Worthing/Littlehampton	UK0010			m		m		n		n
Leicester Urban Area	UK0011			y		y		n		n
Portsmouth Urban Area	UK0012			m		m		n		n
Teesside Urban Area	UK0013			y		y		n		n
The Potteries	UK0014			m		m		n		n
Bournemouth Urban Area	UK0015			m		m		n		n
Reading/Wokingham Urban Area	UK0016			m		m		n		n
Coventry/Bedworth	UK0017			m		m		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			m		m		n		n
Blackpool Urban Area	UK0022			m		m		n		n
Preston Urban Area	UK0023			m		m		n		n
Glasgow Urban Area	UK0024			y		y		n		n
Edinburgh Urban Area	UK0025			y		y		n		n
Cardiff Urban Area	UK0026			y		y		n		n
Swansea Urban Area	UK0027			y		y		n		n
Belfast Urban Area	UK0028			y		y		n		n
Eastern	UK0029			y		y		y		y

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 West	UK0030			m		m		m		m
South East	UK0031			y		y		y		y
East Midlands	UK0032			y		y		m		m
North West & Merseyside	UK0033			m		m		m		m
Yorkshire & Humberside	UK0034			y		y		m		m
West Midlands	UK0035			y		y		m		m
North East	UK0036			m		m		m		m
Central Scotland	UK0037			y		y		m		m
North East Scotland	UK0038			m		m		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

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

Zone	Zone code	LV (24hr mean) Stage 1			LV (annual mean) Stage 1		
		>LV+MOT	≤LV+MOT; >LV	≤LV	>LV+MOT	≤LV+MOT; >LV	≤LV
East Midlands	UK0032			y			y
North West & Merseyside	UK0033			y			y
Yorkshire & Humberside	UK0034			y			y
West Midlands	UK0035			m			m
North East	UK0036			m			m
Central Scotland	UK0037			y			y
North East Scotland	UK0038			y			y
Highland	UK0039			y			y
Scottish Borders	UK0040			m			m
South Wales	UK0041			y			y
North Wales	UK0042			y			y
Northern Ireland	UK0043			m			m

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			m
Tyneside	UK0005			m
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			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			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			m
Leicester Urban Area	UK0011			y
Portsmouth Urban Area	UK0012			m
Teesside Urban Area	UK0013			y
The Potteries	UK0014			y
Bournemouth Urban Area	UK0015			m
Reading/Wokingham Urban Area	UK0016			m
Coventry/Bedworth	UK0017			y
Kingston upon Hull	UK0018			m
Southampton Urban Area	UK0019			y
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			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			y
West Midlands	UK0035			y
North East	UK0036			m
Central Scotland	UK0037			y
North East Scotland	UK0038			m
Highland	UK0039			m
Scottish Borders	UK0040			m
South Wales	UK0041			m
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			m
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			m
Bristol Urban Area	UK0009			y
Brighton/Worthing/Littlehampton	UK0010			m
Leicester Urban Area	UK0011			y
Portsmouth Urban Area	UK0012			m
Teesside Urban Area	UK0013			y
The Potteries	UK0014			m
Bournemouth Urban Area	UK0015			m
Reading/Wokingham Urban Area	UK0016			m
Coventry/Bedworth	UK0017			m
Kingston upon Hull	UK0018			y
Southampton Urban Area	UK0019			y
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			y
Cardiff Urban Area	UK0026			y
Swansea Urban Area	UK0027			y
Belfast Urban Area	UK0028			m
Eastern	UK0029			m
South West	UK0030			m
South East	UK0031			m
East Midlands	UK0032			y
North West & Merseyside	UK0033			m
Yorkshire & Humberside	UK0034			m
West Midlands	UK0035			m
North East	UK0036			m
Central Scotland	UK0037			m
North East Scotland	UK0038			m
Highland	UK0039			m
Scottish Borders	UK0040			m
South Wales	UK0041			m
North Wales	UK0042			m
Northern Ireland	UK0043			m

7.2 Measured exceedences of Limit Values + Margins of Tolerance

Measured exceedences of limit values plus margins of tolerance are listed in Form 11 of the questionnaire (CDR, 2009).

7.3 Comparison with previous years

Tables 7.7 and 7.8 provide a comparison of the monitoring and modelling results for 2008 with the results of the air quality assessments reported to the EU for 2001, 2002, 2003, 2004, 2005, 2006 and 2007 (Stedman et al., 2002, Stedman et al., 2003, Stedman et al., 2005, Stedman et al., 2006a, Kent et al., 2007a, Kent et al., 2007b, Grice et al., 2009). The listed numbers of zones exceeding the LV in Table 7.8 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.

No modelled exceedences of the 1-hour LV and 24-hour LV for SO_2 were reported for 2008. Modelled exceedences of the 1-hour LV and 24-hour LV for SO_2 were reported for 2006, 2005 and 2004. These exceedences were limited to Stewartby in the Eastern zone and were associated with the emissions from a brick works which is now closed. There were also 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 was observed in London for 2008. The exceedence was initially reported in 2003 has been observed in all subsequent years (2004, 2005, 2006 and 2007) in London. The reason for this exceedence at the London Marylebone Road site appears to be related to an increase in primary NO_2 emissions (Abbott, 2005). Increasing contributions to ambient NO_2 from primary NO_2 directly emitted from road traffic sources have been the focus of research by the Air Quality Expert Group (AQEG, 2007). 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 in 2008 was similar to the number in 2007. In 2008 the number of zones with exceedences of the average mean LV was also similar to the number in 2007. There were no reported exceedences of the annual mean LV for NO_X in vegetation areas.

Fewer zones exceeded the LV for PM_{10} in 2008 than in 2007. This is partly a consequence of the lower secondary inorganic aerosol concentration experienced during 2008. The results of two different assessments for PM_{10} are listed in the tables for 2005 and 2006. Evidence emerged during 2008 that the data for the gravimetric samples used to calibrate the models for these years were subject to an over-read (Maggs et al., 2008). The table includes the results of the original assessment (in plain text) and the revised assessment based on the corrected data (in square brackets in italic text).

There were no exceedences for lead in 2001, 2002, 2003, 2004, 2005, 2006, 2007 or 2008.

There were no exceedences of the benzene LV reported in 2008. One exceedence of the benzene LV was modelled in 2006 but there were no modelled exceedences of the LV + MOT. These exceedences were modelled in close proximity to a large oil refinery at Killingholme.

CO concentrations were below the LV in all zones in 2008, 2007, 2006 and 2005.

Exceedences of ‘old’ directives are listed in Table 7.19. Directive 85/203/EEC was exceeded at one monitoring site, Marylebone Road, in 2008 as in the past 5 years.

Table 7.7. Exceedences of limit values plus margins of tolerance for 1st and 2nd Daughter Directives

Pollutant	**Averaging time**	**2008**	**2007**	**2006**	**2005**	**2004**	**2003**	**2002**	**2001**
SO_2	1-hour	n/a	n/a	n/a	n/a	1 zone modelled (Eastern)	1 zone modelled (Eastern)	none	none
SO_2	24-hour[1]	n/a	n/a	n/a	n/a	none	1 zone modelled (Eastern)	none	1 zone measured (Belfast Urban Area)
SO_2	Annual[2]	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a
SO_2	Winter[2]	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a
NO_2	1-hour[3]	2 zones measured (Greater London Urban Area & Glasgow Urban Area)	1 zone measured (Greater London Urban Area)	1 zone measured (Greater London Urban Area)	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	40 zones (7 measured + 33 modelled)	39 zones (6 measured + 33 modelled)	38 zones (6 measured + 32 modelled)	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[2]	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a
PM_{10}	24-hour (Stage 1)	n/a	n/a	n/a	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)	n/a	n/a	n/a	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)
Lead	Annual	n/a	n/a	n/a	n/a	none	none	none	none
Benzene	Annual	none	none	none	none	none	none	not assessed	not assessed
CO	8-hour	n/a	n/a	n/a	n/a	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

Table 7.8. Exceedences of limit values for 1st and 2nd Daughter Directives [revised assessment for PM_{10} in 2005 and 2006 shown in italics]

Pollutant	Averaging time	2008	2007	2006	2005	2004	2003	2002	2001
SO_2	1-hour	None	none	1 zone modelled (Eastern)	1 zone modelled (Eastern)	1 zone modelled (Eastern)	1 zone modelled (Eastern)	none	none
SO_2	24-hour[1]	None	none	1 zone modelled (Eastern)	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	none	none	none
SO_2	Winter[2]	None	none	none	none	none	none	none	not assessed
NO_2	1-hour[3]	3 zones measured	2 zones measured (London, Glasgow)	1 zone measured (Greater London Urban Area)	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	40 zones (7 measured + 33 modelled)	41 zones (8 measured + 33 modelled)	39 zones (7 measured + 32 modelled)	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	none	none	None
PM_{10}	24-hour (Stage 1)[4]	2 zones (1 measured + 1 modelled)	6 zones (3 measured + 3 modelled)	30 zones (5 measured + 25 modelled) *[15 zones (5 measured + 10 modelled)]*	29 zones (3 measured + 26 modelled) *[8 zones (3 measured + 5 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]	None	1 zone (measured)	2 zones (1 measured + 1 modelled) *[1 zone (measured)]*	4 zones (1 measured + 3 modelled) *[1 zone (measured)]*	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)
Lead	Annual	None	none	none	none	none	none	none	none

Pollutant	**Averaging time**	**2008**	**2007**	**2006**	**2005**	**2004**	**2003**	**2002**	**2001**
Benzene	Annual	None	none	1 zone modelled (Yorkshire & Humberside)	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	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] Numbers given in italics are corrected for the bias of Partisol measurements (see text at beginning of Section 7.3)

Table 7.9. Exceedences of old Directives

Pollutant	Averaging time	**2008 c**oncentration (µg m^{-3})	**2007** concentration (µg m^{-3})	**2006** concentration (µg m^{-3})	**2005** concentration (µg m^{-3})	**2004** concentration (µg m^{-3})
NO_2	1-hour 98%ile	252 (measured at London Marylebone Road)	229 (measured at London Marylebone Road)	244 (measured at London Marylebone Road)	256 (measured at London Marylebone Road)	233 (measured at London Marylebone Road)

8 Acknowledgements

This work was funded by the UK Department for Environment, Food and Rural Affairs, Welsh Assembly Government, the Scottish Government, the Department of the Environment in Northern Ireland and the Government of Gibraltar. Permission to include monitoring data and detailed information on site locations for the verification sites were kindly provided by the Local Authorities listed in Table A1.1 in Appendix 1. The authors would also like to thank: EA and JEP for providing SO_2 concentration data and emissions information for power stations; ERG for providing monitoring data from the LAQN and other regional monitoring networks; CEH Edinburgh for providing national sulphate, nitrate, ammonium and rural trace metals particle data and measurements of trace metals measured by wet deposition; and, NPL for providing data from the national benzene and urban trace metals networks.

The maps in this report are reproduced from Ordnance Survey material with the permission of Ordnance Survey on behalf of the Controller of Her Majesty's Stationery Office © Crown copyright. Unauthorised reproduction infringes Crown copyright and may lead to prosecution or civil proceedings. Defra, Licence number 100022861 [2009].

9 References

Abbott, J. (2005). Primary nitrogen dioxide emissions from road traffic: analysis of monitoring data. AEA Technology, National Environmental Technology Centre. Report AEAT – 1925.

Abbott, J. (2008). Modelling re-suspended heavy metal emissions. AEA report. AEAT/ENV/R/2926 Issue 2. http://www.airquality.co.uk/reports/reports.php?action=latest

Abbott, J. and Downing, C. (2000). The addition of background concentrations to modelled contributions from discharge stacks. Environment Agency, Report TR P361A (ISBN 1 85705 338 9)

Abbott, J., Stedman, J. and Bower, J. (2005). Review of background air-quality data and methods to combine these with process contributions: technical modelling aspects. A report produced on behalf of the Environment Agency by AEA Energy and Environment. Science Report: SC030174/SR2. Report available from: http://publications.environment-agency.gov.uk/epages/eapublications.storefront/

Abbott, J. and Vincent, K. (1999). Annual average sulphur dioxide concentration maps derived by dispersion modelling. AEA Technology, National Environmental Technology Centre. Report AEAT – 4629. http://www.aeat.co.uk/netcen/airqual/reports/kvann1/so2ann.html

Abbott, J. and Vincent, K.J. (2006). Annual audits of the contribution to pollutant concentrations from processes regulated by the Environment Agency: Application of method for current case. Environment Agency (Science Report: DRAFT March 06/TR, *in publication*)

Abdalmogith, S.S., Harrison, R.M. and Derwent, R.G. (2006). Particulate sulphate and nitrate in Southern England and Northern Ireland during 2002/3 and its formation in a photochemical trajectory model. *Science of the Total Environment*, **368**, 769-780.

Airborne Particles Expert Group (APEG). Source Apportionment of Airborne Particulate Matter in the United Kingdom. ISBN 0-7058-1771-7, January 1999. http://www.defra.gov.uk/environment/airquality/airbornepm/index.htm

Air Quality Expert Group (AQEG, 2004). Nitrogen Dioxide in the United Kingdom. http://www.defra.gov.uk/environment/airquality/publications/nitrogen-dioxide/index.htm

Air Quality Expert Group (AQEG, 2005). Particulate Matter in the United Kingdom. http://www.defra.gov.uk/environment/airquality/publications/particulate-matter/index.htm

Air Quality Expert Group (AQEG 2007). Trends in Primary NO_2 in the United Kingdom. http://www.defra.gov.uk/environment/airquality/publications/primaryno2-trends/index.htm

Boulter, P.G., Hickman, A.J., McCrae, I.S. (2003). The DMRB air quality screening method (version 1.02): calibration report. Transport Research Laboratory (TRL) (2003). Transport Research Laboratory (TRL) Limited. Report PA/SE/4029/03. http://www.trl.co.uk/files/general/DMRB1.pdf

Bush, T. (2000). Article 5 Assessment of Nitrogen Dioxide, PM10, sulphur dioxide and lead in the UK. Report to the Department for Environment, Food and Rural Affairs, the Scottish Executive, Welsh Assembly Government and the Department of the Environment in Northern Ireland. AEA Technology, National Environmental Technology Centre. Report AEAT/R/ENV/0165. http://www.defra.gov.uk/environment/airquality/article5/index.htm

Bush, T. (2002). Preliminary Assessment of Benzene and Carbon Monoxide levels in the U.K. Report to the Department for Environment, Food and Rural Affairs, the Scottish Executive, Welsh Assembly Government and the Department of the Environment in Northern Ireland. AEA Technology, National Environmental Technology Centre. Report AEAT/ENV/R/1333. http://www.airquality.co.uk/archive/reports/cat09/art5_dd2_v3aeat.pdf

CDR (2009) Annual report (questionnaire) on air quality for 2008 (2004/461/EC). http://cdr.eionet.europa.eu/gb/eu/annualair/envsnuava

CERC (2008) Cambridge Environmental Research Consultants. http://www.cerc.co.uk/software/adms4.htm.

Council Directive 96/62/EC, of 27 September 1996. On ambient air quality assessment and management (The Framework Directive). From the Official Journal of the European Communities, 21.11.1996, En Series, L296/55.

Council Directive 1999/30/EC, of 22 April 1999 relating to limit values for sulphur dioxide, nitrogen dioxide and oxides of nitrogen, particulate matter and lead in ambient air (The First Daughter Directive). From the Official Journal of the European Communities, 29.6.1999, En Series, L163/41.

Council Directive 2000/69/EC, of 16 November 2000 relating to limit values for benzene and carbon monoxide in ambient air (The Second Daughter Directive). From the Official Journal of the European Communities, 13.12.2000, En Series, L313/12.

Council Directive 2002/3/EC, of 12 February 2002 relating to ozone in ambient air (The Third Daughter Directive). From the Official Journal of the European Communities, 9.3.2002, En Series, L67/14.

Council Directive 2004/107/EC, of 15 December 2004 relating to arsenic, cadmium, mercury, nickel and polycyclic aromatic hydrocarbons in ambient air (The Fourth Daughter Directive). From the Official Journal of the European Communities, 26.1.2005, En Series, L23/3.

Council Directive 2008/50/EC, of 21 May 2008. On ambient air quality and cleaner air for Europe. From the Official Journal of the European Union, 11.6.2008, En series, L152/1

Derwent, R.G., Simmonds, P.G., O'Doherty, S., Stevenson, D.S., Collins, W.J., Sanderson, M.G., Johnson, C.E., Dentener, F., Cofala, J., Mechler, R. and Amann, M. (2005). External influences on Europe's air quality: baseline methane, carbon monoxide and ozone from 1999 to 2030 at Mace Head, Ireland. *Atmospheric Environment*, **40**, 844-855.

Department for Environment, Food and Rural Affairs (Defra) (2009). UK Notification to the European Commission to secure additional time to meet the limit values for particulate matter for certain zones/agglomerations in accordance with the Council Directive 2008/50/EC on Ambient Air Quality and Cleaner Air for Europe. http://www.defra.gov.uk/environment/quality/air/airquality/eu-int/eu-directives/airqual-directives/notification.htm

Department for Transport (DfT) (2004). The Future of Transport White Paper CM6234. http://www.dft.gov.uk/stellent/groups/dft_about/documents/divisionhomepage/031259.hcsp

Green, D., Baker, T. and Fuller, G. (2007). The King's College London Volatile Correction Model for PM10 Development, Testing and Application. Environmental Research Group, King's College London. http://www.airquality.co.uk/archive/reports/cat13/0711261345_KCL_Volatile_Correction_Model_for_PM10.pdf

Green, D., Baker, T. and Fuller, G. (2008). Volatile Correction Model (VCM) for PM10 Application to hourly time resolution and AURN FDMS purge measurements. Environmental Research Group, King's College London. http://www.airquality.co.uk/reports/cat13/0902231025VCM_Application_to_Hourly_and_AURN_FDMS_Purge_Measurements.pdf

Grice, S.E., Cooke, S.L., Stedman, J.R., Bush, T.J., Vincent, K.J., Hann, M., Abbott, J. and Kent, A.J. (2009). UK air quality modelling for annual reporting 2007 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, the Scottish Executive, Welsh Assembly Government and the Department of the Environment in Northern Ireland. AEA report. AEAT/ENV/R/2656 Issue 1. http://www.airquality.co.uk/reports/cat09/0905061048_dd12007mapsrep_v8.pdf

Harrison, R.M., Yin., J., Tilling, R.M., Cai, X., Seakins, P.W., Hopkins, J.R., Lansley, D.L., Lewis, A.C., Hunter, M.C., Heard, D.E., Carpenter, L.J., Creasey, D.J., Lee, J.D., Pilling, M.J., Carslaw, N., Emmerson, K.M., Redington, A., Derwent, R.G., Ryall, D., Mills, G. and Penkett, S.A. (2006).

Measurement and modelling of air pollution and atmospheric chemistry in the U.K. West Midlands conurbation: Overview of the PUMA consortium project. *Science of the Total Environment*, **360**, 5-25

Harrison, R.M. and Yin, J. (2006). Characterisation of particulate matter in the United Kingdom. Final Project Report. University of Birmingham. CPEA 6.

Harrison, D. (2006). UK Equivalence Programme for Monitoring of Particulate Matter, Bureau Veritas http://www.airquality.co.uk/archive/reports/cat05/0606130952_UKPMEquivalence.pdf

Department of Environment, Transport and Regions (DETR, 2000). Personal communication from Sandra Simoni, August 2000.

Department for Transport (DfT, 2003). Personal communication from Malcolm Jay, April 2003.

ENTEC (2008). UK ship emissions inventory. ENTEC report to the NAEI work programme. In preparation.

Jenkin, M.E. (2004). Analysis of sources and partitioning of oxidant in the UK-Part 1: the NOx-dependence of annual mean concentrations of nitrogen dioxide and ozone. *Atmospheric Environment*, **38**, 5117–5129.

Kent, A.J., Grice, S.E., Stedman, J.R., Bush, T.J., Vincent, K.J., Abbott, J., Hobson, M. and Derwent, R.G. (2007a). 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, the Scottish Executive, Welsh Assembly Government and the Department of the Environment in Northern Ireland. AEA report. AEAT/ENV/R/2278 Issue 1. http://www.airquality.co.uk/archive/reports/reports.php?report_id=453

Kent, A.J., Grice, S.E., Stedman, J.R., Cooke, S., Bush, T.J., Vincent, K.J. and Abbott, J. (2007b). UK air quality modelling for annual reporting 2006 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, the Scottish Executive, Welsh Assembly Government and the Department of the Environment in Northern Ireland. AEA report. AEAT/ENV/R/2502 Issue 1.

Kent, A.J. and Stedman, J.R. (2009). UK and Gibraltar air quality modelling for annual reporting 2008 on ambient air quality assessment under Council Directives 96/62/EC and 2002/3/EC relating to ozone in ambient air, AEA Technology Energy & Environment. Report AEAT/ENV/R/2861. http://www.airquality.co.uk/reports/reports.php?action=latest

Land Cover Map 2000 (2009). http://www.ceh.ac.uk/sci_programmes/BioGeoChem/LandCoverMap2000.html.

LAQM. TG(03). Local Air Quality, Technical Guidance 03. Defra. Product code PB7514. http://www.airquality.co.uk/archive/laqm/documents/laqm-pg03.pdf

Personal communication from Helen Lawrence, AEA (2009). AEA Technology, Harwell, UK.

Lee, D.S., Kingdon, R.D., Jenkin, M.E. and Garland, J.A. (2000). Modelling the atmospheric oxidised and reduced nitrogen budgets for the UK with a Lagrangian multi-layer long-range transport model. *Environmental Modelling and Assessment*, **5**, 83-104.

Maggs, R., Harrison, D., Carslaw, D. and Stevenson, D. (2008). Analysis of Trends in Gravimetric Particulate Mass Measurements in the United Kingdom, Bureau Veritas HS&E Limited. http://www.airquality.co.uk/archive/reports/cat09/0806161031_080528_Trends_in_Gravimetric_PM_Measurements_in_the_UK.pdf

Murrells, T., Cooke, S., Kent, A., Grice, S., Derwent, R., Jenkin, M., Pilling, M., Rickard, A. and Redington, A., (2008). Modelling of Tropospheric Ozone: First Annual Report. AEA Report AEAT/ENV/R/2567. http://www.airquality.co.uk/archive/reports/cat07/0804291542_ED48749_Ann_Rep1_2007_tropospheric_ozone_final_AQ03508.pdf

Murrells, T.P., Passant, N.R., Thistlethwaite, G., Wagner, A., et al., (2009). UK Emissions of Air Pollutants 1970 to 2007. National Atmospheric Emissions Inventory, AEA Technology. Report AEAT/ENV/R/2856. http://www.naei.org.uk/reports.php

Pankow, J.F. (1995). An absorption model of gas/particle partitioning involved in the formation of secondary organic aerosol. *Atmospheric Environment,* **28**, 189-193.

Stedman, J. R. and Bush, T. (2000). Mapping of nitrogen dioxide and PM10 in the UK for Article 5 Assessment. AEA Technology, National Environmental Technology Centre. Report AEAT/ENV/R/0707. http://www.aeat.co.uk/netcen/airqual/reports/aeat-env-r0707.pdf

Stedman, J.R., Linehan, E. and Conlan, B. (2001a). Receptor Modelling of PM_{10} Concentrations at a United Kingdom National Network Monitoring Site in Central London. *Atmospheric Environment*, **35**, 297-304.

Stedman, J.R., Bush, T.J., Murrells, T.P. and King, K. (2001b). Baseline PM_{10} and NO_x projections for PM_{10} objective analysis. AEA Technology, National Environmental Technology Centre. Report AEAT/ENV/R/0726. http://www.aeat.co.uk/netcen/airqual/reports/naqs2001/aeat-env-r-0726.pdf

Stedman, J.R., Goodwin, J.W.L., King, K., Murrells, T.P. and Bush, T.J. (2001c). An Empirical Model For Predicting Urban Roadside Nitrogen Dioxide Concentrations in the UK. *Atmospheric Environment*. **35** 1451-1463.

Stedman, J.R., Bush, T.J. and Vincent, K.J. (2002). UK air quality modelling for annual reporting 2001 on ambient air quality assessment under Council Directives 96/62/EC and 1999/30/EC. AEA Technology, National Environmental Technology Centre. Report AEAT/ENV/R/1221. http://www.airquality.co.uk/archive/reports/cat05/aeat-env-r-1221.pdf

Stedman, J.R., Bush, T.J., Vincent, K.J. and Baggott S. (2003). UK air quality modelling for annual reporting 2002 on ambient air quality assessment under Council Directives 96/62/EC and 1999/30/EC. AEA Technology, National Environmental Technology Centre. Report AEAT/ENV/R/1564. http://www.airquality.co.uk/archive/reports/cat05/0402061100_dd12002mapsrep1-2.pdf

Stedman, J.R., Bush, T.J., Grice, S.E., Kent, A.J., Vincent, K.J. and Abbott, J. (2005). UK air quality modelling for annual reporting 2003 on ambient air quality assessment under Council Directives 96/62/EC, 1999/30/EC and 2000/69/EC. AEA Technology, National Environmental Technology Centre. Report AEAT/ENV/R/1790. http://www.airquality.co.uk/archive/reports/cat05/0501121424_dd12003mapsrep4.pdf

Stedman, J.R., Bush, T. J., Grice, S.E., Kent, A.J., Vincent, K.J., Abbott, J. and Derwent, R.G. (2006a). UK air quality modelling for annual reporting 2004 on ambient air quality assessment under Council Directives 96/62/EC, 1999/30/EC and 2000/69/EC. AEA Technology, National Environmental Technology Centre. Report AEAT/ENV/R/2052. http://www.airquality.co.uk/archive/reports/cat09/0610161501-416_dd12004mapsrep_v1e.pdf

Stedman, J.R., Kent, A.J., Grice, S., Bush, T.J. and Derwent, R.G. (2007). A consistent method for modelling PM_{10} and $PM_{2.5}$ concentrations across the United Kingdom in 2004 for air quality assessment. *Atmospheric Environment,* **41**, 161-172.

Tang, S. (2009). CEH Edinburgh, Centre for Ecology and Hydrology, Natural Environment Research Council. http://www.uk-pollutantdeposition.ceh.ac.uk/nitric_acid_network

Personal communication from Brian Underwood, AEA (2009). AEA Technology, Harwell, UK.

Whyatt, J.D., Metcalfe, S.E., Nicholson, J., Derwent, R.G., Page, T. and Stedman, J. (2007). Regional scale modelling of particulate matter in the UK: source attribution and an assessment of uncertainties. *Atmospheric Environment*, **41**, 3315-3327.

Yap, F.W., Kent, A.J., Stedman, J.R., Grice, S.E. and Vincent, K.J. (2009). UK air quality modelling for annual reporting 2008 on ambient air quality assessment under Council Directives 96/62/EC, 1999/30/EC and 2004/107/EC. Report to The Department for Environment, Food and Rural Affairs, Welsh Assembly Government, the Scottish Government and the Department of the Environment for Northern Ireland. AEA Report. AEAT/ENV/R/2860 Issue 1. http://www.airquality.co.uk/reports/reports.php?action=latest

Appendices

Appendix 1: Monitoring sites used to verify the mapped estimates
Appendix 2: Small point source model
Appendix 3: Dispersion kernels for area source model
Appendix 4: Revised method for calculating and mapping emissions from aircraft and shipping
Appendix 5: Application of the Volatile Correction Model (VCM) to AURN TEOM data
Appendix 6: Air Quality monitoring data from Gibraltar in 2008

Appendix 1 Monitoring sites used to verify the mapped estimates

Table A1.1. Monitoring sites used to verify the mapped estimates (PM_{10} measurements by gravimetric and TEOM instruments were used in the verification)

Site name	Site type	LA/Network	Benzene	CO	NO_2	PM_{10}	SO_2
Aberdeen Anderson Dr	ROADSIDE	Aberdeen City Council			Y	Y	
Aberdeen Market St	ROADSIDE	Aberdeen City Council			Y		
Aberdeen Union St	ROADSIDE	Aberdeen City Council				Y	
Abingdon	URBAN BACKGROUND	Vale of White Horse DC				Y	Y
Anglesey Brynteg	RURAL	Isle of Anglesey County Council					
Anglesey Llynfaes	RURAL	Isle of Anglesey County Council				Y	
Antrim Greystone Estate	URBAN BACKGROUND	Antrim BC					Y
Ascot Rural	RU	ERG			Y		
Aylesbury Bicester Road	ROADSIDE	Aylesbury Vale District Council			Y		
Barking and Dagenham 1 - Rush Green	S	ERG			Y		Y
Barking and Dagenham 2 - Scrattons Farm	S	ERG			Y	Y	
Barking and Dagenham 3 - North Street	K	ERG			Y		
Barnet 1 - Tally Ho Corner	K	ERG			Y	Y	
Barnet 2 - Finchley	U	ERG			Y		
Barnsley Old Mill Lane Roadside	ROADSIDE	Barnsley MBC			Y	Y	Y
Bedford - Kempston	I	ERG					Y
Belfast Roadside	ROADSIDE	Belfast City Council			Y		
Belfast Stockman's Lane	ROADSIDE	Belfast City Council			Y		
Bexley 2 - Belvedere	S	ERG			Y		
Bexley 3 - Thamesmead	S	ERG					
Bexley 4 - Erith	I	ERG			Y		
Bexley 7 - Thames Rd North	R	ERG			Y		
Bexley 7 (FDMS) - Thames Rd North	R	ERG				Y	
Bexley 8 - Thames Rd South	R	ERG			Y		
Birmingham Airport 2	AIRPORT	Birmingham International Airport		Y	Y	Y	Y
Bolton College	URBAN BACKGROUND	Bolton Council					Y
Boston Haven Bridge Road	KERBSIDE	Boston BC			Y		
Brent 1 - Kingsbury	S	ERG		Y	Y	Y	Y
Brent 4 - Ikea	R	ERG			Y		Y
Brent 5 - Neasden Lane	I	ERG			Y	Y	
Brent 6 - John Keble Primary School	R	ERG			Y		Y
Brent 7 - St Mary's Primary School	U	ERG			Y	Y	
Brentwood 1 - Town Hall	U	ERG			Y		

Bromley 7 - Central	R	ERG		Y	Y		
Broxbourne (Roadside)	R	ERG			Y	Y	
Broxtowe	ROADSIDE	Broxtowe Borough Council			Y		
Caerphilly White Street	URBAN CENTRE	Caerphilly County Borough Council			Y		
Cambridge Gonville Place	ROADSIDE	Cambridge City Council			Y	Y	
Cambridge Newmarket Road	ROADSIDE	Cambridge City Council			Y		
Cambridge Parker Street	ROADSIDE	Cambridge City Council			Y	Y	
Camden Shaftesbury Avenue	ROADSIDE	London Borough of Camden			Y		
Canterbury Backgrnd - Chaucer TS	U	ERG			Y		
Canterbury PM10	ROADSIDE	Kent & Medway Air Quality Network				Y	
Canterbury Roadside	ROADSIDE	Kent & Medway Air Quality Network			Y		
Canterbury Roadside - St. Dunstan's	R	ERG			Y		
Carrickfergus Rosebrook Avenue	URBAN BACKGROUND	Carrickfergus BC				Y	Y
Castle Point 1 - Town Centre	U	ERG			Y		Y
Castlereagh Lough View Drive	ROADSIDE	Castlereagh BC			Y	Y	
Chatham Luton Background	URBAN BACKGROUND	Kent & Medway Air Quality Network		Y	Y	Y	Y
Chatham Roadside	ROADSIDE	Kent & Medway Air Quality Network			Y	Y	
Chatham Roadside - A2	R	ERG			Y		
Chichester Roadside	R	ERG			Y		
Chichester Roadside (FDMS)	R	ERG				Y	
City of London 1 - Senator House	U	ERG			Y		Y
City of London 3 - Sir John Cass School	U	ERG			Y		
City of London 6 - Wallbrook Wharf	R	ERG		Y	Y		
Crawley 2 - Gatwick Airport	U	ERG			Y		
Croydon 2 - Purley Way	R	ERG			Y		
Croydon 4 - George Street	R	ERG			Y	Y	
Croydon 5 - Norbury	K	ERG			Y		
Croydon 6 - Euston Road	S	ERG			Y		
Crystal Palace 1 - C Palace Parade	R	ERG		Y	Y	Y	Y
Cwmbran PM10	URBAN BACKGROUND	Torfaen County Borough Council				Y	
Dartford Bean Interchange Roadside	ROADSIDE	Kent & Medway Air Quality Network			Y	Y	
Dartford St Clements Roadside	KERBSIDE	Kent & Medway Air Quality Network			Y	Y	
Dartford Town Centre Roadside	ROADSIDE	Kent & Medway Air Quality Network			Y	Y	
Derry Brandywell	URBAN BACKGROUND	Derry City Council				Y	Y
Dover Background 1 - Langdon Cliff	U	ERG					Y
Dover Centre Roadside	ROADSIDE	Kent & Medway Air Quality Network				Y	
Dover Langdon Cliff	URBAN BACKGROUND	Kent & Medway Air Quality Network					Y

Dover Old Town Hall Roadside	ROADSIDE	Kent & Medway Air Quality Network			Y		
Dundee Broughty Ferry Road	URBAN INDUSTRIAL	Dundee City Council				Y	Y
Dundee Lochee Road	ROADSIDE	Dundee City Council			Y		
Dundee Mains Loan	URBAN BACKGROUND	Dundee City Council				Y	
Dundee Seagate	KERBSIDE	Dundee City Council			Y		
Dundee Union Street	KERBSIDE	Dundee City Council			Y	Y	
Dundee Whitehall Street	KERBSIDE	Dundee City Council			Y		
E. Herts Sawbridgeworth (Background)	U	ERG			Y	Y	
E. Herts Sawbridgeworth (Roadside)	R	ERG			Y	Y	
Ealing 1 - Ealing Town Hall	U	ERG			Y		Y
Ealing 10 - Greenford	U	ERG				Y	
Ealing 2 - Acton Town Hall	R	ERG		Y	Y		
Ealing 2 (FDMS) - Acton Town Hall	R	ERG				Y	
Ealing 7 - Southall	U	ERG			Y	Y	
Ealing 8 - Horn Lane	I	ERG				Y	
East Dunbartonshire Bearsden	ROADSIDE	East Dunbartonshire Council			Y	Y	
East Dunbartonshire Bishopbriggs	ROADSIDE	East Dunbartonshire Council			Y	Y	
East Dunbartonshire Kirkintilloch	ROADSIDE	East Dunbartonshire Council			Y		
Eastbourne Background	U	ERG			Y		
Edinburgh Gorgie Road	ROADSIDE	City of Edinburgh Council			Y		
Edinburgh Haymarket	ROADSIDE	City of Edinburgh Council			Y	Y	
Edinburgh Queen Street	ROADSIDE	City of Edinburgh Council			Y	Y	
Edinburgh Roseburn	ROADSIDE	City of Edinburgh Council			Y	Y	
Edinburgh St John's Road	KERBSIDE	City of Edinburgh Council			Y		
Enfield 1 - Bushhill Park	S	ERG			Y		
Enfield 4 - Derby Road Upper Edmonton	R	ERG			Y		Y
Falkirk Grangemouth MC	URBAN BACKGROUND	Falkirk Council			Y	Y	Y
Falkirk Hope St	ROADSIDE	Falkirk Council			Y	Y	Y
Falkirk Park St	ROADSIDE	Falkirk Council			Y	Y	Y
Farnborough - Medway Drive	R	ERG			Y		
Fife Cupar	ROADSIDE	Welsh Air Quality Forum			Y	Y	
Fife Dunfermline	ROADSIDE	Fife Council			Y		
Fife Rosyth	ROADSIDE	Fife Council			Y		
Folkestone Suburban	SUBURBAN	Kent & Medway Air Quality Network			Y	Y	Y
Folkestone Suburban - Cheriton	S	ERG			Y		
Gatwick LGW3	AIRPORT	BAA			Y	Y	
Glasgow Abercromby Street	ROADSIDE	Glasgow City Council				Y	

Glasgow Anderston	URBAN BACKGROUND	Glasgow City Council			Y	Y	Y
Glasgow Battlefield Road	ROADSIDE	Glasgow City Council			Y	Y	
Glasgow Broomhill	ROADSIDE	Glasgow City Council				Y	
Glasgow Byres Road	ROADSIDE	Glasgow City Council		Y	Y	Y	
Glasgow Nithsdale Road	ROADSIDE	Glasgow City Council				Y	
Glasgow Queen Street Station	SPECIAL	Glasgow City Council				Y	Y
Glasgow Waulkmillglen Reservoir	RURAL	Glasgow City Council			Y	Y	
Gravesham A2 Roadside	ROADSIDE	Kent & Medway Air Quality Network			Y	Y	
Gravesham Ind Bgd - Northfleet	U	ERG			Y		
Gravesham Industrial Background	URBAN BACKGROUND	Kent & Medway Air Quality Network			Y	Y	
Greenwich 10 - A206 Burrage Grove	R	ERG			Y		
Greenwich 12 - Millennium Village	U	ERG			Y		
Greenwich 13 - Plumstead High Street	R	ERG			Y		
Greenwich 5 - Trafalgar Road	R	ERG			Y	Y	
Greenwich 7 - Blackheath	R	ERG			Y		
Greenwich 8 - Woolwich Flyover	R	ERG			Y	Y	
Greenwich 9 - Westhorne Ave	R	ERG			Y		
Greenwich Bexley 6 - A2 Falconwood	R	ERG			Y	Y	
Hackney 4 - Clapton	U	ERG		Y	Y		
Hackney 6 - Old Street	R	ERG			Y	Y	
Hammersmith and Fulham 1 - Broadway	R	ERG			Y		
Hammersmith and Fulham 2 - Brook Green	U	ERG			Y		
Harrow 1 - Stanmore Background	U	ERG			Y		Y
Harrow 2 - North Harrow Roadside	R	ERG			Y	Y	
Hastings Roadside	R	ERG			Y		
Havering 1 - Rainham	R	ERG			Y		
Heathrow Green Gates	AIRPORT	BAA			Y	Y	
Heathrow Oaks Road	AIRPORT	BAA			Y	Y	
Henley Roadside	R	ERG			Y		
Hertsmere Borehamwood 2 (Background)	U	ERG			Y	Y	
Hillingdon 1 - South Ruislip	R	ERG			Y	Y	
Hillingdon 2 - Hillingdon Hospital	R	ERG			Y	Y	
Hillingdon 3 - Oxford Avenue	R	ERG			Y	Y	
Horsham Roadside (Park Way)	R	ERG			Y	Y	
Hounslow 2 - Cranford	S	ERG			Y	Y	Y
Hounslow 4 - Chiswick High Rd	R	ERG			Y	Y	Y
Hounslow 5 - Brentford	R	ERG			Y	Y	

Hounslow 7 - Hatton Cross	U	ERG			Y	Y	
Hove Roadside	R	ERG			Y		
Islington 2 - Holloway Road	R	ERG		Y	Y	Y	
Islington 4 - Foxham Gardens	U	ERG				Y	
Islington 5 - Duncan Terrace	R	ERG				Y	
Islington 6 - Arsenal	U	ERG			Y		
Kens and Chelsea 2 - Cromwell Rd	R	ERG		Y	Y		Y
Kens and Chelsea 3 - Knightsbridge	R	ERG			Y		
Kens and Chelsea 4 - Kings Rd	R	ERG			Y		
Kens and Chelsea 5 - Earls Court Rd	K	ERG				Y	
Lambeth 1 - Christchurch Road	R	ERG			Y		Y
Lambeth 3 - Loughborough Junct	U	ERG			Y		Y
Lambeth 4 - Brixton Road	K	ERG			Y		Y
Lambeth 5	R	ERG			Y		Y
Lewes 2 Roadside	R	ERG			Y	Y	
Lewisham 1 - Catford	U	ERG			Y		Y
Lewisham 2 - New Cross	R	ERG			Y	Y	Y
Lisburn Dunmurry High School	URBAN BACKGROUND	Lisburn City Council				Y	Y
Lisburn Island Civic Centre	URBAN BACKGROUND	Lisburn City Council				Y	
Lisburn Lagan Valley Hospital	ROADSIDE	Lisburn City Council			Y	Y	
Liverpool Islington	ROADSIDE	Liverpool City Council			Y		
London Hillingdon Harmondsworth	ROADSIDE	London Borough of Hillingdon			Y	Y	
London Hillingdon Harmondsworth Os	ROADSIDE	London Borough of Hillingdon					
Luton (Background)	U	ERG		Y	Y	Y	Y
Luton Background	U	ERG			Y		
Macclesfield Disley	ROADSIDE	Macclesfield BC			Y		
Macclesfield Mere	ROADSIDE	Cheshire East Council			Y	Y	
Macclesfield Poynton	ROADSIDE	Cheshire East Council			Y		
Maidenhead Roadside	R	ERG			Y		
Maidstone A229 Kerbside	KERBSIDE	Kent & Medway Air Quality Network		Y	Y	Y	
Maidstone Rural	RURAL	Kent & Medway Air Quality Network			Y	Y	Y
Maidstone Rural - Detling	RU	ERG			Y		
Manchester South SO2	SUBURBAN	Manchester City Council					Y
Marchlyn Mawr	REMOTE	Welsh Air Quality Forum			Y		
Midlothian Dalkeith	KERBSIDE	Midlothian Council			Y	Y	Y
Midlothian Pathhead	KERBSIDE	Midlothian Council				Y	Y
Mole Valley 3 - Dorking	U	ERG			Y	Y	

N Lanarkshire Chapelhall	ROADSIDE	North Lanarkshire Council			Y	Y	
N Lanarkshire Coatbridge Ellis St	ROADSIDE	North Lanarkshire Council			Y		
N Lanarkshire Coatbridge Whifflet	URBAN BACKGROUND	North Lanarkshire Council			Y	Y	
N Lanarkshire Croy	ROADSIDE	North Lanarkshire Council			Y	Y	Y
N Lanarkshire Harthill	ROADSIDE	North Lanarkshire Council		Y	Y	Y	Y
N Lanarkshire Motherwell	ROADSIDE	North Lanarkshire Council				Y	
N. Herts Breechwood Green (Background)	U	ERG			Y	Y	
New Forest - Fawley	I	ERG					Y
New Forest - Holbury	I	ERG					Y
New Forest - Lyndhurst	R	ERG			Y		
New Forest - Totton	R	ERG			Y		
Newham Cam Road	ROADSIDE	London Borough of Newham		Y		Y	Y
Newham Wren Close	URBAN BACKGROUND	London Borough of Newham			Y		Y
Newport Malpas Depot	URBAN BACKGROUND	Newport County BC			Y		
North Down Bangor	URBAN BACKGROUND	North Down BC				Y	Y
North Down Holywood A2	ROADSIDE	North Down BC			Y	Y	
North Lincs Appleby Village	URBAN BACKGROUND	North Lincolnshire Council				Y	
North Lincs Broughton	URBAN BACKGROUND	North Lincolnshire Council				Y	
North Lincs Killingholme	URBAN INDUSTRIAL	North Lincolnshire Council			Y	Y	
North Lincs Santon	URBAN INDUSTRIAL	North Lincolnshire Council			Y	Y	Y
Norwich Castle Meadow	ROADSIDE	Norwich City Council					
Oldham West End House	URBAN BACKGROUND	Oldham MBC		Y	Y	Y	Y
Oxford High St	ROADSIDE	Oxford City Council			Y	Y	
Paisley Central Road	ROADSIDE	Renfrewshire Council			Y		
Paisley Gordon Street	ROADSIDE	Renfrewshire Council			Y		
Perth Atholl Street	ROADSIDE	Perth and Kinross Council			Y	Y	
Perth High Street	ROADSIDE	Perth and Kinross Council			Y	Y	
Port Talbot Dyffryn School	URBAN INDUSTRIAL	Welsh Air Quality Forum				Y	
Redbridge 1 - Perth Terrace	U	ERG			Y		
Redbridge 3 - Fullwell Cross	K	ERG			Y		
Redbridge 4 - Gardner Close	R	ERG		Y	Y		Y
Redbridge 5 - A406 Southend Rd	R	ERG		Y	Y		
Reigate and Banstead 2 - Horley South	S	ERG			Y		
Reigate and Banstead 3 - Poles Lane	RU	ERG			Y		
Rhondda Broadway	ROADSIDE	Welsh Air Quality Forum			Y		
Rhondda-Cynon-Taf Nantgarw	ROADSIDE	Welsh Air Quality Forum				Y	
Richmond 1 - Castelnau	R	ERG			Y	Y	

Richmond 2 - Barnes Wetlands	S	ERG			Y	Y	
Richmond 29 - Mortlake Road Kew	R	ERG		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	
Scunthorpe Allanby Street	ROADSIDE	North Lincolnshire Council				Y	
Scunthorpe East Common Lane	URBAN BACKGROUND	North Lincolnshire Council				Y	
Scunthorpe Gallagher Retail Park	ROADSIDE	North Lincolnshire Council			Y		
Scunthorpe Kingsway House	ROADSIDE	North Lincolnshire Council			Y		
Scunthorpe Lincoln Gardens	URBAN BACKGROUND	North Lincolnshire Council				Y	
Sevenoaks Background - Greatness	U	ERG		Y	Y	Y	
Sevenoaks Roadside - Bat and Ball	R	ERG			Y		
Sipson	URBAN BACKGROUND	London Borough of Hillingdon			Y		
Slough Chalvey	ROADSIDE	Slough BC			Y		
Slough Colnbrook	URBAN BACKGROUND	Slough BC			Y	Y	
Slough Colnbrook Osiris	URBAN BACKGROUND	Slough Borough Council				Y	
Slough Town Centre A4	URBAN BACKGROUND	Slough BC			Y		
South Beds Dunstable (Background)	U	ERG			Y	Y	
South Holland	RURAL	South Holland DC			Y	Y	
South Lanarkshire East Kilbride	ROADSIDE	South Lanarkshire Council			Y		
Southwark 1 - Elephant and Castle	U	ERG		Y	Y	Y	Y
Spalding Monkhouse School	URBAN BACKGROUND	South Holland DC				Y	
St. Albans Fleetville (Background)	U	ERG			Y		
Stansted 3	AIRPORT	BAA			Y	Y	
Stansted 4	AIRPORT	BAA			Y		
Stevenage (Roadside)	R	ERG			Y	Y	
Stockport Shaw Heath 2	URBAN BACKGROUND	Stockport		Y	Y	Y	Y
Strabane Springhill Park	URBAN BACKGROUND	Strabane DC				Y	Y
Sutton 3 - Carshalton	S	ERG			Y		
Sutton 4 - Wallington	K	ERG			Y		
Sutton 5 - Beddington Lane	I	ERG			Y		
Swale Ospringe Roadside 2	ROADSIDE	Kent & Medway Air Quality Network			Y		
Swale Sheerness	URBAN BACKGROUND	Kent & Medway Air Quality Network			Y	Y	Y
Swansea Morfa Roadside	ROADSIDE	Welsh Air Quality Forum		Y	Y		Y
Swansea Morriston Roadside	ROADSIDE	Welsh Air Quality Forum		Y	Y		Y
T. Wells Background - Town Hall	U	ERG			Y		

Tameside Two Trees School	URBAN BACKGROUND	Tameside MBC			Y	Y	Y
Telscombe Cliffs Roadside	R	ERG			Y	Y	
Thanet Airport	URBAN BACKGROUND	Kent & Medway Air Quality Network	Y		Y		
Thanet Airport - Manston	U	ERG			Y		
Thanet Background - Margate	U	ERG			Y		
Thanet Birchington Roadside	ROADSIDE	Kent & Medway Air Quality Network			Y	Y	
Thanet Margate Background	URBAN BACKGROUND	Kent & Medway Air Quality Network			Y		
Thanet Ramsgate Roadside	ROADSIDE	Kent & Medway Air Quality Network			Y	Y	
Thanet Roadside - Ramsgate	R	ERG			Y		
Three Rivers Rickmansworth (Background)	U	ERG			Y	Y	
Tonbridge Roadside 2	ROADSIDE	Kent & Medway Air Quality Network			Y		
Tower Hamlets 1 - Poplar	U	ERG			Y		
Tower Hamlets 3 - Bethnal Green	U	ERG			Y		Y
Tower Hamlets 4 - Blackwall	R	ERG			Y		
Trafford	URBAN BACKGROUND	Trafford MBC			Y	Y	
Trafford A56	ROADSIDE	Trafford MBC			Y	Y	
Tunbridge Wells A26 Roadside	ROADSIDE	Kent & Medway Air Quality Network			Y	Y	
Tunbridge Wells Town Centre	URBAN BACKGROUND	Kent & Medway Air Quality Network			Y		
Twynyrodyn	SPECIAL	Merthyr Tydfil County Borough Council				Y	
V Glamorgan Fonmon	RURAL	Welsh Air Quality Forum			Y		Y
V Glamorgan Penarth	ROADSIDE	Welsh Air Quality Forum			Y		
Waltham Forest 1 - Dawlish Road	U	ERG			Y	Y	Y
Waltham Forest 4 - Crooked Billet	K	ERG			Y		
Waltham Forest 5 - Leyton	U	ERG			Y		Y
Wandsworth 2 - Town Hall	U	ERG		Y	Y		
Watford (Roadside)	R	ERG			Y		
Watlington Roadside	R	ERG			Y		
Welwyn Hatfield WGC	U	ERG			Y		
West Berks Newbury	ROADSIDE	West Berkshire District Council			Y		
West Dunbartonshire Clydebank	ROADSIDE	West Dunbartonshire Council			Y		
West Dunbartonshire Glasgow Road	ROADSIDE	West Dunbartonshire Council			Y		
West Lothian Linlithgow High Street	ROADSIDE	West Lothian Council			Y		
Westminster 4 - Charing Cross Library	R	ERG			Y		
Wigan Centre PM10	URBAN BACKGROUND	Wigan Council				Y	
Wigan Leigh 2	URBAN BACKGROUND	Wigan Metropolitan Borough Council			Y	Y	
Windsor Roadside	R	ERG			Y		
Wokingham Winnersh	URBAN BACKGROUND	Wokingham DC			Y	Y	

Wrexham Isycoed	URBAN INDUSTRIAL	Welsh Air Quality Forum			Y	Y	Y
Wycombe Abbey	URBAN BACKGROUND	Wycombe District Council		Y	Y		Y
Wycombe Stokenchurch	URBAN BACKGROUND	Wycombe District Council			Y		

Data were collected from the following sources: AEA's Calibration Club, the Welsh Air Quality Forum (http://www.welshairquality.co.uk/), the Scottish Air Quality Archive (http://www.scottishairquality.co.uk/), the Kent and Medway Air Quality Monitoring Network (http://www.kentair.org.uk/) and monitoring data held by the Environmental Research Group (ERG) at King's College, London (http://www.londonair.org.uk/london/asp/default.asp).

Table A1.2. Additional monitoring sites maintained by the electricity generating companies used to calibrate the SO_2 models

Site	Data supplier
Aberthaw	EA (AQMAU)
Bentley Hall Farm	JEP (RWE-npower)
Bexleyheath	JEP (RWE-npower)
Blair Mains	JEP (RWE-npower)
Bottesford	JEP (RWE-npower)
Bowaters Farm	JEP (RWE-npower)
Carr Lane	JEP (RWE-npower)
Cottam & West Burton	EA (AQMAU)
Didcot	EA (AQMAU)
Downe's Ground	JEP (RWE-npower)
Fawley	EA (AQMAU)
Ferrybridge (Drax)	EA (AQMAU)
Fiddler's Ferry	EA (AQMAU)
Font-y-Gary	JEP (RWE-npower)
Gainsborough Cemetery	JEP (RWE-npower)
Gillingham	JEP (RWE-npower)
Grove Reservoir	JEP (RWE-npower)
Hemingbrough Landing	JEP (RWE-npower)
Ironbridge	EA (AQMAU)
Kingsnorth & Grain	EA (AQMAU)
Littlebrook	EA (AQMAU)
Longniddry West	JEP (RWE-npower)
Marton School	JEP (RWE-npower)
Northfleet	JEP (RWE-npower)
Park Farm	JEP (RWE-npower)
Ratcliffe-on-Soar	EA (AQMAU)
Rosehurst Farm	JEP (RWE-npower)

EA (AQMAU) = Environment Agency Air Quality Modelling and Assessment Unit

Appendix 2 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 3.0 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^{-1}
T is the discharge temperature, 373 K
c is the emission concentration at reference conditions, 3 g m^{-3}
v is the discharge velocity, 10 m s^{-1}

Table A2.1 shows the modelled stack heights and diameters.

Table A2.1. Modelled stack heights and diameters for sulphur dioxide

Emission rate			Stack height, m	Stack diameter, m
g s^{-1}	kg h^{-1}	t a^{-1}		
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 A2.2 shows the modelled stack heights and diameters.

Table A2.2. Modelled stack heights and diameters for oxides of nitrogen

Emission rate		Height, m	Diameter, m
g s^{-1}	t a^{-1}		
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 3.0 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 A2.3 shows the predicted “in-square average” concentration for the 1 km square centred on the emission source for 2000 meteorological data.

Table A2.3. Predicted in-square concentration, for sulphur dioxide

Emission rate, g s^{-1}	Average in square concentration, $\mu g\ m^{-3}$
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 A2.3 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^{-1}. A is a proportionality factor (2.07 in 2000)

Table A2.4 shows the predicted in-square concentration for an emission rate of 10 g s^{-1} for meteorological years 1993-2002. Table A2.4 also shows the inter-annual variation in the factor A.

Table A2.4. 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 A2.1 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 A2.1 does not include results for the 1 km source square.

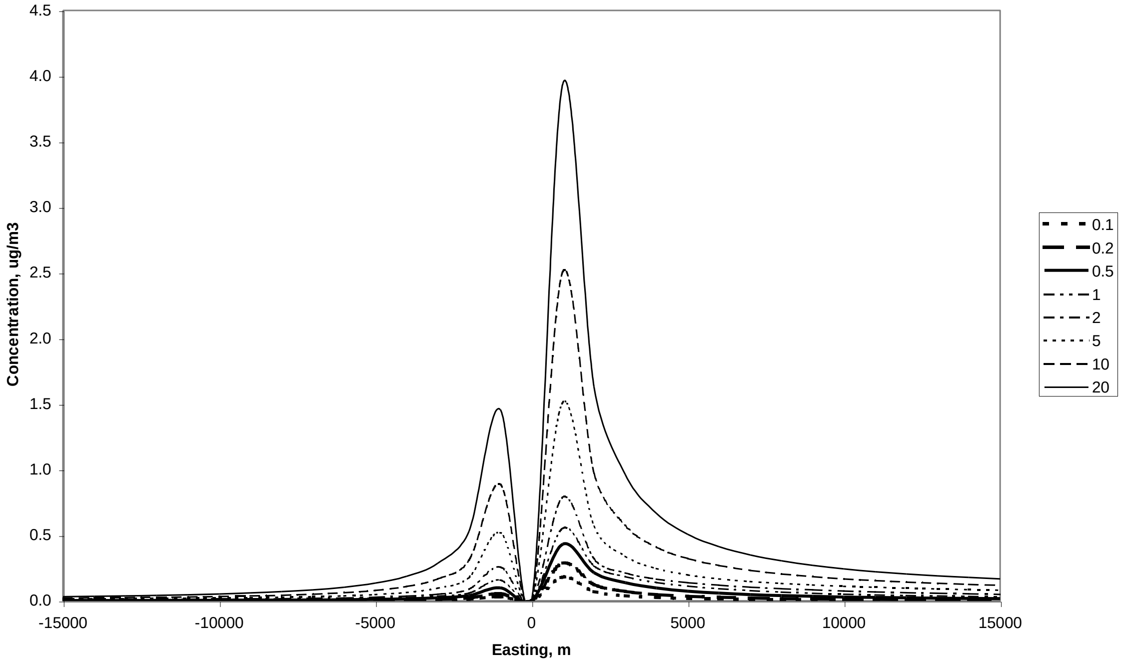


Figure A2.1. Sulphur dioxide concentration on east-west axis, 2000 meteorological data

Figure A2.2 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.

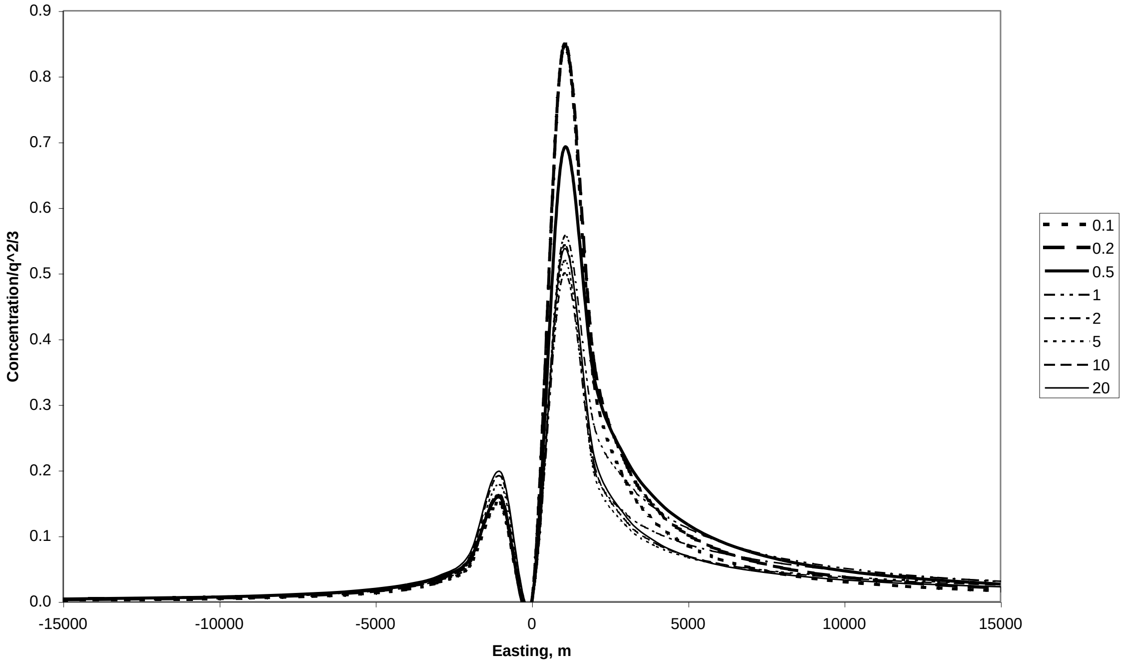


Figure A2.2. Reduced sulphur dioxide concentrations on the east-west axis, 2000 meteorological data

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^{-1}) at each receptor location. Separate kernels have been created from each meteorological data year 1993-2002.

Oxides of nitrogen

Table A2.5 shows the predicted “in-square average” concentration for the 1 km square centred on the emission source for 2000 meteorological data.

Table A2.5. In-square oxides of nitrogen concentrations, 2000

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

The results shown in Table A2.5 may be approximated in the range 0.1-20 g s^{-1} by the relationship

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

where: C is the in-square concentration, μg m^{-3} and q is the emission rate, g s^{-1}. and B is a numerical constant, 1.68 in 2000.

For emission rates in the range 20-100 g s^{-1}, the in-square concentration is approximately 4 μg m^{-3}.

Table A2.6 shows the predicted in-square concentration for an emission rate of 20 g s^{-1} for meteorological years 1993-2002. Table A2.6 also shows the inter-annual variation in the factor B.

Table A2.6. 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 A2.3 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^{-1}).

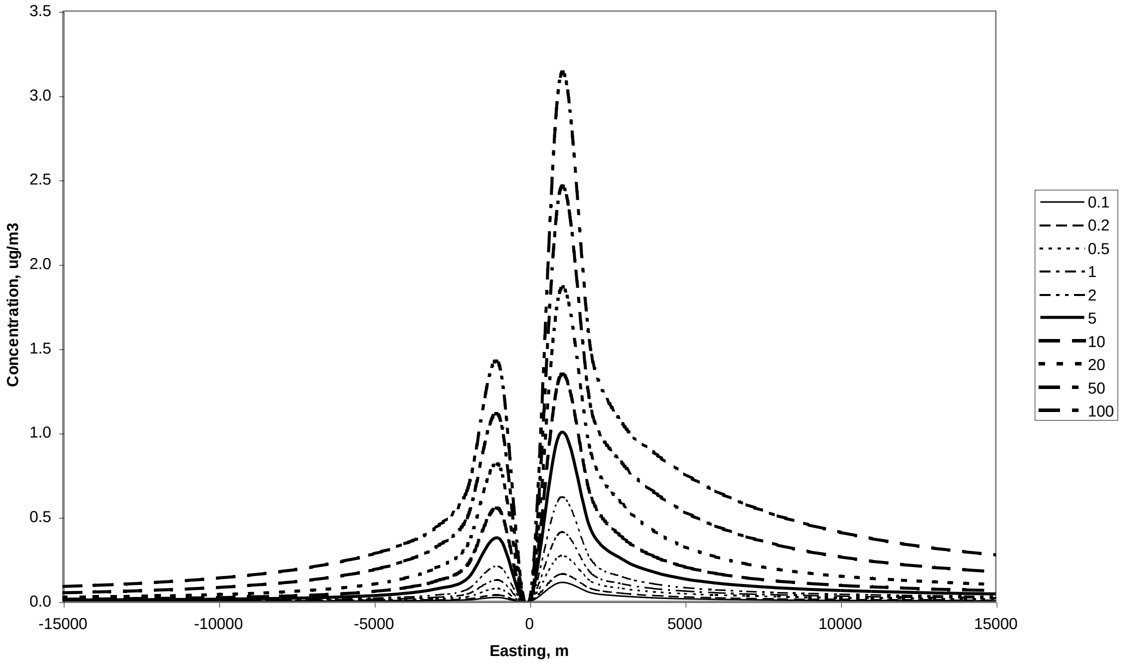


Figure A2.3. Oxides of nitrogen concentration on east-west axis, 2000 meteorological data

Figure A2.4 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.

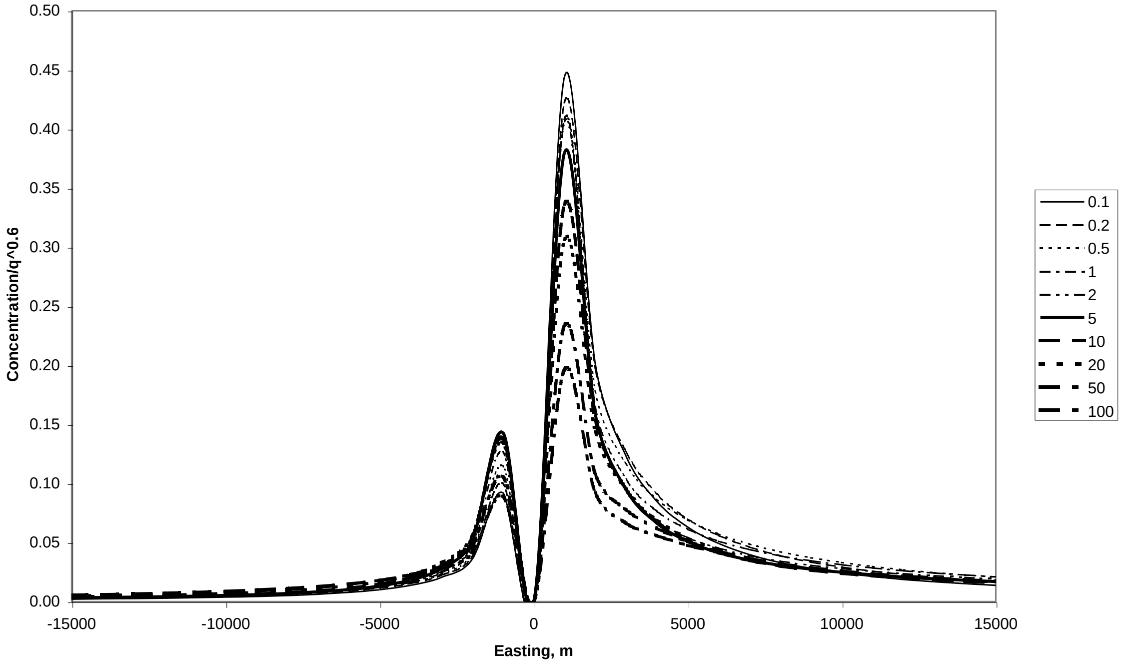


Figure A2.4. Reduced oxides of nitrogen concentrations on the east-west axis, 2000 meteorological data

Thus it is proposed to use the results for an emission rate of 20 g s^{-1} for all emission rates in the range 0.1-100 g s^{-1} 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^{-1} 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^{-1}) 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, µg m^{-3} and q is the emission rate, g s^{-1} 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^{-1} 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^{-1}) 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^{-1} 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^{-1} 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^{-1}) 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^{-1}) 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

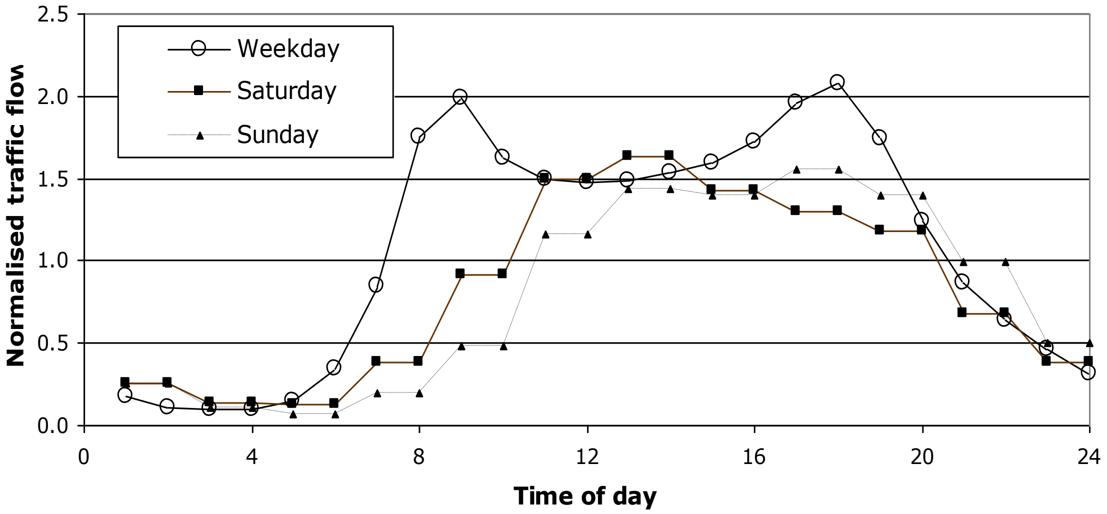
The method for benzene was the different. Point sources with combustions emissions greater than or equal to 5 tonnes per year (0.16 g s^{-1}) have been modelled explicitly using ADMS. Fugitive and process point sources have been modelled using a different small points model, as described in Section 5.3.

Appendix 3 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 2008 using sequential meteorological data from Waddington. The dispersion parameters used to calculate the kernels are listed in Table A3.1. The emission profile used to represent traffic emissions for the traffic kernels is shown in Figure A3.1. This was obtained from a distribution of all traffic in the United Kingdom by time of day (DETR, 2000).

Figure A3.1. Temporal profile of traffic emissions



The dispersion kernels were revised for the 2007 modelling for all pollutants and the same method was applied for 2008. For NO_x, PM_{10}, benzene and CO the kernels are now on a 1 km x 1 km resolution matrix and are made using ADMS 4.0 (rather than the 3 km x 3 km resolution matrix used in previous years). The centre squares have been scaled to remove the impact of sources within 50 m of the receptor location in that square on the basis that background sites are not located very close to specific sources such as major roads. Different kernels have been made for different area types, to take into account different dispersion conditions in urban areas of different sizes. Previously this was accounted for in the PCM models by the application of different empirical calibration coefficients in inner conurbations and other locations. The kernels have been made specific to different types of location by varying minimum Monin Obukhov Length (LMO). The location of the different area types are shown in Figure A3.2 and surface roughness due to different land use. This has replaced the use of different calibration coefficients for inner conurbations and elsewhere.

Table A3.1. Summary of inverted dispersion kernel parameters

Kernel name	Area types	Type of location	LMO (m)	Surface roughness	Height (m) of volume source	Variable emission profile?	Emission rate (g m^{-3} s^{-1})
Non road transport	1,2,4	Conurbation	75	1	30	N	3.33E-08
Non road transport	3,4,5,6,7,8	Smaller urban	20 [A]	1	30	N	3.33E-08
Non road transport	9,10	Rural	10	1	30	N	3.33E-08
Road transport	1,2,4	Conurbation	75	1	10	Y	1.0E-7

Table A3.1. (cont.): Summary of inverted dispersion kernel parameters

Kernel name	Area types	Type of location	LMO (m)	Surface roughness	Height (m) of volume source	Variable emission profile?	Emission rate (g m^{-3} s^{-1})
Road transport	3,4,5,6,7,8	Smaller urban	10	1	10	Y	1.0E-7
Road transport	9,10	Rural	20 ^{A}	1	10	Y	1.0E-7

ADMS 4.0 recommends using a minimum Monin Obukhov Length (LMO) of 30 m for an urban area. However, sensitivity testing showed 20 m works better in ADMS 4.0.

The dispersion kernels used for fugitive and process point sources of benzene are the same as the non road transport kernels but with the values for the central receptor location calculated as described in Section 5.3.

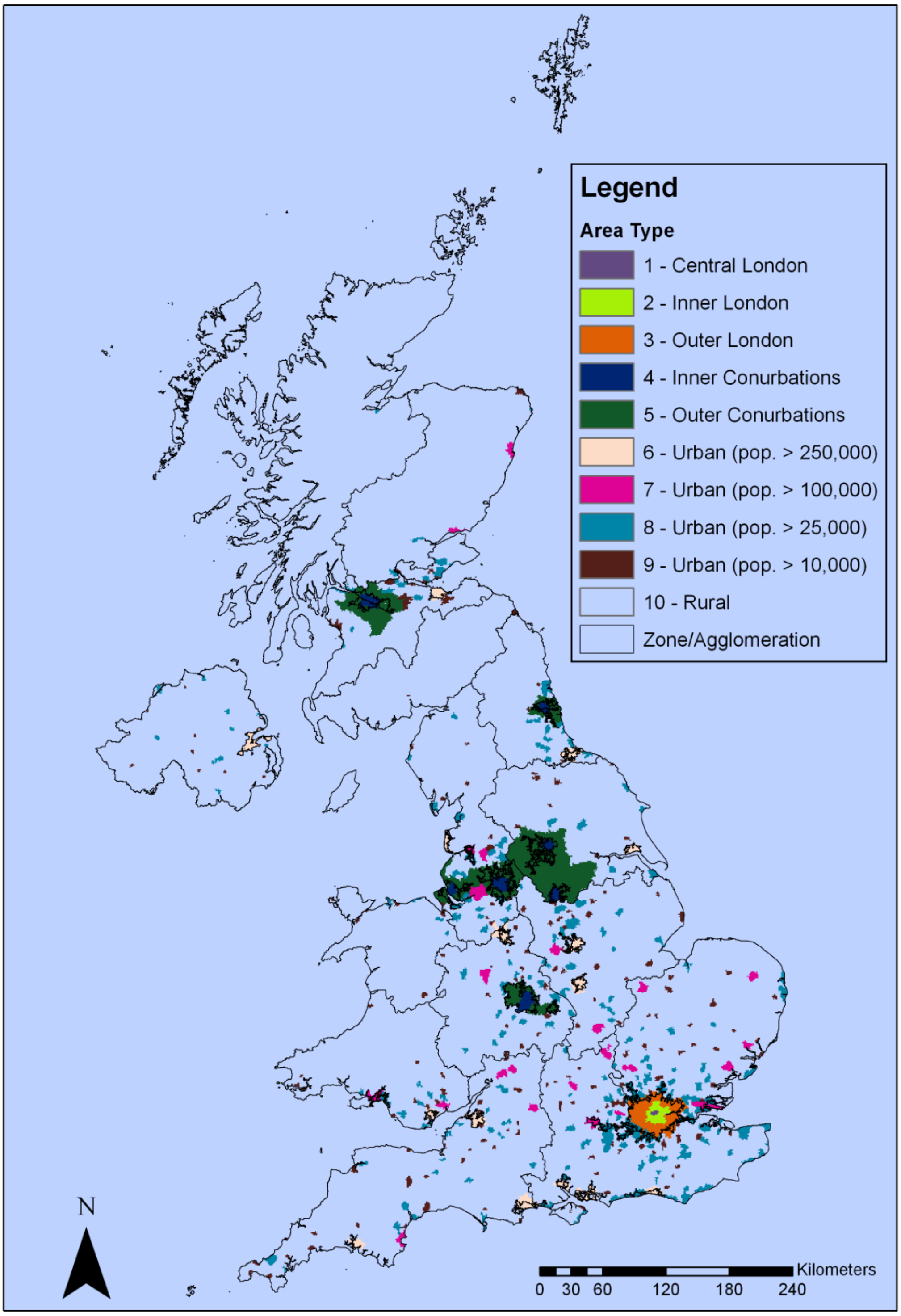


Figure A3.2. Map of UK area types

© Crown copyright. All rights reserved Defra, Licence number 100022861 [2009]

Appendix 4 Revised method for calculating and mapping emissions from aircraft and shipping

Revised method for calculating and mapping emissions from aircraft

As noted in Section 1.7, the method for calculating emissions from aircraft and ships has been revised for the 2008 modelling. Aircraft emissions were calculated using data obtained from the NAEI (Murrells et al., 2009) for emissions from planes in various phases of flying (e.g. take off, landing, taxiing). NAEI provides estimates of total emissions for aircraft, which include emissions up to a height of 1000 m. Spatial distributions for aircraft and air support activities were updated by the NAEI for 2007. Detailed GIS analysis was carried out to improve the spatial distribution and to take account of the different spatial patterns for ground level and non-ground level emissions. Ground level emissions for use in PCM modelling were calculated on the basis of:

Ground level emissions = Taxi out + Hold + Taxi in + APU arrival + APU departure +
(0.5 x Take off) + (0.5 x Landing) + (0.5 x Reverse thrust).

The factor of 0.5 has been chosen on the basis of findings from detailed studies (Underwood, 2009). Initial climb, climb-out and approach are included in the emission inventory but excluded from ground level emissions used for the PCM model.

Figures A.4.1 and A.4.2 show good agreement between the measured and modelled annual mean ground-level NO_X concentrations at monitoring sites in the vicinity of Heathrow and Gatwick airports for 2008, respectively, based on this new approach.

Figure A4.1. Comparison of the measured and modelled annual mean NO_X at Heathrow Airport for 2008

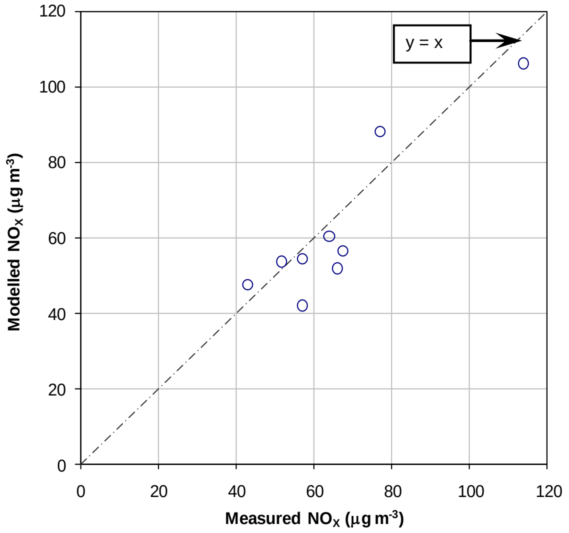
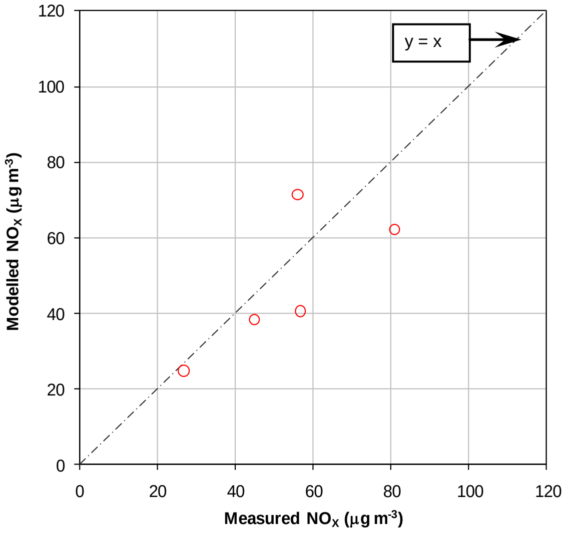


Figure A4.2. Comparison of the measured and modelled annual mean NO_X at Gatwick Airport for 2008



Revised method for calculating and mapping emissions from ships and shipping

ENTEC (2008) have provided maps of shipping emissions for 2007 on a 5 km EMEP projection grid. The NAEI (Murrells et al., 2009) then extracted the emissions for UK waters and calculated 1 km emission estimates on the GB OS grid by assigning the 5 km EMEP values on an area weighted mean basis for squares in the sea only.

These new maps of shipping emissions were tested for suitability for use in the PCM model by recalculating total NO_x concentrations for 2007 with the shipping emissions as estimated in the original modelling (Grice et al., 2009), which used shipping emissions maps from the 2006 NAEI, with the new maps of shipping emissions. Both the original and revised totals were then compared with measurement data for national network and verification sites. An empirical factor of 0.25 was found to provide the best agreement with measurement data for the emissions estimates used by Grice et al. (2009).

The revised maps of shipping emissions were found to provide a much better agreement with measurement data without the systematic overestimate found previously. The new maps were however found to lead to overestimates of concentration close to some ports. We think that this is caused by the additional uncertainties associated with assigning the 5 km x 5 km grid emissions estimates to 1 km x 1 km grid squares, particularly at port areas where the larger grid squares include a significant proportion of land area.

We therefore reviewed the monitoring 2007 data available for sites close to some of the largest predicted shipping emissions close to ports. These data provide some insight into reasonable concentrations at ports. The measured annual mean NO_X concentration at Dover Docks in 2007 was 135 $\mu g\ m^{-3}$ (as NO_2). This site is right in the docks close to the ships. The Castle Point 1 Town Centre site had an annual mean of 34 $\mu g\ m^{-3}$ (as NO_2) in 2007. This site about 3 km from significant shipping emissions. Similarly the Southampton Centre national network site is about 2 km from significant shipping emissions and had a concentration in 2007 of 67 $\mu g\ m^{-3}$ (as NO_2).

This suggests that a contribution of more than about 30 $\mu g\ m^{-3}$ (as NO_2) is not reasonable as a grid square average with significant shipping emissions, given that the measured value at Dover Docks is very close to (within 100 m or so) of the ships. The emissions maps for NO_X from shipping were therefore capped to ensure that the modelled contribution from shipping emissions was no greater than this value. Equivalent values for the cap to be applied for the other air pollutants covered in this report were calculated by multiplication by the ratio of total UK shipping emissions for these pollutants to the total of UK shipping emissions for NO_X.

Appendix 5 Application of the Volatile Correction Model (VCM) to AURN TEOM data

The UK has used the Volatile Correction Model (VCM) to adjust TEOM PM_{10} (method M3) monitoring data to account for the loss of volatile component. In previous years the UK has used a factor of 1.3 to scale TEOM PM_{10} measurements but this has been found to overestimate concentrations relative to reference methods. The VCM model makes use of the measurements of the volatile component made at other monitoring sites within 200 km for which TEOM FDMS (M3a) measurements are available. The model has been described by Green et al. (2007; 2008). Further information is available from http://www.volatile-correction-model.info/.

Appendix 6 Air Quality monitoring data from Gibraltar in 2008

Introduction

Gibraltar is subject to the same European environmental legislation as the UK. Gibraltar is comprised of a single non-agglomeration zone for which no modelling assessment has been undertaken but data from automatic monitoring are presented in this report. The exceedence status of the Gibraltar zone has been determined from monitoring data only. This Appendix summarises ambient air quality concentrations reported in 2008 for Gibraltar in the context of the Daughter Directive Limit Values. The ozone air quality assessment for Gibraltar is covered in Kent and Stedman (2009), whilst the air quality assessment for heavy metals and BaP can be found in Yap et al. (2009).

Table A6.1. Gibraltar air quality monitoring network site details

Site	Site type	Latitude	Longitude	Altitude	Pollutants
Bleak House	URBAN BACKGROUND	36 06 46N	05 21 01W	50 m	NO_2, O_3
Rosia Road	ROADSIDE	36 08 00N	05 21 11W	15 m	Benzene, CO, NO_2, PM_{10}, $PM_{2.5}$, SO_2, lead
Witham's Road	ROADSIDE	36 07 42N	05 21 05W	25 m	NO_2

Annual summary

Tables A6.2 to A6.4 show summary concentrations for different metrics for all pollutants reported at the three Gibraltar air quality monitoring stations respectively. Data capture statistics are provided.

Table A6.2. Gibraltar Bleak House monitoring data, 2008

	Pollutant	
Metric	**NO_2**	**O_3**
Maximum 15-minute mean (µg m^{-3})	189	142
Maximum hourly mean (µg m^{-3})	120	140
Maximum running 8-hour mean (µg m^{-3})	87	134
Maximum running 24-hour mean (µg m^{-3})	60	118
Maximum daily mean (µg m^{-3})	57	118
Annual average (µg m^{-3})	26	60
Data capture (%)	89	99

Table A6.3. Gibraltar Rosia Road monitoring data, 2008

	Pollutant						
Metric	**Benzene (µg m^{-3})**	**CO (mg m^{-3})**	**PM_{10} (µg m^{-3})**	**$PM_{2.5}$ (µg m^{-3})**	**NO_2 (µg m^{-3})**	**SO_2 (µg m^{-3})**	**lead (µg m^{-3})**
Maximum 15-minute mean	-	10.3	-	-	210	165	-
Maximum hourly mean	52.7	5.5	-	-	134	128	-
Maximum running 8-hour mean	25.4	2.4	-	-	103	80	-
Maximum running 24-hour mean	13.9	1.4	-	-	88	49	-
Maximum daily mean	12.3	1.3	179	48	81	43	-
Annual average	1.8	0.5	41	16	45	11	0.01
Data capture (%)	92	98	91	97	92	96	100

Table A6.4. Gibraltar Witham's Road monitoring data, 2008

	Pollutant
Metric	**NO_2**
Maximum 15-minute mean (µg m^{-3})	220
Maximum hourly mean (µg m^{-3})	151
Maximum running 8-hour mean (µg m^{-3})	121
Maximum running 24-hour mean (µg m^{-3})	104
Maximum daily mean (µg m^{-3})	102
Annual average (µg m^{-3})	53
Data capture (%)	62

All mass concentrations units are quoted as their equivalent values at 20°C and 1013 mb.

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

The tables presented below are from Form 8 of the questionnaire and are equivalent tables for Gibraltar as those shown for the UK in Section 7.1. 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.

The results of the air quality assessments in Gibraltar for SO_2, NO_2 and NO_X, PM_{10}, lead, benzene and CO are listed in Tables A6.4 to A6.9.

Table A6.4. Exceedence situation in Gibraltar showing whether 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
Gibraltar Zone	UK(GIB)			y		y		n		n

Table A6.5. Exceedence situation in Gibraltar showing whether 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
Gibraltar Zone	UK(GIB)			y	y				n

Table A6.6. Exceedence situation in Gibraltar showing whether 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+ MOT	≤LV+ MOT; >LV	≤LV	>LV+ MOT	≤LV+ MOT; >LV	≤LV
Gibraltar Zone	UK(GIB)	y			y		

Table A6.7. Exceedence situation in Gibraltar showing whether 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
Gibraltar Zone	UK(GIB)			y

Table A6.8. Exceedence situation in Gibraltar showing whether 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
Gibraltar Zone	UK(GIB)			y

Table A6.9. Exceedence situation in Gibraltar showing whether 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
Gibraltar Zone	UK(GIB)			y

Measured exceedences of Limit Values + Margins of Tolerance

Individual exceedences of Limit Values and Limit Values + Margin of Tolerance are presented in the questionnaire in Form 11 (CDR, 2009).