UK modelling under the Air Quality Directive (2008/50/EC) for 2009 covering the following air quality pollutants: SO_2, NO_x, NO_2, PM_{10}, $PM_{2.5}$, lead, benzene, CO, and ozone

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

AEAT/ENV/R/3069 Issue 1
ED46644
Date 01/12/2010

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:

AQ0634

Confidentiality, copyright & reproduction:

This report is the Copyright of Defra and has been prepared by AEA Technology plc under contract to Defra dated 06/07/2010. 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 Defra. 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.

AEA reference:

ID: AEAT/ENV/R/3069 Issue 1
Ref: ED46644

Contact:

John Stedman
AEA Technology plc
Gemini Building, Harwell, Didcot, OX11 0QR

t: 0870 190 6573

f: 0870 190 6318

e: john.stedman@aeat.co.uk

AEA is a business name of AEA Technology plc

AEA is certificated to ISO9001 and ISO14001

Author:

Susannah E Grice, Daniel M Brookes, John R Stedman, Andrew J Kent, Helen L Walker, Sally L Cooke, Keith J Vincent, Justin J N Lingard, Tony J Bush, John Abbott, Fee Wen Yap

Approved By:

John Stedman

Date:

01 December 2010

Signed:

John Stedman.

File reference:

W:\dd2009\reporting\1_dd13mappingreport\AQD2009mapsrep_v0.pdf

Executive summary

European Union directives on ambient air quality require member states including the UK to undertake air quality assessments, and to report the findings of these assessments to the European Commission on an annual basis. Historically this has been performed according to:

- The Air Quality Framework Directive (1996/62/EC)
- The four Daughter Directives 1999/30/EC, 2000/69/EC, 2002/3/EC and 2004/107/EC.

In June 2008, a new directive came into force: the Council Directive on ambient air quality and cleaner air for Europe (2008/50/EC), which is known as the ‘Air Quality Directive’ (AQD). This directive consolidates the first three Daughter Directives, and was transposed into Regulations in England, Scotland, Wales and Northern Ireland in June 2010. The 4th Daughter Directive (AQDD4), 2004/107/EC, remains in force.

In 2009 the UK undertook the annual air quality assessment in accordance with the requirements of the AQD and the AQDD4. This assessment takes the form of comparisons of measured and modelled air pollutant concentrations with the limit values, target values and long term objectives set out in the directives. Air quality modelling has been carried out to supplement the information available from the UK national air quality monitoring networks. The results were submitted to the European Commission in the form of a standard questionnaire (the ‘questionnaire’) which each member state must complete and upload onto the Common Data Repository of the European Environment Agency: http://cdr.eionet.europa.eu/gb/eu/annualair.

One important change between the Framework and Daughter Directives and the AQD 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 it was included for the first time in the assessment of concentrations for 2008 and is also included in this assessment for 2009.

The AQD sets limit values for the ambient concentrations to be achieved for:

- sulphur dioxide (SO_2)
- nitrogen dioxide (NO_2) and oxides of nitrogen (NO_x)
- particles (PM_{10})
- lead (Pb)
- benzene (C_6H_6)
- carbon monoxide (CO)

The AQD also includes:

- a target value, limit values, an exposure concentration obligation and exposure reduction targets for fine particles ($PM_{2.5}$)
- target values and long-term objectives for ozone (O_3)

This report provides a summary of key results from the questionnaire for the AQD pollutants and additional technical information on the modelling methods that have been used.

Full details of the assessment carried out under AQDD4 for the heavy metals and PAH’s (indicator species BaP) are included in the accompanying report (Walker et al., 2010)

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, target values and long term objectives has been assessed. The results of the assessment against limit values + margins of tolerance and limit values are summarised in Table E1. Table E2 summarises the results of the assessment for O_3 in terms of the numbers of zones with exceedances of the target values and long term objectives. Table E3 shows that there were no exceedances of the target value for $PM_{2.5}$. Table E4 contains details of exceedances of old directives.

Table E1. Summary results of air quality assessment for 2009: comparison with limit values and limit values + margins of tolerance

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)	2 zones measured (Greater London Urban Area & Glasgow Urban Area)
NO_2	Annual	40 zones (9 measured + 31 modelled)	40 zones (9 measured + 31 modelled)
NO_x	Annual[2]	n/a	none
PM_{10}	24-hour	n/a	3 zones (1 measured + 2 modelled) *1 zone modelled after subtraction of natural contribution*
PM_{10}	Annual	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. Summary results of air quality assessment for 2009 for O_3: comparison with target values and long term objectives

Pollutant	Averaging time	Number of zones exceeding target value	Number of zones exceeding long term objective
O_3	8-hour	none	39 zones (25 measured + 14 modelled)
O_3	AOT40	none	10 zones (8 measured + 2 modelled)

Table E3. Summary results of air quality assessment for 2009 for $PM_{2.5}$: comparison with target value

Pollutant	Averaging time	Number of zones exceeding target value
$PM_{2.5}$	Annual	none

Table E4. Exceedances of old Directives

Pollutant	Directive	Averaging time (limit value)	Concentration ($\mu g\ m^{-3}$)
NO_2	85/203/EEC	1-hour 98%ile ($200\mu g\ m^{-3}$)	227 (measured at London Marylebone Road)

Table of contents

1 Introduction

1.1 The EU ambient air quality directives

European Union directives on ambient air quality require member states including the UK to undertake air quality assessments, and to report the findings of these assessments to the European Commission on an annual basis. Historically this has been performed according to:

- The Air Quality Framework Directive (1996/62/EC)
- The four Daughter Directives 1999/30/EC, 2000/69/EC, 2002/3/EC and 2004/107/EC.

In June 2008, a new directive came into force: the Council Directive on ambient air quality and cleaner air for Europe (2008/50/EC), which is known as the 'Air Quality Directive' (AQD). This directive consolidates the first three Daughter Directives, and was transposed into Regulations in England, Scotland, Wales and Northern Ireland in June 2010. The 4th Daughter Directive (AQDD4), 2004/107/EC, remains in force.

In 2009 the UK undertook the annual air quality assessment in accordance with the requirements of the AQD and the AQDD4. This assessment takes the form of comparisons of measured and modelled air pollutant concentrations with the limit values, target values and long term objectives set out in the directives. The results were submitted to the European Commission in the form of a standard questionnaire (the 'questionnaire') which each member state must complete and upload onto the Common Data Repository of the European Environment Agency: http://cdr.eionet.europa.eu/gb/eu/annualair (CDR, 2010).

The AQD sets limit values for the ambient concentrations to be achieved for:

- sulphur dioxide (SO_2)
- nitrogen dioxide (NO_2) and oxides of nitrogen (NO_x)
- particles (PM_{10})
- lead (Pb)
- benzene (C_6H_6)
- carbon monoxide (CO)

The AQD also includes:

- a target value, limit values, an exposure concentration obligation and exposure reduction targets for fine particles ($PM_{2.5}$)
- target values and long-term objectives for ozone (O_3)

AQDD4 sets target values to be achieved for:

- arsenic (As)
- cadmium (Cd)
- nickel (Ni)
- polycyclic aromatic hydrocarbons with benzo(a)pyrene (BaP) as an indicator species

The number of monitoring sites required for compliance defined within the directives is significantly reduced if other means of assessment, in addition to fixed monitoring sites, are available for inclusion in the annual air quality assessment. Air quality modelling has therefore been carried out to supplement the information available from the UK national air quality monitoring networks.

One important change between the Framework and Daughter Directives and the AQD 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 it was included for the first time in the assessment of concentrations for 2008 and is also included in this assessment for 2009.

1.2 This report

This report covers assessments required under the AQD. Specifically it provides detailed information on the modelling methods used to assess relevant metrics throughout the UK and a summary of the key results of the assessment. Full details of the assessment carried out under AQDD4 for the heavy metals and PAH's (indicator species BaP) are included in the accompanying report (Walker et al., 2010). A third report summarising the UK's 2009 submission on air quality to the European Commission and presenting air quality modelling data and measurements from the UK national air quality monitoring networks has also been uploaded onto the CDR (Air Pollution in the UK, 2009, Edition A. September 2010).

Sections 2 to 9 of this report describe the Pollution Climate Mapping (PCM) modelling methods that have been used to calculate concentrations of SO_2, NO_x, NO_2, PM_{10}, $PM_{2.5}$, Pb, C_6H_6, CO and O_3. 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, target values and long term objectives for the AQD pollutants have been reported to the EU in the questionnaire (CDR, 2010) and a summary of the results of the assessments are included in Section 10. The status has been determined from a combination of monitoring data and model results. Section 10 also includes a comparison of the results of similar assessments carried out since 2001 (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, Grice et al., 2010).

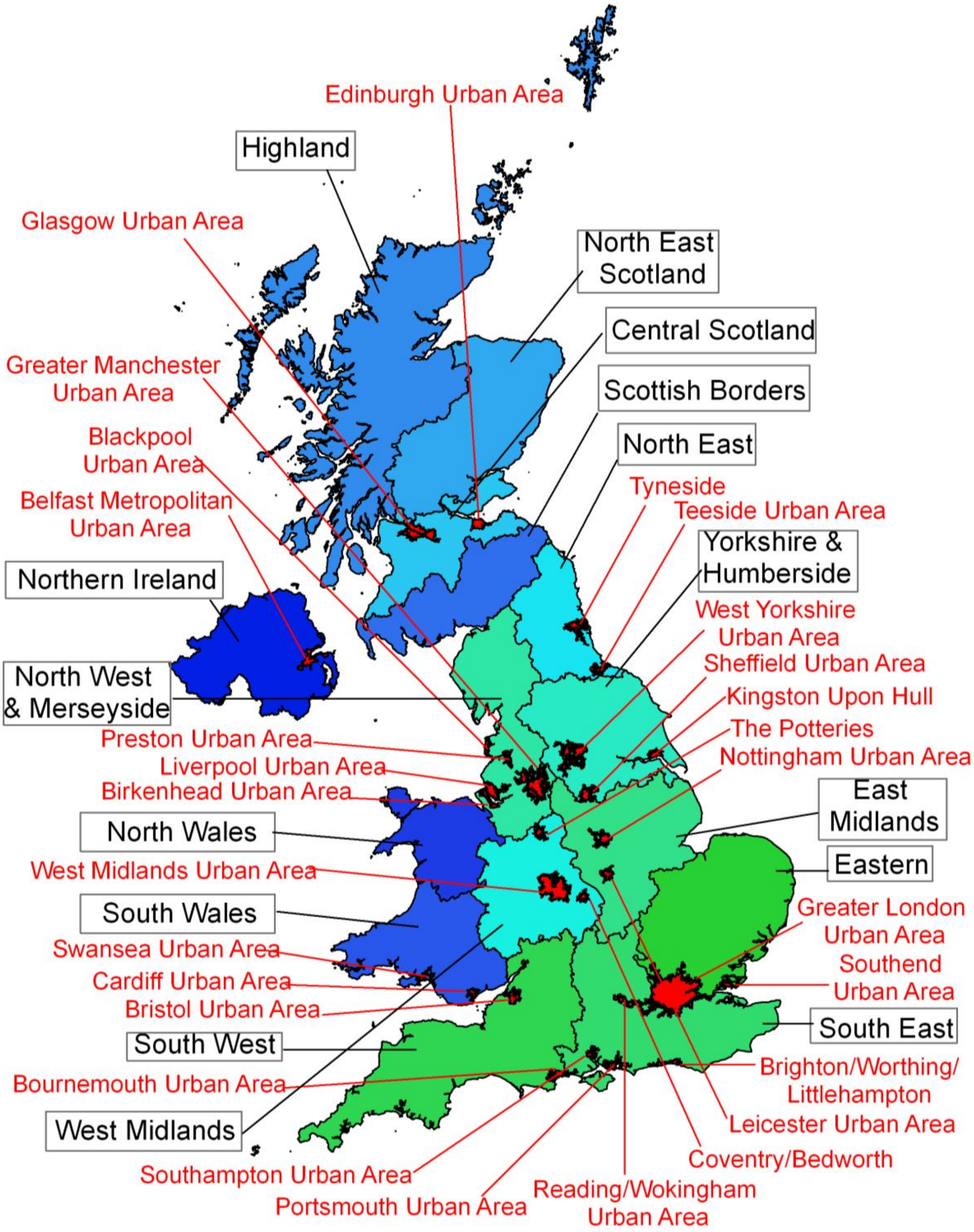
1.3 Assessment regime and definition of zones

The Framework Directive included 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 were 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 the first, second and third Daughter Directives have been prepared (Bush, 2000; Bush, 2002; Bush and Kent, 2003). The AQD includes a similar requirement for continued assessment under Article 5. The classification of zones in relation to assessment thresholds should be reviewed at least every five years or more frequently in the event of significant changes in activities relevant to ambient concentrations of the AQD pollutants.

The preliminary assessments included the definition of a set of zones to be used for air quality assessment in the UK. The AQD continues the requirement for the establishment of zones and agglomerations under Article 4.

Table 1.1 contains details of area, population (from 2001 census) and urban road length contained in each UK 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 2009



Agglomeration zones (red)

Non-agglomeration zones (blue/green)

Table 1.1 - Zones for Air Quality Directive 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	1909	1895.3
West Midlands Urban Area	UK0002	ag	2284093	599.7	385	544.7
Greater Manchester Urban Area	UK0003	ag	2244931	556.5	554	670.9
West Yorkshire Urban Area	UK0004	ag	1499465	370.0	282	422.6
Tyneside	UK0005	ag	879996	210.7	167	206.0
Liverpool Urban Area	UK0006	ag	816216	186.1	251	213.6
Sheffield Urban Area	UK0007	ag	640720	162.2	113	161.8
Nottingham Urban Area	UK0008	ag	666358	158.4	124	134.5
Bristol Urban Area	UK0009	ag	551066	139.8	112	116.2
Brighton/Worthing/Littlehampton	UK0010	ag	461181	94.1	60	90.7
Leicester Urban Area	UK0011	ag	441213	101.6	66	81.3
Portsmouth Urban Area	UK0012	ag	442252	94.4	56	78.5
Teesside Urban Area	UK0013	ag	365323	114.3	62	72.1
The Potteries	UK0014	ag	362403	96.6	112	129.0
Bournemouth Urban Area	UK0015	ag	383713	108.1	48	72.2
Reading/Wokingham Urban Area	UK0016	ag	369804	93.2	65	76.8
Coventry/Bedworth	UK0017	ag	336452	75.5	29	39.9
Kingston upon Hull	UK0018	ag	301416	80.4	38	60.1
Southampton Urban Area	UK0019	ag	304400	72.8	61	77.5
Birkenhead Urban Area	UK0020	ag	319675	89.1	64	71.9
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	219	325.5
Edinburgh Urban Area	UK0025	ag	452194	120.1	60	102.3
Cardiff Urban Area	UK0026	ag	327706	75.6	38	58.8
Swansea Urban Area	UK0027	ag	270506	79.7	30	71.3
Belfast Metropolitan Urban Area	UK0028	ag	515484	198.1	34	200.2
Eastern	UK0029	non-ag	4909880	19133.7	571	806.6
South West	UK0030	non-ag	4039460	23562.6	428	647.8
South East	UK0031	non-ag	6160630	18672.6	797	1290.0
East Midlands	UK0032	non-ag	3261330	15495.9	400	658.1
North West & Merseyside	UK0033	non-ag	3470620	13722.9	511	833.9
Yorkshire & Humberside	UK0034	non-ag	3003870	14796.6	313	567.2
West Midlands	UK0035	non-ag	2624020	12186.3	329	505.8
North East	UK0036	non-ag	1443910	8291.4	180	272.1
Central Scotland	UK0037	non-ag	1883010	9347.6	213	345.2
North East Scotland	UK0038	non-ag	976022	18631.4	129	226.7
Highland	UK0039	non-ag	341329	39134.5	10	35.4
Scottish Borders	UK0040	non-ag	250529	11184.1	35	47.3
South Wales	UK0041	non-ag	1698080	12228.4	163	316.9
North Wales	UK0042	non-ag	702506	8382.6	84	157.1
Northern Ireland	UK0043	non-ag	1149150	13974.1	90	288.1
Total			61392538	244813.3	9306	13134.7

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

1.4 Monitoring sites

The monitoring stations operating during 2009 for the purpose of the AQD reporting are listed in Form 3 of the questionnaire, which can be found on the CDR (2010). Data capture statistics for these sites are also presented in Form 3; not all sites had sufficient data capture during 2009 for data to be reported. The data quality objective (DQO) for AQD measurements is 90% data capture, however, all measurements from monitoring sites with at least 75% data capture for the entire year have been included in the analysis to ensure that a greater number of operational monitoring sites have been used for reporting purposes.

1.5 Limit Values, Margins of Tolerance and Critical Levels

Limit values (LV) for the protection of human health for SO_2, NO_2, PM_{10}, Pb, C_6H_6 and CO are defined in Annex XI of the AQD, a margin of tolerance (MOT) has also been defined for many of the LV's. Where the LV is already in force the LV + MOT for these pollutants is effectively the same as the LV since compliance with the LV is already required. Where the LV is yet to come into force (i.e. for NO_2 and C_6H_6) the MOT decreases each year, until it is zero in the year that compliance with the LV is required.

Critical levels (CL's) for the protection of vegetation for SO_2 and NO_x are also defined in Annex XIII of the AQD, there is no MOT for these CL's. Table 1.2 – Table 1.7 give details of LV's, LV's + MOT and CL's defined in the AQD for each pollutant.

All exceedances of LV's and CL's must be reported to the EU. Exceedances of the LV + MOT (if applicable) must also be reported to the EU. A reported exceedance of the LV + MOT also means that an air quality plan for attaining the limit value within the specified time limit specified by the AQD and a report to the EU on this air quality plan must be prepared. Where a limit value which is already in force has been exceeded an air quality plan is required showing how compliance will be achieved as soon as possible.

Table 1.2 - Limit values and critical levels for SO_2

Objective	Averaging period	LV/CL	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	Already in force
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	Already in force
3. CL for the protection of vegetation	Calendar year and winter	20 $\mu g\ m^{-3}$	Already in force

Table 1.3 - Limit values and critical levels for NO_2 and NO_x

Objective	**Averaging period**	**LV/critical level**	**LV + MOT for 2009**	**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	210 $\mu g\ m^{-3}$, 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	42 $\mu g\ m^{-3}$, NO_2	1 January 2010
3. CL for the protection of vegetation	Calendar year	30 $\mu g\ m^{-3}$ NO_X, as NO_2	No MOT defined	Already in force

Table 1.4 - Limit values for PM_{10}

Objective	**Averaging period**	**LV**	**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	Already in force
2. Annual LV for the protection of human health	Calendar year	40 $\mu g\ m^{-3}$	Already in force

Table 1.5 - Limit values for Pb

Objective	**Averaging period**	**LV**	**Date by which LV is to be met**
Annual LV for the protection of human health	Calendar year	0.5 $\mu g\ m^{-3}$	Already in force

Table 1.6 - Limit values for C_6H_6

Objective	**Averaging period**	**LV**	**LV + MOT for 2009**	**Date by which LV is to be met**
Annual LV for the protection of human health	Calendar year	5 $\mu g\ m^{-3}$	6 $\mu g\ m^{-3}$	1 January 2010

Table 1.7 - Limit values for CO

Objective	**Averaging period**	**LV**	**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}	Already in force

1.6 Target Values and Long Term Objectives for ozone

The following metrics are relevant to the annual air quality assessment for O_3:

- Number of days above 120 μg m^{-3} in 2009
- Number of days above 120 μg m^{-3} per year averaged over three years 2007-2009
- AOT40 wheat crops in 2009
- AOT40 wheat crops averaged over five years 2005-2009

The AQD defines AOT40 as:

> "AOT40 (expressed in (μg m^{-3}) hours) means the sum of the difference between hourly concentrations greater than 80 μg m^{-3} (= 40 parts per billion) and 80 μg m^{-3} over a given period using only the one-hour values measured between 8.00 and 20.00 Central European Time (CET) each day."

The AQD target values (TV) and long term objectives (LTO) for O_3 are listed in Table 1.8 and Table 1.9.

Table 1.8 - Target values for O_3

Objective	Averaging period	TV	Date by which TV is to be met[1]
Protection of human health	Maximum daily eight-hour mean[2]	120 μg m^{-3} not to be exceeded on more than 25 days per calendar year averaged over three years	1 January 2010
Protection of vegetation	May to July	AOT40 (calculated from 1 h values) 18 000 μg m^{-3}. h averaged over five years[3]	1 January 2010

Table 1.9 - Long term objectives for O_3

Objective	Averaging period	LTO	Date by which LTO is to be met
Protection of human health	Maximum daily eight-hour mean within a calendar year	120 μg m^{-3}	Not defined
Protection of vegetation	May to July	AOT40 (calculated from 1 h values) 6000 μg m^{-3}. h	Not defined

In addition, Annex XII of the AQD includes Alert and Information Thresholds designed to inform the public and organisations representing sensitive population groups on occasions when there is increased a risk to human health from exposure to elevated levels of SO_2, NO_2 or ozone.

---

[1] Compliance with target values will be assessed as of this date. That is, 2010 will be the first year the data for which is used in calculating compliance over the following three or five years, as appropriate.

[2] The maximum daily eight-hour mean concentration shall be selected by examining eight-hour running averages, calculated from hourly data and updated each hour. Each eight -hour average so calculated shall be assigned to the day on which it ends. i.e. the first calculation period for any one day will be the period from 17:00 on the previous day to 01:00 on that day; the last calculation period for any one day will be the period from 16:00 to 24:00 on the day.

[3] If the three or five year averages cannot be determined on the basis of a full and consecutive set of annual data, the minimum annual data required for checking compliance with the target values will be as follows:
— for the target value for the protection of human health: valid data for one year,
— for the target value for the protection of vegetation: valid data for three years.

1.7 Target Value, Limits Values and National Exposure Reduction Target for $PM_{2.5}$

1.7.1 Target and limit values

The AQD defines a target value, limit values and exposure reduction targets for $PM_{2.5}$. This is the first ambient air quality directive to specify ambient concentrations for $PM_{2.5}$. The target and limit values for $PM_{2.5}$ are listed in Table 1.10 and Table 1.11.

Member states are required to take all necessary measures not entailing disproportionate costs to ensure that concentrations of $PM_{2.5}$ do not exceed the TV from the date specified. Member states are required to ensure that concentrations of $PM_{2.5}$ do not exceed the LV from the date specified.

Table 1.10 - Target values for $PM_{2.5}$

Objective	Averaging period	TV	Date by which TV is to be met
Protection of human health	Calendar year	25 µg m^{-3}	1 January 2010

Table 1.11 - Limit values for $PM_{2.5}$

Objective	Averaging period	LV	LV + MOT for 2009	Date by which LV is to be met
STAGE 1				
Protection of human health	Calendar year	25 µg m^{-3}	29 µg m^{-3}	1 January 2015
STAGE 2*				
Protection of human health	Calendar year	20 µg m^{-3}	No MOT defined	1 January 2020

* Indicative limit value to be reviewed by the commission in 2013.

1.7.2 Average exposure indicator

Annex XIV of the Air Quality Directive defines an average exposure indicator:

"The Average Exposure Indicator expressed in µg m^{-3} (AEI) shall be based upon measurements in urban background locations in zones and agglomerations throughout the territory of a Member State. It should be assessed as a three-calendar year running annual mean concentration averaged over all sampling points established pursuant to Section B of Annex V. The AEI for the reference year 2010 shall be the mean concentration of the years 2008, 2009 and 2010.

However, where data are not available for 2008[4], Member States may use the mean concentration of the years 2009 and 2010 or the mean concentration of the years 2009, 2010 and 2011. Member States making use of these possibilities shall communicate their decisions to the Commission by 11 September 2008.

---

[4] Measurement data are not available for the UK for 2008 and hence the AEI will be determined from the mean concentration of the years 2009, 2010 and 2011.

The AEI for the year 2020 shall be the three-year running mean concentration averaged over all those sampling points for the years 2018, 2019 and 2020. The AEI is used for the examination whether the national exposure reduction target is met.

The AEI for the year 2015 shall be the three-year running mean concentration averaged over all those sampling points for the years 2013, 2014 and 2015. The AEI is used for the examination whether the exposure concentration obligation is met."

1.7.3 National exposure reduction target

Member states are required to take all steps not entailing excessive costs to reduce exposure to $PM_{2.5}$ with a view to attaining the national exposure reduction target list in Table 1.12. Member states are also required to ensure that the average exposure indicator for the year 2011 does not exceed the exposure concentration obligation listed in Table 1.13.

Table 1.12 - National exposure reduction target for $PM_{2.5}$

Exposure reduction target relative to the AEI in 2010		Year by which the exposure reduction target should be met
Initial concentration in µg m^{-3}	Reduction target in %	
≤ 8.5	0	2020
> 8.5 – < 13	10	
13 – < 18	15	
18 – < 22	20	
≥ 22	All appropriate measures to achieve 18 µg m^{-3}	

1.7.4 Exposure concentration obligation

Table 1.13 - Exposure concentration obligation for $PM_{2.5}$

Exposure concentration obligation	Year by which the obligation value is to be met
20 µg m^{-3}	2015

The air quality assessment for 2009 included a comparison of $PM_{2.5}$ concentrations with the target value.

1.8 Data quality objectives for modelling results and model verification

The AQD sets data quality objectives (DQO's) for modelling accuracy, within supplementary assessment under the AQD. Accuracy is defined in the Directive as the maximum deviation of the measured and calculated concentration levels for 90% of individual monitoring points over the period considered by the limit value, without taking into account the timing of events. The uncertainty of modelling should be interpreted as applicable in the region of the appropriate LV or TV. The fixed measurements that have been selected for comparison with the modelling results should be representative of the scale covered by the model. Final guidance clarifying the recommended methods for assessing model performance with respect to the DQOs has yet to be agreed. The comparisons with monitoring data presented in this report have therefore included data from all sites including those with measured values not in the vicinity of the LV or TV and a highly detailed assessment of the spatial representativity of the sites has not been carried out.

DQO's have been set at 50% for hourly averages, daily averages and 8 hour averages. DQO's have been set at 30% for annual averages of SO_2, NO_2 and NO_x. For PM_{10}, $PM_{2.5}$ and Pb the DQO for annual averages is 50%. DQO's have not been defined for daily averages of PM_{10}.

The models used to calculate the maps of air pollutants presented in this report have been calibrated using data from the national monitoring network 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 DQO's 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. For 2009 monitoring data has also been obtained from the London Air Quality Network (LAQN) and Hertfordshire and Bedfordshire Air Quality Monitoring Network, courtesy of ERG (Green, pers. comm., 2010). 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.

1.9 Air quality modelling

Full details of the modelling methods implemented are given in Sections 2-9. A brief introduction is presented here.

1.9.1 Background concentration maps

Maps showing background concentrations for NO_X, SO_2, C_6H_6 and CO have been calculated for the relevant metrics laid out in the AQD at a 1 km x 1 km resolution. These maps have been calculated by summing concentrations from the following layers:

- Large point sources[5] – modelled using the air dispersion model ADMS and emissions estimates from the National Atmospheric Emissions Inventory (NAEI)
- Small point sources – modelled using the small points model and emissions estimates from the NAEI
- Distant sources – characterised by the rural background concentration
- Area sources[6] – modelled using a dispersion kernel and emissions estimates from the NAEI
- Fugitive point source emissions – modelled using fugitive source kernel model and an estimate of the fugitive component of emissions derived from the NAEI (C_6H_6 only).

For PM_{10} and $PM_{2.5}$ a similar approach has been used to generate 1 km x 1 km background concentration maps. For these pollutants, the following layers have been included:

- 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

---

[5] Point source emissions are defined as emissions of a known amount from a known location (e.g. a power station).

[6] Area source emissions are defined as 'diffuse emissions' from many unspecified locations. (e.g. emissions from domestic heating, or from shipping).

- 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

1 km x 1 km background concentration maps for Pb have been calculated from the following layers:

- Large point source emissions – modelled using ADMS and emissions estimates from the NAEI
- Small point source emissions – modelled using a small points kernel model and emissions estimates from the NAEI
- Fugitive point source emissions – modelled using fugitive source kernel model and an estimate of the fugitive component of emissions derived from the NAEI
- Area sources emissions – modelled using a dispersion kernel and emissions estimates from the NAEI
- Regional concentration of Pb – derived from estimates of primary PM from regional sources calculated using the TRACK model and emissions estimates from the NAEI and EMEP
- Re-suspension of Pb from bare soils – derived from estimates of re-suspension of PM modelled using a dispersion kernel and information on land use
- Re-suspension of Pb as a result of vehicle movements – derived from estimates of re-suspension of PM modelled using a dispersion kernel and vehicle activity data for heavy duty vehicles

1.9.2 Roadside concentration maps

Maps showing modelled roadside concentrations of NO_X, PM_{10}, $PM_{2.5}$, C_6H_6 and CO have been calculated for 9306 urban major road links (A-roads and motorways) across the UK. These have been calculated by adding a ‘roadside increment’ concentration component to the modelled background concentration for each road. This roadside increment concentration is calculated as a function of a road link emission that has been adjusted to take into account traffic flow. The roadside increment model is then calibrated using monitoring data from the AURN. This is a similar approach to that used within the DMRB Screening Model (Boulter, Hickman, and McCrae, 2003).

1.9.3 NO_2 maps

Background and roadside NO_2 concentration maps have been calculated by applying a calibrated version of the updated oxidant-partitioning model. This model describes the complex inter-relationships between NO, NO_2 and O_3 as a set of chemically coupled species (Jenkin, 2004; Murrells et al., 2008).

1.9.4 Key input data

Emissions inventory data used in this modelling is taken from the NAEI for 2008 (Murrells et al., 2010). Emission estimates for area sources have been scaled forward to 2009. The method for calculating emissions from aircraft and shipping was revised for the 2008 modelling and the same approach has been used in the air quality modelling for 2009. The work carried out to check that the revised aircraft and shipping emissions were suitable for use in the PCM model is described in Appendix 4. Dispersion modelling has been done using ADMS 4.2 using meteorological data from Waddington for 2009. UK national network monitoring data has used to calibrate the background and roadside models.

1.9.5 Ozone maps

Maps of the O_3 metrics specified in the AQD have been calculated using a different modelling approach to the approach used for other pollutants in this report. This is because of the complex chemistry involved in the production and destruction of O_3. The more empirical methods used to model O_3 concentrations are described in Section 9.

1.10 Air quality in Gibraltar in 2009

Air quality monitoring and assessments are also undertaken in Gibraltar and the results of the assessment are submitted to the Commission each year via a separate questionnaire to that compiled for the UK (CDR, 2010). Further information on air quality monitoring in Gibraltar can be found at http://www.gibraltarairquality.gi/.

2 NO_2/NO_X

2.1 Introduction

2.1.1 Limit values

Two limit values for ambient NO_2 concentrations are set out in the Air Quality Directive (AQD). These have been specified for the protection of human health and have come into force from 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 exceedances each year

A critical level for NO_X for the protection of vegetation has also been specified in the directive:

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

As this critical level is designed to protect vegetation it only applies in vegetation areas defined in the directive. This critical level is already in force.

2.1.2 Annual mean modelling

Annual mean concentrations of NO_X and NO_2 have been modelled for the UK for 2009 at background and roadside locations. Figure 2.1 and Figure 2.2 present maps of annual mean NO_2 concentrations for these locations in 2009. These maps have been used for comparison with the annual mean NO_2 limit value described above. To calculate NO_2 annual mean maps, NO_X annual mean concentration maps at background and roadside locations were first calculated.

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., 2001a, Stedman et al., 2001b, 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, Grice et al., 2010).

2.1.3 Outline of the annual mean model for NO_X

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 2009. 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 2.2.

2.1.4 Outline of the annual mean model for NO_2

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.

2.1.5 Annual mean NO_X concentration in vegetation areas

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 critical level described above. This map is shown in Figure 2.3. 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 x 1 km grid squares for a 30 km x 30 km grid so that it complies with the criteria set out in the Directive. Mean concentrations on a 30 km x 30 km 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 critical level.

2.1.6 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 2.4, which is a scatter plot of annual mean NO_2 in 2009 against the 99.8th percentile of hourly mean concentration (equivalent to 18 exceedances 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.

The only site on the scatter plot where the hourly limit value appears more stringent that the annual limit value is Glasgow Centre. At this site the relatively high number of hours exceeding the hourly limit value can be attributed to the presence of a generator used in a Christmas market in close proximity to the monitoring site (Willis, pers. comm, 2010).

2.1.7 Chapter structure

This chapter describes modelling work carried out for 2009 to assess compliance with the NO_X and NO_2 limit values and critical level described above. Section 2.2 describes the NO_X modelling methods. Details of the methods used to estimate ambient NO_2 from NO_X are presented in Section 2.3. The modelling results are presented in Section 2.4.

Figure 2.1 - Annual mean background NO_2 concentration, 2009 ($\mu g\ m^{-3}$)

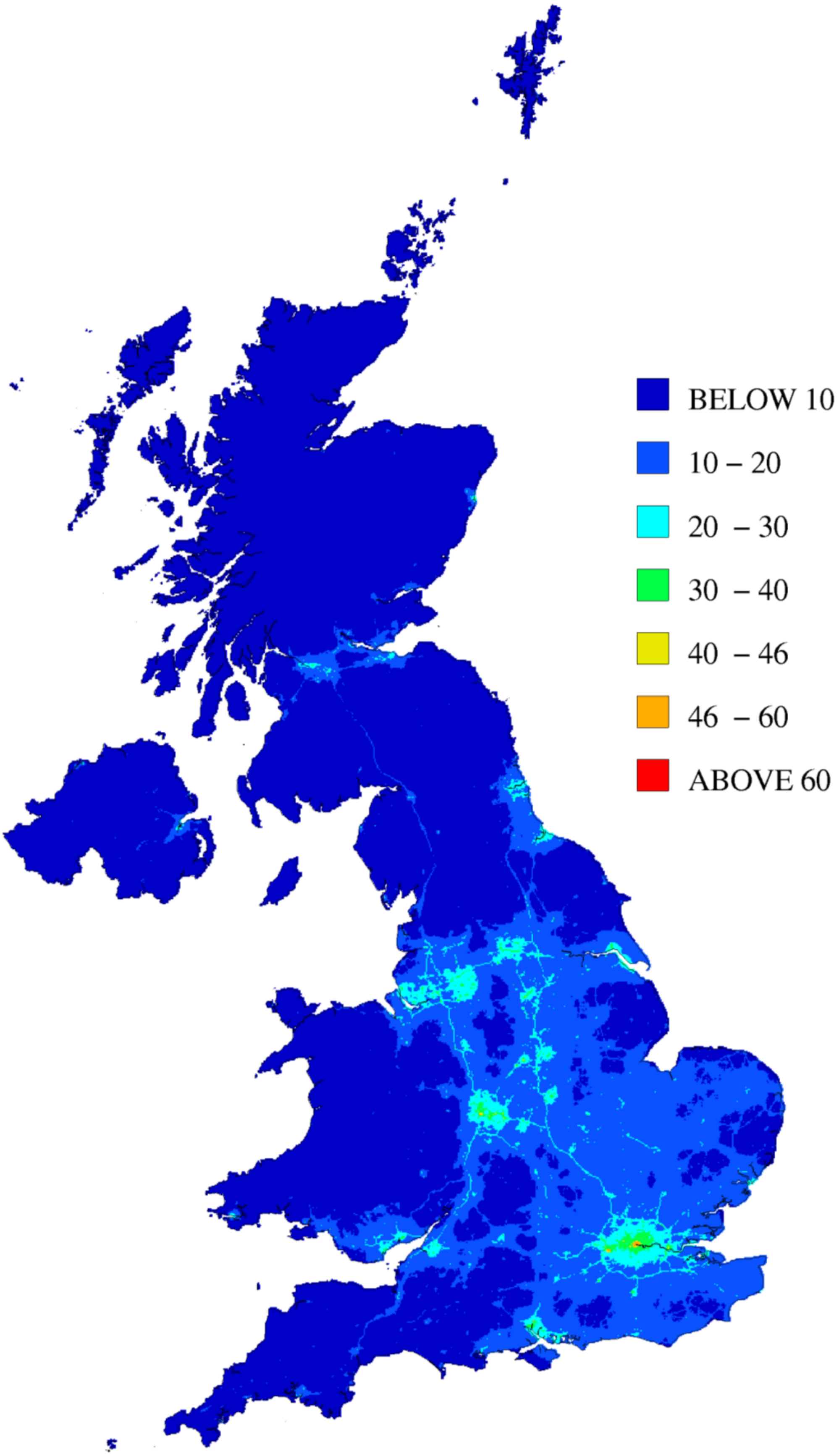


Figure 2.2 - Urban major roads, annual mean roadside NO_2 concentration, 2009 ($\mu g\ m^{-3}$)

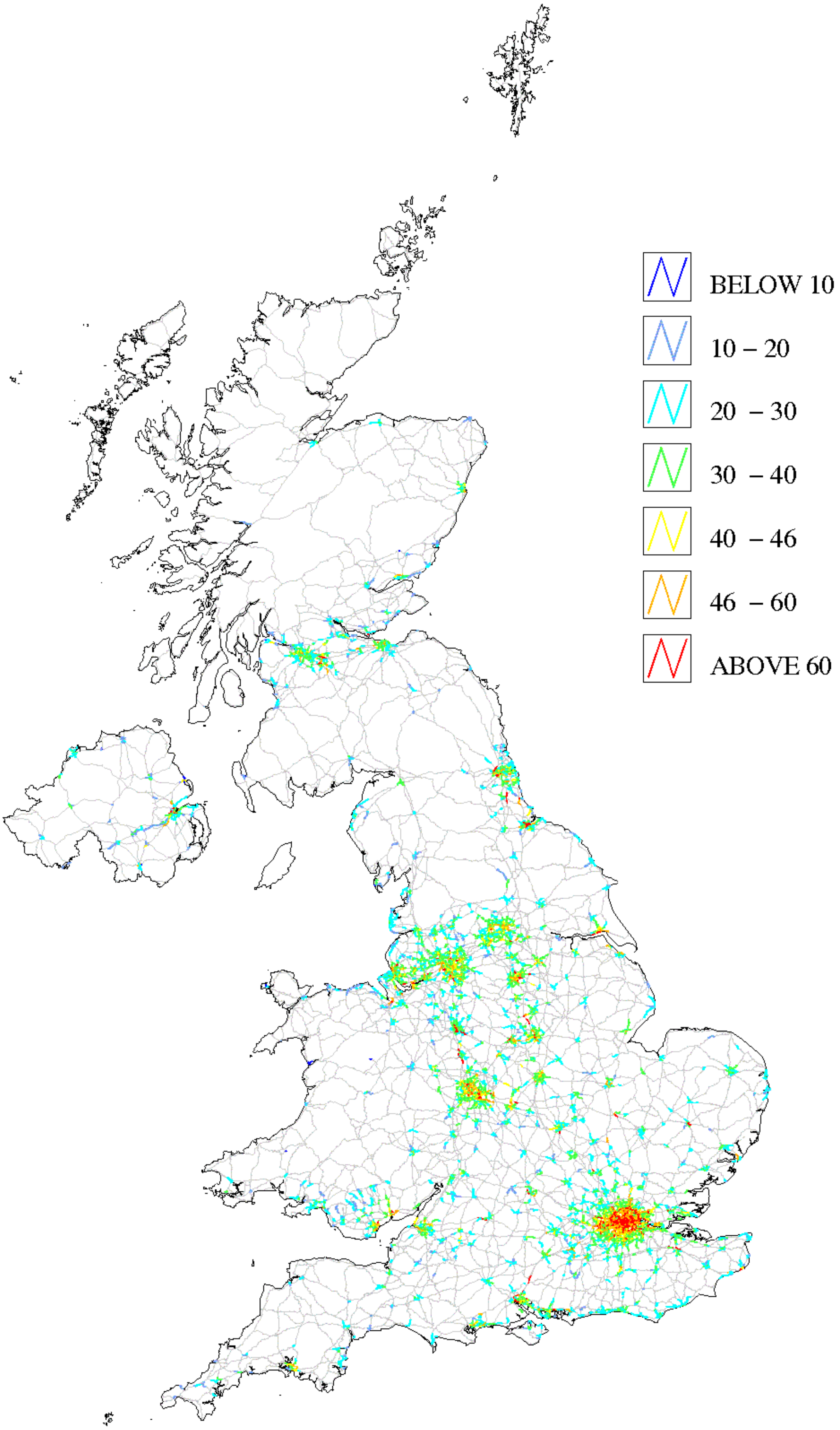


Figure 2.3 - Annual mean map of NO_x concentrations for comparison with the NO_x vegetation critical level, 2009 (µg m^{-3}, as NO_2)

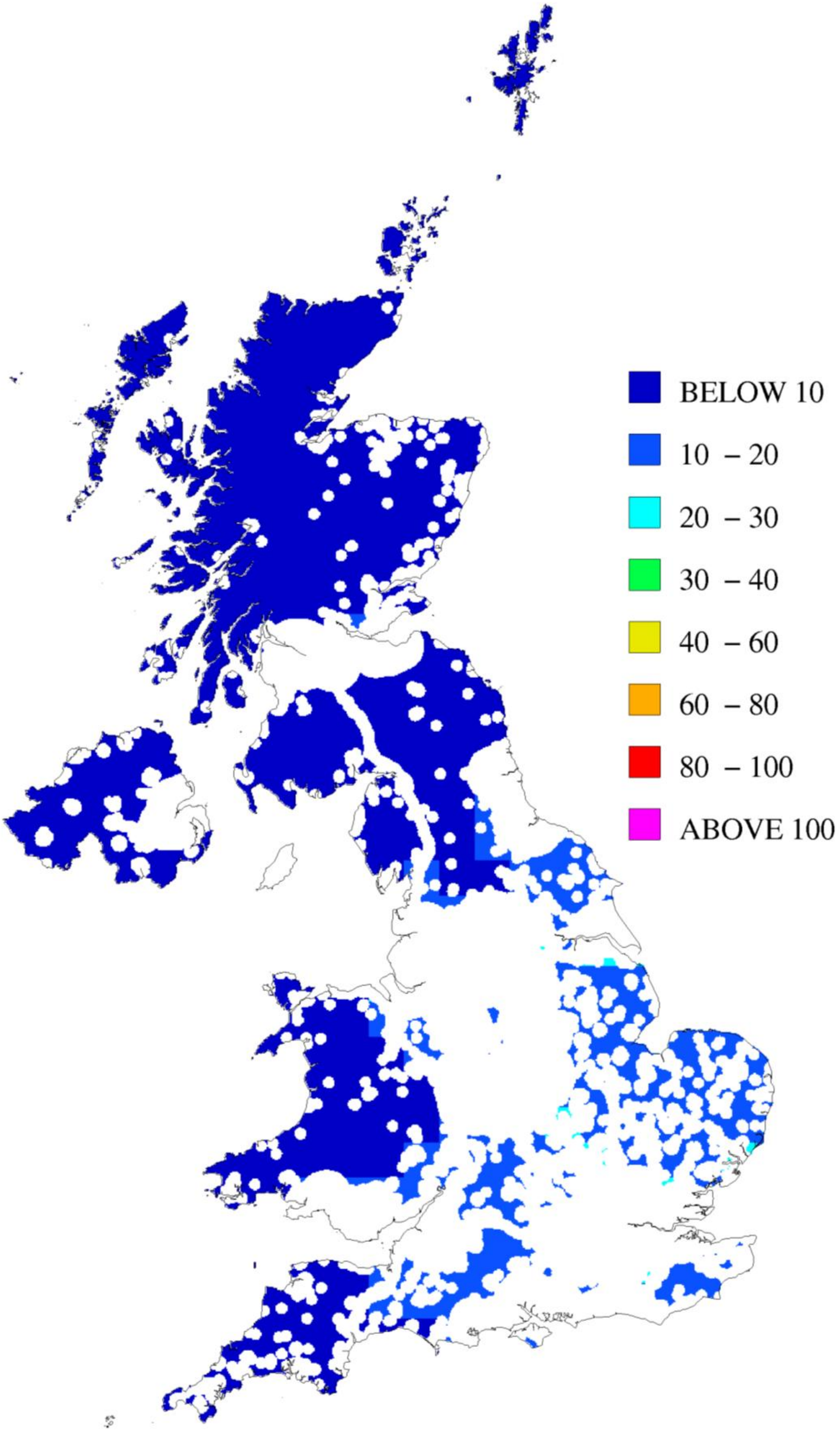
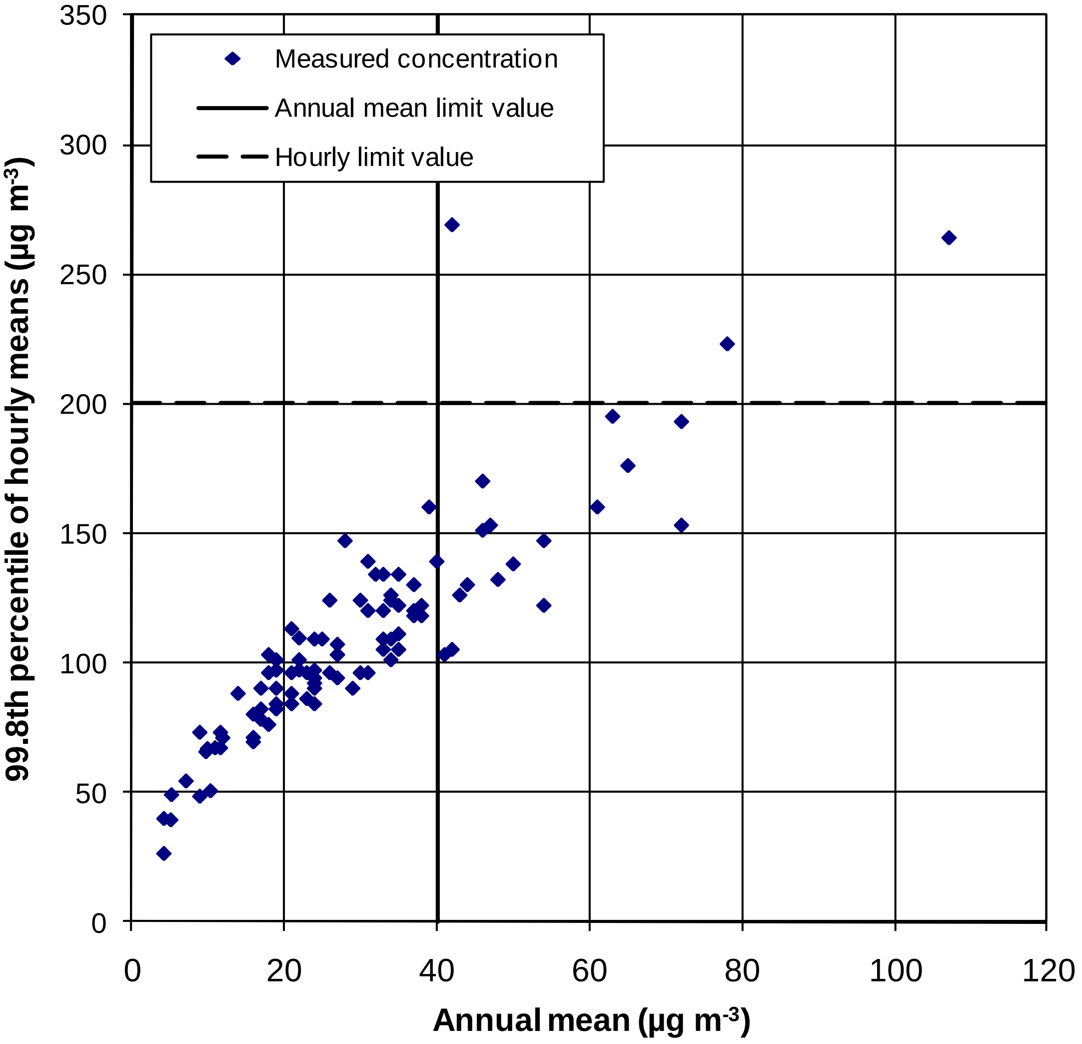


Figure 2.4 - Plot of annual mean against 99.8th percentile hourly NO_2 concentrations in 2009



2.2 NO_x modelling

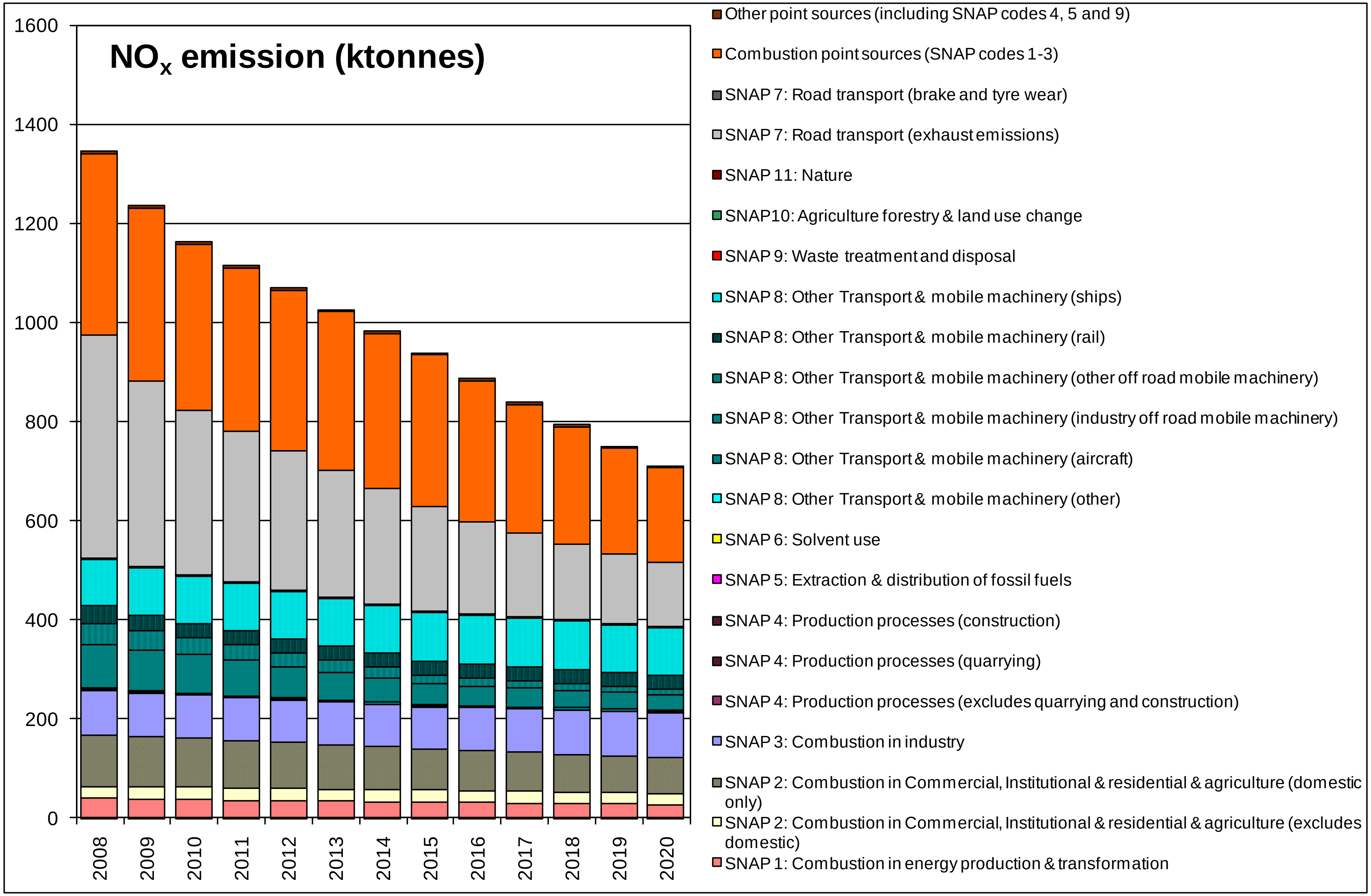
2.2.1 NO_x emissions

The NO_X modelling is underpinned by the NAEI 2008 NO_X emissions estimates (Murrells et al., 2010). Figure 2.5 shows UK total NO_X emissions for 2008 and emissions projections up to 2020 split by SNAP code. This shows that NO_X emissions in 2008 are dominated by two main sources:

- SNAP 7: road transport (exhaust emissions)
- Combustion point sources (SNAP codes 1, 2 and 3)

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

Figure 2.5 - Total UK NO_X emissions for 2008 and emissions projections up to 2020 by SNAP code from NAEI 2008



2.2.2 NO_X contributions from large point sources

Point sources in the 2008 NAEI have been classified as large if they fulfil either of the following criteria:

- NO_X emissions in the 2008 NAEI are greater than 500 tonnes for any given plant
- Stack parameters are already available for any given plant in the PCM stack parameters database (described in more detail below)

Contributions to ground level annual mean NO_X concentrations from large point sources in the 2008 NAEI were estimated by modelling each source explicitly using an atmospheric dispersion model (ADMS 4.2) and sequential meteorological data for 2009 from Waddington. A total of 167 large point sources were modelled for NO_X. Surface roughness was assumed to be 0.1 m at the dispersion site and 0.02 m at the meteorological site. 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 the PCM 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.

There are some point sources in the 2008 NAEI which closed before the start of 2009. Hence, these point sources have been removed from the modelling for 2009.

2.2.3 NO_X contributions from small point sources

Contributions from NO_X point sources in the 2008 NAEI which were not classified as large point sources (see above) were modelled using the small points model described in Appendix 2.

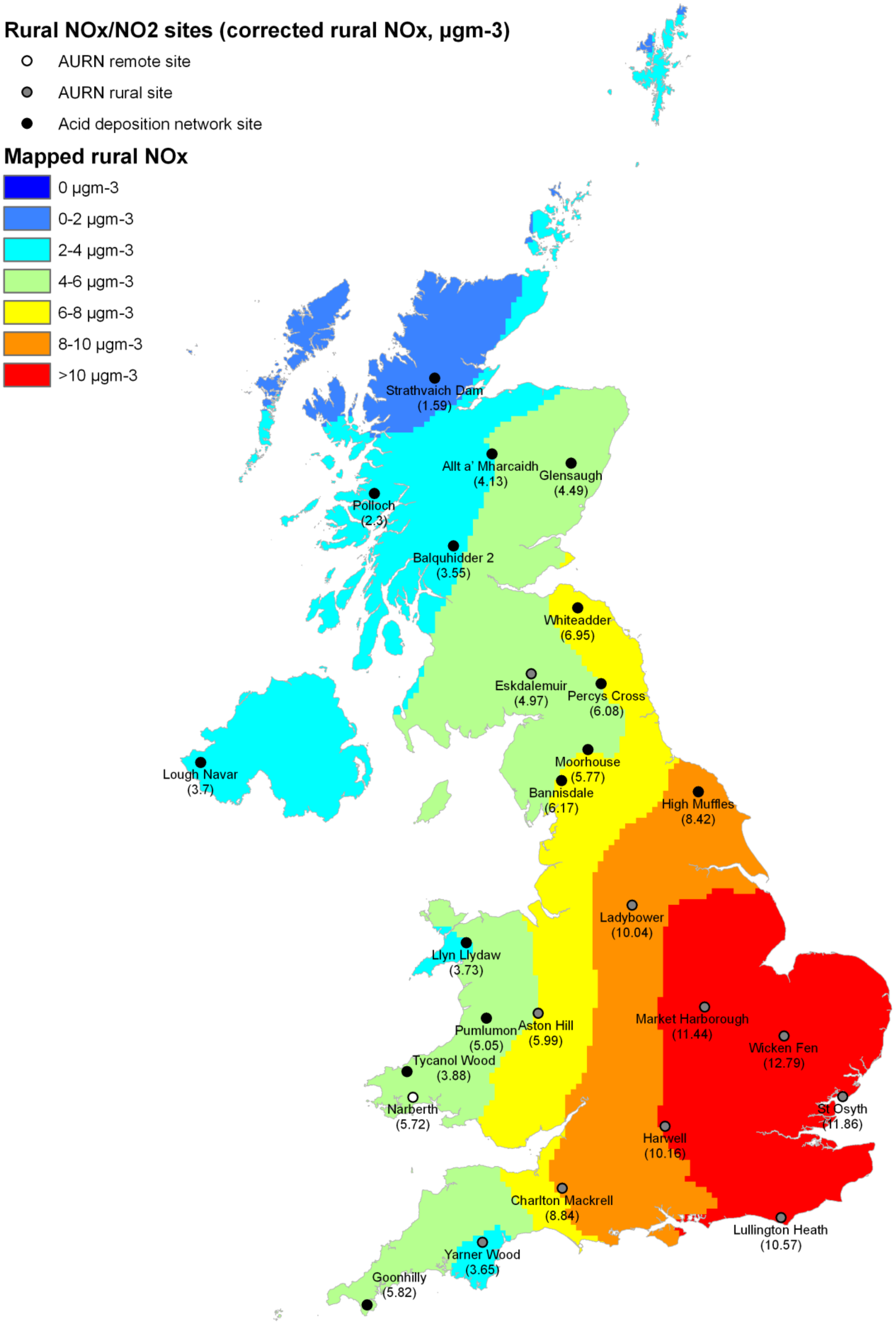
2.2.4 NO_X contribution from rural background concentrations

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 15 rural NO_2 diffusion tube sites from the Acid Deposition Monitoring Network.

Figure 2.6 shows the locations of these monitoring sites and the interpolated rural map.

Figure 2.6 - Rural background NO_X concentrations map with monitoring sites used in the interpolation (annual mean NO_X concentrations for 2009 ($\mu g\ m^{-3}$, as NO_2) are shown below the site name)



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 (µg m^{-3}*) = Uncorrected rural background (µg 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 2008 modelling,

B is the sum of contributions from large point sources in 2009 modelling,

C is the sum of contributions from small point sources in 2009 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.

2.2.5 NO_X contributions from local area sources

In the 2008 NAEI, NO_X area source emissions maps are calculated for each source code-activity code combination using distribution grids that have been generated using appropriate surrogate statistics. These NO_X emissions grids are then added together to give SNAP code sector NO_X area source emission grids. The full method is described in Tsagatakis et al. (2010). To calculate NO_X area source emission grids for 2009, emissions projections from the NAEI (Wagner pers. comm. 2010) have been used for each source code-activity code combination to scale 2008 emissions forwards to 2009. The emissions projections are based on DECC's UEP38 energy projections (DECC, 2009). The 2009 area source NO_X emissions have then been mapped using the same distribution grids as for the 2008 maps.

The 2009 area source emissions maps have then be used to calculate uncalibrated area source concentration maps for each SNAP code sector. This has been done by applying an ADMS 4.2 derived dispersion kernel to the emission maps 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 2009 has been used to construct the dispersion kernels. Appendix 3 describes these kernels in more detail and explains how they have been calculated.

Figure 2.7 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 concentration is compared with the modelled area source contribution to annual mean NO_X concentrations to calculate the calibration coefficients used in the area source modelling.

As part of the calibration process concentration caps have been applied to certain sectors. This is because the use of surrogate statistics for mapping area source emissions sometimes results in unrealistically large concentration in some grid squares for a given sector. The concentration caps applied are given in Table 2.1.

The modelled area source contributions for each sector were 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 2.7 - Calibration of area source NO_x model, 2009 ($\mu g\ m^{-3}$, as NO_2)

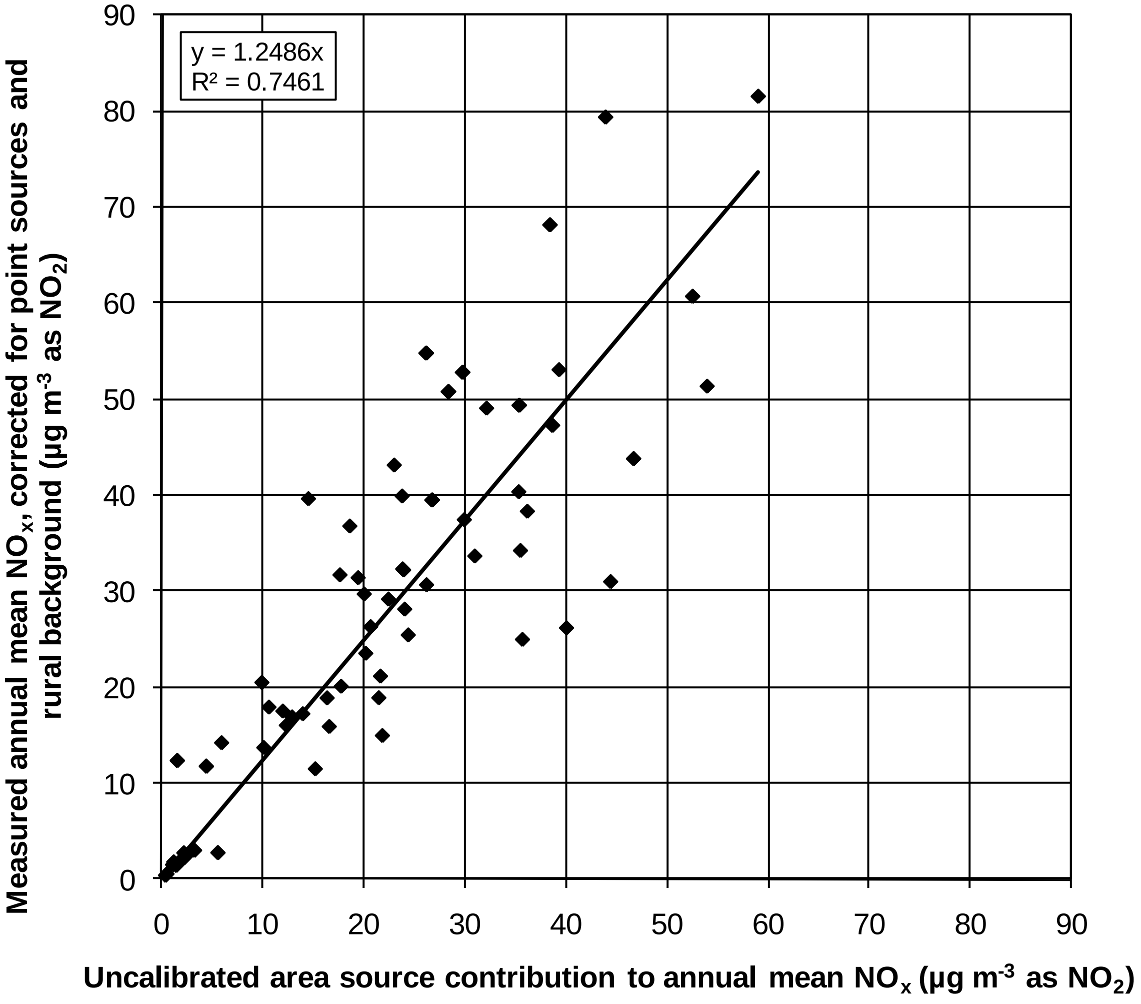


Table 2.1 - Concentration caps applied to NO_X sector grids

SNAP code	Description	Cap applied ($\mu g\ m^{-3}$)*
SNAP 1	Combustion in Energy Production & Transformation	12.0
SNAP 3	Combustion in Industry	24.0
SNAP 4	Production process	12.0
SNAP 8 (industrial off road machinery only)	Other Transport & Mobile Machinery	36.0
SNAP 8 (shipping only)	Other Transport & Mobile Machinery	24.0

*Caps listed are for calibrated concentrations

2.2.6 NO_X Roadside concentrations

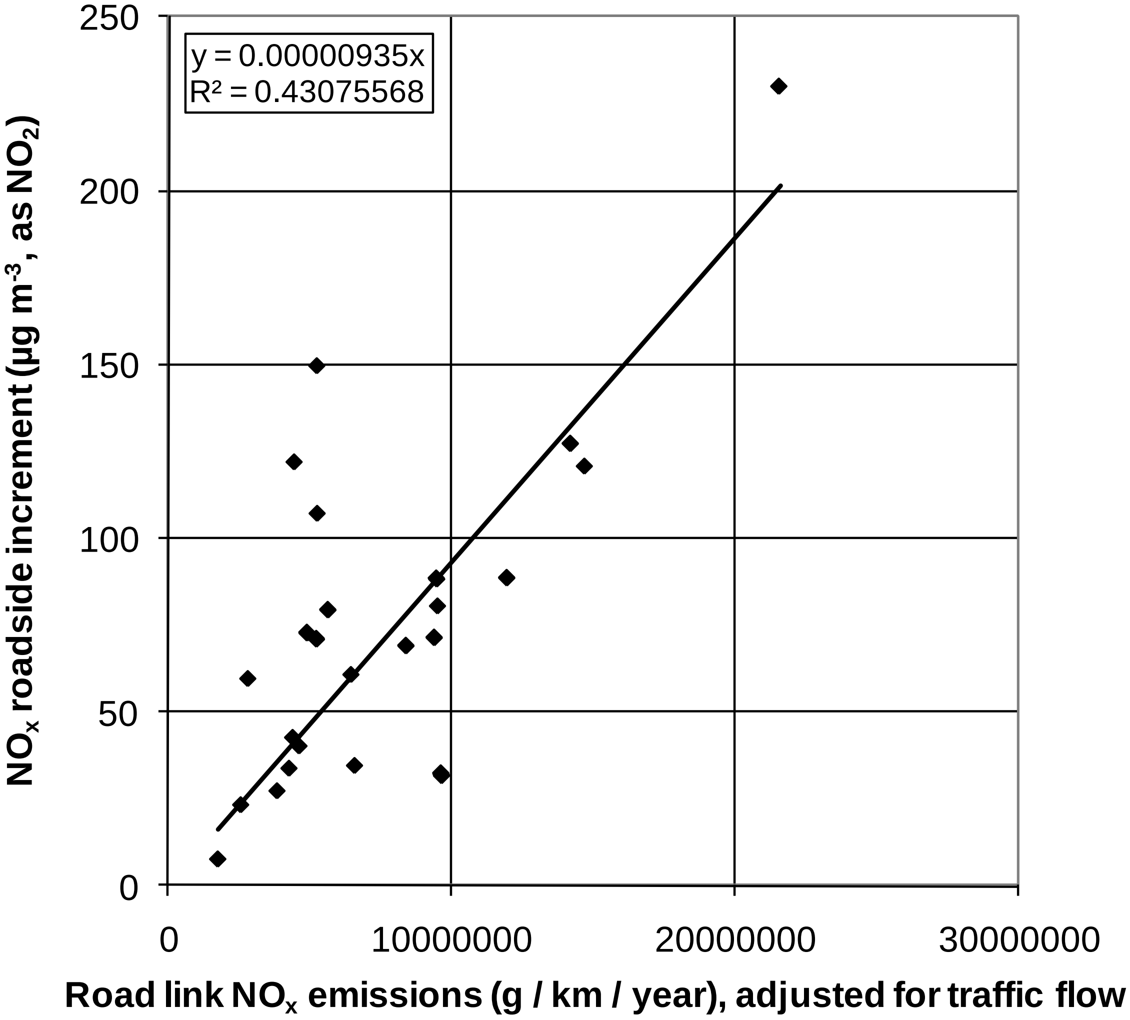
The annual mean concentration of NO_X at roadside locations has been assumed to be made up of two parts: the background concentration (as described above) and a roadside increment:

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 2008 (Murrells et al., 2010) and these have been adjusted to provide estimates of emissions in 2009. Figure 2.8 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 2.2.4 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 2.8). The average distance from the kerb for the roadside and kerbside monitoring sites used to calibrate the roadside increment model is about 4 m. The calculated roadside concentrations are therefore representative of this distance from the kerb. Roadside concentrations for urban major road links (A-roads and motorways) only are reported to the EU and included in this report.

Figure 2.8 - Calibration of NO_X roadside increment model, 2009 ($\mu g\ m^{-3}$, as NO_2)



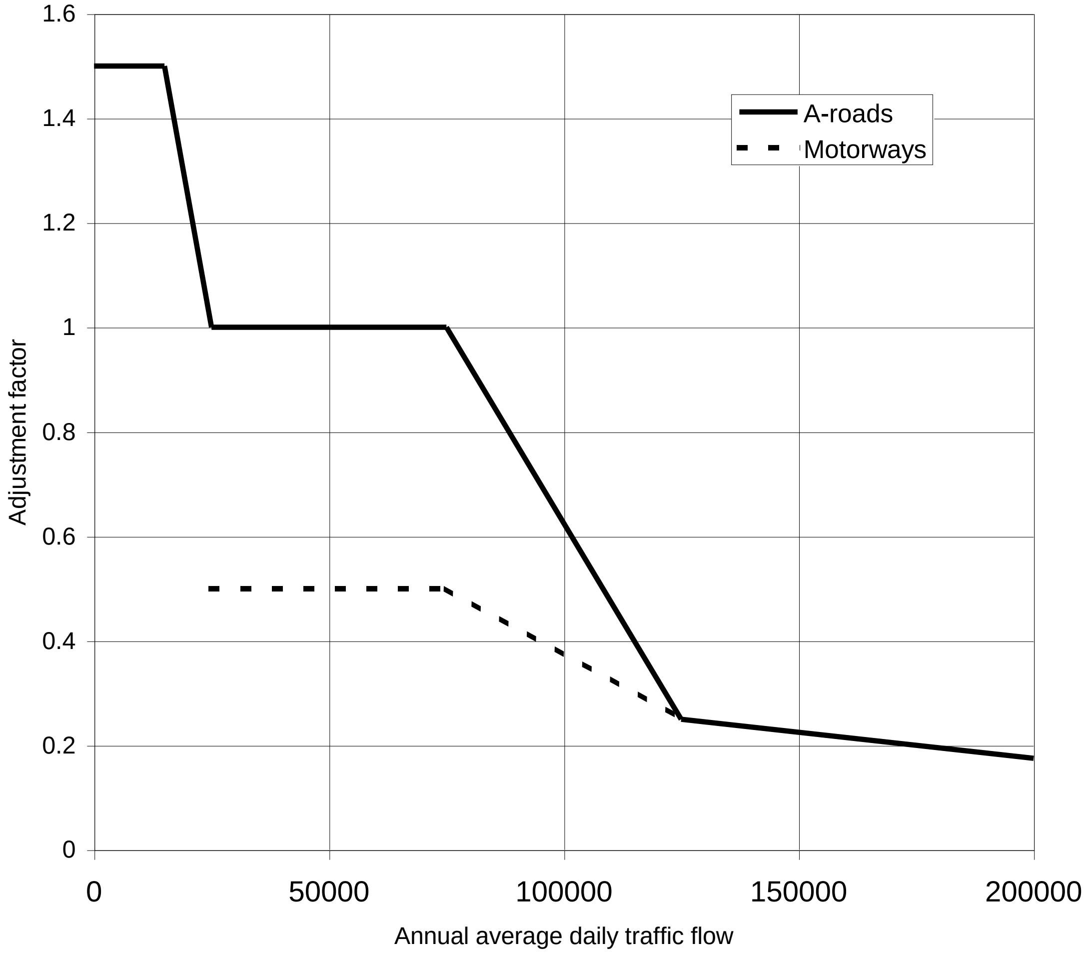
The dispersion of emissions from vehicles travelling along an urban road is influenced by a number of factors. These factors generally contribute to make the dispersion of emissions less efficient on urban roads with lower flows. Factors include:

- 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 (buildings close to the road result in a more confined setting and hence reduced dispersion)

Only urban roads have been considered 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. An approach similar to that used within the DMRB Screening Model (Boulter, Hickman, and McCrae, 2003) has therefore been adopted and adjustment factors applied to the estimated emissions. These adjustment factors are illustrated in Figure 2.9 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 2.9.

Figure 2.9 - The adjustment factors applied to road link emissions



2.3 NO_2 Modelling

2.3.1 Introduction

Maps of estimated annual mean NO_2 concentrations (Figure 2.1 and Figure 2.2) have been calculated from the 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 emission scenarios can be directly addressed by varying regional oxidant levels and/or primary NO_2 emissions.

2.3.2 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):

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

Where [OX] is the total oxidant (the sum of NO_2 and O_3), f-NO2 is the primary NO_2 emission fraction (defined as the proportion of NO_X emitted directly as NO_2) and $[OX]_B$ 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 have been used in the modelling here. These are better than the original equations presented in Jenkin (2004) because they account 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:

- One 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 2.2 below. They have been derived to apply at sites with different levels of inter-hour 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 2.2 - 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 $y = [NO_2]/[OX]$ and $x = [NO_x]$, 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 2.3.3), local oxidant calculations for background and roadside locations (Section 2.3.4), calculating $[NO_2]/[OX]$ in the PCM model and how the updated oxidant-partitioning model has been applied in the UK to background and roadside locations (Section 2.3.5).

2.3.3 UK regional oxidant map

A map of UK regional oxidant for 2009 ($[OX]_B$ 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:

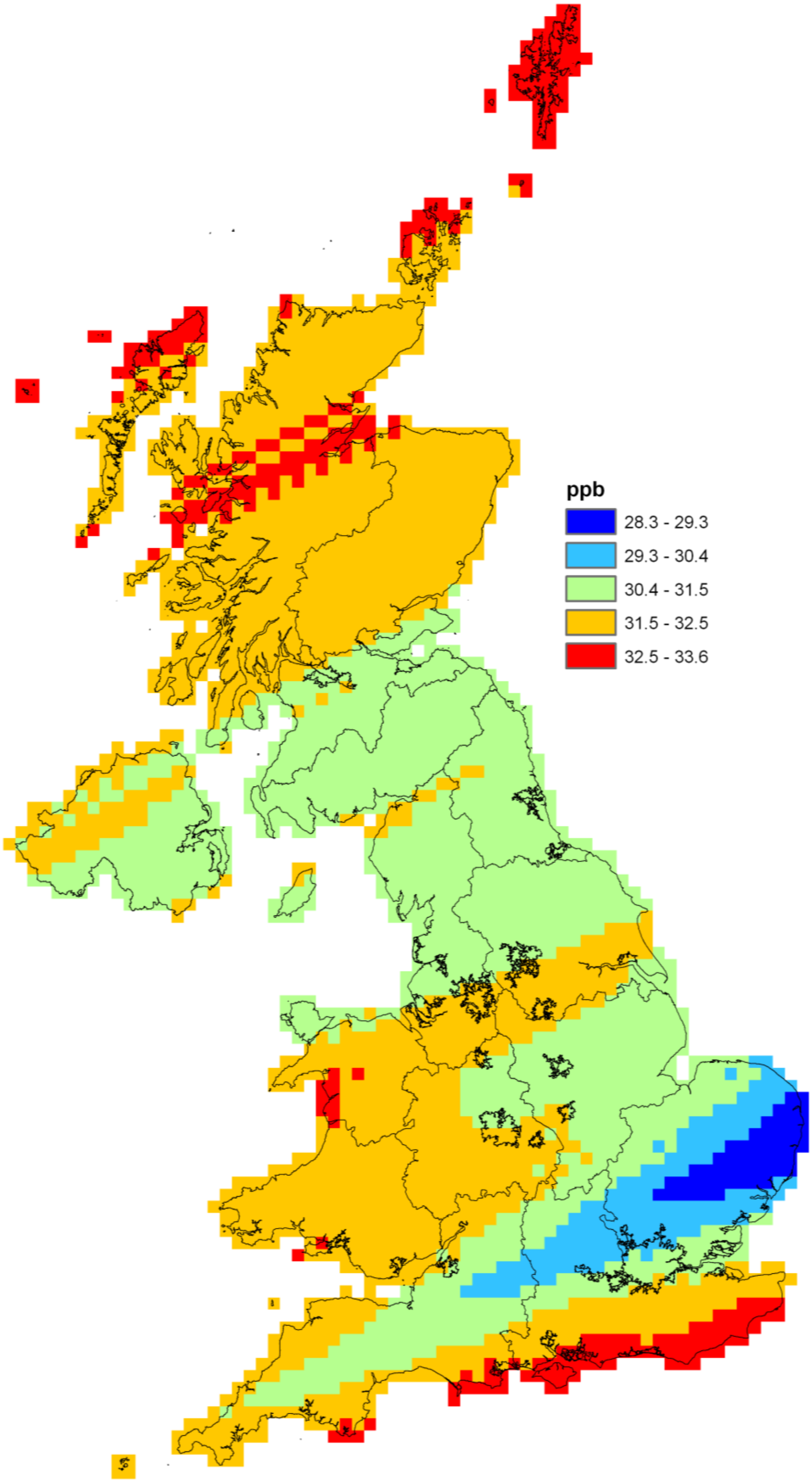
$$[OX]_B = [OX]_H + [OX]_R \,, \qquad (iv)$$

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 2.10 shows the map of regional oxidant for 2009. Values have been calculated on a 10 km x 10 km grid.

Figure 2.10 - Regional oxidant $[OX]_B$ for 2009 (ppb)



2.3.4 Local oxidant calculations

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

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

Where $f\text{-}NO_2$ is the fraction of NO_x emissions emitted as primary NO_2 (by volume). Therefore to calculate local oxidant levels, the $f\text{-}NO_2$ levels from different local sources need to be understood. In general it is possible to make a distinction between $f\text{-}NO_2$ from road traffic sources and $f\text{-}NO_2$ from non-road traffic sources. $f\text{-}NO_2$ from road traffic sources is thought to be generally rising, although this trend displays considerable variation with location (AQEG, 2007). By comparison, $f\text{-}NO_2$ from non-traffic sources has remained relatively constant with time.

2.3.4.1 $f\text{-}NO_2$ for road traffic sources on individual road links

Figure 2.11 shows fleet average $f\text{-}NO_2$ projections by vehicle type for London and the rest of the UK from the NAEI 2008.

This shows that London buses in 2009 had a much higher $f\text{-}NO_2$ (up to 28.8%) than buses outside of London (approximately 12.8%). A rapid decline in $f\text{-}NO_2$ from London buses is expected so that by 2020 they are expected reach a similar level to buses outside London at approximately 10%.

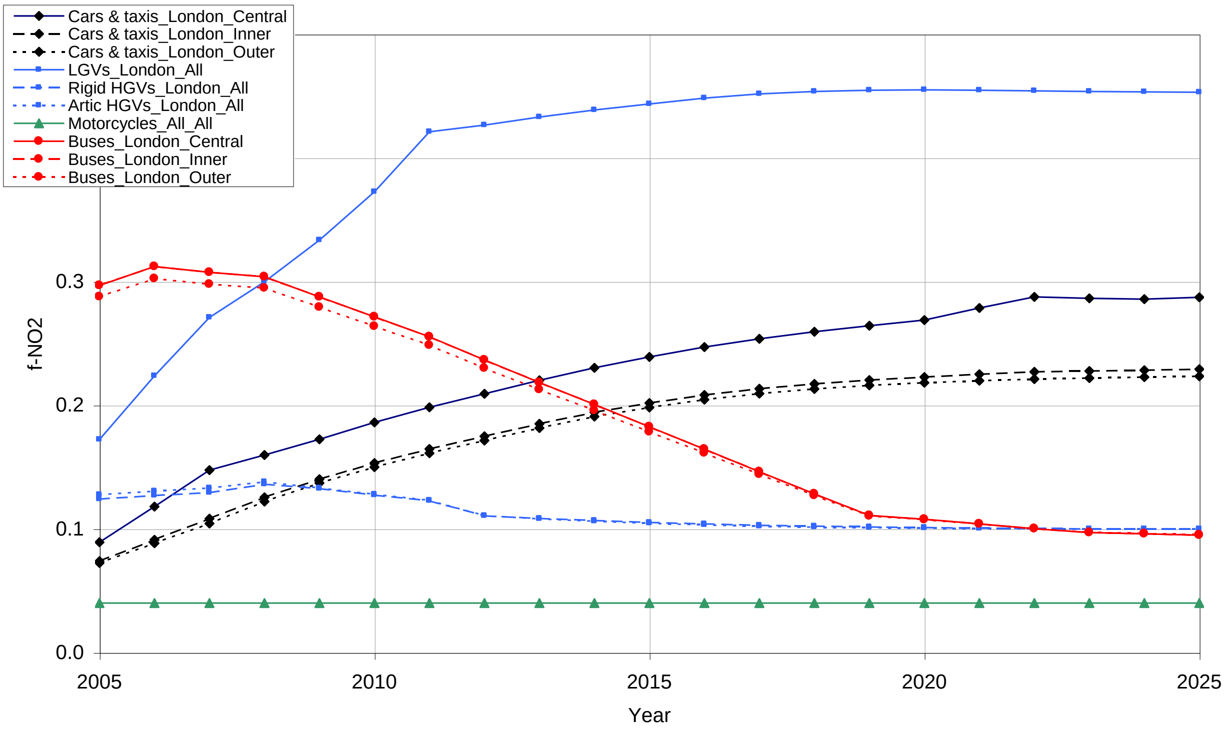
Cars and taxis are lumped together in these fleet average $f\text{-}NO_2$ projections. Three distinct geographical areas are picked out: London, Northern Ireland and the rest of the UK. For all three locations, $f\text{-}NO_2$ from cars and taxis is expected to rise significantly between 2005 and 2020. 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 $f\text{-}NO_2$ than petrol cars.

Fleet average $f\text{-}NO_2$ 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 steeper in London because of the impact of the Low Emission Zone (LEZ) on LGV fleet make up in London.

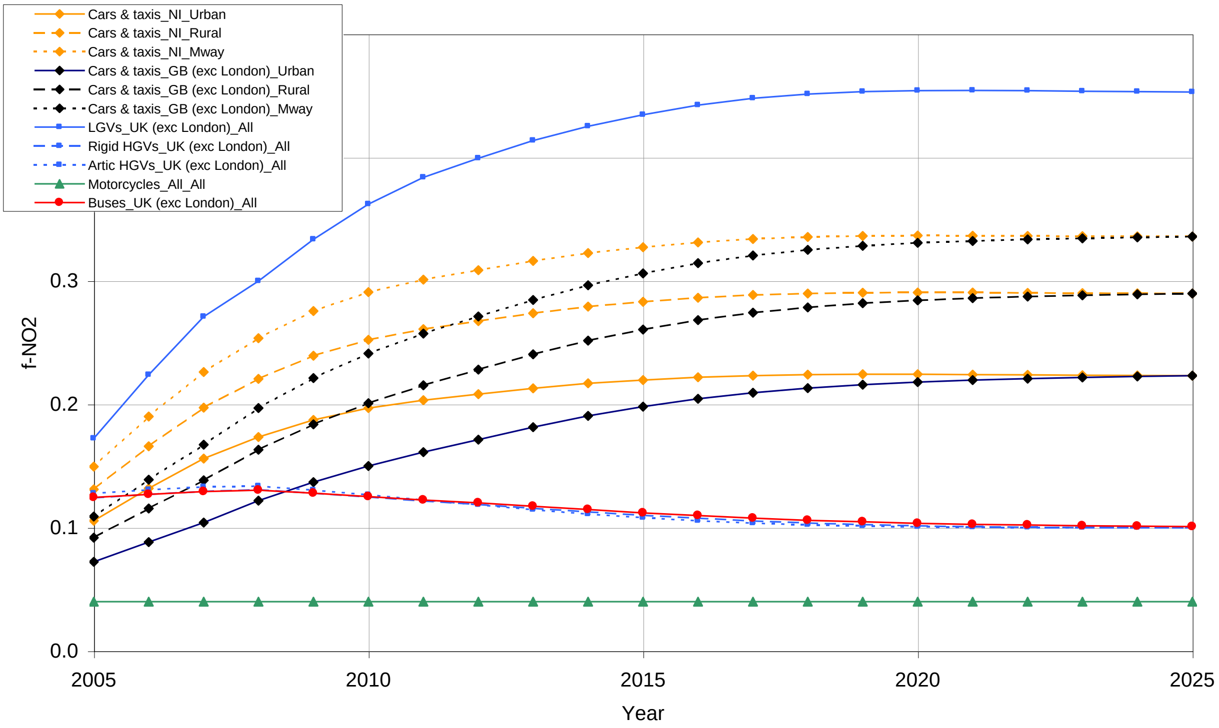
For each road link, these vehicle specific $f\text{-}NO_2$ factors have been applied to NO_X road link emissions for each vehicle class to calculate a road link specific $f\text{-}NO_2$ from traffic sources. This method therefore takes into account the vehicle split on each road link, but assumes that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

Figure 2.11 - Fleet average f-NO2 projections by vehicle type for a) London and b) rest of the UK from NAEI 2008

a) London



b) Rest of the UK



2.3.4.2 *f-NO_2 for background sources*

Table 2.3 shows the *f-NO_2* values used for background sources in 2009.

The non-road *f-NO_2* values used for background calculations in Table 2.3 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 2.3 - Local oxidant coefficients (f-NO_2) for background concentrations in 2009

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	0.237
2	Inner London	0.128	0.214
3	Outer London	0.093	0.192
4	Inner Conurbations	0.093	0.160
5	Outer Conurbations	0.093	0.166
6	Urban (population > 250,000)	0.093	0.163
7	Urban (population > 100,000)	0.093	0.162
8	Urban (population > 25,000)	0.093	0.166
9	Urban (population > 10,000)	0.093	0.169
10	Rural	0.093	0.177

[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. A map of the area type is included in Appendix 3.

2.3.4.3 *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

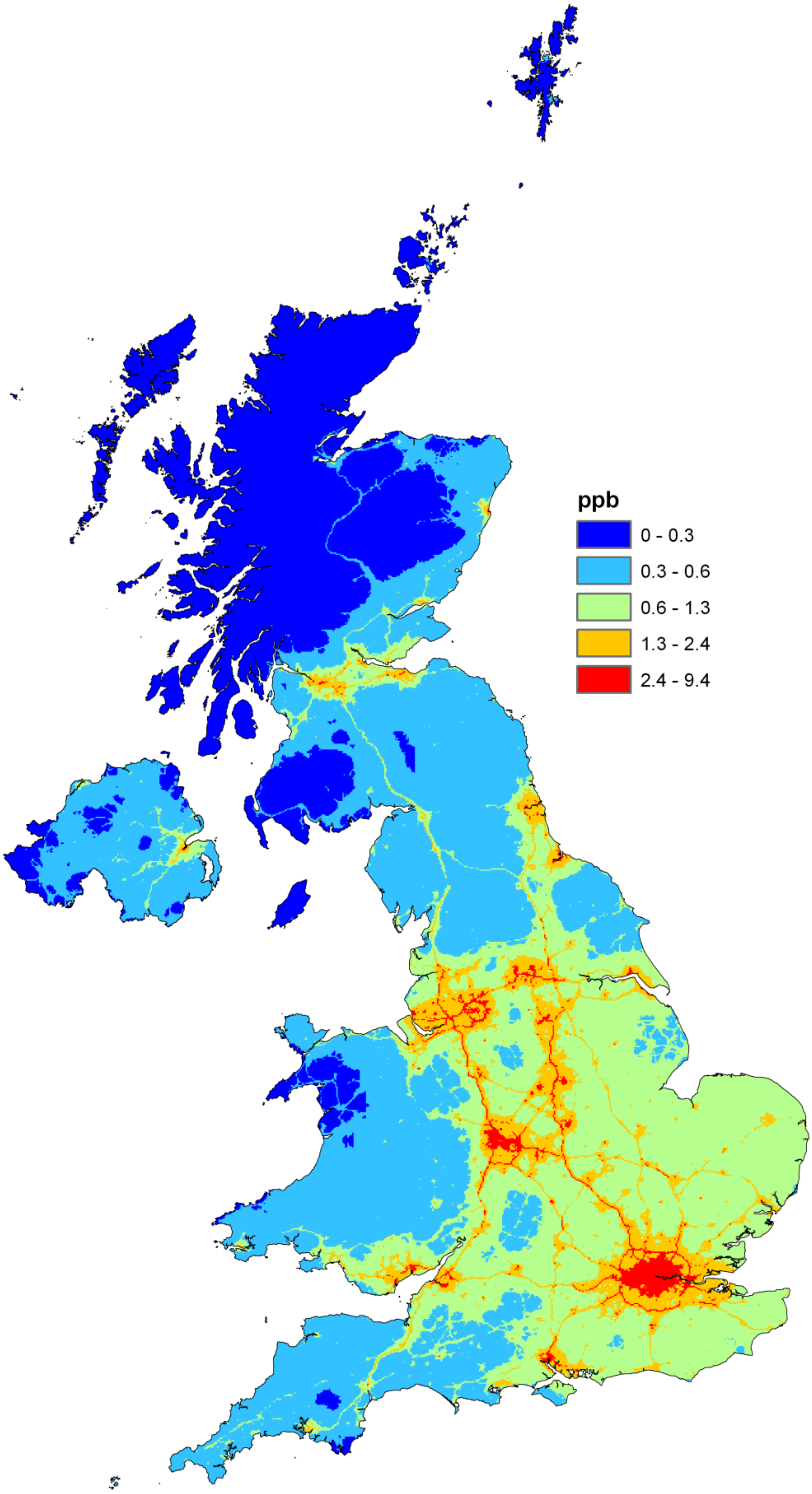
These components were multiplied by the relevant *f-NO_2* value from Table 2.3 and then added together to give a total local oxidant. Figure 2.12 shows the UK background local oxidant map for 2009.

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 2.3 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 2.12 - Background local oxidant map for 2009 (ppb)



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

As described in Section 2.3.2, 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.

2.3.5.1 Roadside

For roadside locations, the category 4 (IIIa) relationship has been selected and an additional calibration has been applied using data from AURN roadside and kerbside sites for 2009. 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 2009 and comparing with the measured NO_2 at these sites. The model has been calibrated 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 2009 and then fitting a curve through these points. Figure 2.13 shows this ratio for each site and also the curve that was 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 2.14 shows a verification plot of measured NO_2 against modelled NO_2 calculated from measured NO_X using the uncalibrated category 4 (IIIa) relationship. Figure 2.15 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 µg m^{-3}. The oxidant partitioning curves are only valid for annual mean NO_X concentrations up to 350 µg m^{-3}, hence NO_X concentrations above this value have been set to 350 µg m^{-3}.

Figure 2.13 - Roadside NO_2 calibration curve (NB verification sites are shown for reference here, but were not used in calculating the calibration)

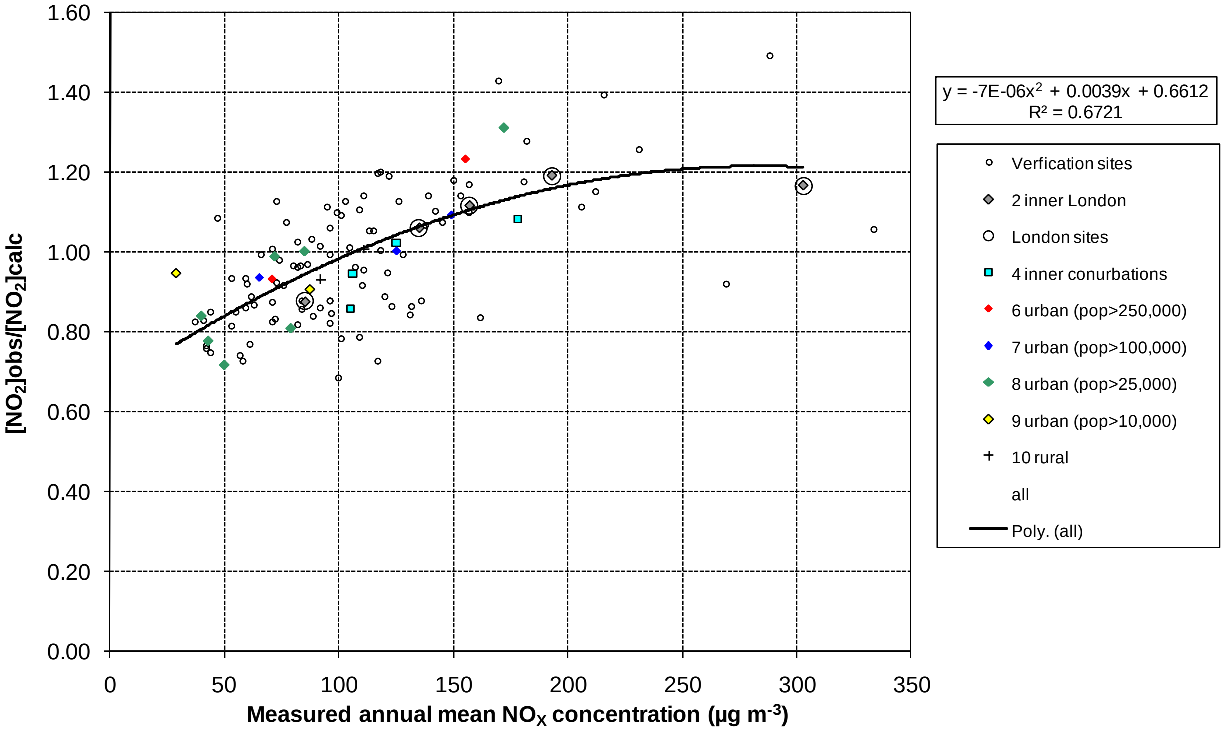


Figure 2.14 - Verification of uncalibrated category 4 (IIIa) relationship at roadside locations in 2009

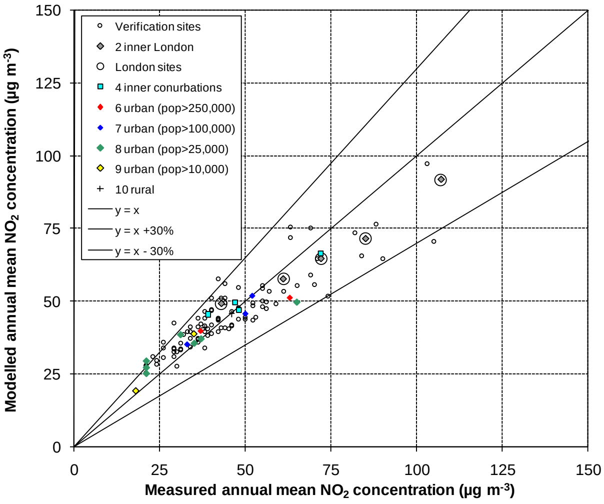
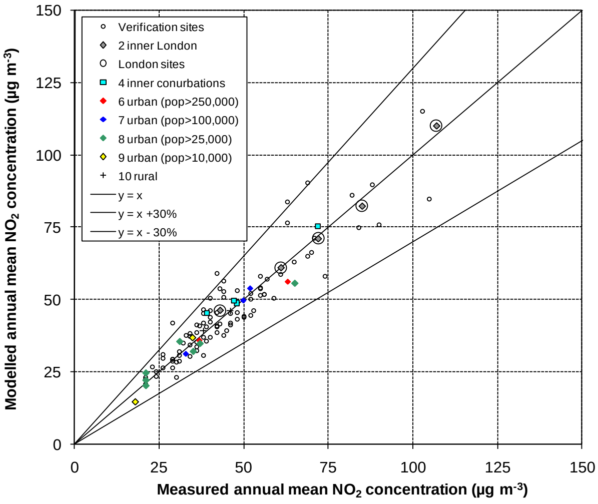


Figure 2.15 - Verification of calibrated category 4 (IIIa) relationship at roadside locations in 2009



2.3.5.2 Background

For background locations, the category 4 (IIIa) relationship has been calibrated using data from AURN background sites for 2009. 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 2.16. Figure 2.17 and Figure 2.18 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 $f\text{-}NO_2$ concentration in the range from 20-40 µg m^{-3}.

The results for this modelling are presented in Section 2.4.

Figure 2.16 - Background NO_2 calibration curve (NB verification sites are shown for reference here, but were not used in calculating the calibration)

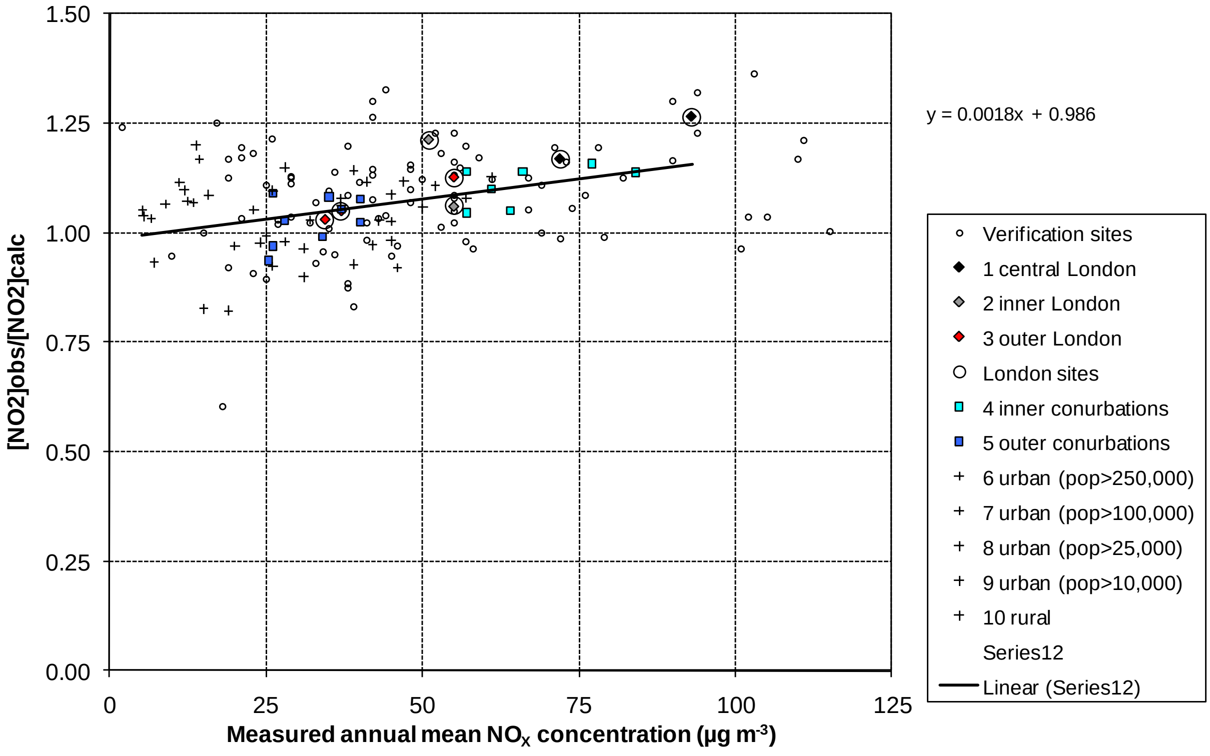


Figure 2.17 - Verification of uncalibrated category 4 (IIIa) relationship at background locations in 2009

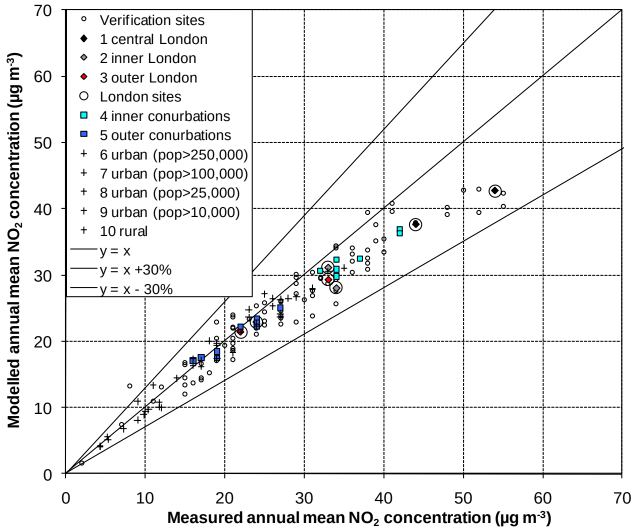
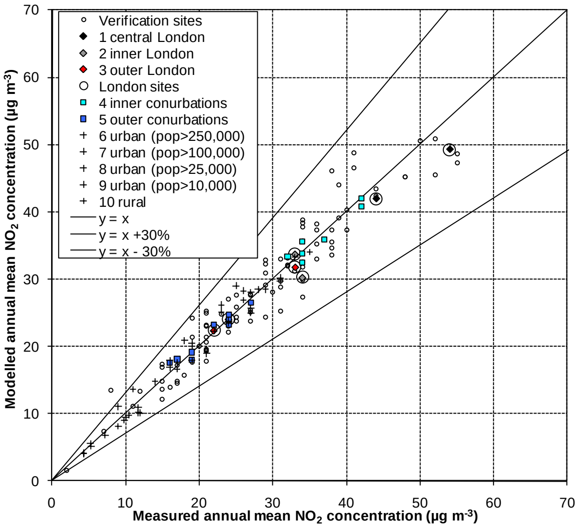


Figure 2.18 - Verification of calibrated category 4 (IIIa) relationship at background locations in 2009



2.4 Results

2.4.1 Verification of mapped values

Figure 2.19 and Figure 2.20 show comparisons of modelled and measured annual mean NO_X and NO_2 concentration in 2009 at background monitoring site locations. Figure 2.21 and Figure 2.22 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 AQD data quality objective for modelled annual mean NO_2 and NO_X concentrations – see Section 1.8). There is no requirement under AQD 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 the 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 Table 2.4 and Table 2.5. The percentages of monitoring sites for which the modelled annual mean concentrations fall outside the data quality objectives is generally greater for NO_X than for NO_2, for the reasons discussed above.

Figure 2.19 - Verification of background annual mean NO_X model 2009

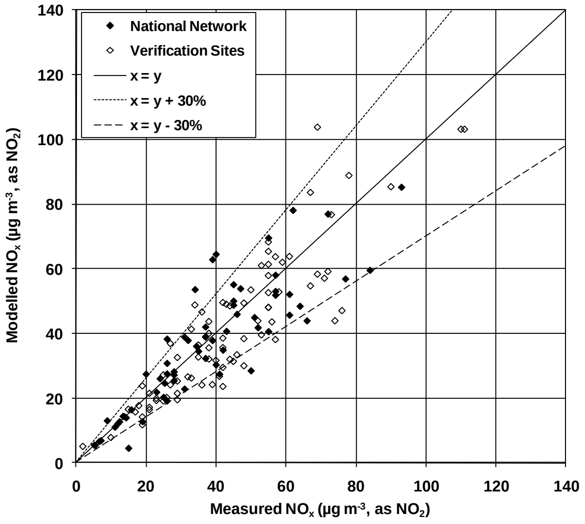


Figure 2.20 - Verification of background annual mean NO_2 model 2009

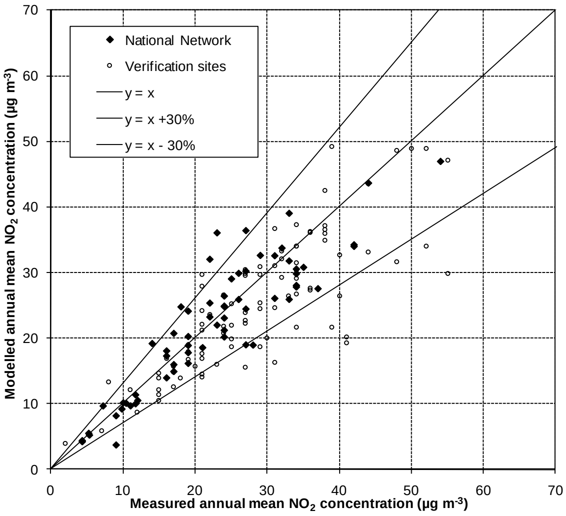


Figure 2.21 - Verification of roadside annual mean NO_X model 2009

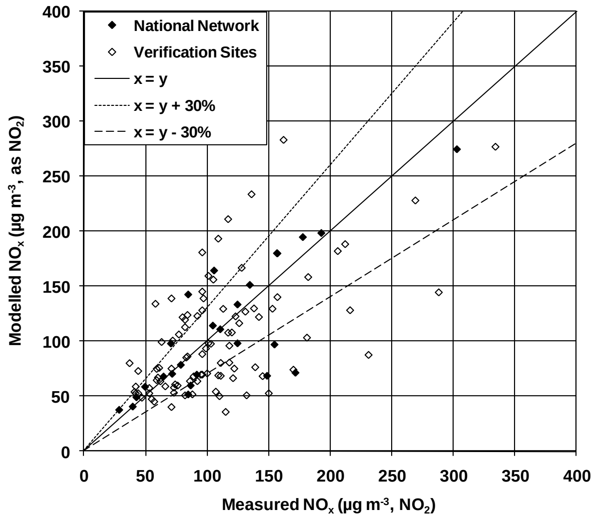


Figure 2.22 - Verification of roadside annual mean NO_2 model 2009

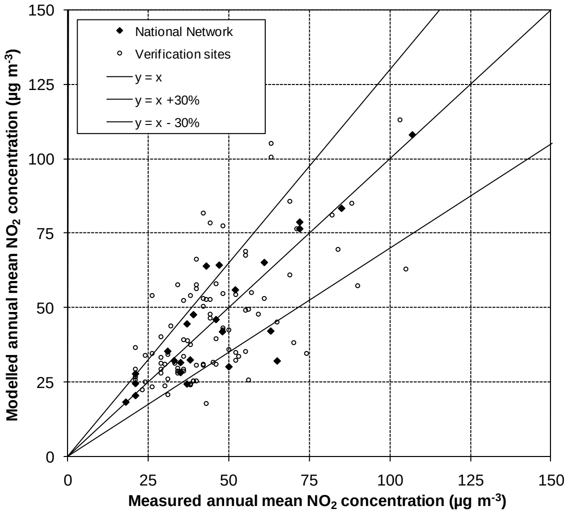


Table 2.4 - Summary statistics for comparison between modelled and measured NO_x and NO_2 concentrations at background sites ($\mu g\ m^{-3}$, as NO_2)

		Mean of measurements ($\mu g\ m^{-3}$, as NO_2)	Mean of model estimates ($\mu g\ m^{-3}$, as NO_2)	R^2	% outside data quality objectives	Number of sites in assessment
NO_X	National Network	36.9	35.8	0.77	16.9	65
	Verification Sites	44.6	41.7	0.79	29.3	92
NO_2	National Network	22.6	22.1	0.82	12.5	64
	Verification Sites	28.6	25.3	0.67	20.7	92

Table 2.5 - Summary statistics for comparison between modelled and measured NO_x and NO_2 concentrations at roadside sites (µg m^{-3}, as NO_2)

		Mean of measurements (µg m^{-3}, as NO_2)	Mean of model estimates (µg m^{-3}, as NO_2)	R^2	% outside data quality objectives	Number of sites in assessment
NO_X	National Network	112.5	107.4	0.66	36.0	25
	Verification Sites	108.2	102.5	0.35	49.5	93
NO_2	National Network	47.1	46.3	0.75	28.0	25
	Verification Sites	45.2	44.6	0.41	39.8	93

2.4.2 Source apportionment

Figure 2.23 and Figure 2.24 show the modelled NO_X source apportionment at AURN background and roadside sites respectively for 2009. 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 2.23 - 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 2.3)

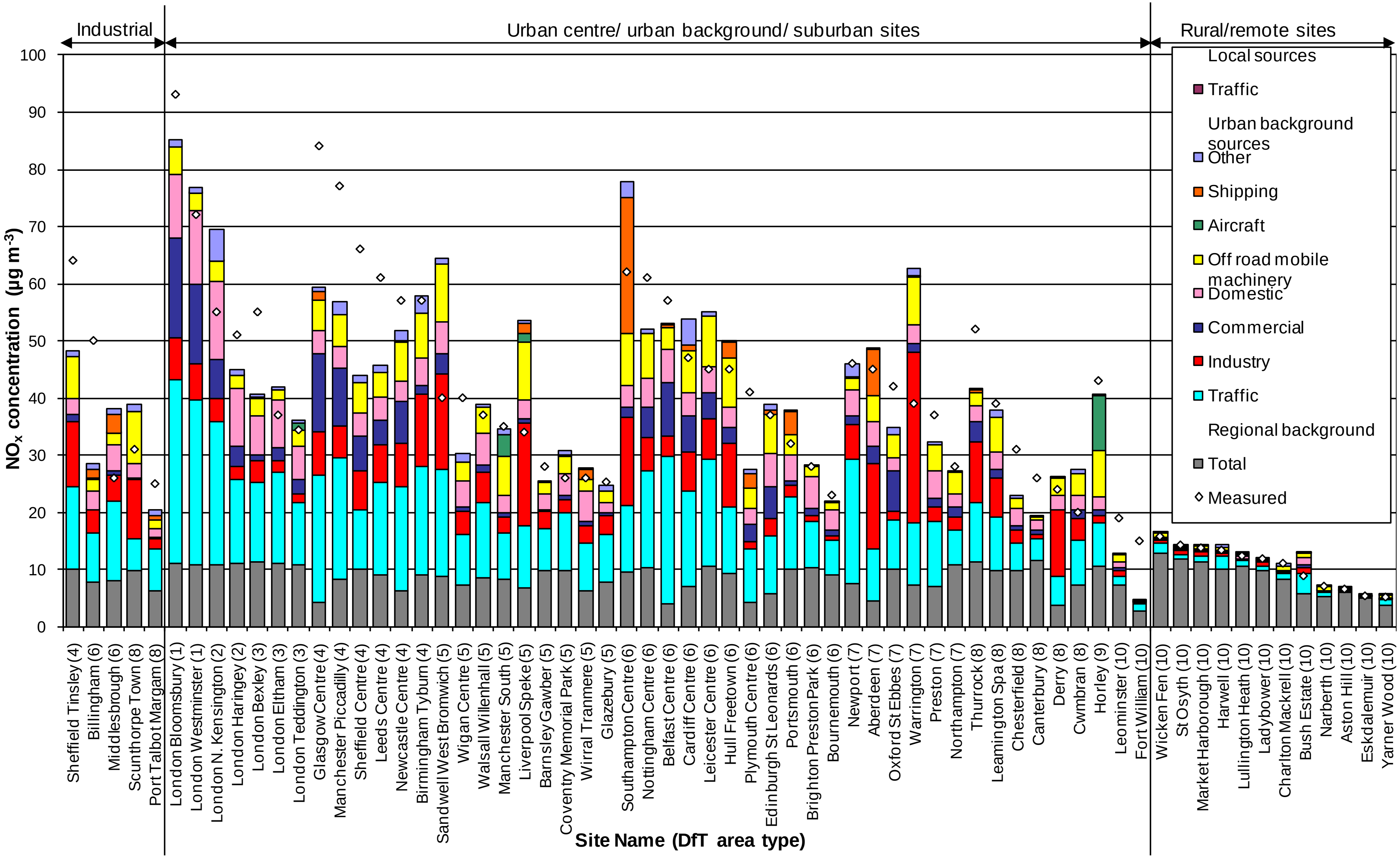
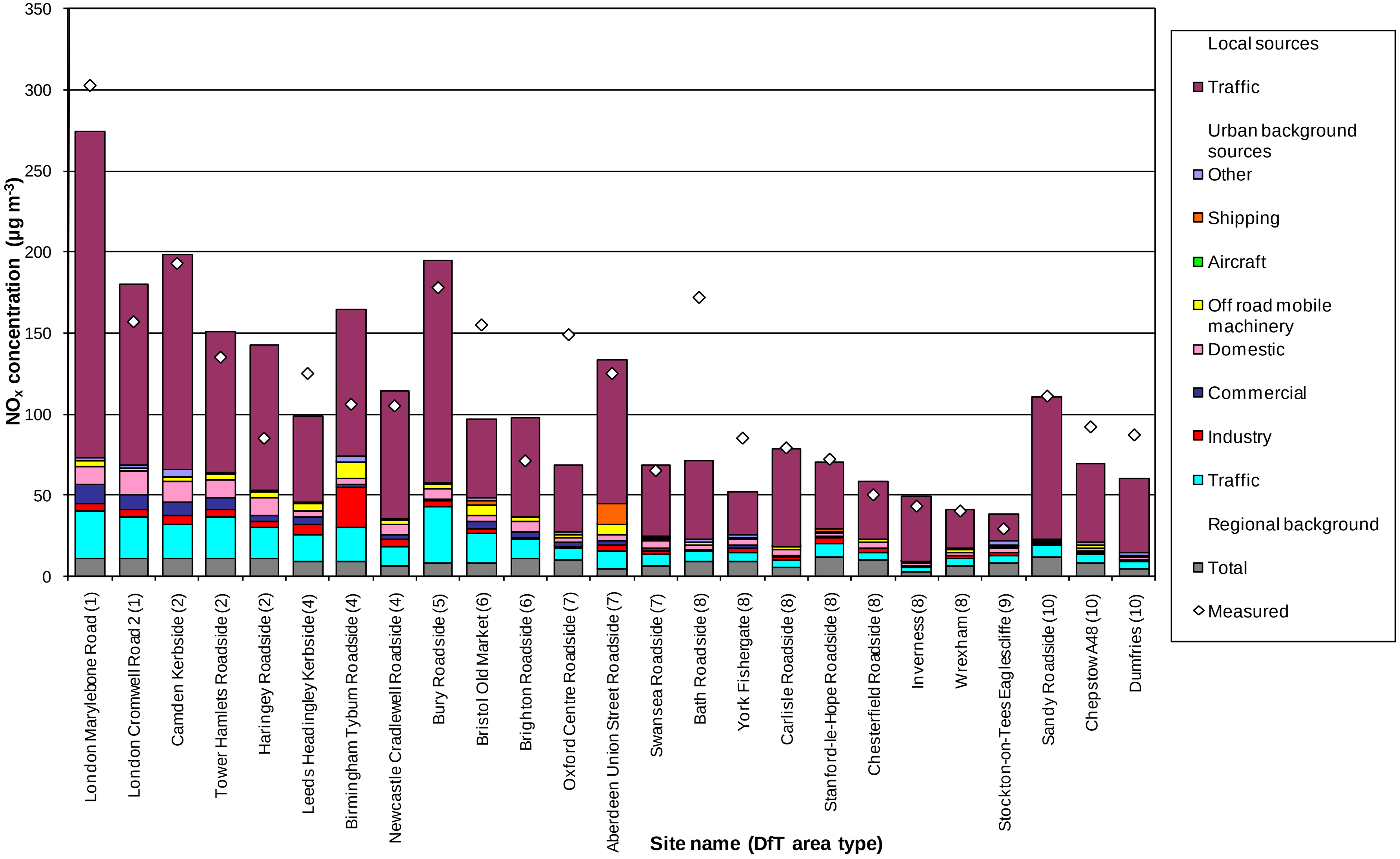


Figure 2.24 - Annual mean NO_X *source apportionment at roadside AURN monitoring sites (area type of each site is shown in parenthesis after its name)*



2.4.3 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 2.6. These data have also been presented in Form 19b of the questionnaire. The NO_X annual mean critical level for the protection of vegetation was not exceeded in vegetation areas in any of the non-agglomeration zones in 2009. This critical level 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 of population exposed using maps of roadside concentrations as these maps will only apply to within approximately 4 m from the road kerb.

Table 2.6 - Tabular results of and methods used for supplementary assessment for NO_2

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	47	A	1264.5	A	291228	A
West Midlands Urban Area	UK0002	10	A	239.0	A	18389	A
Greater Manchester Urban Area	UK0003	0	A	212.0	A	0	A
West Yorkshire Urban Area	UK0004	0	A	121.4	A	0	A
Tyneside	UK0005	0	A	51.9	A	0	A
Liverpool Urban Area	UK0006	0	A	67.3	A	0	A
Sheffield Urban Area	UK0007	1	A	65.0	A	284	A
Nottingham Urban Area	UK0008	0	A	43.0	A	0	A
Bristol Urban Area	UK0009	0	A	31.2	A	0	A
Brighton/Worthing/Littlehampton	UK0010	0	A	3.2	A	0	A
Leicester Urban Area	UK0011	0	A	25.3	A	0	A
Portsmouth Urban Area	UK0012	0	A	16.8	A	0	A
Teesside Urban Area	UK0013	0	A	15.3	A	0	A
The Potteries	UK0014	0	A	20.7	A	0	A
Bournemouth Urban Area	UK0015	0	A	12.0	A	0	A
Reading/Wokingham Urban Area	UK0016	0	A	4.7	A	0	A
Coventry/Bedworth	UK0017	0	A	15.2	A	0	A
Kingston upon Hull	UK0018	0	A	37.9	A	0	A
Southampton Urban Area	UK0019	2	A	39.1	A	7028	A
Birkenhead Urban Area	UK0020	0	A	11.0	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	4.9	A	0	A
Glasgow Urban Area	UK0024	0	A	91.9	A	0	A
Edinburgh Urban Area	UK0025	0	A	16.3	A	0	A
Cardiff Urban Area	UK0026	0	A	18.8	A	0	A
Swansea Urban Area	UK0027	0	A	5.4	A	0	A
Belfast Metropolitan Urban Area	UK0028	0	A	57.9	A	0	A
Eastern	UK0029	2	A	71.1	A	165	A
South West	UK0030	0	A	65.6	A	0	A
South East	UK0031	2	A	138.0	A	372	A
East Midlands	UK0032	3	A	85.9	A	3966	A
North West & Merseyside	UK0033	0	A	75.4	A	0	A
Yorkshire & Humberside	UK0034	0	A	69.1	A	0	A
West Midlands	UK0035	2	A	64.1	A	1169	A
North East	UK0036	0	A	59.4	A	0	A
Central Scotland	UK0037	0	A	31.4	A	0	A
North East Scotland	UK0038	0	A	24.9	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	39.1	A	0	A
North Wales	UK0042	0	A	11.0	A	0	A
Northern Ireland	UK0043	0	A	34.0	A	0	A
Total		69	A	3269.4	A	322601	A

3 SO_2

3.1 Introduction

3.1.1 Limit values

Two limit values for ambient SO_2 concentrations are set out in the Air Quality Directive (AQD). These have been specified for the protection of human health and are already in force. These limit values are:

- An hourly concentration of 350 µg m^{-3}, with 24 permitted exceedances each year
- A 24-hour mean concentration of 125 µg m^{-3}, with 3 permitted exceedances each year.

A critical level for SO_2 for the protection of vegetation has also been specified in the directive:

- An annual mean and winter mean concentration of 20 µg m^{-3}.

As this critical level is designed to protect vegetation it only applies in vegetation areas as defined in the directive. This critical level is also already in force.

3.1.2 Annual mean and winter mean modelling

A map of annual mean SO_2 concentration for 2009 in vegetation areas is shown in Figure 3.1. This map has been calculated by removing non-vegetation areas from the background SO_2 annual mean map and calculating the zonal mean of the 1 km x 1 km grid squares for a 30 km x 30 km grid.

Mean concentrations on a 30 km x 30 km 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 2008/50/EC for monitoring sites used to assess concentrations for the vegetation critical level.

A map of winter mean SO_2 concentrations for the period October 2008 to March 2009 has also been calculated and is shown in Figure 3.2. This map was calculated by multiplying the annual mean map for 2009 by 1.23, which is the ratio between the average concentration measured at rural SO_2 monitoring sites during the 2008-2009 winter periods and annual concentration for 2009.

3.1.3 Outline of annual mean and winter mean modelling

The 1 km x 1 km annual mean background SO_2 concentration map has been calculated by summing the contributions from:

- Large point sources
- Small point sources
- Local area sources
- Distant sources (characterised by a residual)

The area source contribution has been scaled using the calibration coefficient from the NO_x modelling. The contributions from each of the above components are described in Section 3.3.1.

3.1.4 Modelling for comparison with the hourly and 24-hour limit values

Maps of 99.73 percentile of hourly mean and 99.18 percentile of 24-hour mean SO_2 concentrations have been calculated for 2009. They are shown in Figure 3.3 and Figure 3.4 respectively. These percentile concentrations correspond to the number of allowed exceedances of the 1-hour and 24-hour limit values for SO_2.

3.1.5 Outline of modelling for comparison with the hourly and 24-hour limit values

The 1 km x 1 km percentile SO_2 concentration maps have been calculated by summing the contributions from:

- Large point sources
- Small point sources
- Local area sources
- Distant sources (characterised by a residual)

Details of the method can be found in Section 3.3.2.

3.1.6 Chapter structure

This chapter describes modelling work carried out for 2009 to assess compliance with the SO_2 limit values described above. Emission estimates for SO_2 are described in Section 3.2. Section 3.3.1 describes the SO_2 modelling methods for the annual and winter means. Section 3.3.2 describes the SO_2 modelling methods for the percentile metrics (for comparison with the hourly and 24-hour limit values). The modelling results are presented in Section 3.4.

Figure 3.1 - Annual mean SO_2 concentration, 2009 ($\mu g\ m^{-3}$) in vegetation areas

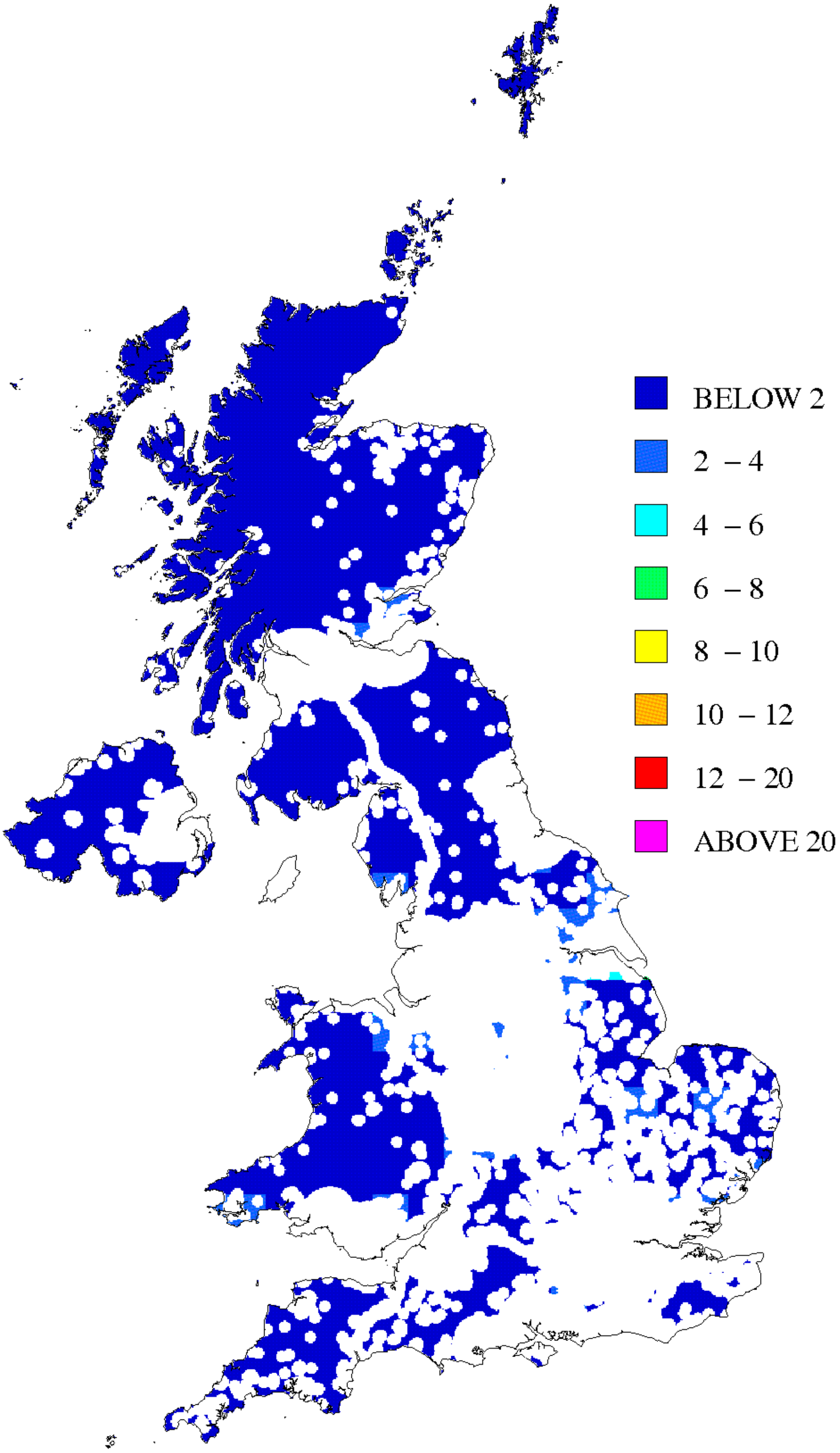


Figure 3.2 - Winter mean SO_2 concentration, 2008-2009 ($\mu g\ m^{-3}$) in vegetation areas

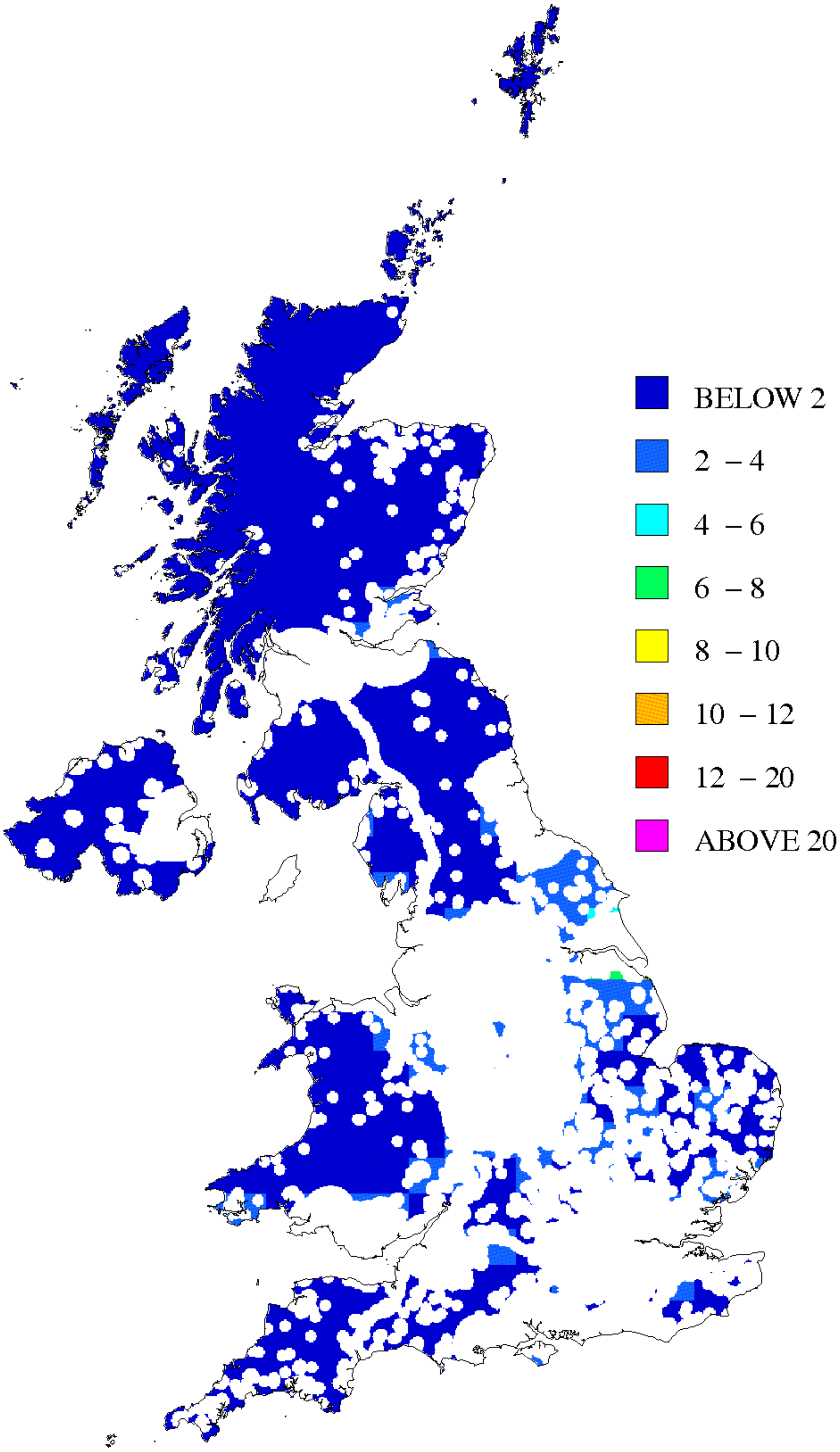


Figure 3.3 - 99.73 percentile of 1-hour mean SO_2 concentration, 2009 (µg m^{-3})

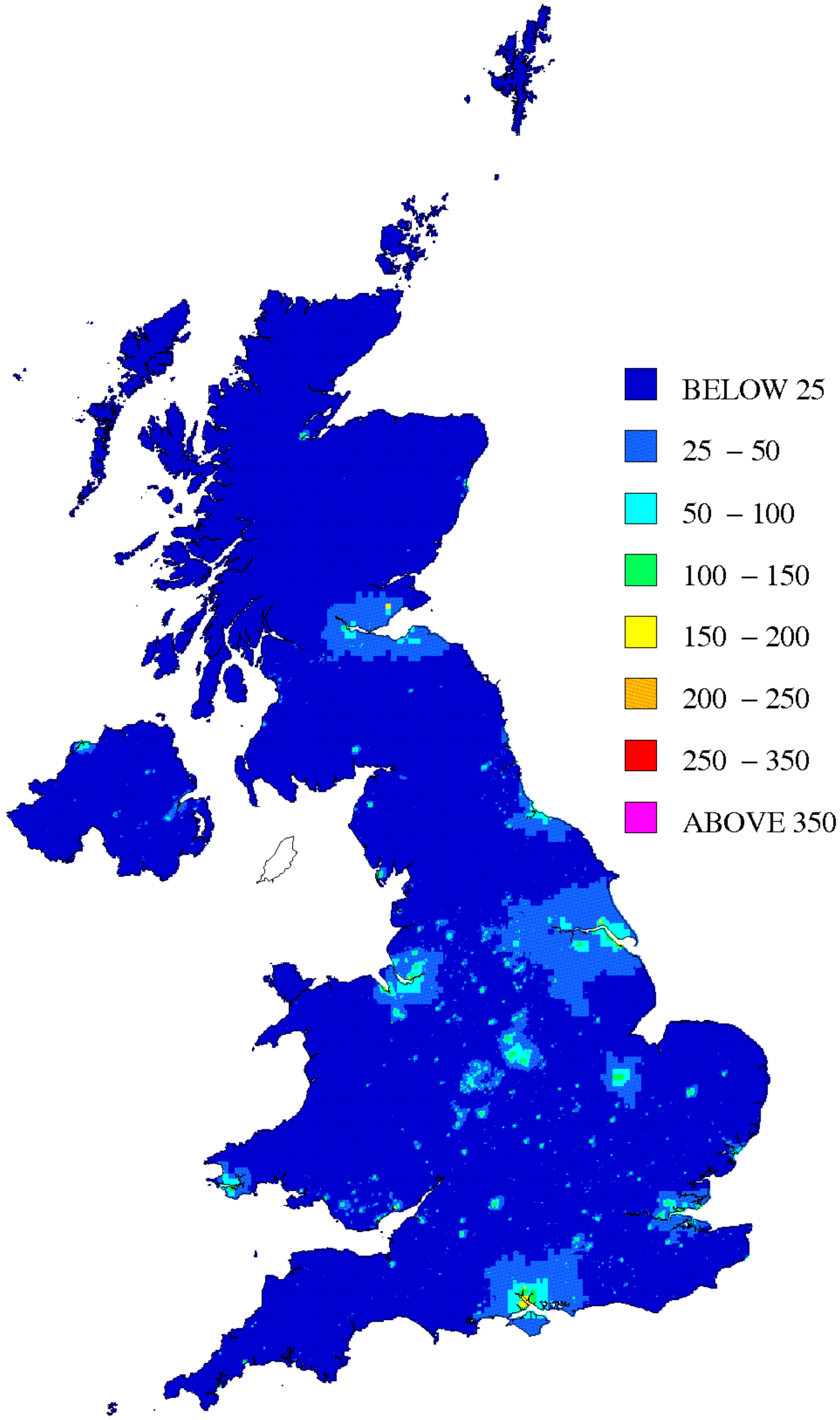
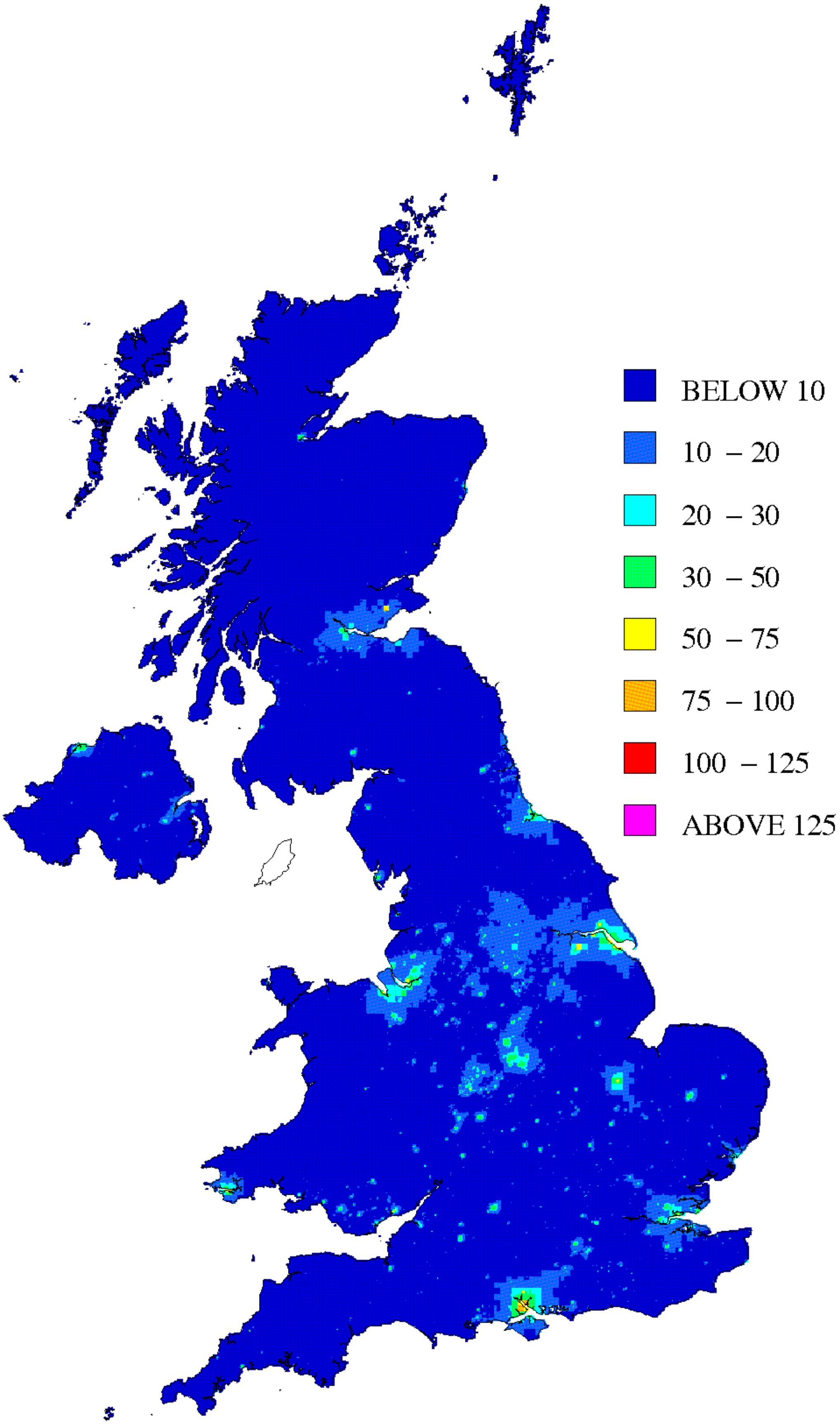


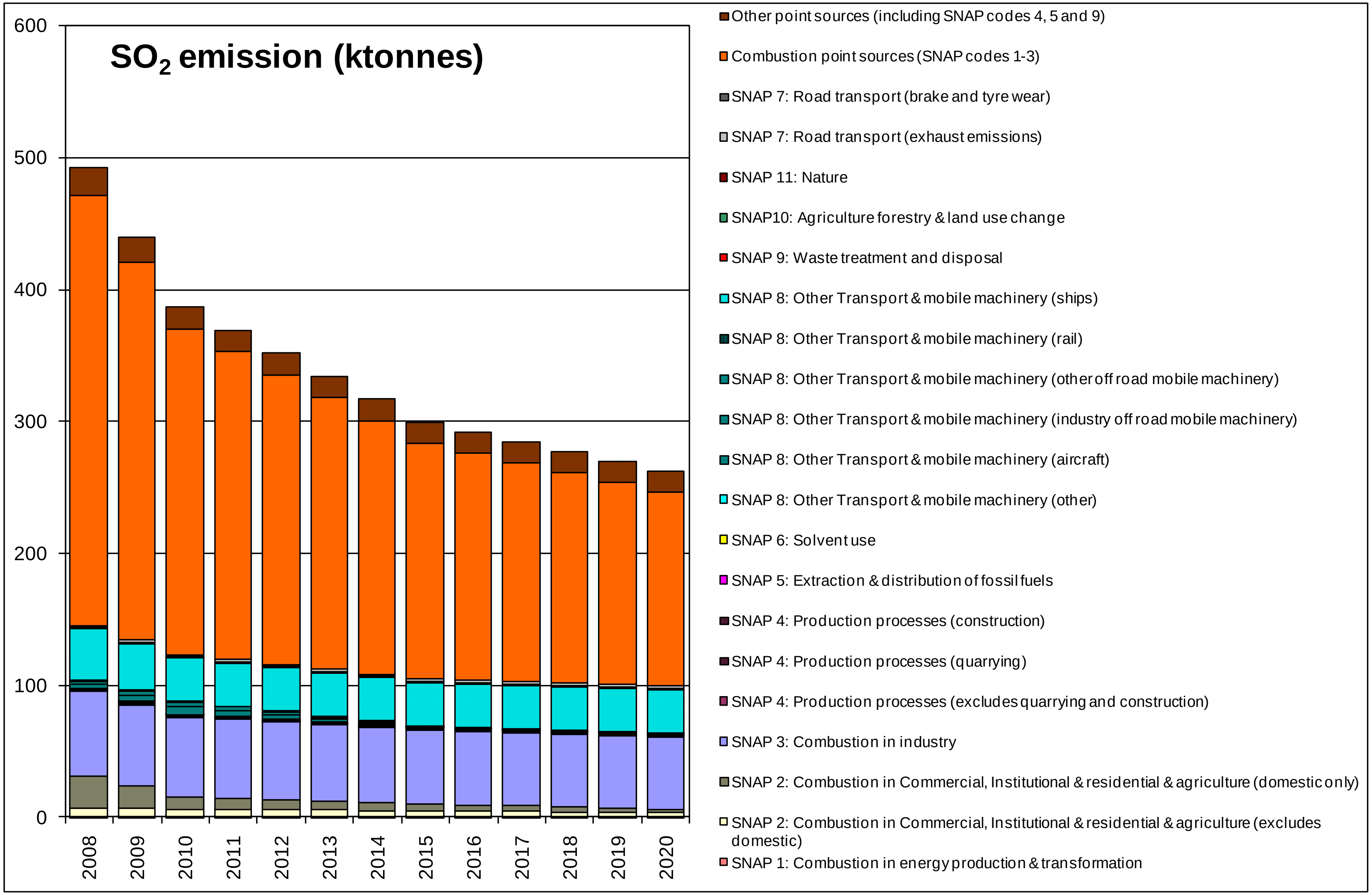
Figure 3.4 - 99.18 percentile of 24-hour mean SO_2 concentration, 2009 (µg m^{-3})



3.2 SO_2 emissions

Figure 3.5 shows the total UK SO_2 emissions for each year from 2008 to 2020 and the emissions broken down by SNAP code. The emissions are dominated by point source emissions from combustion in energy production and transformation. The total emissions are predicted to decrease into the future, especially the emissions from combustion point sources.

Figure 3.5 - Total UK SO_2 emissions for 2008 and emissions projections up to 2020 by SNAP code from NAEI 2008



3.3 SO_2 modelling

The modelling methods were developed by Abbott and Vincent (1999, 2006). Emissions from point and area sources have been modelled separately and the results combined within a geographical information system to produce the concentration maps.

3.3.1 Annual mean and winter mean modelling

3.3.1.1 Large and small point sources

Point sources in the 2008 NAEI have been classified as large if they fulfil either of the following criteria:

- SO_2 emissions in the 2008 NAEI are greater than 500 tonnes for any given plant
- Stack parameters are already available for any given plant in the PCM stack parameters database

Emissions from larger point sources were modelled using the dispersion model ADMS 4.2. Hourly emissions profiles for the power stations in England and Wales for 2009 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 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 2008; 2009 emissions for these types of sources were not available when the modelling work was conducted.

For the large point emission sources, concentrations were predicted for 5 km x 5 km receptors within a number of receptor areas (or tiles), which together cover 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 2009 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. While not essential for the estimation of the annual mean this method enables both the annual mean and high percentiles to be calculated from the same set of dispersion model calculations.

3.3.1.2 Area sources

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 2009, using UK sector total emissions for 2008 and 2009. Concentrations are predicted for 1 km x 1 km receptors. Dispersion kernels were calculated using ADMS 4.2 and hourly sequential meteorological data for 2009 from Waddington. Modelling of the area sources is described in more detail in Appendix 3.

3.3.1.3 Calculating the total concentrations

Details of the method to combine the component parts are described below. The map of winter mean SO_2 concentrations was derived from the annual mean map using a factor of 1.23, which is the ratio between the average concentration measured at rural SO_2 monitoring sites during the 2008-2009 winter periods and annual concentration for 2009, respectively.

The factors used to combine the point source and area source contributions are shown in Table 3.1. 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

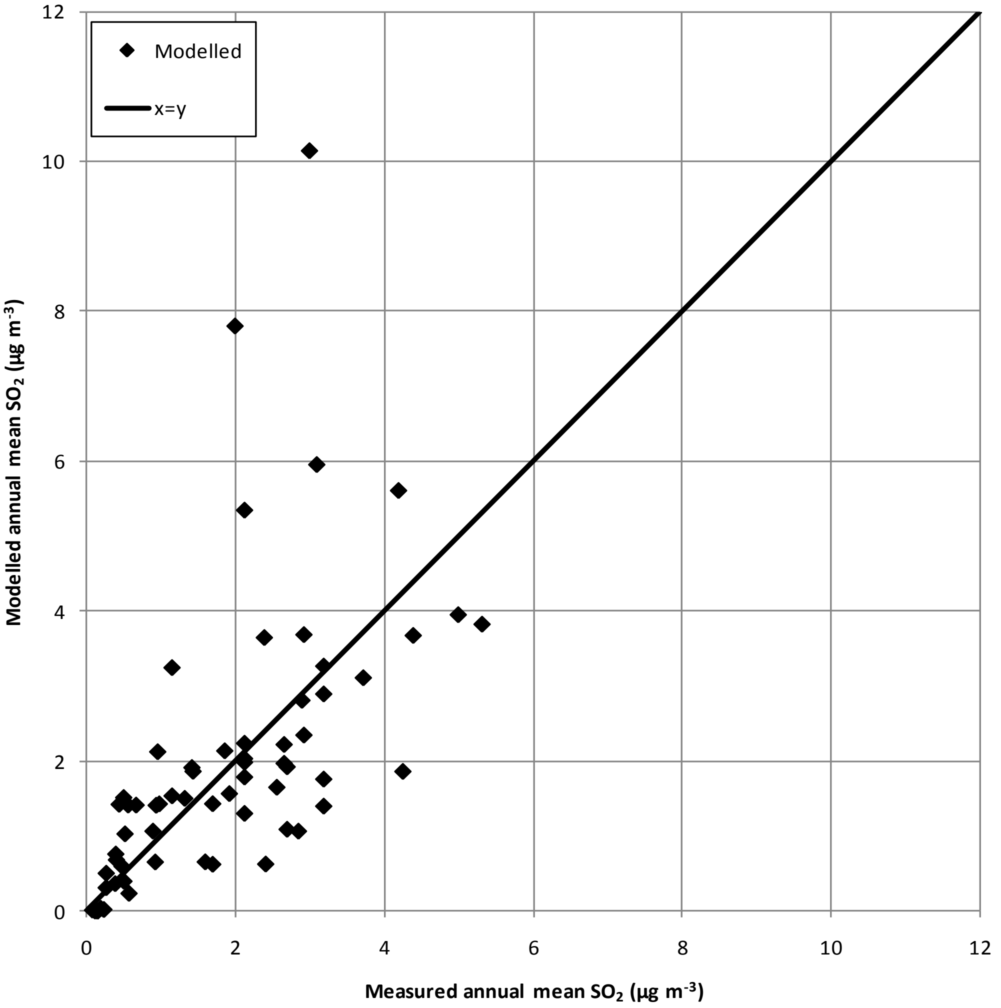
European sources that are not explicitly modelled. The area coefficient was derived from the NO_X calibration with measured data. The local contribution to ambient NO_X concentrations is dominated by area sources. The calibration of the area source model for NO_X should therefore provide a robust coefficient for the area sources of other pollutants.

Table 3.1 - Coefficients for annual mean model

	Points coefficient	Area coefficient	Constant ($\mu g\ m^{-3}$)
Annual mean	1	1.2486	0.19

Measured concentrations from Rural SO_2 Monitoring Network sites (Tang, 2010), 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 results from 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 2009 is shown in Figure 3.6.

Figure 3.6 - Comparison plot for 2009 annual mean SO_2 concentration



3.3.2 Modelling percentile concentrations for comparison with the 1-hour and 24-hour limit values

The methodology to produce the percentile 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:

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

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 3.2 presents the *A* and *k* factors used in the derivation of the maps. The *k* factors include the calibration factor of 1.2486 derived for NO_X.

Table 3.2 - Factors for percentile models

Metric	Constant (*A*)	Background multiplier factor (*k*)	c_{long_range}
99.73 percentile of 1-hour values	1.09	10.1	0.19
99.18 percentile of 24-hour values	1.23	3.3	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.

Figure 3.7 and Figure 3.8 provide an intermediate quality check at rural, industrial and suburban sites which form part of the national network and at sampling sites operated by the electricity supply companies.

Figure 3.7 - Comparison plot for 2009 99.73 percentile of 1-hour mean SO_2 concentrations

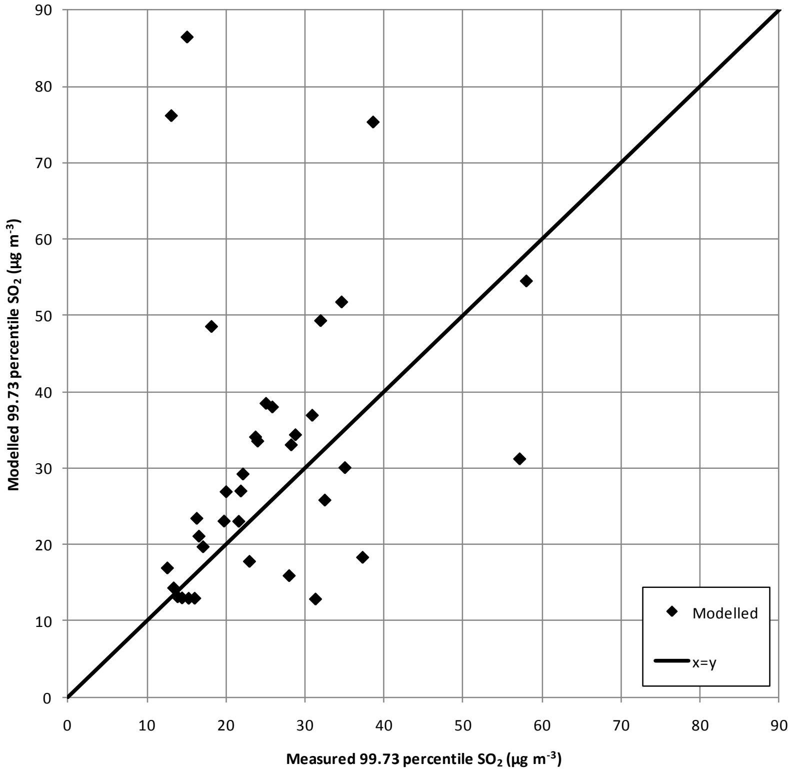
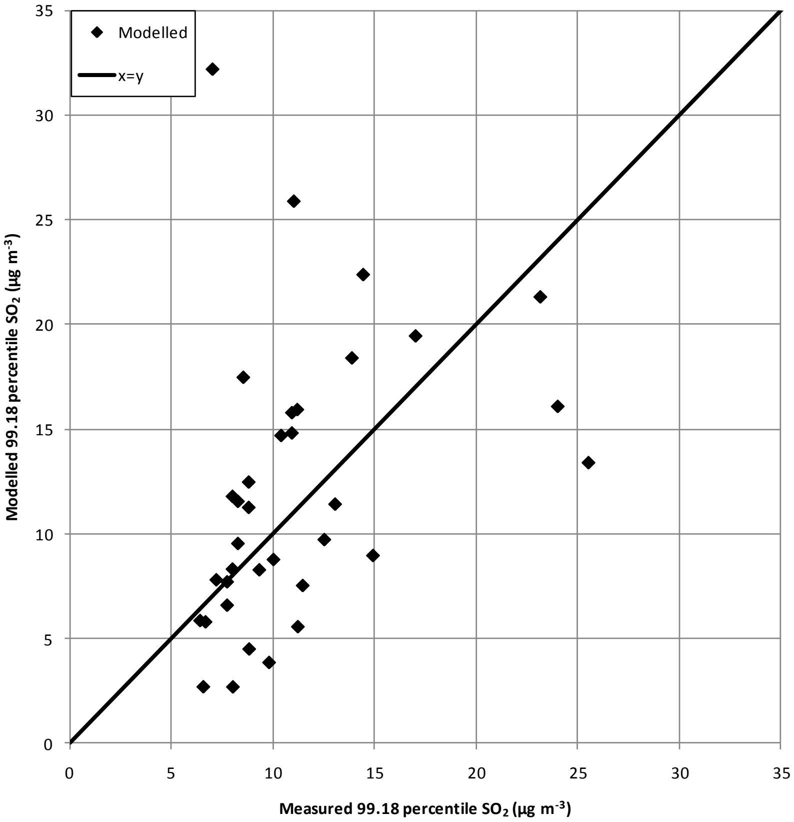


Figure 3.8 - Comparison plot for 2009 99.18 percentile of 24-hour mean SO_2 concentrations



An alternative method was used to derive the high percentile concentrations in Northern Ireland. This was required because area sources, predominately emissions from domestic solid and liquid fuel use, 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 2009 at national network and AEA Calibration Club monitoring sites. Figure 3.9 and Figure 3.10 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 = 7.10 × Modelled Annual Mean + 3.83

Predicted 99.18 %ile in Northern Ireland = 2.55 × Modelled Annual Mean + 3.47.

Figure 3.9 - Relationship between mean concentration and 99.73 percentile of 1-hour concentrations at sampling sites in Northern Ireland

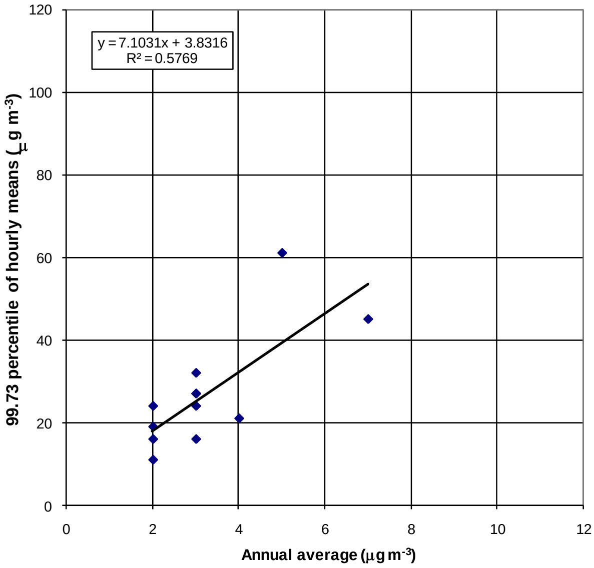
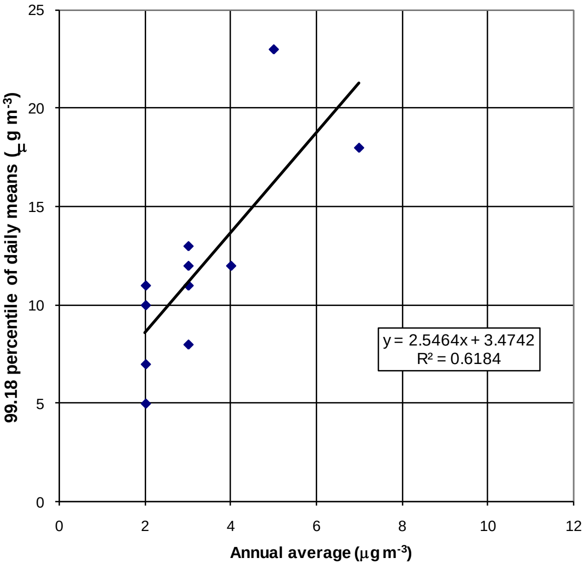


Figure 3.10 - Relationship between mean concentration and 99.18 percentile of 24-hour concentrations at sampling sites in Northern Ireland



3.4 Results

3.4.1 Verification of mapped values

Figure 3.11, Figure 3.12 and Figure 3.13 show comparisons of modelled and measured annual mean, 99.73 percentile of 1-hour mean and 99.18 percentile of 24-hour mean SO_2 concentrations in 2009 at monitoring site locations in the UK. Both the national network sites and the verification sites are shown. Lines representing y = x – 30 % and y = x + 30% or y = x – 50 % and y = x + 50% are also shown (the AQD data quality objective for modelled annual mean and percentile SO_2 concentrations respectively – see Section 1.8). The ‘Quality Check Sites’ include the electricity generating company sites and selected AURN sites. Urban background and urban centre 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 other 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.

Figure 3.11 - Verification of annual mean SO_2 model 2009

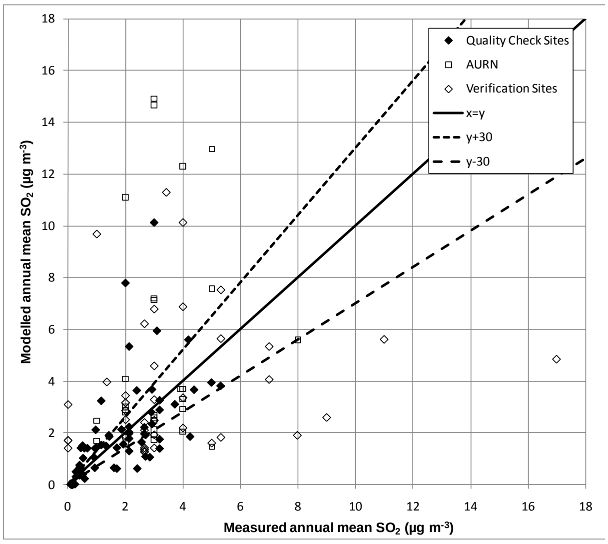


Figure 3.12 - Verification of 99.73 percentile of 1-hour mean SO_2 model 2009

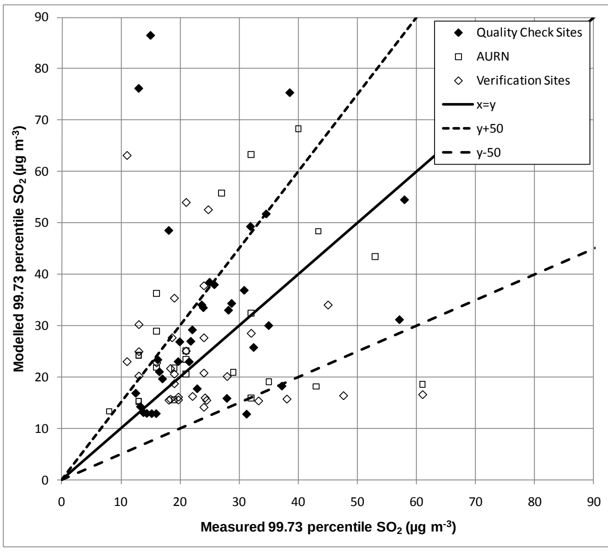
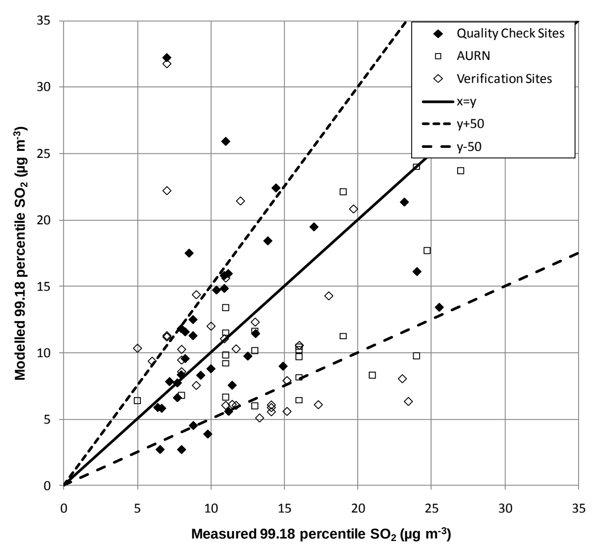


Figure 3.13 -Verification of 99.18 percentile of 24-hour mean SO_2 model 2009



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 Table 3.3, Table 3.4 and Table 3.5.

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 x 1 km grid annual mean map is not compared directly with the annual mean limit value; the zonal mean of the 1 km x 1 km grid squares in vegetation areas has been calculated for a 30 km x 30 km 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 Table 3.3 to Table 3.5 for national network sites were comparable to those reported in previous years.

Table 3.3 - 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	1.01	1.29	0.28	64	67 [a]
Verification sites	3.48	4.13	0.03	70	40

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

Table 3.4 - 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	18.41	26.81	0.10	44	39 [b]
Verification sites	39.38	44.00	0.23	52	44

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

Table 3.5 - Summary statistics for comparison between modelled and measured 99.18 percentile of 24-hour mean concentrations of SO_2 at background sites

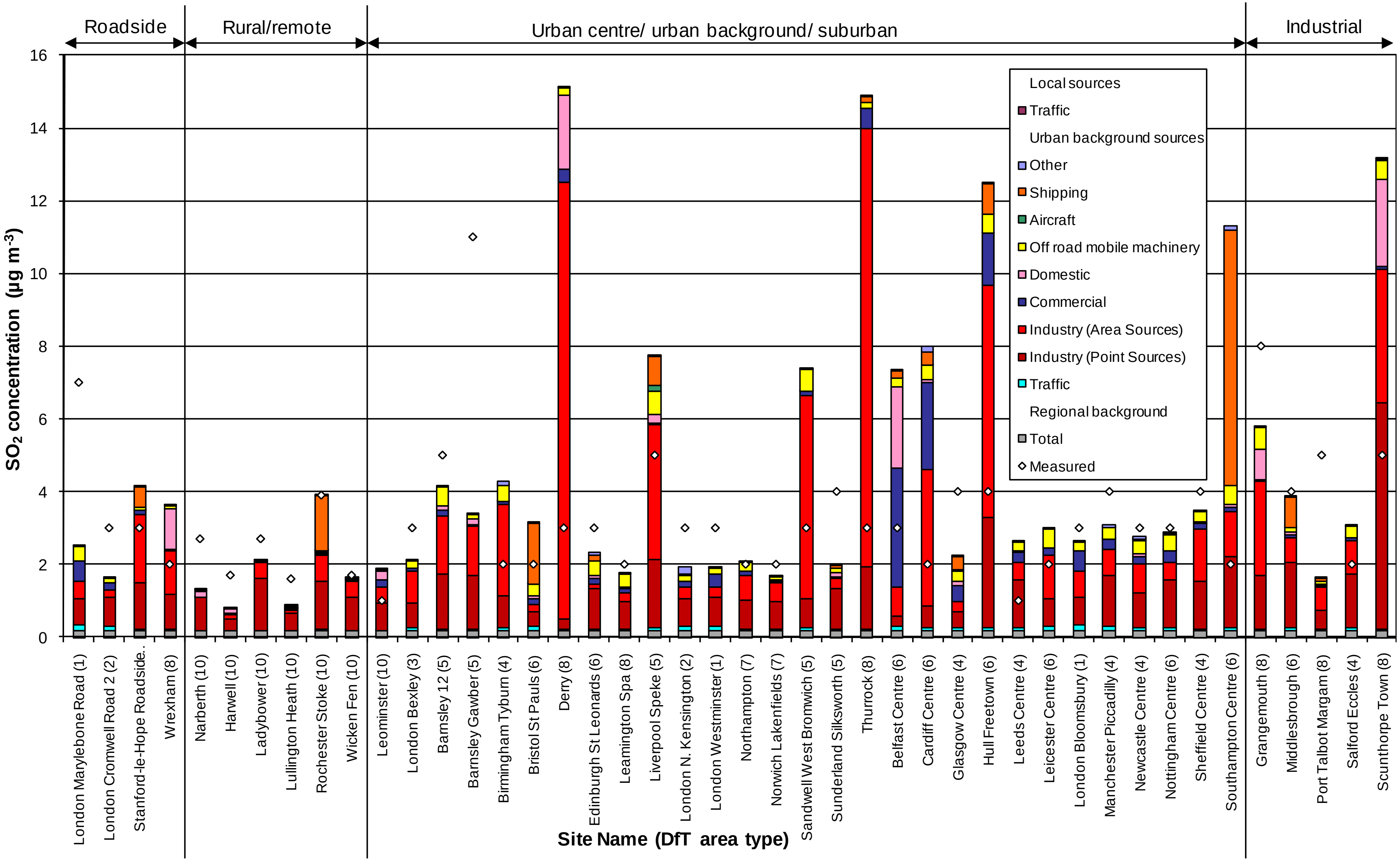
	Mean of measurements ($\mu g\ m^{-3}$)	Mean of model estimates ($\mu g\ m^{-3}$)	R^2	% of sites outside DQO of ±50%	Number of sites in assessment
National Network	12.46	10.30	0.19	33	39 [c]
Verification sites	21.09	17.83	0.12	57	44

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

3.4.2 Source apportionment

Figure 3.14 shows the source apportionment for modelled annual mean concentrations of SO_2 at AURN monitoring sites for 2009. 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 and Thurrock sites, where the measured concentration is considerably lower than the model estimate.

Figure 3.14 - Annual mean SO_2 source apportionment at AURN monitoring sites (the area type of each site is shown in parenthesis after its name – see Table 2.3)



3.4.3 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 2009 were below the limit values for all zones.

4 PM_{10}

4.1 Introduction

4.1.1 Limit values

Two limit values for ambient PM_{10} concentrations are set out in the Air Quality Directive (AQD). These have been specified for the protection of human health and came into force from 01/01/2005. These limit values are:

- An annual mean concentration of 40 µg m^{-3}.
- A 24-hour mean concentration of 50 µg m^{-3}, with 35 permitted exceedances each year

4.1.2 Annual mean model

Maps of annual mean PM_{10} in 2009 at background and roadside locations are shown in Figure 4.1 and Figure 4.2. These maps have been calibrated using measurements from TEOM FDMS instruments within the national network for which co-located $PM_{2.5}$ measurements are also available for 2009. 2009 is the first year for which $PM_{2.5}$ measurements from an extensive network of sites in the UK are available. The models for PM_{10} and $PM_{2.5}$ are designed to be fully consistent. Each component is either derived from emission estimates for PM_{10} or $PM_{2.5}$ or the contributions to the fine and coarse particle size fractions are estimated separately. This enables us to carry out an additional reality check that the calibration parameters for the two pollutants are reasonably consistent. Measurements from national network sites without collocated $PM_{2.5}$ instruments have been used as an additional verification dataset (and similarly $PM_{2.5}$ sites without PM_{10} have been used as an additional verification dataset for $PM_{2.5}$). 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 has been provided by Stedman et al. (2007). The methods used to derive the maps for 2009 are largely the same as was adopted for the 2008 maps described in Grice et al. (2010) except for the more direct linkages with the calibration of the models for $PM_{2.5}$.

4.1.3 Outline of the annual mean model

The maps of annual mean 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)
- Regional 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.

The results from the annual mean model can be directly compared with the annual mean limit value in order to carry out the air quality assessment.

Figure 4.1 - Annual mean background PM_{10} concentration, 2009 ($\mu g\ m^{-3}$, gravimetric)

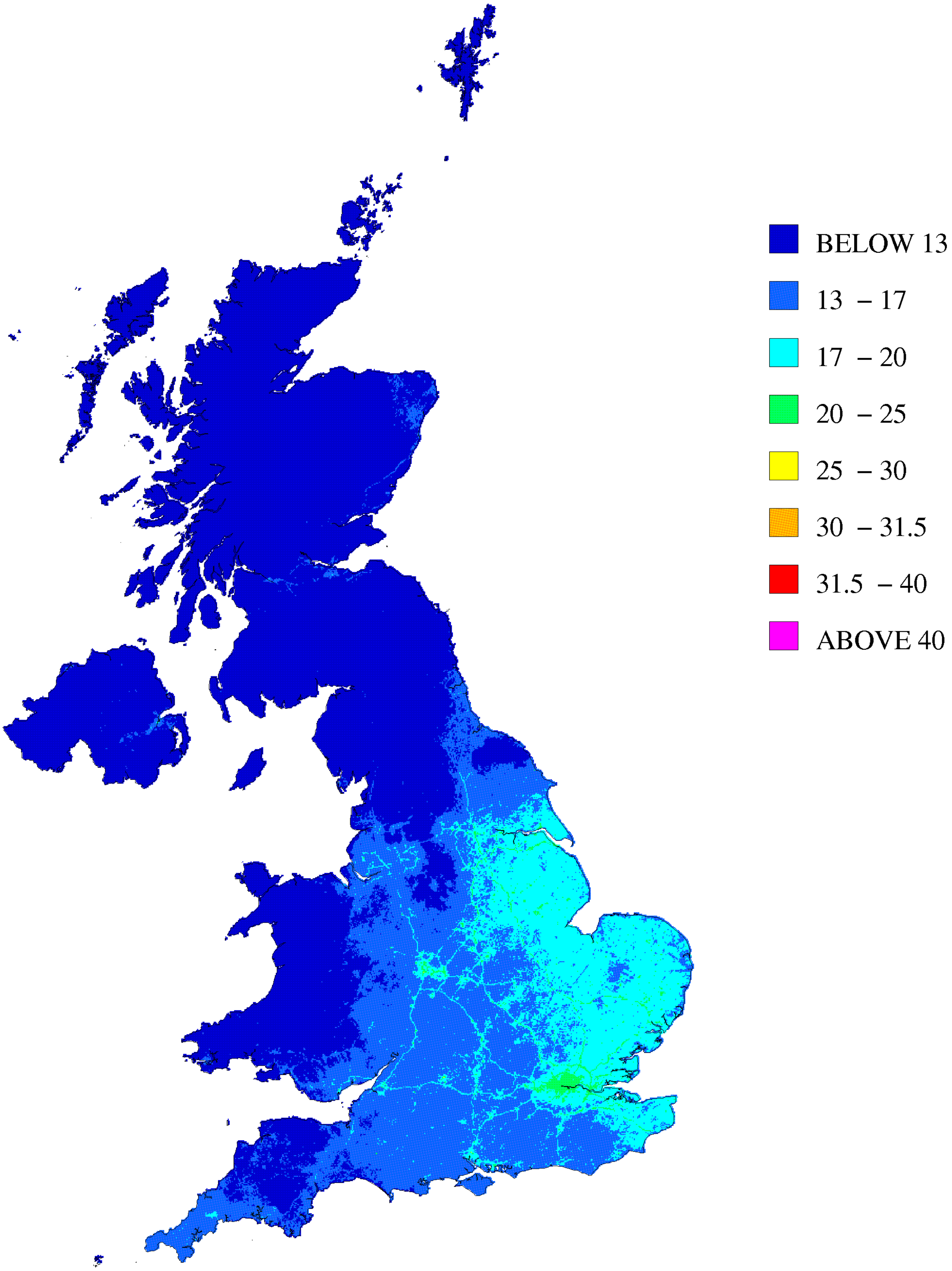
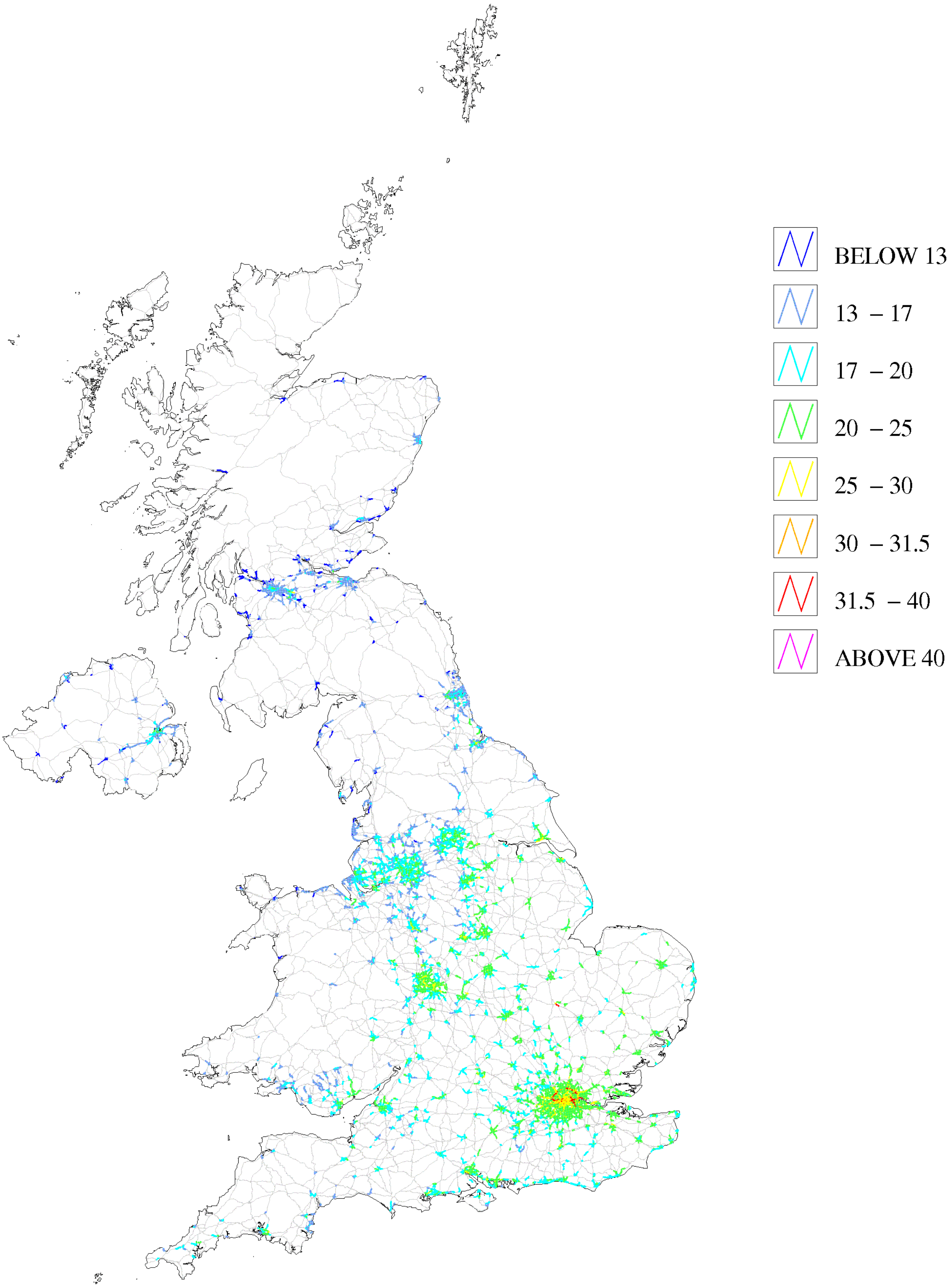


Figure 4.2 - Urban major roads, annual mean roadside PM_{10} concentration, 2009 ($\mu g\ m^{-3}$, gravimetric)



4.1.4 Compliance assessment for the 24-hour limit value

24-hour mean concentrations have not been explicitly modelled for comparison with the 24-hour limit value. 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). A modelled annual mean concentration of greater than this value has been taken to indicate a modelled exceedance of the 24-hour mean limit value. This equivalence has been derived from an analysis of monitoring data (Stedman et al., 2001a) and is reproduced Figure 4.3. An analysis of more recent monitoring data is shown in Figure 4.4, which shows data for the period 2003 to 2006. This analysis suggests that the value of 31.5 µg m^{-3} was still valid for this period, 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}. This figure also shows data for 2009, for which, in contrast to the earlier data, the analysis only includes data from FDMS, gravimetric and TEOM instruments adjusted using the VCM model. An examination of the 2009 data suggests that the value of 31.5 µg m^{-3} remains valid, or in fact somewhat precautionary, for 2009.

Thus compliance with the 24-hour mean limit value has been assessed by comparing the results from the annual mean model with a concentration of 31.5 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)

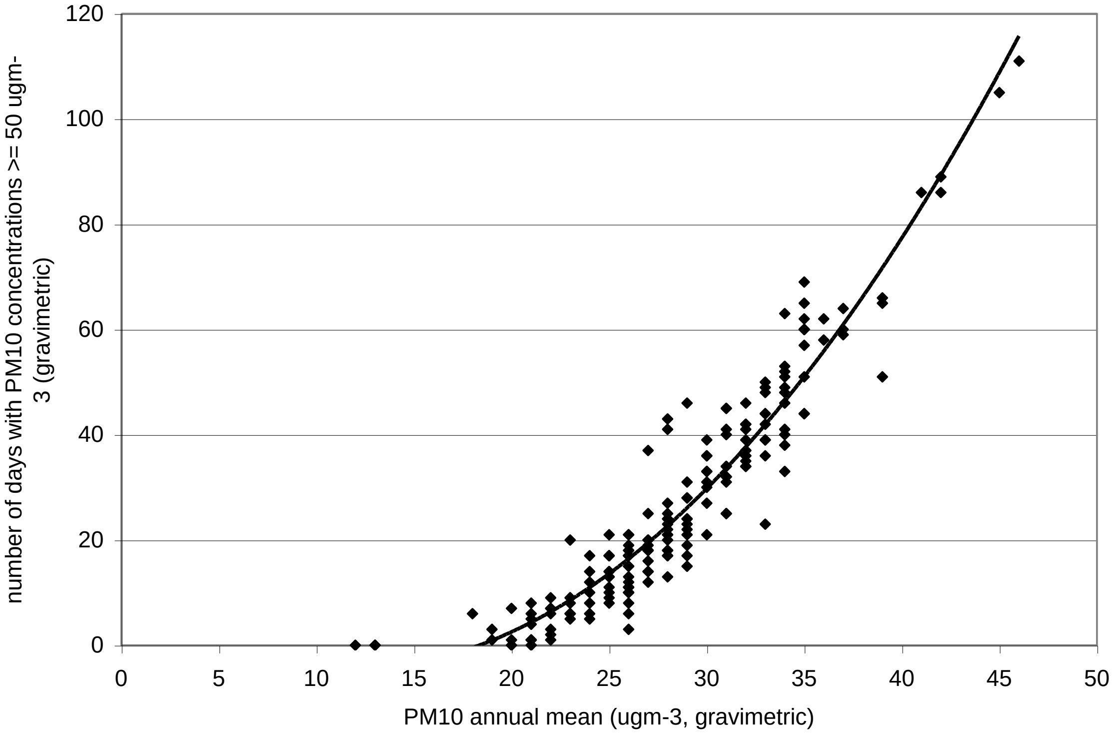
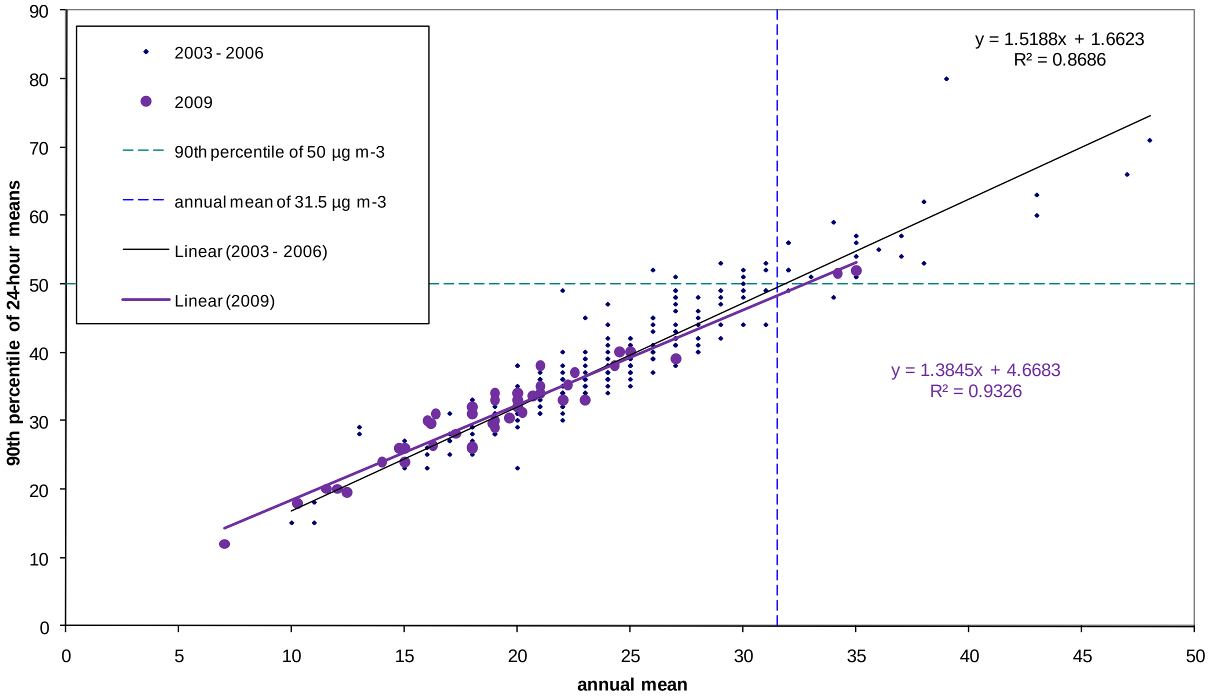


Figure 4.4 - The relationship between the 90th percentile of 24-hour mean PM_{10} concentration and annual mean concentration (µg m^{-3}) (2003-2006 and 2009)



4.1.5 Chapter structure

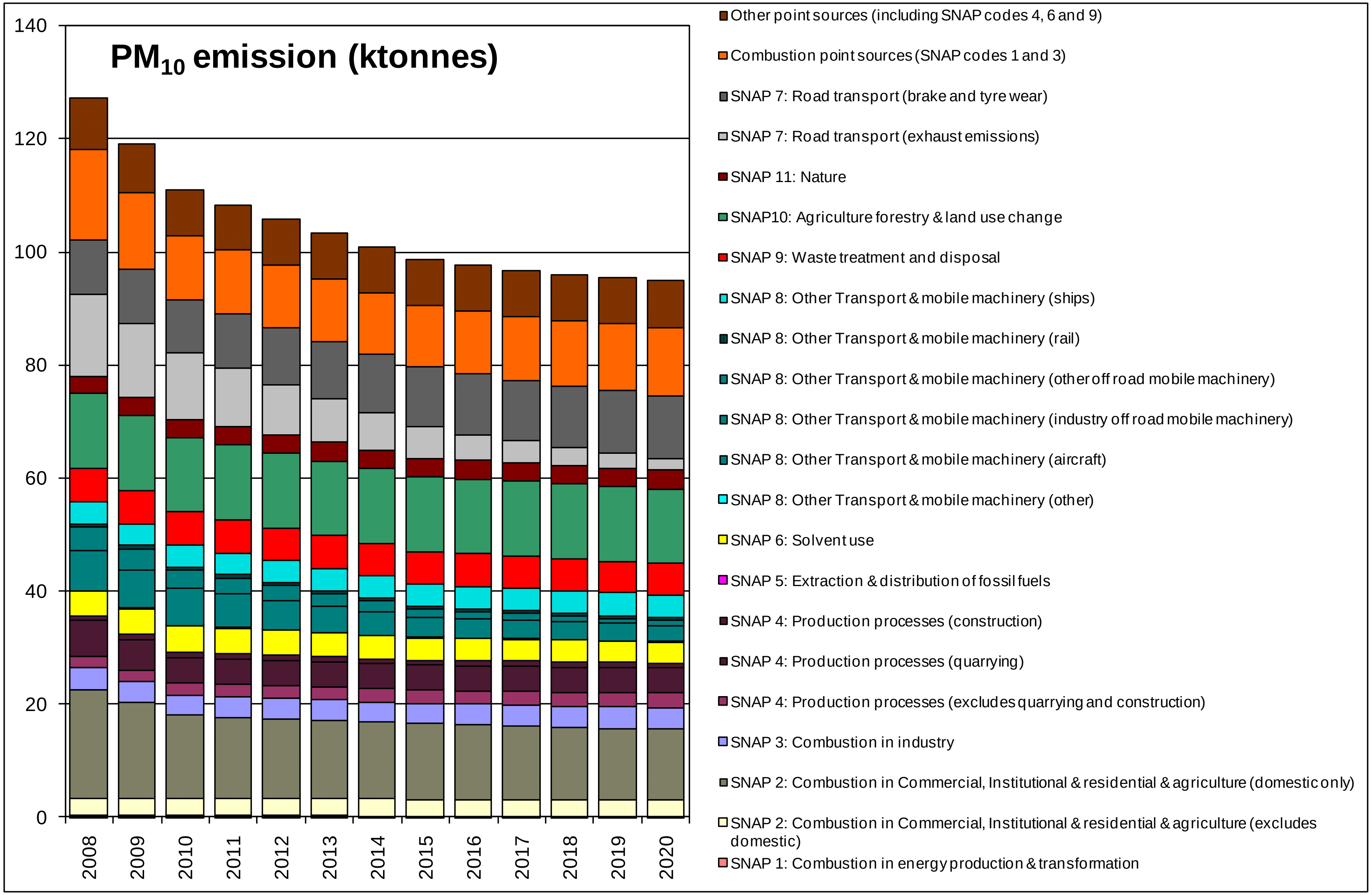
This chapter describes modelling work carried out for 2009 to assess compliance with the PM_{10} limit values described above. Emission estimates for primary PM are described in Section 4.2. Section 4.3 describes the PM_{10} modelling methods. The modelling results are presented in Section 4.4.The methods used to subtract the contribution from natural sources (sea salt) and the results of this subtraction are presented in Section 4.5.

4.2 PM_{10} emissions

Estimates of the emissions of primary PM from the 2008 UK National Atmospheric Emission Inventory (NAEI) have been used in this study (Murrells et al., 2010). Figure 4.5 shows UK total PM_{10} emissions for 2008 and emissions projections up to 2020 split by SNAP code. This shows that PM_{10} emissions in 2008 include contributions from a wide range of different source sectors. Some of the sectors with the largest contribution to the total in 2008 include road traffic exhaust, off-road mobile machinery and domestic combustion.

Maps of emissions from area sources for 2009 were derived from the 2008 inventory maps using specific scaling factors derived for each combination of source and activity (typically fuel type). The emissions from point sources were not scaled and the emissions for 2008 were assumed to apply in 2009. 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 - Total UK PM_{10} emissions for 2008 and emissions projections up to 2020 by SNAP code from NAEI 2008



4.3 PM_{10} modelling

4.3.1 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 2009 (Tang, 2010). 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. The revised method has also been used in this 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 have 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 mode	0.556	1.279	0.00
	Coarse mode fine	0.222	1.60	1.32
	Coarse mode 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	1.00	1.0	0.00
	Coarse	0.0	1.0	0.00

4.3.2 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. 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 it has been assumed 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, the modelled summer time value has been considered to provide a reasonable estimate of the annual mean and the results have not been scaled. SOA is assumed to be volatile (Pankow, 1995) and thus contributes to gravimetric but not TEOM PM concentrations (Table 4.1). The SOA component has been assumed to all within the $PM_{2.5}$ fraction.

4.3.3 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, or for which emission release characteristics are known) have been estimated by modelling each source explicitly using the atmospheric dispersion model ADMS 4.2. Hourly sequential meteorological data for 2009 from Waddington was applied. Surface roughness was assumed to be 0.1 m at the dispersion site and 0.02 m at the meteorological site. 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. A total of 249 point sources were modelled explicitly.

Contributions from PM point sources with less than 200 tonnes per annum release and for which emission characteristics were not known 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.

4.3.4 Contributions from distant sources of primary particles

Contributions from long-range transport of primary particles on a 20 km x 20 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.

4.3.5 Iron and calcium rich dusts

4.3.5.1 Introduction

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

- Regional 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. The PCM models were revised for 2008 in order to incorporate a more process-based modelling approach for regional calcium rich dusts from re-suspension of soils and iron rich dusts from re-suspension due to vehicle activity. The revised models were developed from those proposed by Abbott (2008) were also used for this 2009 assessment. The models for urban calcium rich dusts and regional iron rich dusts remain largely unchanged and are based 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.

4.3.5.2 Regional calcium rich dusts

The regional concentration of Ca rich dusts was assumed to be a constant value across the UK in the 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.

The method of Abbott (2008) has been adapted 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 regional 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 $\mu g\ m^{-3}$ within the map. This value has been chosen as an 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.

4.3.5.3 Urban calcium rich dusts

A more empirical method has been used to estimate the urban increment for Ca rich dusts. The normalized distribution of resident population on a 1 km x 1 km grid has been used as a surrogate for urban emissions within the area source model. The model has been calibrated 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 $\mu g\ m^{-3}$ within the map. This value has been chosen as an 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.

4.3.5.4 Regional iron rich dusts

A constant value for the regional contribution to Fe rich dusts of 1 $\mu g\ m^{-3}$ 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.

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

The 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 soils because there is little information on the availability of material on road surfaces to be re-suspended.

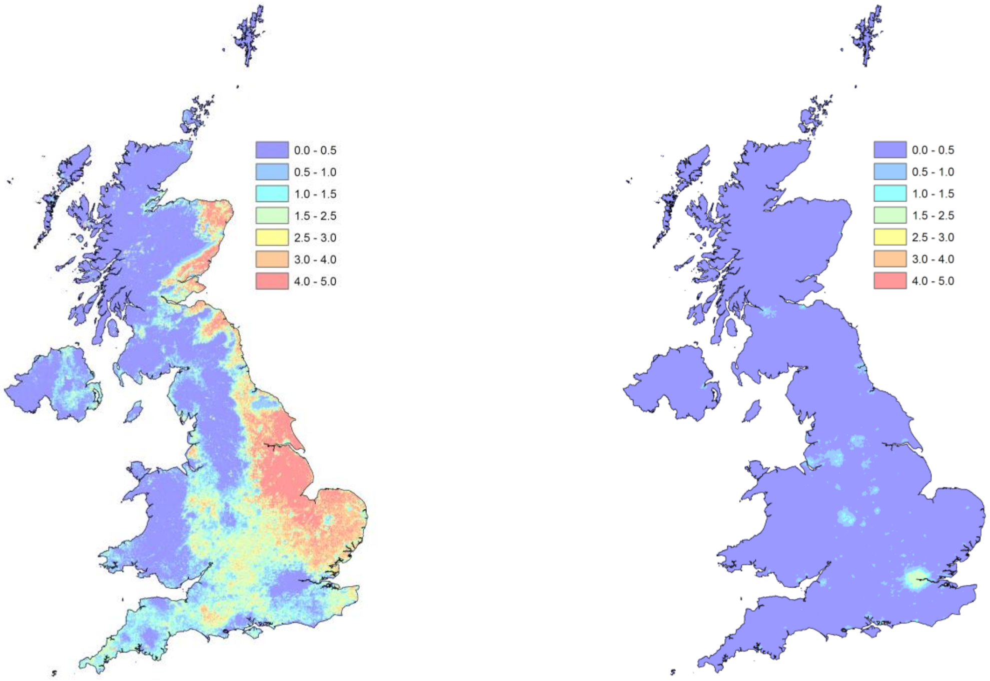
Abbott (2008) calculated two sets of combined emission and dispersion kernels for each of the 12 meteorological stations for 1999: one to represent rural conditions and one to represent urban conditions. The estimated re-suspension rate was considerably higher for rural conditions due to the higher speeds 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. The urban kernels have therefore been chosen to apply to all roads within the 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 $\mu g\ m^{-3}$ within the map. This value has been chosen as an 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

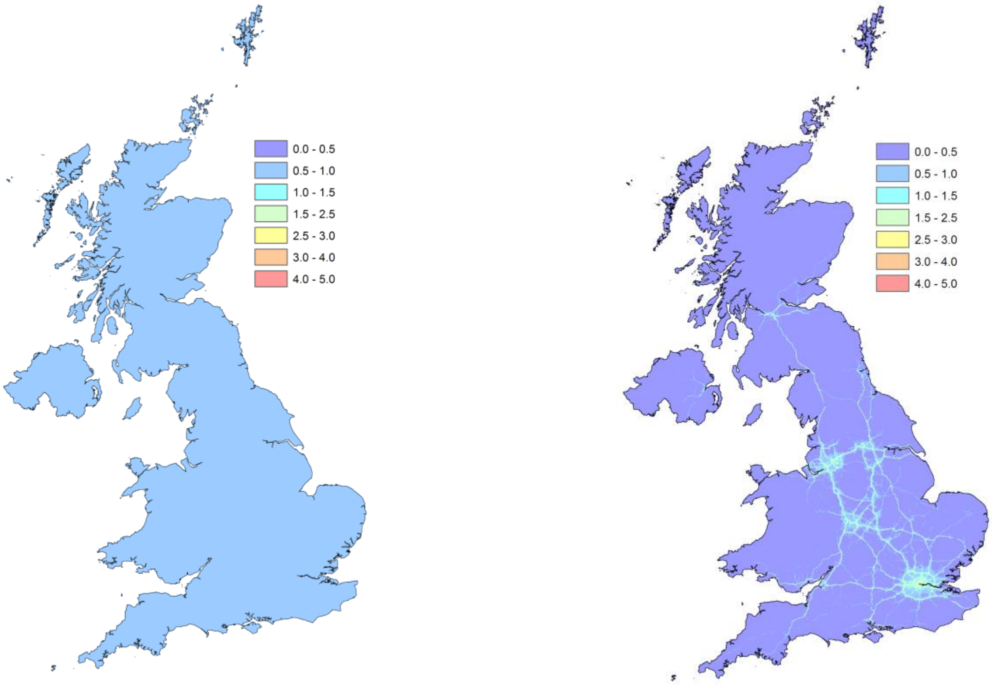
a) Contribution to PM_{10} from regional Ca rich dusts associated with re-suspension from soils ($\mu g\ m^{-3}$)

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



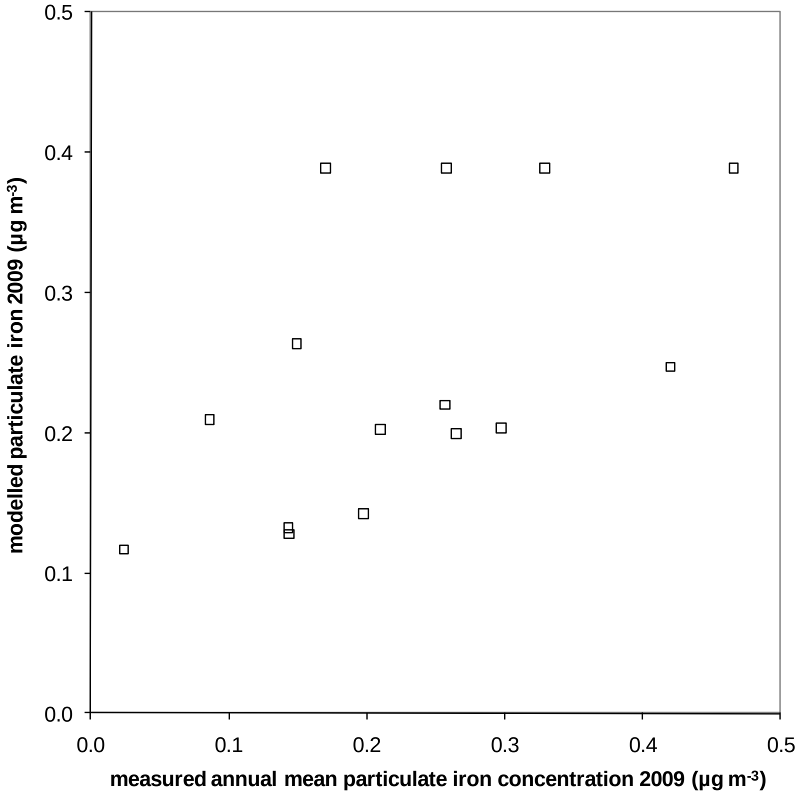
c) Contribution to PM_{10} from regional Fe rich dusts ($\mu g\ m^{-3}$)

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



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 2009 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 2009 (µg m^{-3})



4.3.5.6 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. Section 6 on the modelling of Pb concentrations and the accompanying report (Walker et al., 2010) describe 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.

4.3.6 Sea salt

The contribution to ambient PM from sea salt has been derived directly from measurements of particulate chloride (Tang, 2010). 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).

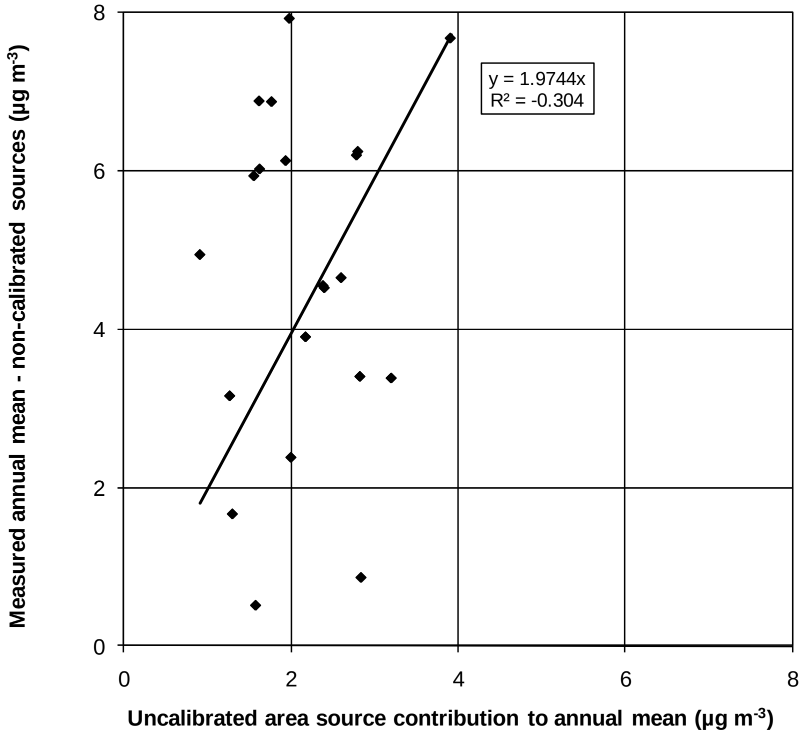
The use of chloride is potentially subject to both positive and negative artefacts. Sea salt is not the only source of particulate chloride in the atmosphere. HCl is emitted from coal burning but reductions in coal use and flue gas abatement are likely to have reduced atmospheric HCl and ammonium chloride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

In addition to selecting chloride as the marker for sea salt, the analysis was simplified by assuming that the sea salt consists of sodium chloride only. Thus the measured chloride concentration has been scaled 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 the modelled concentrations and a sea salt correction has not been applied 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 the 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 the 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, has been included with the rest of the sulphate as anthropogenic.

4.3.7 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 2009 was used to construct the dispersion kernels, as described in Appendix 3. A total of 21 background FDMS monitoring sites within the national network had sufficient data capture for PM_{10} and $PM_{2.5}$ in 2009 to be used to calibrate the model. Only sites with valid data for PM_{10} and $PM_{2.5}$ have been used to calibrate the PM_{10} and $PM_{2.5}$ models for 2009, as described in Section 4.1.

Figure 4.8 - Calibration of PM_{10} area source model 2009 ($\mu g\ m^{-3}$, 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 for both PM_{10} and $PM_{2.5}$ in 2009.

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.

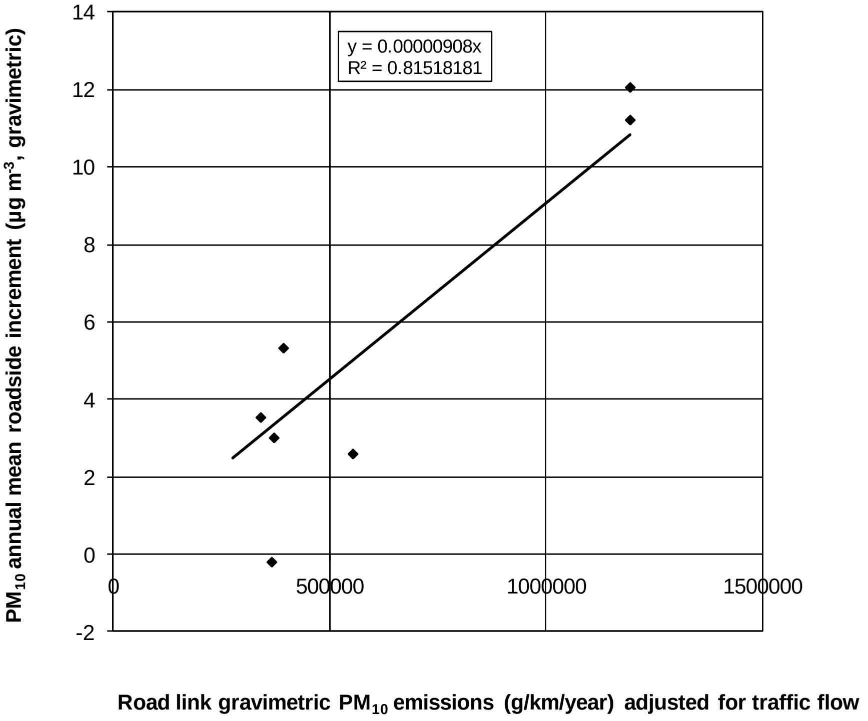
4.3.8 Roadside concentrations

The annual mean concentration of PM_{10} at a roadside location has been considered to be 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 2008 (Murrells et al., 2010) and these have been adjusted to provide estimates of emissions in 2009. The roadside increment model for PM_{10} has been calibrated using data from FDMS or gravimetric monitoring sites with valid data for both PM_{10} and $PM_{2.5}$ in 2009. Figure 4.9 shows a comparison of the roadside increment of annual mean PM_{10} concentrations at roadside or kerbside monitoring sites with PM_{10} emission estimates for the individual road links alongside which these sites are located. 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 2.2.6. Roadside concentrations for urban major road links (A-roads and motorways) only are reported to the EU and included in this report.

Figure 4.9 - Calibration of PM_{10} roadside increment model 2009 (µg m^{-3}, gravimetric)



4.4 Results

4.4.1 Verification of mapped values

Figure 4.10 and Figure 4.11 show comparisons of modelled and measured annual mean PM_{10} concentration in 2009 at background and roadside monitoring site locations. Lines representing y = x – 50 % and y = x + 50% are also shown because 50% is the AQD data quality objective for modelled annual mean PM_{10} concentrations – see Section 1.8. Summary statistics for the comparison between modelled and measured PM_{10} concentrations are presented in Table 4.3 and Table 4.4.

There are a number of different categories of monitoring sites within these tables and graphs. This is because there are some sites in the national network at which only PM_{10} or $PM_{2.5}$ are measured, but not both. TEOM PM_{10} data adjusted using the VCM model are available for some sites. In some instances a composite TEOM VCM/FDMS dataset is available for a national network monitoring site that also has a valid FDMS dataset with more than 75% data capture but lower data capture than the composite dataset.

The agreement between the FDMS, gravimetric (Partisol) and TEOM VCM measurement data and the modelled values is generally good. The TEOM x 1.3 measurement data for verification sites are higher than the modelled estimates. This is as expected since TEOM x 1.3 is known to over predict in comparison to the reference gravimetric monitoring method.

Figure 4.10 - Verification of background annual mean PM_{10} model 2009

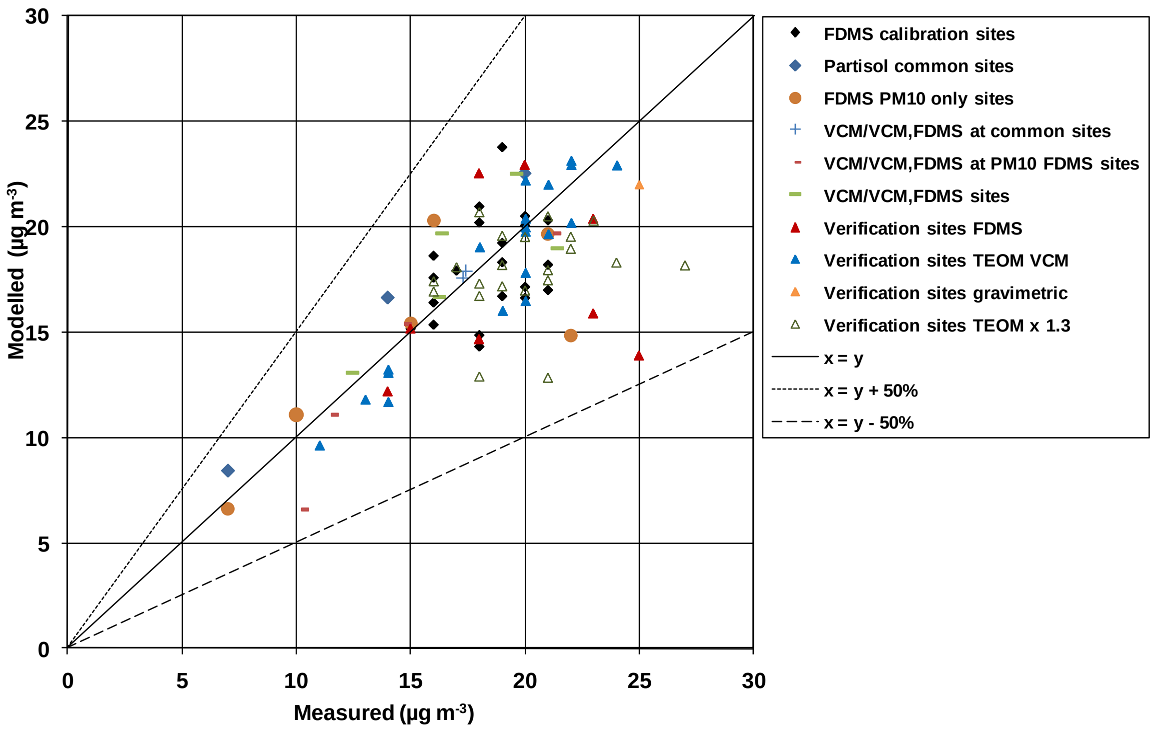


Figure 4.11 - Verification of roadside annual mean PM_{10} model 2009

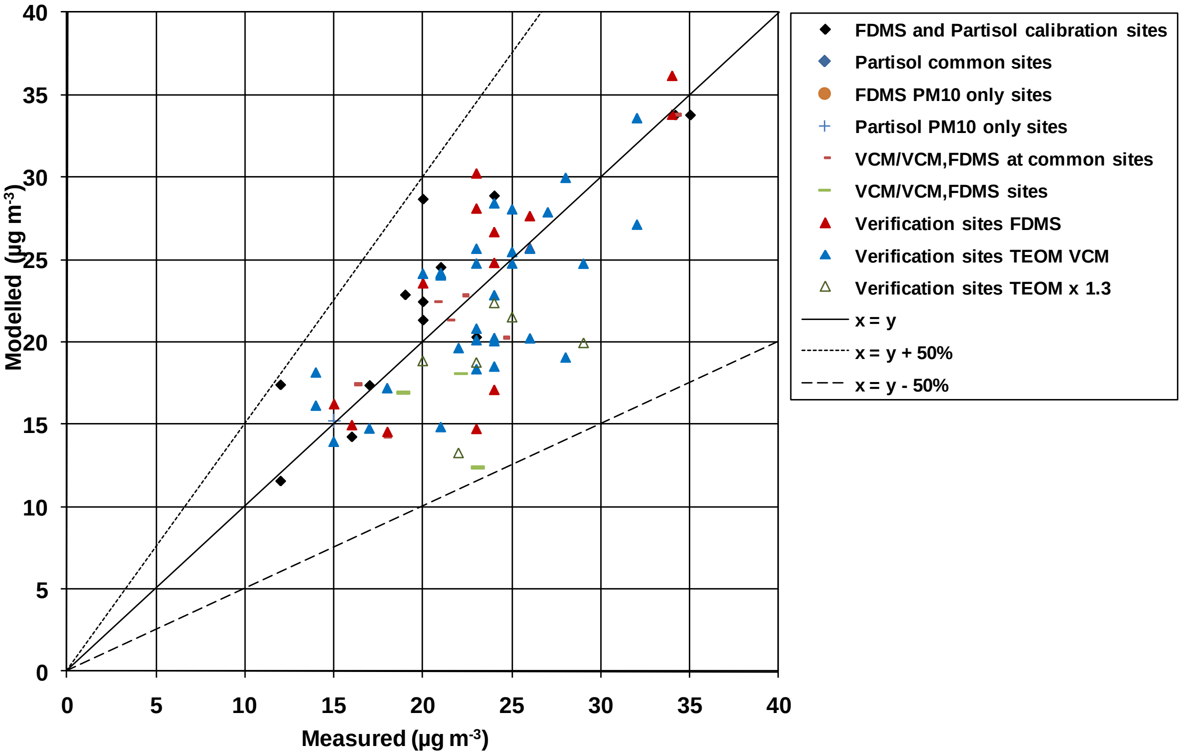


Table 4.3 - Summary statistics for comparison between gravimetric modelled and measured concentrations of PM_{10} at background sites

	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
National network (Calibration)	18.4	18.1	0.13	0	21
National network Partisol	13.7	15.9	1.00	0	3
National network FDMS PM10 only sites	15.2	14.6	0.60	0	6
National network Partisol PM10 only sites	-	-	-	-	-
National Network VCM/VCM,FDMS at common sites	17.3	17.7		0	2
National network VCM/VCM,FDMS at PM10 FDMS sites	14.3	12.4	0.95	0	3
National network VCM/VCM,FDMS sites	17.2	18.2	0.62	0	5
Verification sites FDMS	19.5	17.2	0.04	0	8
Verification sites VCM	18.7	18.0	0.88	0	19
Verification sites gravimetric	25.0	22.0	-	0	1
Verification sites TEOM	20.0	17.9	0.05	0	21

Table 4.4 - 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
National network FDMS (Calibration)	21.0	22.9	0.79	0	13
National network FDMS PM10 only sites	-	-	-	-	-
National network Partisol PM10 only sites	15.0	15.2		0	1
National Network VCM/VCM,FDMS at common sites	22.4	21.8	0.85	0	7
National network VCM/VCM,FDMS at PM10 FDMS sites					
National network VCM/VCM,FDMS sites	21.4	15.8	0.27	0	3
Verification sites FDMS	23.6	23.8	0.66	0	14
Verification sites VCM	23.2	22.4	0.49	0	32
Verification sites gravimetric	-	-	-	-	-
Verification sites TEOM	23.8	19.1	0.16	0	6

4.4.2 PM_{10} source apportionment at monitoring sites

Figure 4.12 and Figure 4.13 show the modelled annual mean PM_{10} source apportionment for 2009 at national network 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, is dominated in most locations by traffic (exhaust emissions and brake and tyre wear), industry and off road mobile machinery.

At roadside locations the source apportionment follows 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 $\mu g\ m^{-3}$ of PM_{10} at the roadside monitoring sites.

4.4.3 Detailed comparison of modelling results with limit values

The modelling results, in terms of a comparison of modelled concentrations with the annual mean and 24-hour mean 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. Compliance with the 24-hour mean limit value has been assessed using an annual mean of greater than 31.5 µg m-3 as indicative of an exceedance of the 24-hour mean limit value, as described in Section 4.1.4. The European Commission have advised that comparisons with the indicative Stage 2 limit values included in the first Daughter Directive (1999/30/EC) 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 4 metres from the road kerbside.

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

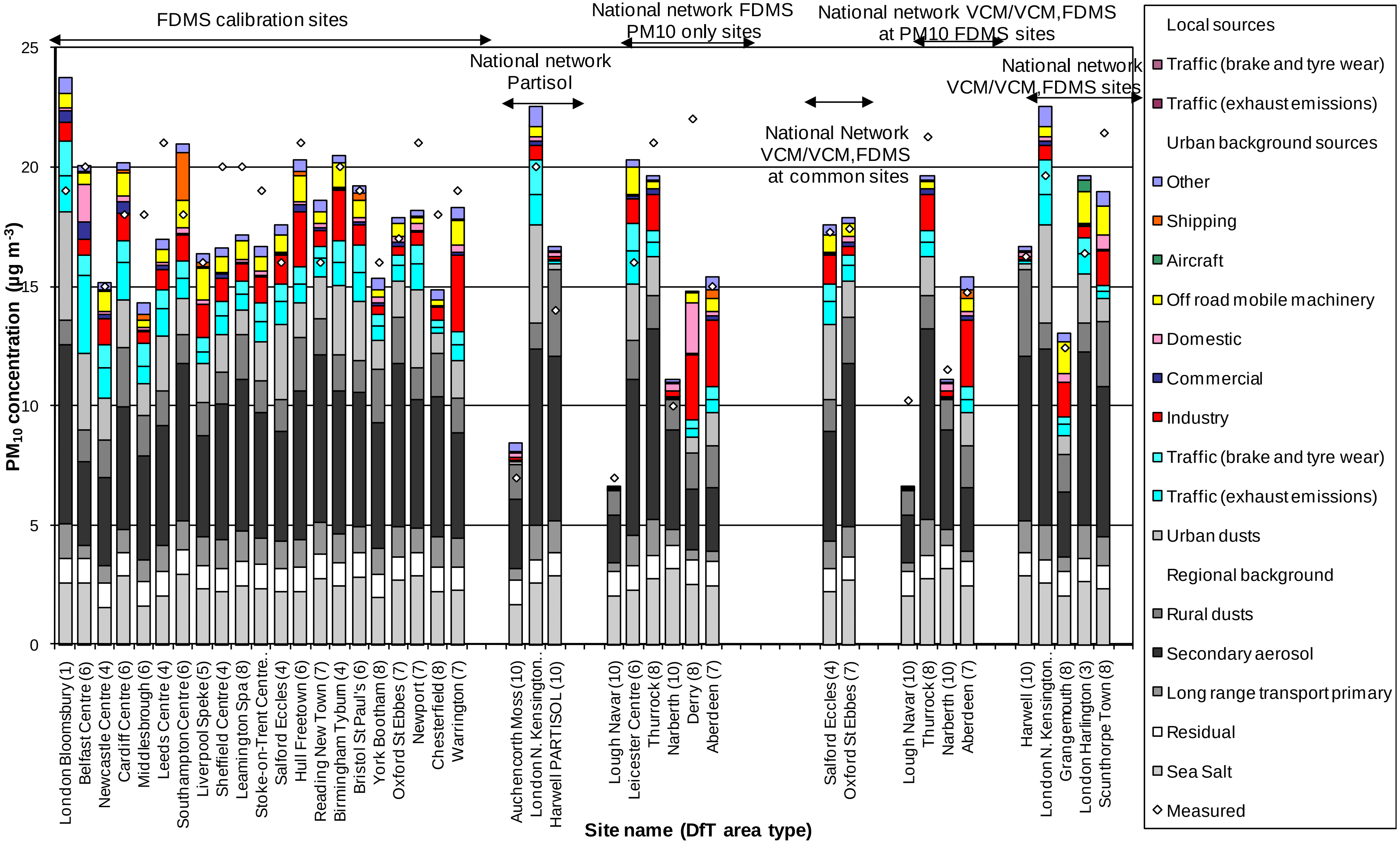


Figure 4.13 - Annual mean PM_{10} source apportionment at national network roadside monitoring sites (the area type of each site is shown in parenthesis after its name)

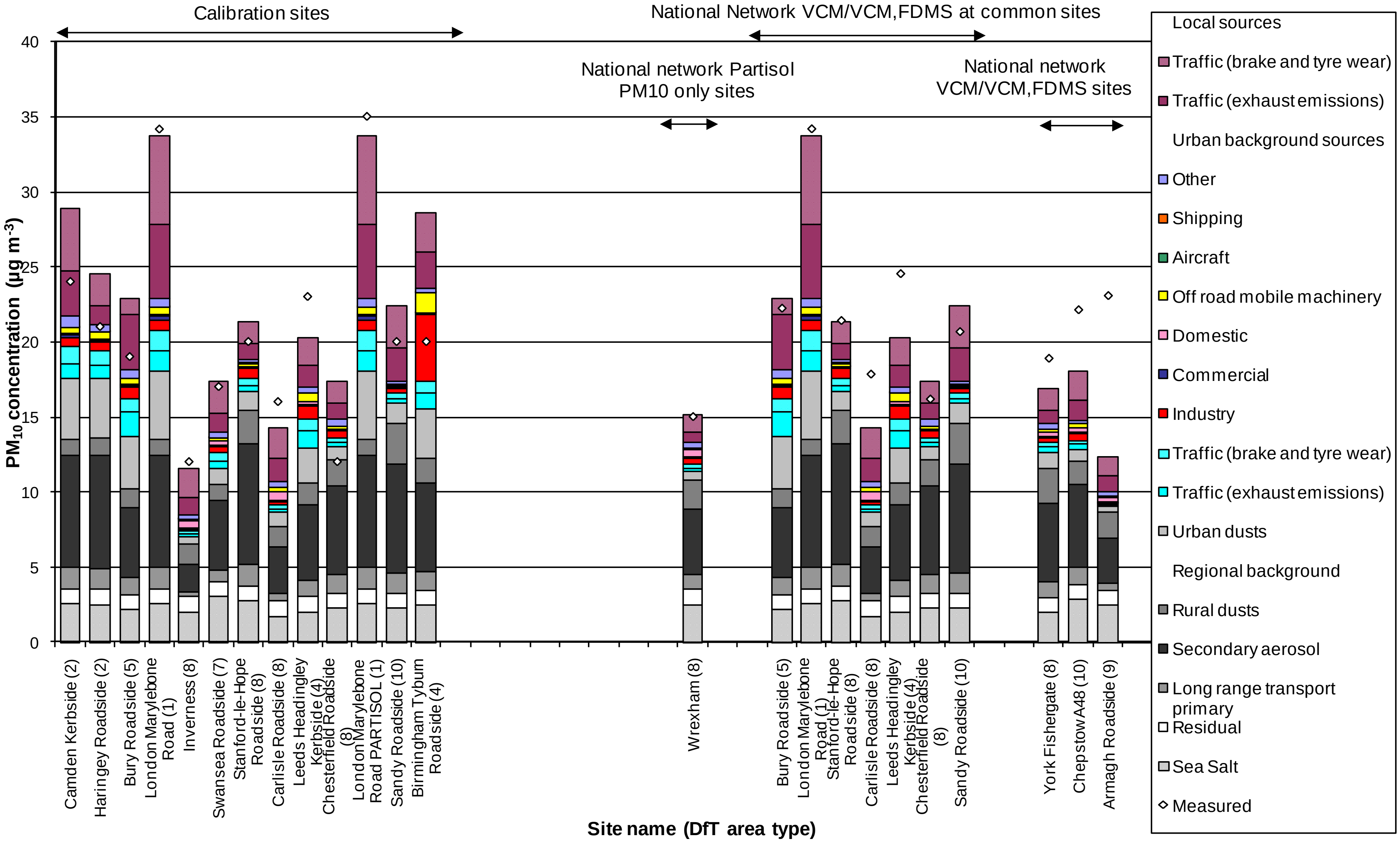


Table 4.5 - Tabular results of and methods used for supplementary assessment for PM10 (Stage 1)

Zone	Zone code	Above LV (24-hr 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	89.1	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	0.4	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
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

Zone	Zone code	Above LV (24-hr 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
Eastern	UK0029	0	A	5.7	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

4.5 Subtraction of sea salt component

4.5.1 Introduction

The AQD requires member states to discount exceedances 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, 2010) 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 exceedances of the limit values. 2009 is the second year for which the contribution from natural sources has been subtracted. Natural sources have been subtracted because this is a requirement of the new directive.

4.5.2 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 4.3.6. 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 4.3.6. It is recognised that the interpolated map of sea salt concentrations will not capture the steep gradients in sea salt concentration very close to the coast. Thus the analysis presented may underestimate the sea salt contribution to exceedances in coastal areas.

4.5.3 Method for the 24-hour limit value

A method has also been developed for estimating the contribution from sea salt to exceedances of the 24-hour limit value for PM_{10} of no more than 35 days with concentration greater than 50 µg 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 µg m^{-3} and annual mean concentrations described in Section 4.1.4 above. There is some scatter around the best-fit line of the relationship shown in Figure 4.3. Using the best-fit line relationship within the annual method for subtracting sea salt has been considered appropriate 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 µg 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 µg m^{-3} minus half the sea salt concentration and the number of days corresponding to 31.5 µg 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 the method based on annual mean sea salt concentrations has been used 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.

4.5.4 Results

The results of the assessment of number of days with a PM_{10} concentration greater than 50 µg m^{-3} with the contribution from sea salt subtracted in zones with measured or modelled exceedances of the 24-hour limit value are shown in Table 4.6. This is a copy of form 23a of the reporting questionnaire. The measured exceedance in the Greater London Urban Area is removed by the subtraction of the contribution from sea salt. The modelled exceedance in the Greater London Urban Area remains. The modelled exceedances in the Southampton Urban Area and Eastern Zone are 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 exceedances of the annual mean limit value for PM_{10} in 2009.

Table 4.6 - Exceedance of limit values of PM_{10} due to natural events or natural contributions - Contribution of natural events to exceedance of the PM_{10} limit value (24-hr mean)

Zone code	Zone	EoI station code	Number of exceedances measured	Natural event code(s)	Estimated number of exceedances after subtraction of natural contribution
UK0001	Greater London Urban Area	GB0949A	36	S8	25
UK0001	Greater London Urban Area	n/a	61	S8	47
UK0019	Southampton Urban Area	n/a	36	S8	25
UK0029	Eastern	n/a	43	S8	32

5 $PM_{2.5}$

5.1 Introduction

5.1.1 Target values

The Air Quality Directive (AQD) includes a target value (TV) for annual mean $PM_{2.5}$ to be achieved by 01/01/2010:

- An annual mean concentration of 25 µg m^{-3}.

Full details of the target value, limit values and national exposure reduction targets for $PM_{2.5}$ are provided in Section 1.7.

5.1.2 Annual mean model

Maps of annual mean $PM_{2.5}$ in 2009 at background and roadside locations are shown in Figure 5.1 and Figure 5.2. 2009 is the first year for which the results of an air quality assessment for $PM_{2.5}$ have been reported to the EU. An assessment for $PM_{2.5}$ is required for compliance with the AQD.

The maps have been calibrated using measurements from TEOM FDMS instruments within the national network for which co-located PM_{10} measurements are also available for 2009. The models for PM_{10} and $PM_{2.5}$ are designed to be fully consistent, with each component either derived from emission estimates for PM_{10} or $PM_{2.5}$, or the contributions to the fine and coarse particle size fractions are estimated separately. This enables us to carry out an additional reality check that the calibration parameters for the two pollutants are reasonably consistent. Measurements from national network sites without collocated $PM_{2.5}$ instruments have been used as an additional verification dataset.

5.1.3 Outline of the annual mean model

Full details of the models used to calculate concentrations of PM_{10} and $PM_{2.5}$ are provided in Section 4. A short summary of the methods is provided here.

The maps of background $PM_{2.5}$ 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 from 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). The mass fractions of each component assigned to $PM_{2.5}$ are listed in Section 5.3.1. The component pieces are then aggregated to a single 1 km x 1 km background $PM_{2.5}$ grid. An additional roadside increment is added for roadside locations.

Figure 5.1 - Annual mean background $PM_{2.5}$ concentration, 2009 ($\mu g\ m^{-3}$, gravimetric)

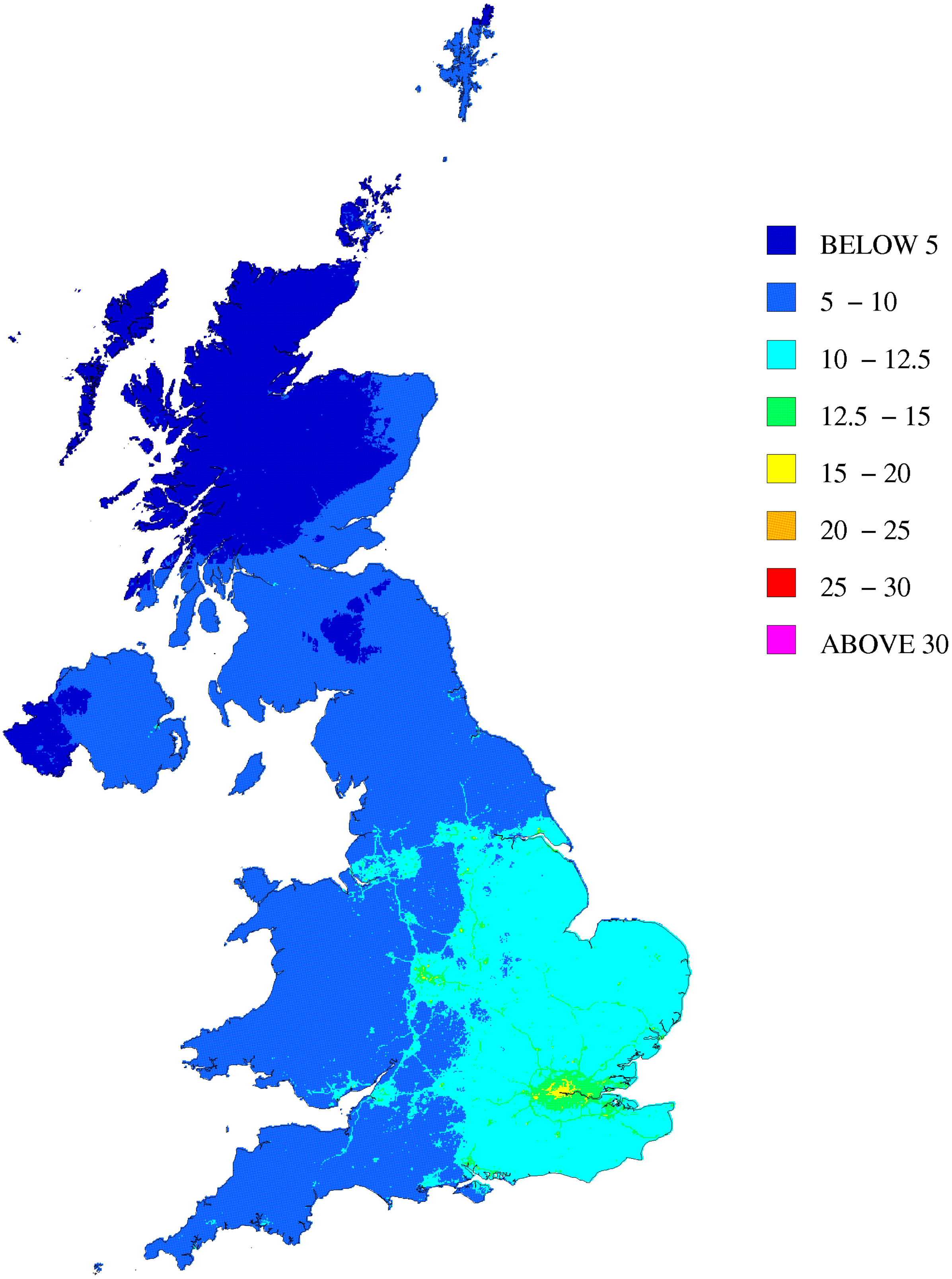
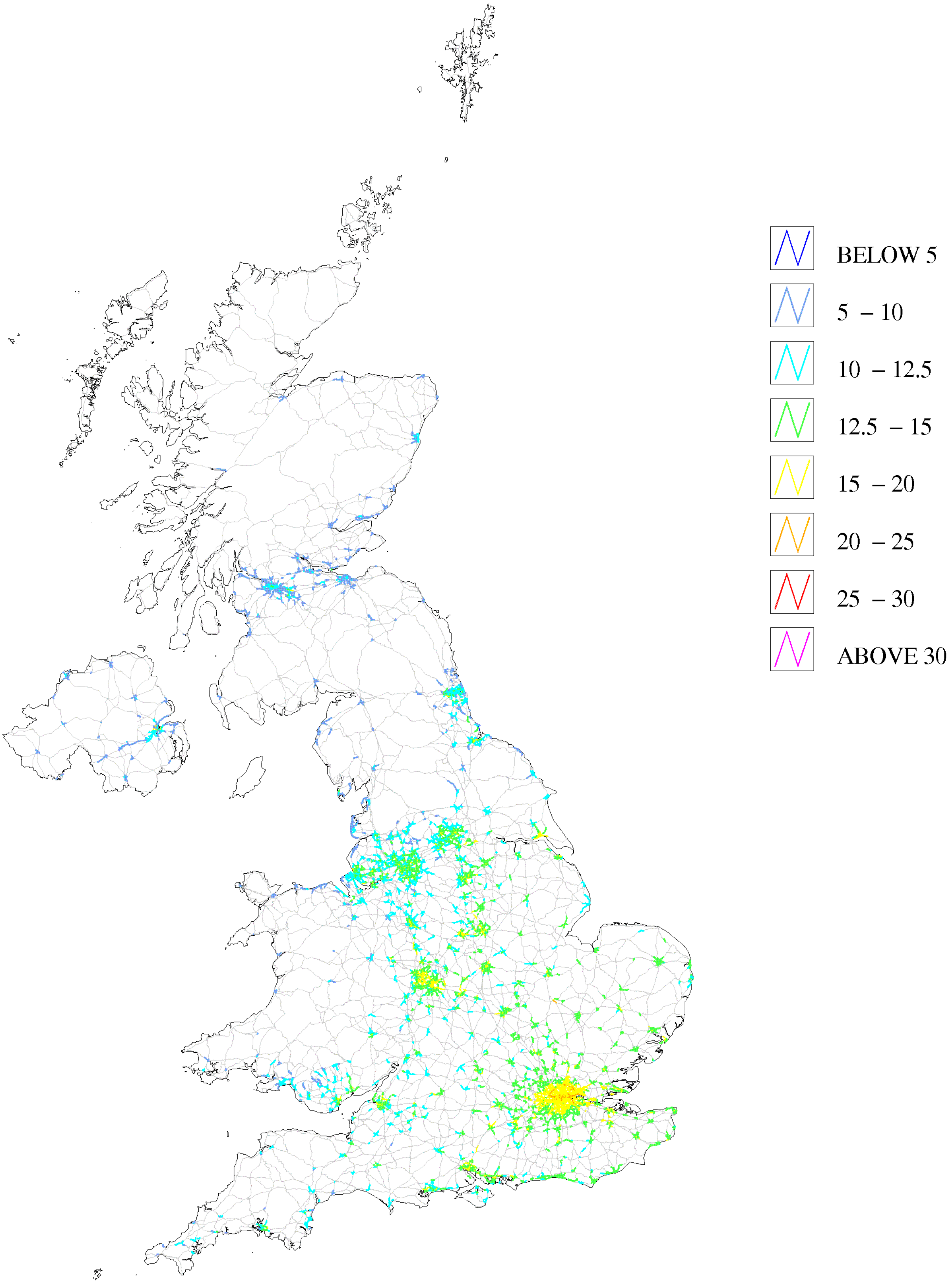


Figure 5.2 - Urban major roads, annual mean roadside $PM_{2.5}$ concentration, 2009 (µg m^{-3}, gravimetric)



5.1.4 Chapter Structure

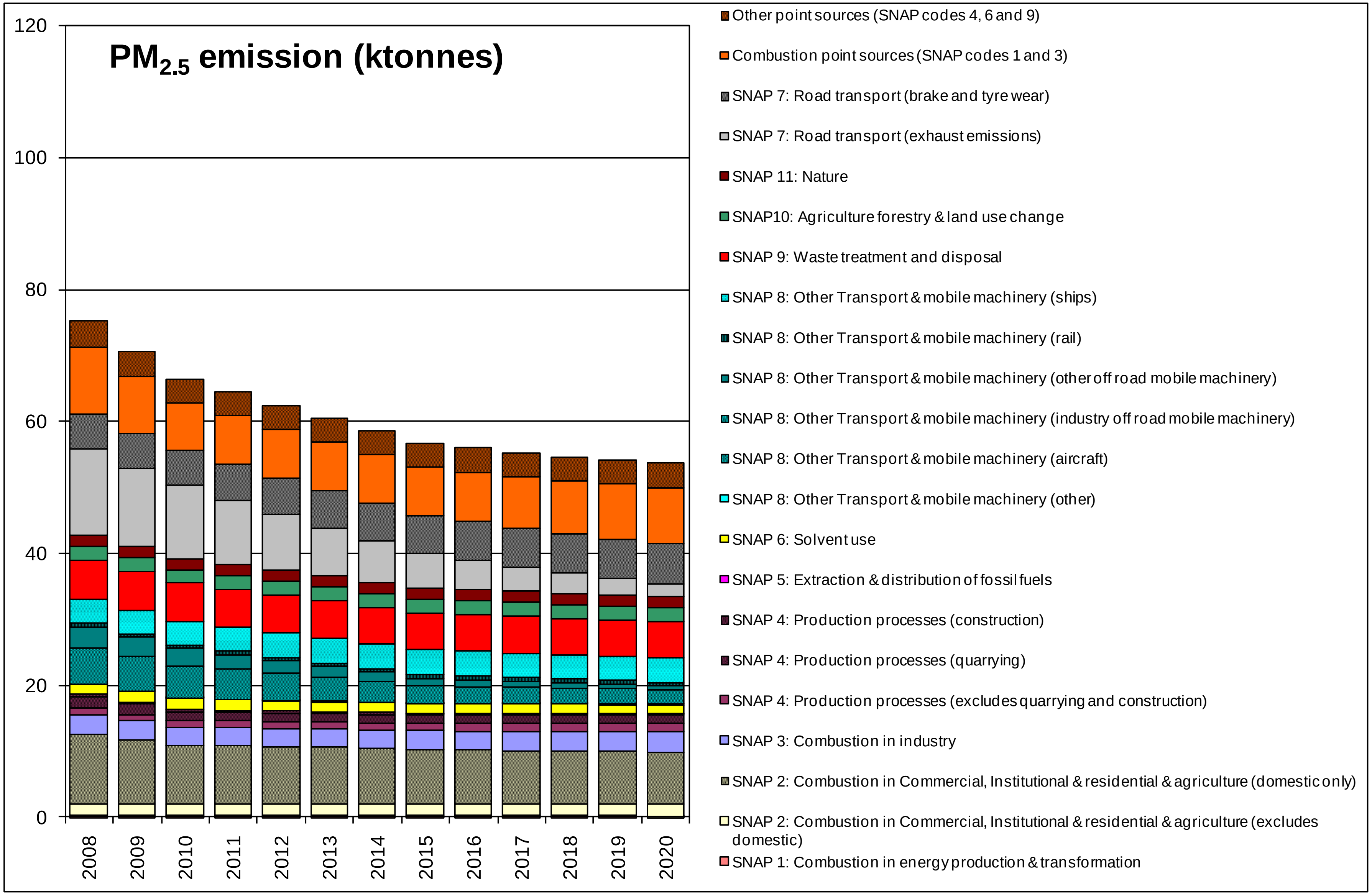
This chapter describes modelling work carried out for 2009 to assess compliance with the $PM_{2.5}$ target values described above. Emission estimates for primary PM are described in Section 5.1.4. Section 5.3 describes the $PM_{2.5}$ modelling methods. The modelling results are presented in Section 5.4.

5.2 $PM_{2.5}$ emissions

Estimates of the emissions of primary PM from the 2008 UK National Atmospheric Emission Inventory (NAEI) have been used in this study (Murrells et al., 2010). Figure 5.3 shows UK total UK $PM_{2.5}$ emissions for 2008 and emissions projections up to 2020 split by SNAP code. This shows that $PM_{2.5}$ emissions in 2008 include contributions from a wide range of different source sectors. Some of the sectors with the largest contribution to the total in 2008 include road traffic exhaust, off-road mobile machinery and domestic combustion.

Maps of emissions from area sources for 2009 were derived from the 2008 inventory maps using specific scaling factors derived for each combination of source activity (typically fuel type). The emissions from point sources were not scaled and the emissions for 2008 were assumed to apply in 2009. The methods used to calculate ambient concentrations from the estimates of primary PM emissions are described below for point, area and regional sources.

Figure 5.3 - Total UK $PM_{2.5}$ emissions for 2008 and emissions projections up to 2020 by SNAP code from NAEI 2008



5.3 $PM_{2.5}$ modelling

5.3.1 $PM_{2.5}$ mass fractions

The proportions of the PM mass for each component assigned to the $PM_{2.5}$ fraction within the PCM models are listed in Table 5.1. The proportions for secondary inorganic aerosols have been derived as described in Section 4.3. The proportions for local point and area sources are based on the NAEI emission inventories for $PM_{2.5}$ and PM_{10} (Murrells et al., 2010). The $PM_{2.5}$ NAEI emission inventory has been derived from the PM_{10} emission inventory by the application of estimates of the mass fraction represented by $PM_{2.5}$ for different sources and fuels. These fractions vary between 0.18 for the emissions associated with some animal wastes and 0.95 for road traffic exhaust emissions. Overall the UK total mass emissions for $PM_{2.5}$ for 2008 were about half of the value for PM_{10}. The proportions for calcium and iron rich dusts have been derived with reference to the monitoring data presented in Section 4.3.2 and to provide good fit to the available co-located $PM_{2.5}$ and PM_{10} measurements. The proportion for sea salt has been derived as described in Section 4.3.6.The proportions for secondary organic aerosol, regional primary particles and the residual have been set at 1.0 for $PM_{2.5}$ so as to provide best fit to the available measurements.

Table 5.1 - The proportion of PM mass assigned to the $PM_{2.5}$ and $PM_{2.5-10}$ size fractions

Component	Fine fraction ($PM_{2.5}$)	Coarse fraction ($PM_{2.5-10}$)
SO_4	0.94	0.06
NO_3	0.556 (fine mode), 0.222 (coarse mode)	- (fine mode), 0.222 (coarse mode)
NH_4	0.97	0.03
SOA	1.0	-
Large point sources of primary particles	$PM_{2.5}$ emission inventory*	PM_{10} emission inventory
Small point sources of primary particles	$PM_{2.5}$ emission inventory*	PM_{10} emission inventory
Regional primary particles	1.00	-
Area sources of primary particles	$PM_{2.5}$ emission inventory*	PM_{10} emission inventory
Rural calcium rich dusts from re-suspension of soils	0.20	0.80
Urban calcium rich dusts from re-suspension of soils due to urban activity	0.50	0.50
Regional iron rich dusts from re-suspension	0.33	0.67
Iron rich dusts from re-suspension due to vehicle activity	0.50	0.50
Sea salt	0.27	0.73
Residual	1.00	-

* The $PM_{2.5}$ NAEI emission inventory has been derived from the PM_{10} emission inventory by the application of estimates of the mass fraction represented by $PM_{2.5}$ for different sources and fuels.

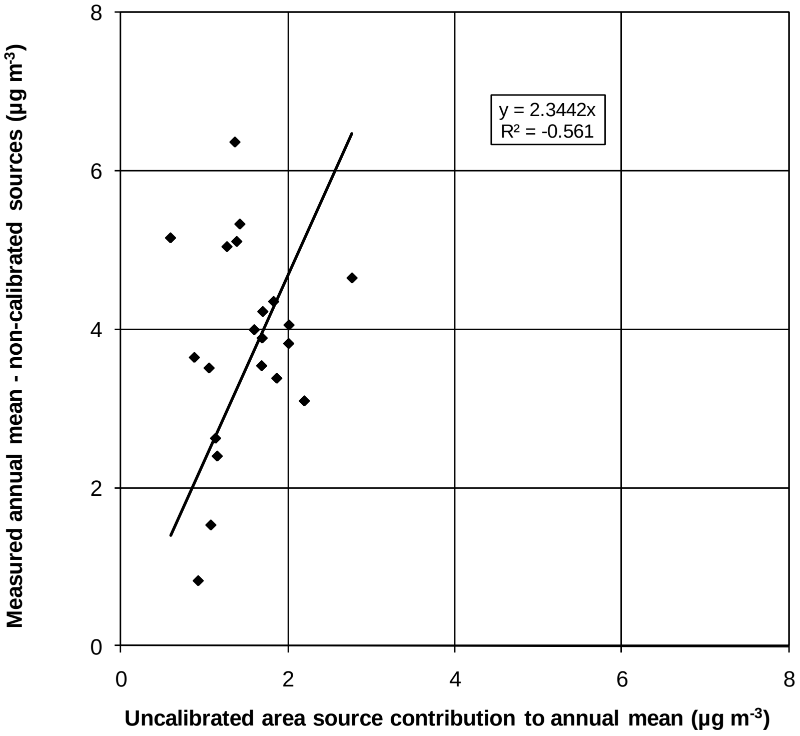
5.3.2 Contributions from large and small point sources

The contributions from large and small point sources have been calculated in the same way as for the PM_{10} model described in Section 4.3.3. A total of 249 point sources were modelled explicitly.

5.3.3 Contributions from area sources

Figure 5.4 shows the calibration of the area source model for $PM_{2.5}$. The calibration coefficient for $PM_{2.5}$ is quite similar to the calibration coefficient for PM_{10} and the difference is considered to be well within the uncertainty of the $PM_{2.5}$ mass fractions within the emission inventory. A reasonably good agreement between the calibration coefficients for area sources is one of the criteria for the choice of mass fraction parameters for $PM_{2.5}$ within the PCM model.

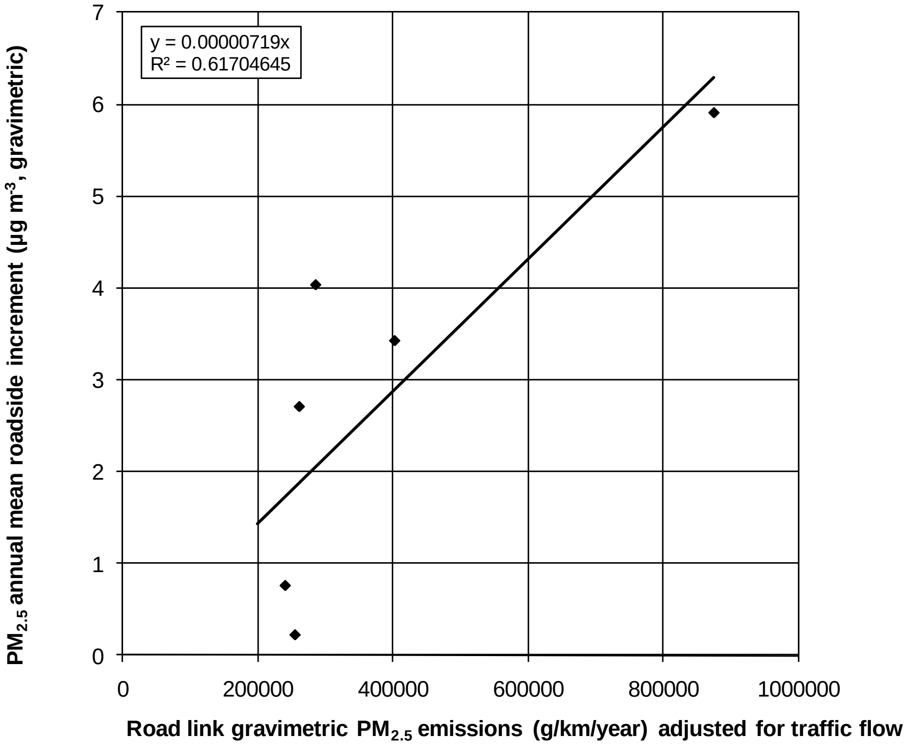
Figure 5.4 - Calibration of $PM_{2.5}$ area source model 2009 (µg m^{-3}, gravimetric)



5.3.4 Roadside concentrations

Figure 5.5 shows the calibration of the roadside increment model for annual mean $PM_{2.5}$ concentrations.

Figure 5.5 - Calibration of $PM_{2.5}$ roadside increment model 2009 (µg m^{-3}, gravimetric)



5.4 Results

5.4.1 Verification of mapped concentrations

Figure 5.6 and Figure 5.7 show comparisons of modelled and measured annual mean $PM_{2.5}$ concentrations in 2009 at background and roadside monitoring site locations. Lines representing y = x – 50 % and y = x + 50% are also shown because 50% is the AQD data quality objective for modelled annual mean $PM_{2.5}$ concentrations – see Section 1.8. Summary statistics for the comparison between modelled and measured $PM_{2.5}$ concentrations are presented in Table 5.2 and Table 5.3.

There are a number of different categories of monitoring sites within these tables and graphs. This is because there are some sites in the national network at which only PM_{10} or $PM_{2.5}$, but not both are measured.

The agreement between the FDMS and gravimetric measurement data and the modelled values is generally good. The TEOM x 1.0 measurement data for verification sites are lower than the modelled estimates. This is as expected since TEOM x 1.0 is known to underestimate in comparison to the reference gravimetric monitoring method as a result of the loss of volatile components.

Figure 5.6 - Verification of background annual mean $PM_{2.5}$ model 2009

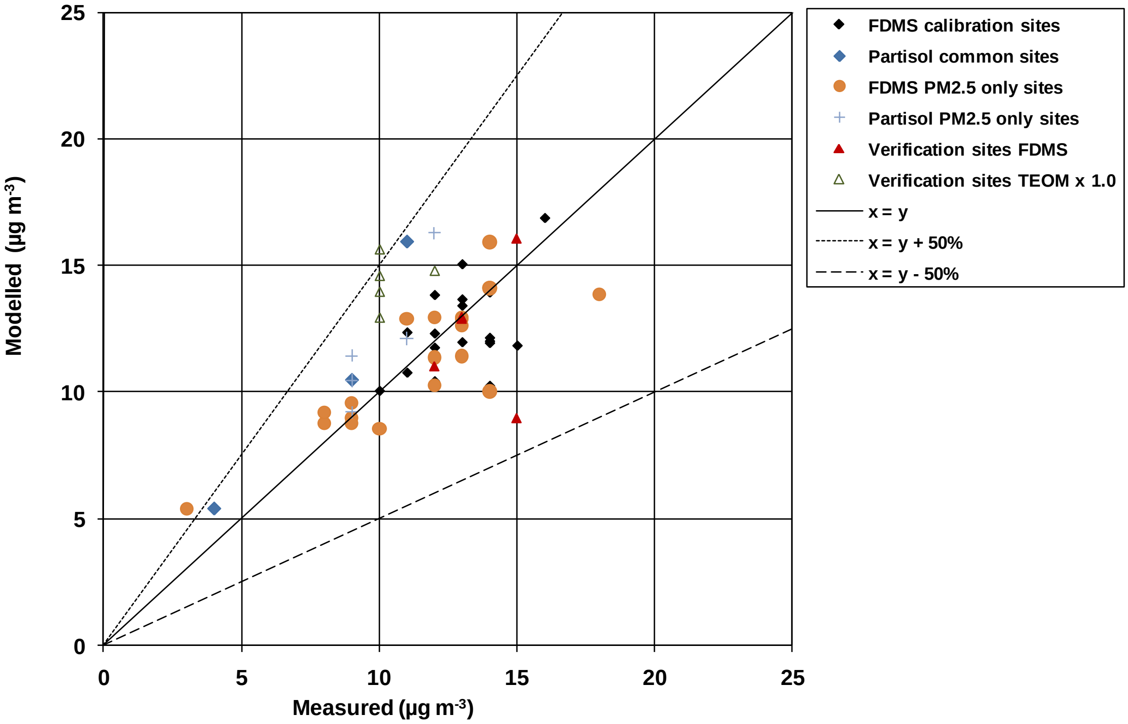


Figure 5.7 - Verification of roadside annual mean $PM_{2.5}$ model 2009

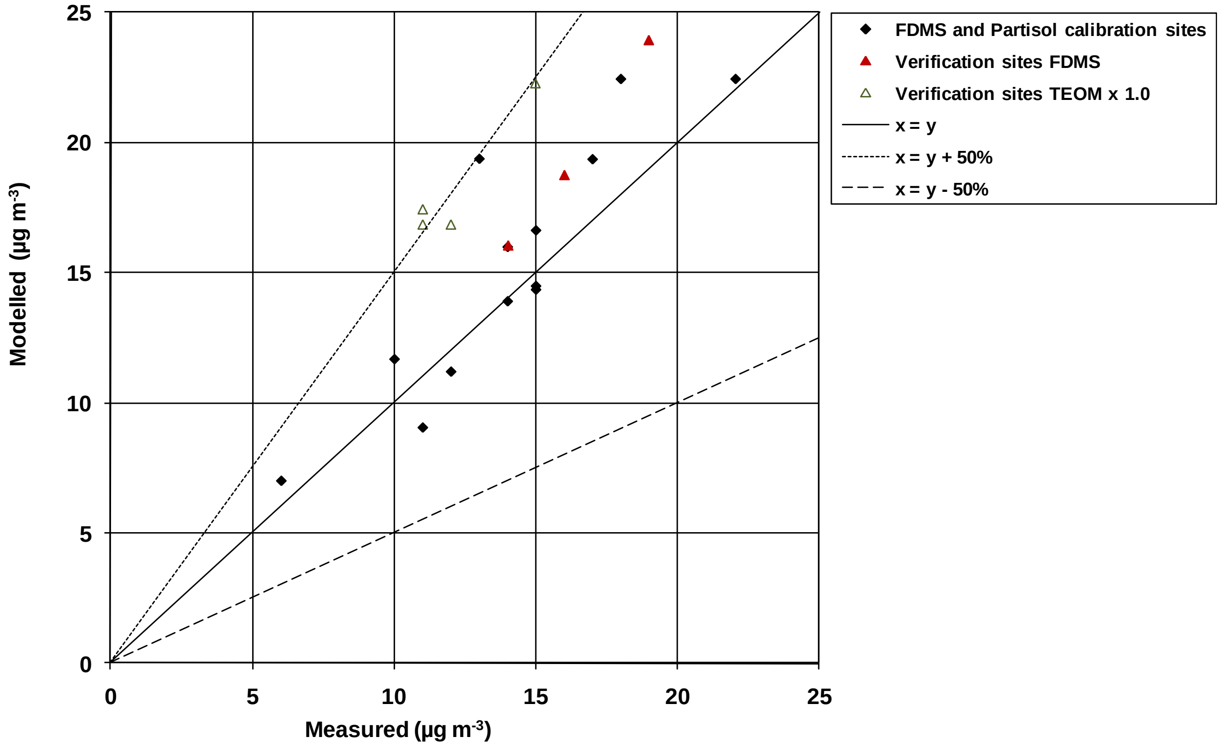


Table 5.2 - Summary statistics for comparison between gravimetric modelled and measured concentrations of $PM_{2.5}$ at background sites

	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)	12.9	12.6	0.23	0	21
National network Partisol	8.0	10.6	0.93	0	3
National network FDMS PM25 only sites	11.5	11.2	0.71	5	20
National network Partisol PM25 only sites	10.0	11.9	0.80	0	5
Verification sites FDMS	13.6	12.4	0.02	0	5
Verification sites gravimetric	-	-	-	-	-

Table 5.3 - Summary statistics for comparison between gravimetric modelled and measured concentrations of PM_{10} at roadside sites

	Mean of measurements (µg m^{-3}, grav)	Mean of model estimates (µg m^{-3}, grav)	R^2	% outside data quality objectives	Number of sites
National network (Calibration)	14.0	15.2	0.78	0	13
National network FDMS PM25 only sites	-	-	-	-	-
National network Partisol PM25 only sites	-	-	-	-	-
Verification sites FDMS	16.3	14.6	1.00	0	3
Verification sites gravimetric	-	-	-	-	-
Verification sites TEOM	12.3	14.6	0.90	50	4

5.4.2 $PM_{2.5}$ source apportionment at monitoring sites

Figure 5.8 and Figure 5.9 show the modelled annual mean $PM_{2.5}$ source apportionment for 2009 at national network 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.

Overall regional secondary PM make a proportionally larger contribution to the total mass for $PM_{2.5}$ than for PM_{10}.

Figure 5.8 - Annual mean $PM_{2.5}$ source apportionment at background national network monitoring sites (the area type of each site is shown in parenthesis after its name)

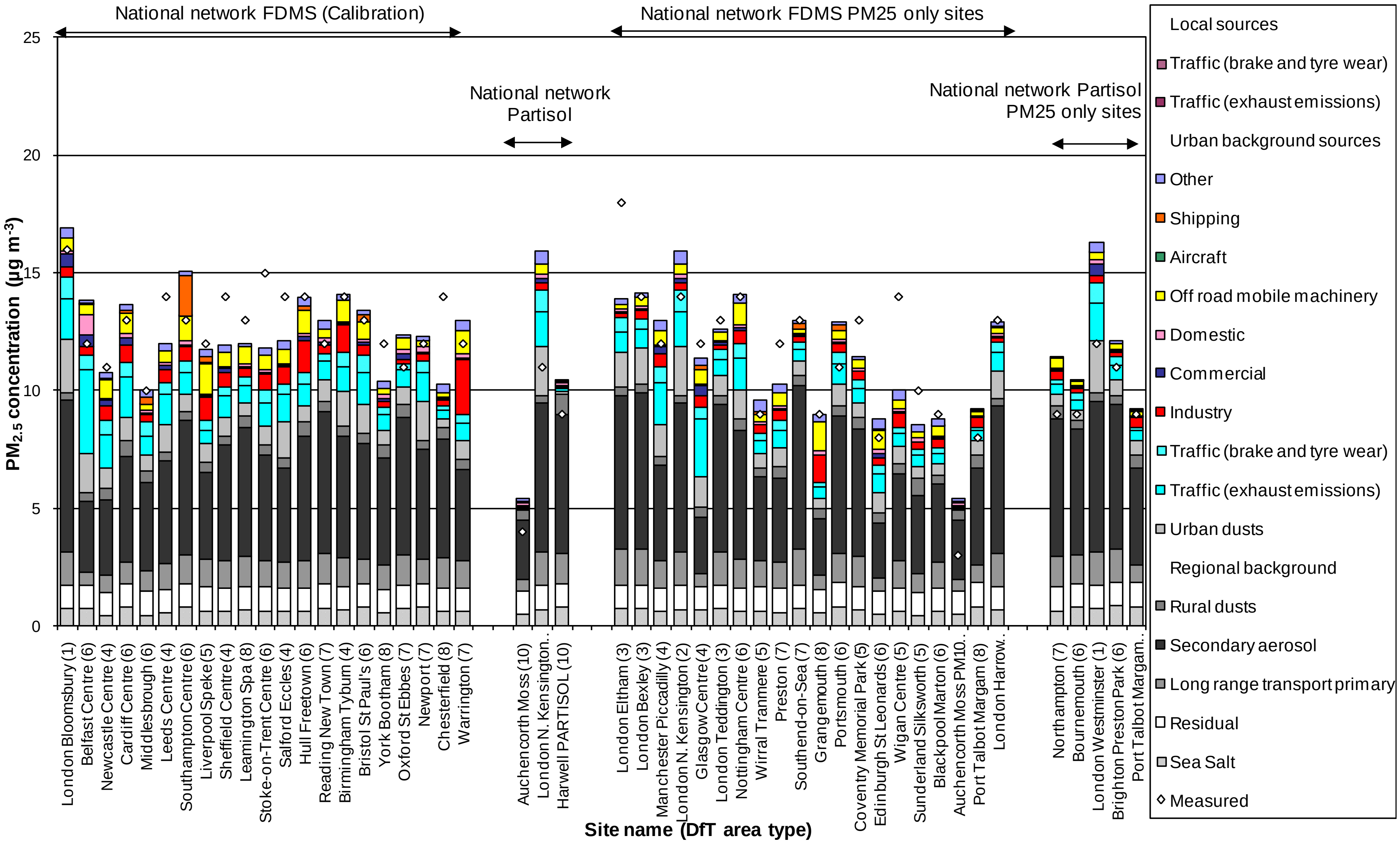
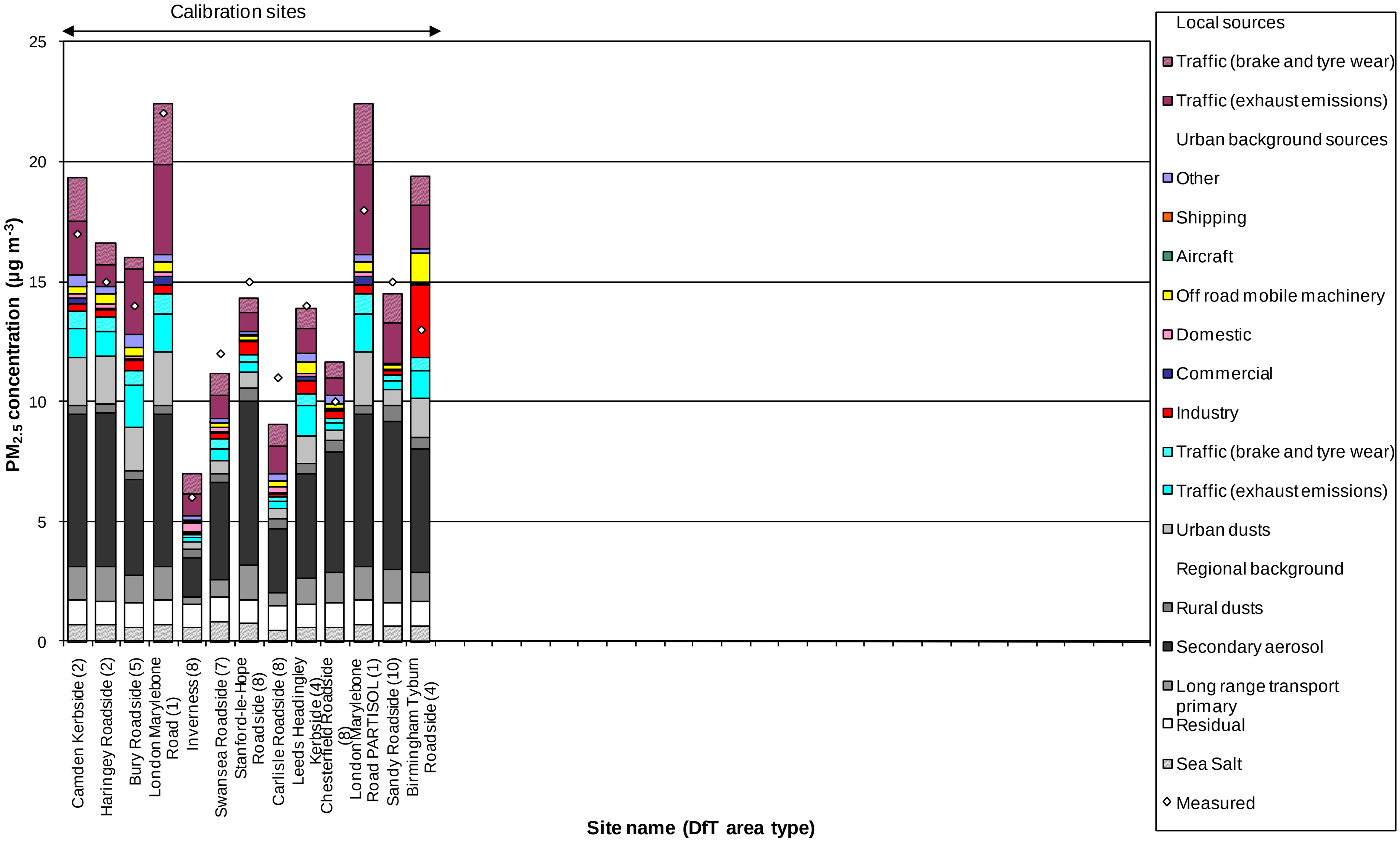


Figure 5.9 - Annual mean $PM_{2.5}$ source apportionment at roadside national network monitoring sites (the area type of each site is shown in parenthesis after its name)



5.4.3 Detailed comparison of modelling results with the target value

There were no measured or modelled exceedances of the annual mean target value for $PM_{2.5}$ in 2009.

6 Lead

6.1 Introduction

6.1.1 Limit values

A single limit value for ambient lead (Pb) concentrations is set out in the Air Quality Directive (AQD). This limit value has been specified for the protection of human health and came into force from 01/01/2005. The limit value is an annual mean concentration of 0.5 µg m^{-3}.

6.1.2 Annual mean model

A map of annual mean Pb in 2009 at background locations is shown in Figure 6.1. This map is presented in ng m^{-3}, where 1000 ng m^{-3} = 1 µg m^{-3}.

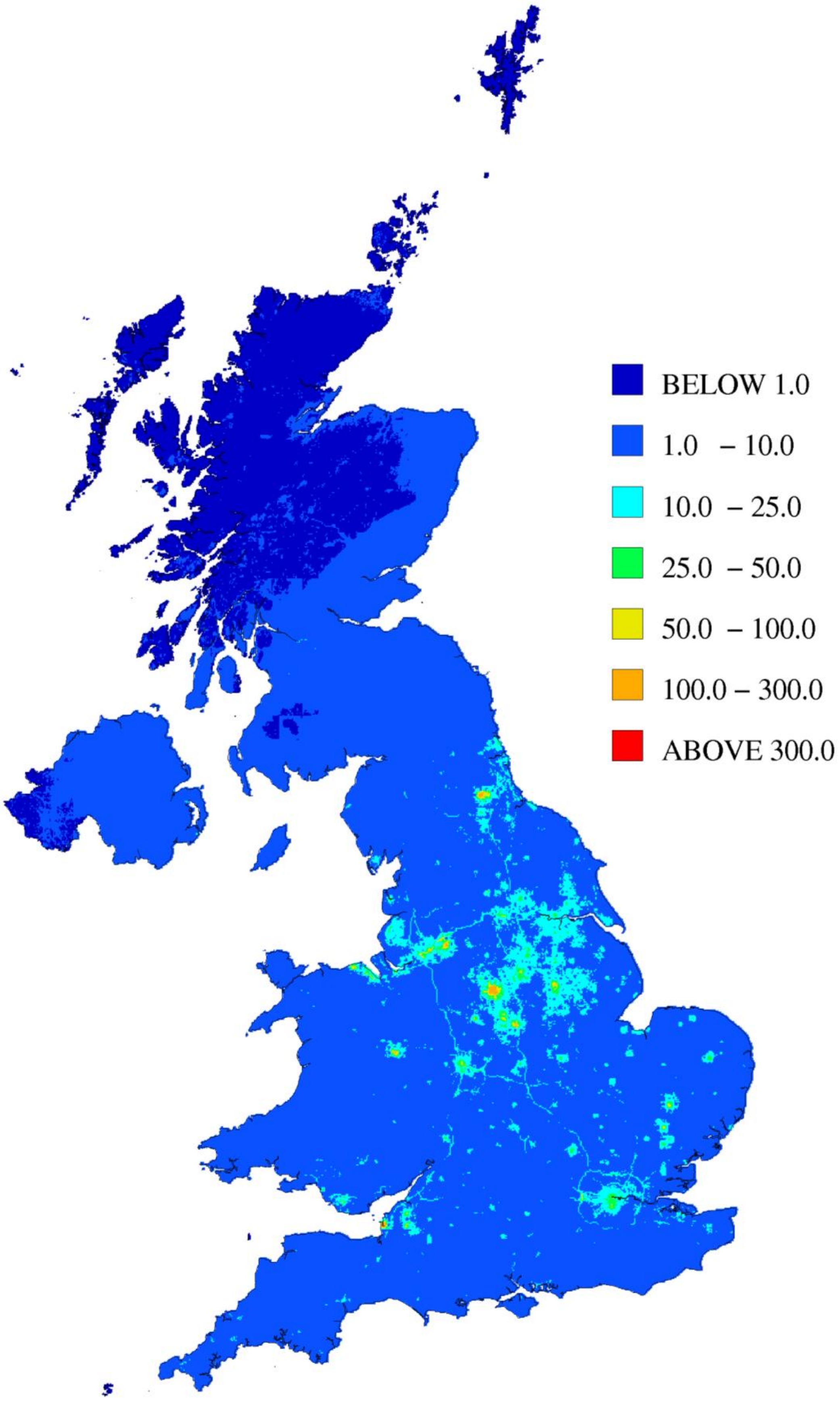
The methods used to derive the map for 2009 are largely the same as was adopted for the 2008 map as described Yap et al. (2009). The main revisions to the method for 2009 are the application of revised scaling factors for the models for the re-suspension and regional contributions.

The maps of background Pb concentrations have been calculated by summing contributions from different sources:

- Large point source emissions (modelled using ADMS and emissions estimates from the NAEI)
- Small point source emissions (modelled using a small points kernel model and emissions estimates from the NAEI)
- Fugitive point source emissions (modelled using fugitive source kernel model and an estimate of the fugitive component of emissions derived from the NAEI)
- Area sources emissions (modelled using a dispersion kernel and emissions estimates from the NAEI)
- Regional concentration of Pb (derived from estimates of primary PM from regional sources calculated using the TRACK model and emissions estimates from the NAEI and EMEP)
- Re-suspension of Pb from bare soils (derived from estimates of re-suspension of PM modelled using a dispersion kernel and information on land use)
- Re-suspension of Pb as a result of vehicle movements (derived from estimates of re-suspension of PM modelled using a dispersion kernel and vehicle activity data for heavy duty vehicles)

These component pieces are then aggregated to a single 1 km x 1 km background Pb grid.

Figure 6.1 - Annual mean background Pb concentration, 2009 (ng m^{-3})



6.1.3 Monitoring sites

Available monitoring data for Pb for 2009 are listed in Table 6.1.

Table 6.1 - Measured annual mean Pb concentrations in 2009 for monitoring sites with > 75% data capture

Site name	Site type	Pb	
		Annual mean (ng m^{-3})	Data capture (%)
Auchencorth	Rural	1.78	94
Bristol Avonmouth	Urban	11.93	98
Banchory	Rural	2.12	80
Beacon Hill	Rural	5.08	76
BELFAST CENTRE METALS	Urban centre	5.65	92
Bristol Hallen	Urban	9.60	100
Cardiff Llandaff	Urban background	11.39	98
Cardiff Rumney	Industrial background	10.12	90
CENTRAL LONDON METALS	Urban	11.41	98
Chadwell St Mary	Industrial background	12.70	98
Cockley Beck	Rural	2.18	77
Cwmystwyth	Rural	1.07	84
Dartford Bean	Urban background	10.33	96
Detling	Rural	8.40	93
Eskdalemuir_METALS	Rural	1.45	98
Heigham Holmes	Rural	4.78	75
London Cromwell Road	Rural	12.84	90
London Marylebone Road Metals	Urban	10.80	87
Manchester Wythenshawe	Urban	9.79	94
Monks Wood	Rural	6.05	76
Motherwell Centre	Urban	3.86	92
Pontardawe*	Suburban	5.30	100
PORT TALBOT MARGAM METALS	Industrial	12.63	92
REDCAR METALS	Industrial background	9.29	94
Redcar Normanby	Urban background	7.06	94
Runcorn Weston Point	Urban	7.11	90
SCUNTHORPE SANTON METALS	Industrial background	34.08	96
SCUNTHORPE TOWN METALS	Urban background	16.10	96
Sheffield Brinsworth	Urban	23.66	96
SHEFFIELD CENTRE METALS	Urban centre	12.07	98
Swansea Coedgwilym	Urban	10.20	96
Swansea Morriston	Urban background	17.37	98
Walsall Centre	Industrial background	19.04	90
WALSALL WILLENHALL METALS	Suburban	76.85	94
Wytham Wood	Rural	5.19	92
Yarner Wood_METALS	Rural	2.06	86

* This site is operated by the local authority and therefore not included in the Questionnaire but is used for model verification.

6.1.4 Chapter structure

This chapter describes modelling work carried out for 2009 to assess compliance with the Pb limit value described above. Emission estimates for Pb are described in Section 6.2, Section

6.3 describes the Pb modelling methods, and the modelling results are presented in Section 6.4.

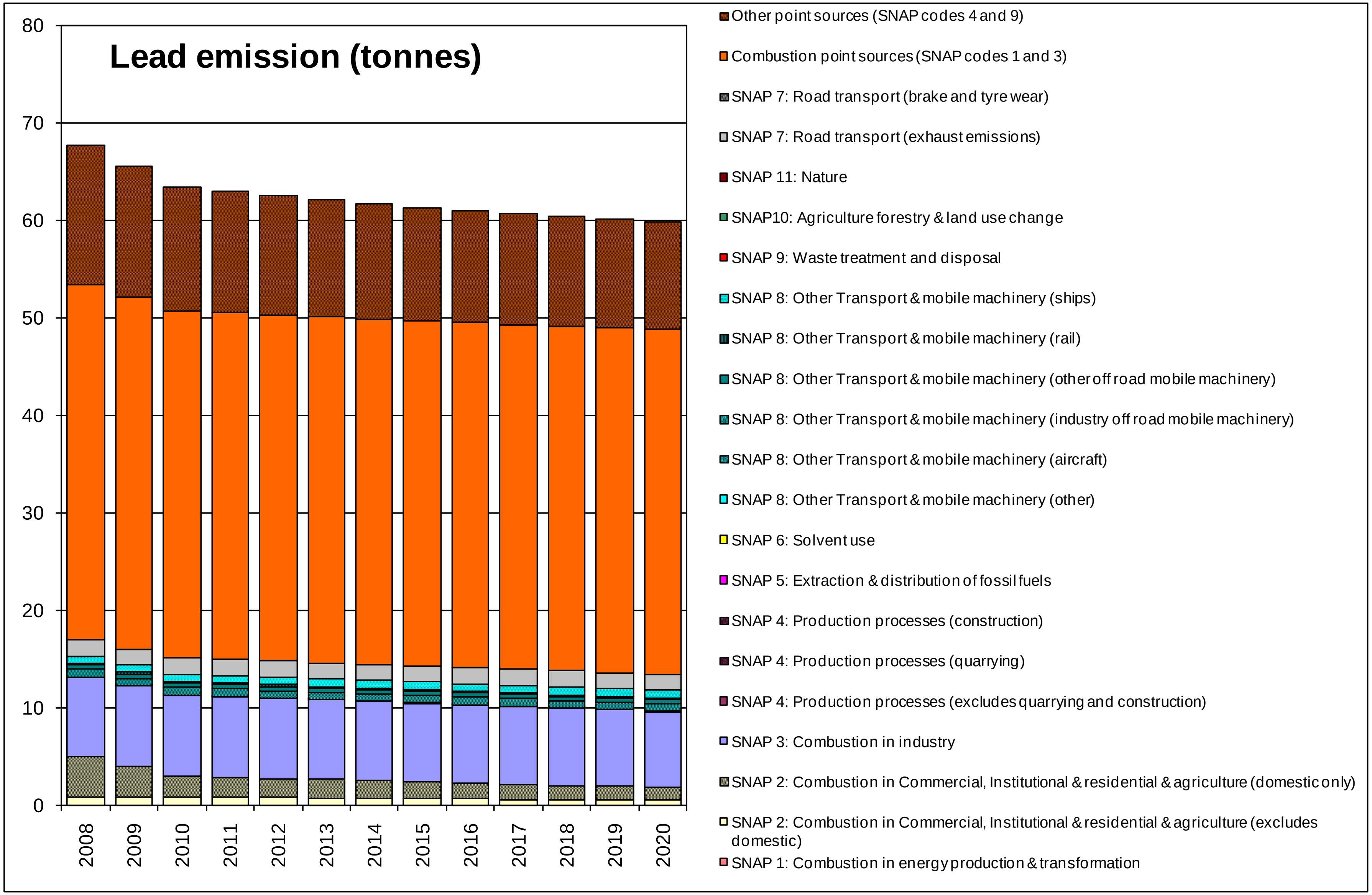
6.2 Lead emissions

Estimates of the emissions of Pb from the 2008 NAEI have been used in this study (Murrells et al., 2010). The projections of the emission estimates to 2009 and to future years 2010, 2015 and 2020 have been derived from the Updated Energy Projections (UEP 38) provided by the Department of Energy and Climate Change (DECC). Values for intermediate years have been interpolated. The estimates of Pb emissions over the period 2008-2020 split by SNAP code are shown in Figure 6.2.

The major area sources for Pb are combustion in industry (SNAP code 3) and domestic combustion (SNAP 2). Pb emissions are dominated by emissions from point sources, particularly from combustion in industry (SNAP code 3) and production processes (SNAP code 4). Pb emissions are primarily from non-fuel related emissions. The source apportionment of ambient concentrations is discussed in Section 6.4.2 and is often very different from the split for total national emissions. Ambient concentrations are influenced by the location and release characteristics of the emissions and are also influenced by sources not included in the inventory, such as re-suspension.

Maps of emissions from area sources for 2009 were derived from the 2008 inventory maps using specific scaling factors derived for each combination of source and activity (typically fuel type). The emissions from point sources were not scaled and the emissions for 2008 were assumed to apply in 2009.

Figure 6.2 - Total UK Pb emissions for 2008 and emissions projections up to 2020 by SNAP code from NAEI 2008



6.3 Lead modelling

6.3.1 Contribution from large point sources

Contributions to ground level annual mean heavy metal concentrations from point sources (those with annual emissions of greater than 1.2 tonnes per year or with stack parameters datasets in the database) in the 2008 NAEI were estimated by modelling each source explicitly using an atmospheric dispersion model ADMS 4.2 and sequential meteorological data for 2009 from Waddington. Surface roughness was assumed to be 0.1 m at the dispersion site and 0.02 m at the meteorological site. 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. A total of 200 point sources were modelled explicitly. For each large point source information was retrieved from the PCM 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

6.3.2 Contributions from small point and fugitive sources

The contributions to ambient concentrations from fugitive and point sources (those without stack parameters datasets) in the 2008 NAEI were modelled using a small point model. The model consists of separate ‘in-square’ and ‘out-of-square’ components, in which concentrations are estimated using a point source dispersion kernel. The dispersion kernel has been calculated by using dispersion model ADMS 4.2 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 with the stack characteristics as presented in Table 6.2. Hourly sequential meteorological data from Waddington in 2009 has been used to construct the dispersion kernels. The greatest concentration would be expected close to the point of emission. The receptor for the central grid square within the dispersion kernel is, however, at exactly the same location as the point of release. The concentration at this location is therefore zero. The value for the central grid square within the dispersion kernel has therefore been assigned to be equal to the highest of the values for the adjacent grid squares.

Table 6.2 - Stack release parameters used to characterise emissions from point sources with no available stack parameters

Variable	Parameters
Stack height	15 m
Diameter	1m
Temperature	15˚C
Emission rate as PM_{10}	1g/s
Surface roughness	0.5

Characterising the amount of heavy metal from industrial plant is notoriously difficult. According to Passant (personal communication 2005) up to approximately three times the reported emission from metal processing industries may be released as a fugitive emission.

The emission release parameters are provided in Table 6.3. Once again, the value for the central grid square within the dispersion kernel has been set to the maximum of the values in the surrounding grid squares.

A fugitive emission of 0.05 times the reported emission has been found to provide the best agreement with available measurement.

Table 6.3- Stack release parameters used to characterise fugitive emission release

Variable	Parameters
Stack height	10m
Diameter	1m
Temperature	15˚C
Emission rate as PM_{10}	1g/s
Surface roughness	0.5

6.3.3 Contributions from local area sources

The uncalibrated modelled area source contribution has been calculated by applying an ADMS 4.2 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 receptor. Hourly sequential meteorological data from Waddington in 2009 has been used to construct the dispersion kernels, as described in Appendix 3.

The area source calibration coefficient of 1.2486 derived within the 2009 PCM model for NO_x has been chosen to use for Pb, see Section 2.2.5. This coefficient has been derived for a pollutant for which both the emissions source apportionment and measurements are well characterised. The source apportionment for heavy metals is subject to greater uncertainty however using the coefficient derived for NO_x was found to provide reasonable estimates of heavy metal concentrations as demonstrated in the verification plots below.

The modelled area source contribution was multiplied by the calibration coefficient to calculate the calibrated area source contribution for each grid square in the country.

6.3.4 Contribution from long range transport of primary particulate matter

The contribution to ambient concentrations from long range transport of heavy metals has been derived from estimates of regional primary particulate matter (PM) used in the 2009 PCM model for PM_{10} mass, see Section 4.3.4.

The contribution to ambient heavy metal concentration from long range transport sources in the modelling work for 2008 described by Yap et al (2009) was derived by calculating a fraction of the PM mass for each heavy metal. This fraction was estimated as the ratio of the UK total emissions for each SNAP sector for each metal to the total PM_{10} emission for this sector. These ratios were also assumed to apply to the contribution from non-UK European sources. This approach was adopted for the 2009 modelling of As, Cd and Ni described by Walker et al (2010). For the 2009 modelling of Pb a revised approach has been adopted in which the contribution calculated by scaling by the relative emissions of Pb to those of PM_{10} has been multiplied by an additional factor of 5. Thus the regional contribution to ambient Pb concentration has been assumed to be greater than implied by the ratio of current emissions. This could be due to the previously significant emissions from road traffic from the use of leaded petrol, although the processes that would be involved in such a contribution are not fully understood. An alternative approach would have been to increase the scaling factors applied to the re-suspension contributions for Pb but the approach adopted was found to provide better agreement with available measurements. This revised method with a greater contribution from regional concentrations provides better agreement with measurements than the method adopted for 2008.

6.3.5 Heavy metal contribution from re-suspension

6.3.5.1 Introduction

The 2009 model for heavy metal concentrations includes a contribution to ambient concentrations from re-suspension calculated in the same way as in the 2008 models (Yap et al, 2009). The contributions from two processes have been included:

- Regional PM dusts from re-suspension of soils and
- PM dusts from re-suspension due to vehicle activity.

The heavy metal contribution from re-suspension has been calculated by using the methods suggested by Abbott (2008). The methods used to estimate the total PM mass from these processes are detailed in Section 4.3.5.

6.3.5.2 Estimating 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 maps of PM mass from re-suspension of soils and re-suspension associated with vehicle movements can be 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.

The National Soil Inventory (http://www.landis.org.uk/data/natmap.cfm) provides a data set of arsenic, cadmium, nickel and lead concentrations in topsoil at 5 km resolution throughout England and Wales. Measurement data on heavy metals concentration in topsoil for other areas of the UK is available from the Geochemical Atlas of Europe developed under the auspices of the Forum of European Geological Surveys (FOREGS) (http://www.gtk.fi/publ/foregsatlas/). These data were interpolated onto a 1 km x 1 km grid. The predicted annual PM emission rates and the contribution to atmospheric concentrations were multiplied by the topsoil concentrations to estimate the annual metal re-suspension rates and the contributions to atmospheric concentrations of the heavy metals.

There is some evidence that metal concentration in the surface soils are higher than in the underlying topsoil. EMEP have suggested in the report by Abbott (2008) that there may be some enhancement of the metal content of the re-suspended dust because the metals may form complexes with humic matter. Abbott (2008) carried out regression analysis of measured heavy metal concentrations against the combined model predictions for sites in the UK Rural Heavy Metal Network and this analysis suggested that there may be other mechanisms that result in heavy metals being concentrated in the small particle fraction of soils. For example, much of the metal content may be present as the result of historical deposition of small particles or the application of sewage sludge and farmyard slurries and these materials may now be only loosely bonded to the surface of the soil particles. The fine particles released by re-suspension mechanisms would therefore be likely to contain a much higher concentration of metals than the underlying topsoil. An enhancement factor of 35 has been applied to the estimates of the contribution from re-suspension processes. This value was chosen to provide the best agreement of the total modelled ambient concentrations with measured concentrations of heavy metals. This value of 35 has also been applied within the 2009 method for As and Cd, as described by Walker et al., (2010). A lower value was found to provide the best fit for Ni. The value of 35 is somewhat higher than the regression coefficients determined by Abbott (2008) for concentrations at rural sites.

A cap of 175 ng m^{-3} has also been applied for the contribution generated from re-suspension of bare soil. This value has been chosen as an estimate of the maximum likely concentration generated from this source.

6.4 Results

6.4.1 Verification of mapped concentrations

Figure 6.3 to Figure 6.6 show a comparison of modelled and measured annual mean Pb concentrations in 2009 at different monitoring site locations. Lines representing y = x – 50% and y = x + 50%, the AQD data quality objective for modelled annual mean Pb concentration (see Section 1.8), are included.

Figure 6.3 - Verification of annual mean Pb at Industrial sites

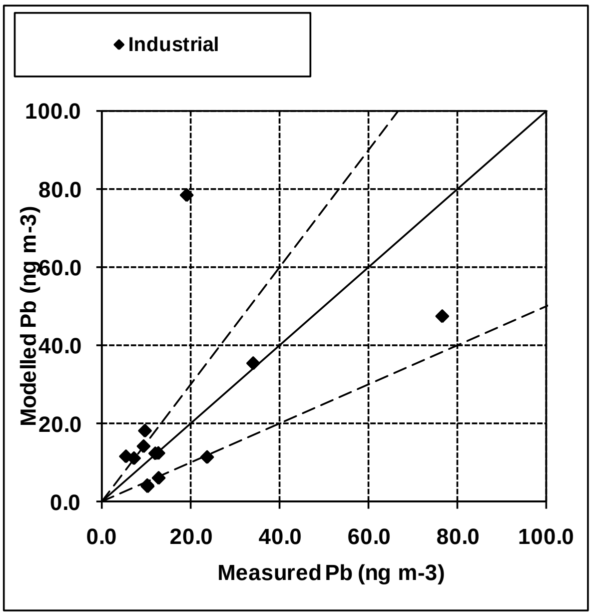


Figure 6.4 - Verification of annual mean Pb at urban background sites

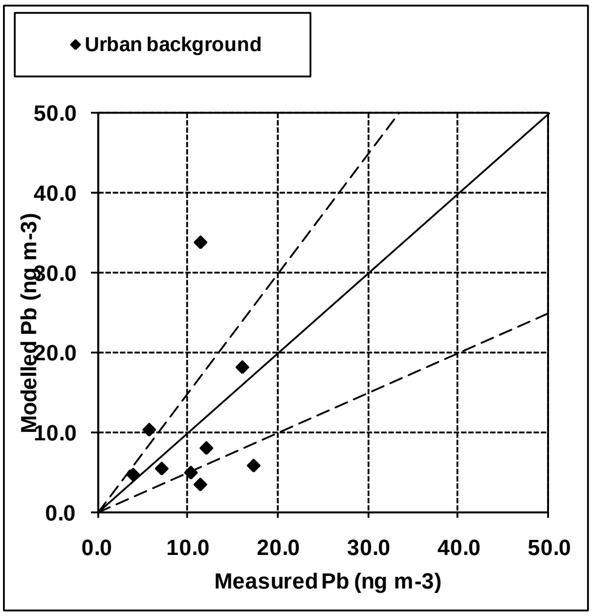


Figure 6.5 - Verification of annual mean Pb at roadside sites

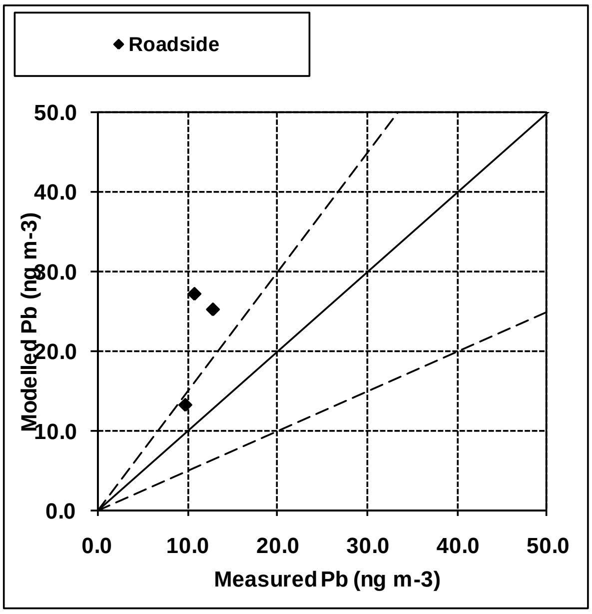
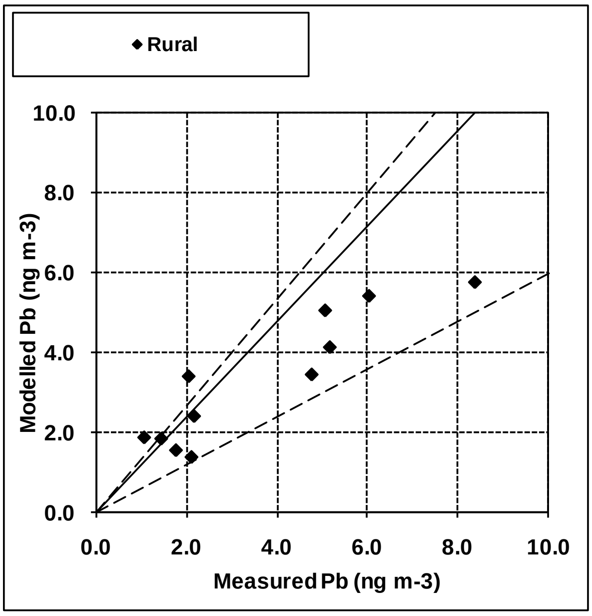


Figure 6.6 - Verification of annual mean Pb at rural sites



Summary statistics for modelled and measured Pb 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 Table 6.4.

The mean measured and modelled concentrations agree reasonably well for the industrial, urban background and rural monitoring sites. The concentrations seem to be over-predicted at roadside sites. The agreement between measured and modelled concentrations on a site-by-site basis (quantified using R^2) is poor for all the monitoring sites, except rural sites. Note that the non-emission inventory sources such as fugitive, re-suspension and long range transport of primary PM result in additional uncertainty in comparison with a pollutant such as NO_x, which has a better characterised source apportionment. However, it can be seen that the revised modelling to account the heavy metal contribution from re-suspension to the ambient Pb concentration has significantly improved the agreement with the measured concentration to the modelling analysis for emission inventory sources only previously presented by Vincent and Passant (2008). The agreement is much better at the rural sites in particular, where the previous assessment predicted much lower concentrations.

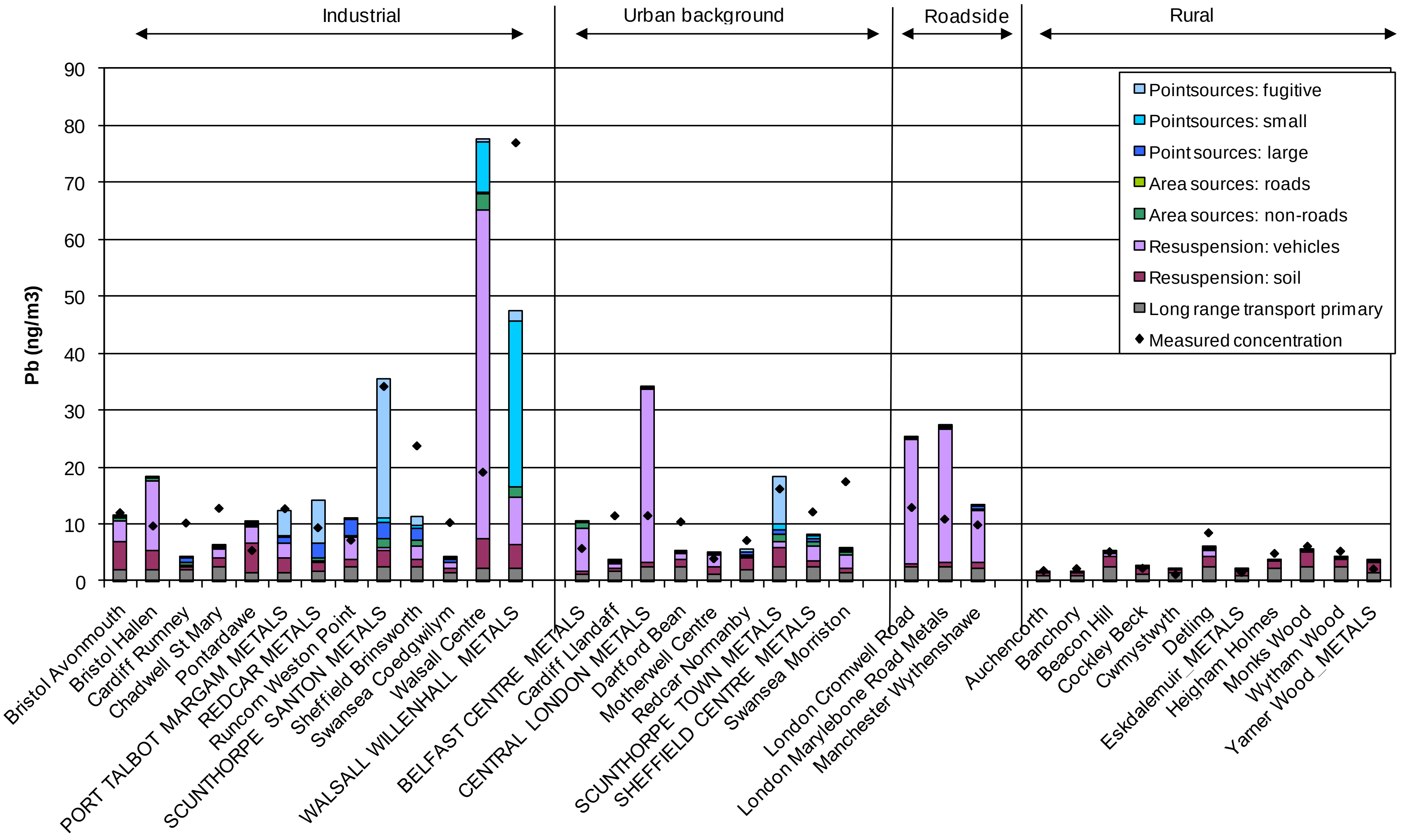
Table 6.4 - Summary statistics for comparison between modelled and measured annual mean concentrations at different monitoring sites

	Mean of measurements (µg/m^3)	Mean of model estimates (µg/m^3)	R^2	% of sites outside DQO of ±50%	Number of sites in assessment
Industrial sites	18.65	20.56	0.04	69	13
Urban background sites	10.58	10.59	0.06	56	9
Roadside sites	11.14	21.86	0.39	67	3
Rural sites	3.65	3.30	0.81	18	11

6.4.2 Pb source apportionment at monitoring sites

A source apportionment graph has been plotted in Figure 6.7 to present the Pb contribution from different sources at monitoring site locations. Concentrations measured at the monitoring sites are also presented. Thus the source apportionment graphs also give an indication of the level of agreement between the modelled and measured concentrations. This analysis suggests that the main sources of this air pollutant at monitoring sites are small point and fugitive industrial emissions and re-suspension processes.

Figure 6.7 - Annual mean Pb source apportionment at background national network monitoring sites



6.4.3 Detailed comparison of modelling results with the limit values

There were no modelled or measured exceedances of the limit value for Pb in 2009.

7 Benzene

7.1 Introduction

7.1.1 Limit values

A single limit value for ambient benzene concentrations is set out in the Air Quality Directive (AQD). This limit value has been specified for the protection of human health and came into force from 01/01/2010. The limit value is an annual mean concentration of 5 µg m^{-3}.

7.1.2 Annual mean model

Maps of annual mean benzene concentrations at background and roadside locations in 2009 are presented in Figure 7.1 and Figure 7.2 respectively.

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 7.1 - Annual mean background benzene concentration, 2009 (µg m^{-3})

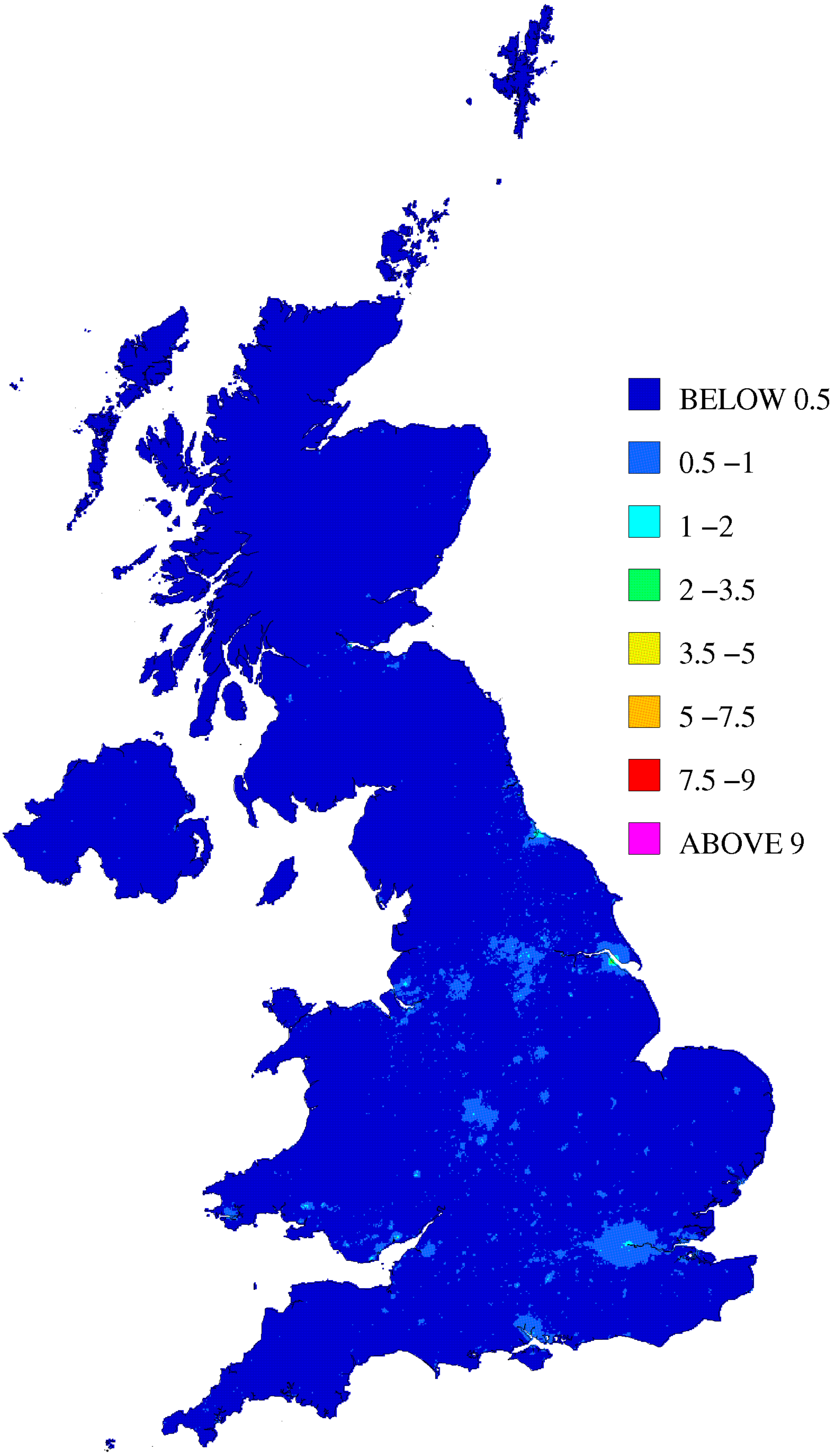
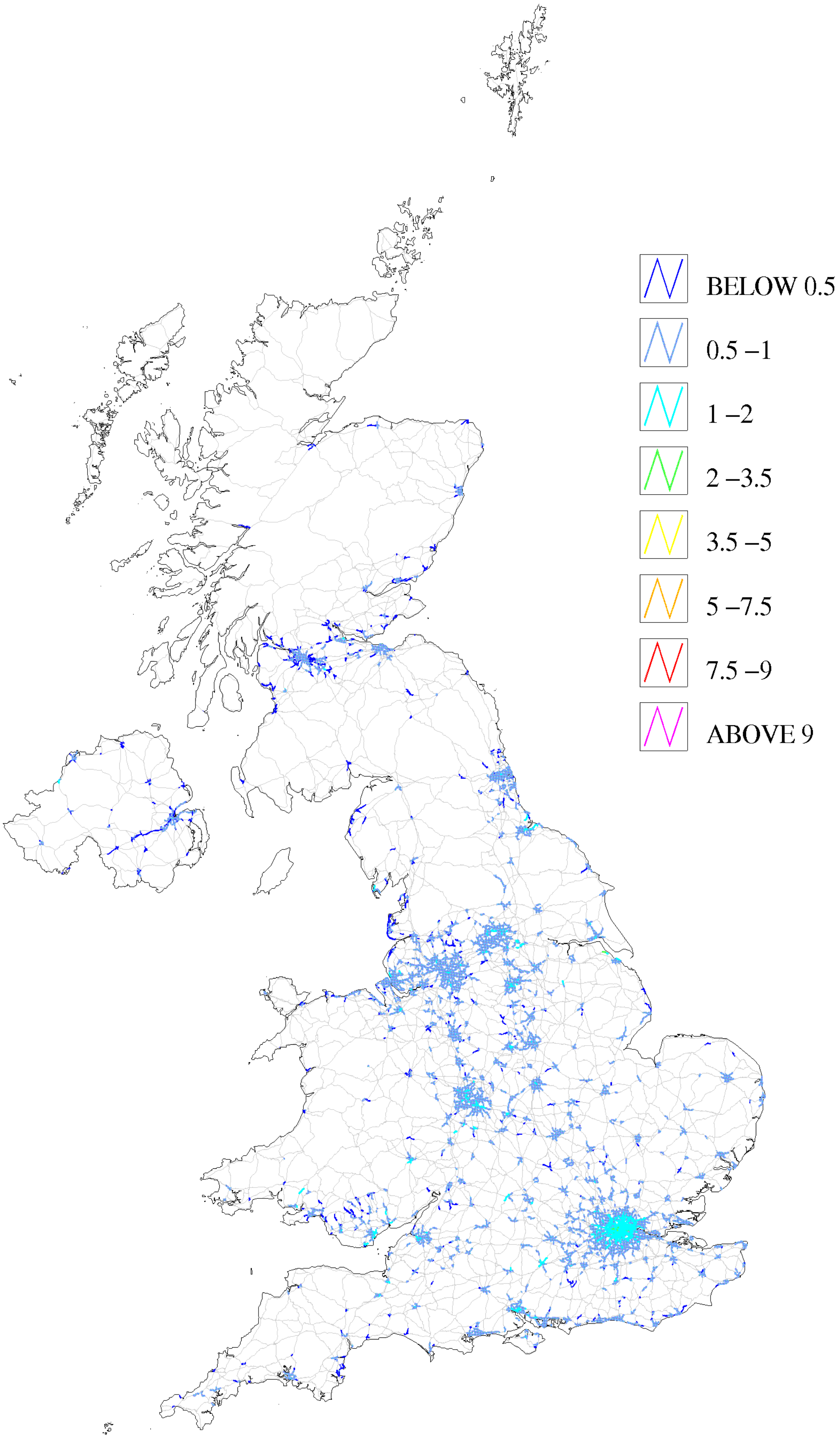


Figure 7.2 - Urban major roads, annual mean roadside benzene concentration, 2009 (µg m^{-3})



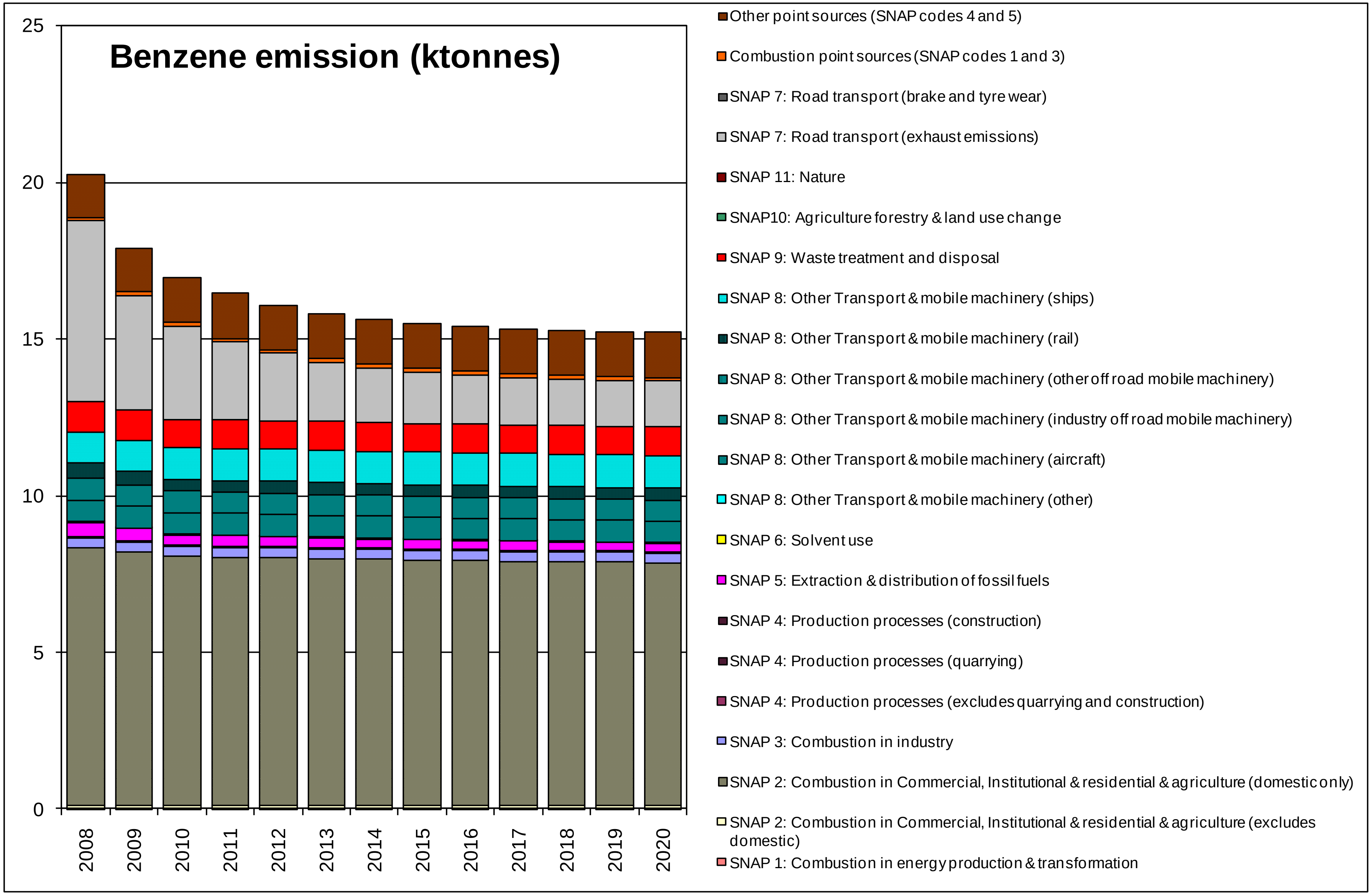
7.1.3 Chapter structure

This chapter describes modelling work carried out for 2009 to assess compliance with the benzene annual mean limit value described above. Emission estimates for benzene are described in Section 7.2, Section 7.3 describes the benzene modelling methods, and the modelling results are presented in Section 7.4.

7.2 Benzene emissions

Figure 7.3 shows the total UK benzene emissions for each year from 2008 to 2020 with the emissions broken down by SNAP code for area sources and into combustion and other for point sources. The emissions are dominated by area source emissions from combustion in commercial, institutional and residential and agriculture, domestic only (SNAP code 2) which are projected to remain relatively flat into the future from 2010. In particular this is related to emissions from combustion of wood for domestic heating for which both the amount of activity and emission factors are subject to considerable uncertainty. Decreases in emissions are largely related to road transport exhaust emissions which are projected to fall progressively over the period.

Figure 7.3 - Total UK benzene emissions for 2008 and emissions projections up to 2020 by SNAP code from NAEI 2008



7.3 Benzene modelling

7.3.1 Contributions from combustion point sources

Following a similar methodology as for NO_x, point sources in the 2008 NAEI have been classified as large if they fulfil either of the following criteria:

- Annual benzene emissions in the 2008 NAEI are greater than 5 tonnes for any given plant
- Stack parameters are already available for any given plant in the PCM stack parameters database (described in more detail in Section 2.2.2)

Contributions to ground level annual mean benzene concentrations from large combustion-related point sources in the 2008 NAEI were estimated by modelling each source explicitly using the atmospheric dispersion model ADMS 4.2 and sequential meteorological data for 2009 from Waddington. A total of 16 point sources were modelled. Surface roughness was assumed to be 0.1 m at the dispersion site and 0.02 m at the meteorological site. 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 the PCM stack parameters database.

There are some point sources in the 2008 NAEI which closed before the start of 2009. Hence, these point sources were removed from the modelling for 2009.

7.3.2 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).

7.3.3 Contributions from rural background concentrations

Regional rural benzene concentrations were estimated from the map of rural NO_X concentration described in Section 2.2.4. The rural NO_X map was scaled using the ratio of measured annual mean benzene and NO_X concentrations at the rural Harwell monitoring site in 2009.

7.3.4 Contributions from area sources

Figure 7.4 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 uncalibrated area source contribution to annual mean benzene.

The 2009 area source benzene emissions maps have been calculated following the method applied for NO_X described in Section 2.2.5. An ADMS derived dispersion kernel has been used to calculate the contribution to ambient concentrations at a central receptor location from the area source emissions within a 33 km x 33 km square surrounding each monitoring site. Hourly sequential meteorological data from Waddington in 2009 has been used to construct the dispersion kernels, as described in Appendix 3.

As part of the calibration process concentration caps have been applied to certain sectors. This is because the use of surrogate statistics for mapping area source emissions sometimes results in unrealistically large concentration in some grid squares for a given sector. The concentration caps applied are given in Table 7.1.

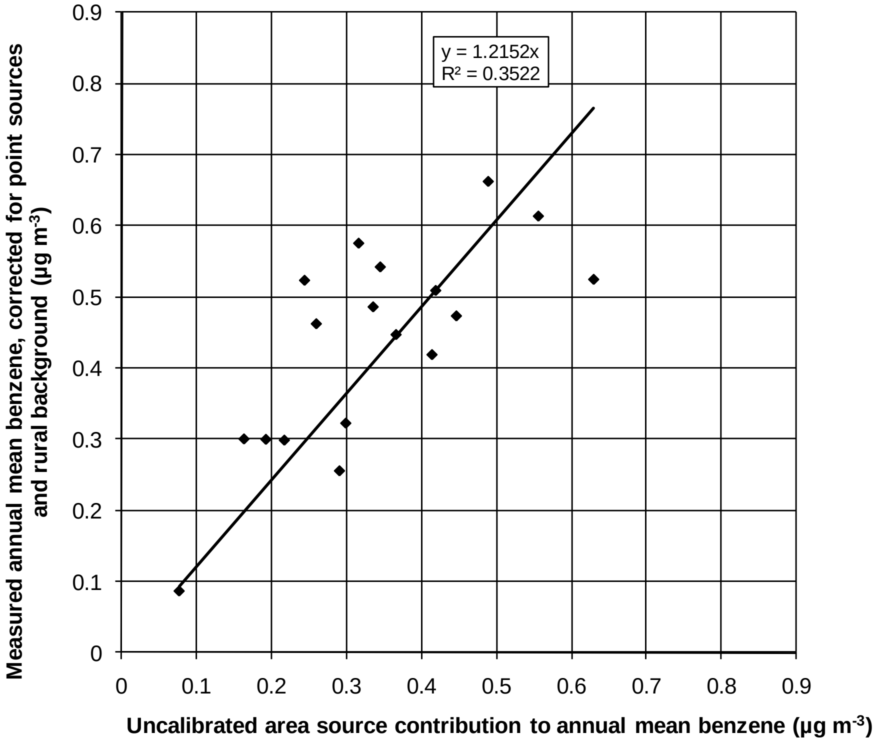
Table 7.1 - Concentration caps applied to benzene sector grids

SNAP code	Description	Cap applied (µg m^{-3})*
SNAP 8 (industrial off road machinery only)	Other Transport & Mobile Machinery	0.2
SNAP 8 (other off road machinery)	Other Transport & Mobile Machinery	0.2
SNAP 8 (shipping only)	Other Transport & Mobile Machinery	0.3
SNAP 9	Waste Treatment & Disposal	0.78

*Caps listed are for calibrated concentrations

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 concentration were then added, resulting in a map of background annual mean benzene concentrations.

Figure 7.4 - Calibration of area source benzene model, 2009 (µg m^{-3})



7.3.5 Roadside concentrations

Roadside concentrations of annual mean benzene for 2009 have been modelled using a similar method to the NO_X modelling described in Section 2.2.6. Calibration of the benzene roadside increment model is shown in Figure 7.5 and Figure 7.6.

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 and therefore calibrating the model using the automatic monitoring measurement reduces the calibration coefficient (Figure 7.5).

As an alternative the calibration of the benzene roadside increment model was done using the pumped tube monitor measurement for London Marylebone Road and this is presented in Figure 7.6. This relationship gives a better agreement with the roadside calibration for NO_X (a slope of 0.00000935, as shown as a dashed line in the figures) and is more consistent with monitoring sites outside London. As a result, the roadside calibration coefficient of 0.00000473 was used.

Figure 7.5 - Calibration of benzene roadside increment model, 2009 (µg m^{-3}) (coefficient for NO_x shown as a dashed line)

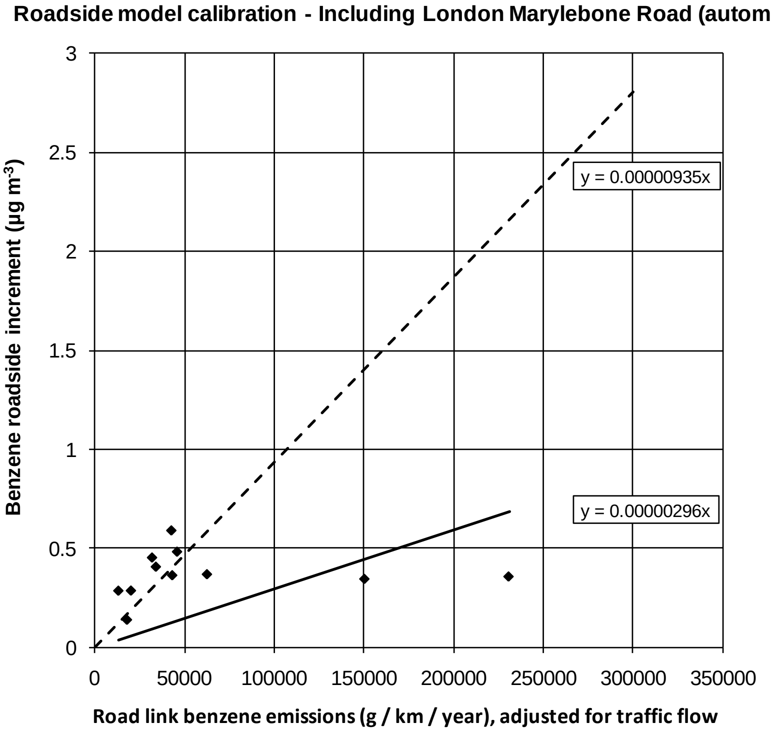
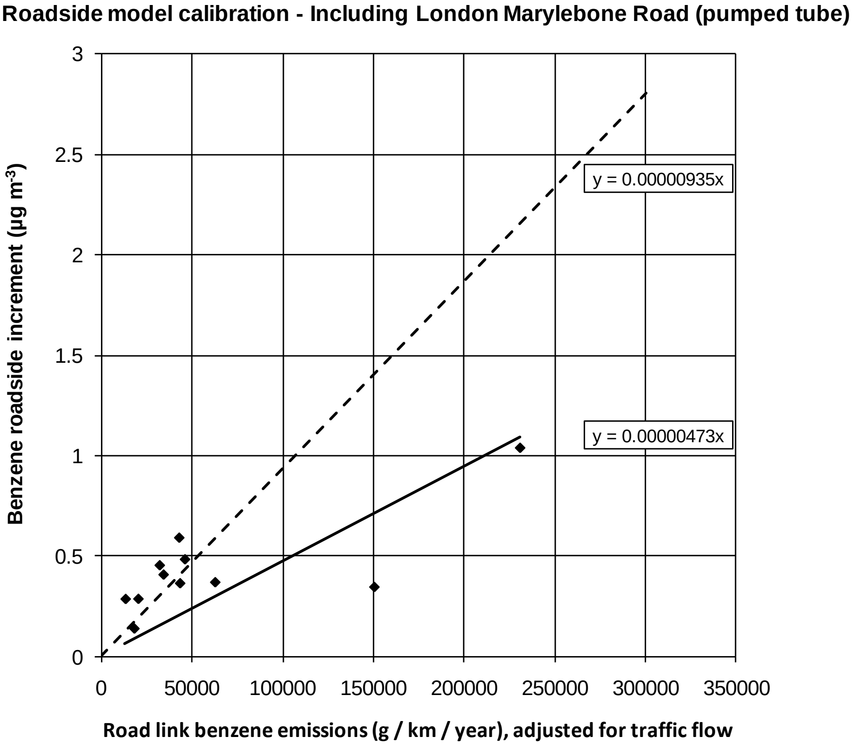


Figure 7.6 - Calibration of benzene roadside increment model, 2009 (µg m-3) (coefficient for NO_x shown as a dashed line)



7.4 Results

7.4.1 Verification of mapped values

Figure 7.7 and Figure 7.8 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 (the data quality objective for modelled benzene concentrations specified by the AQD – see Section 1.8).

Figure 7.7 - Verification of background annual mean benzene model 2009

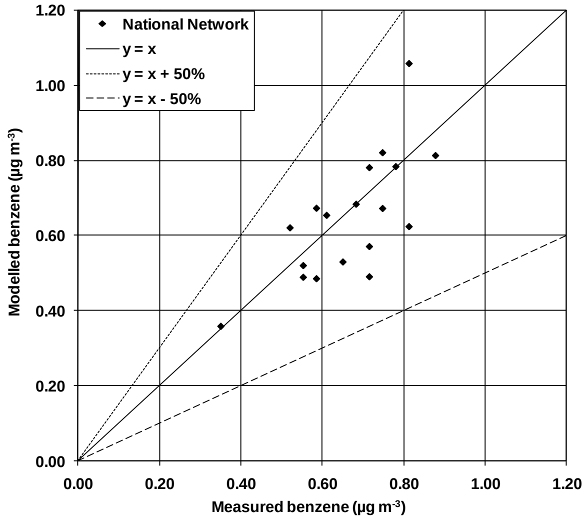
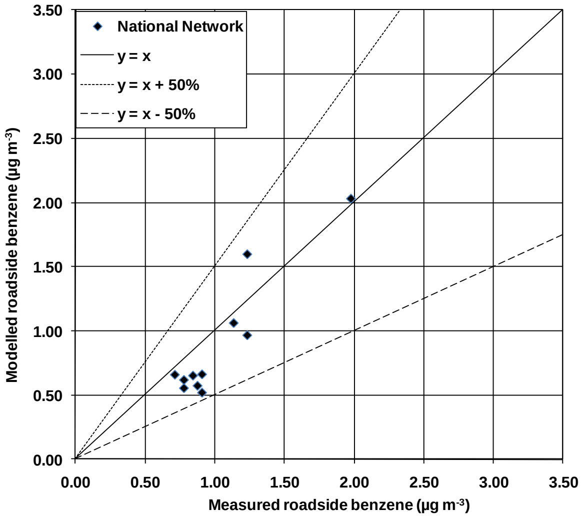


Figure 7.8 - Verification of roadside annual mean benzene model 2009



Summary statistics for the comparison between modelled and measured benzene concentrations are listed in Table 7.2 and Table 7.3. No monitoring sites were available to provide an independent verification of the models (see Table A1.1 of Appendix 1) in Figures 7.7 and 7.8.

Table 7.2 - 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	0.67	0.65	0.51	0	18

Table 7.3 - 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	1.04	0.90	0.86	0	11

7.4.2 Benzene source apportionment at monitoring sites

Figure 7.9 and Figure 7.10 show the modelled annual mean benzene source apportionment for 2009 at AURN background and roadside monitoring sites, respectively. The measured concentration at each site is also shown for reference. Figure 7.9 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. The roadside source apportionment in Figure 7.10 shows that local traffic sources can contribute up to 1.0 µg m^{-3} of benzene at roadside sites.

7.4.3 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 2009 are below the limit value for all zones.

Figure 7.9 - Annual mean benzene source apportionment at background AURN monitoring sites (the area type of each site is shown in parenthesis after its name)

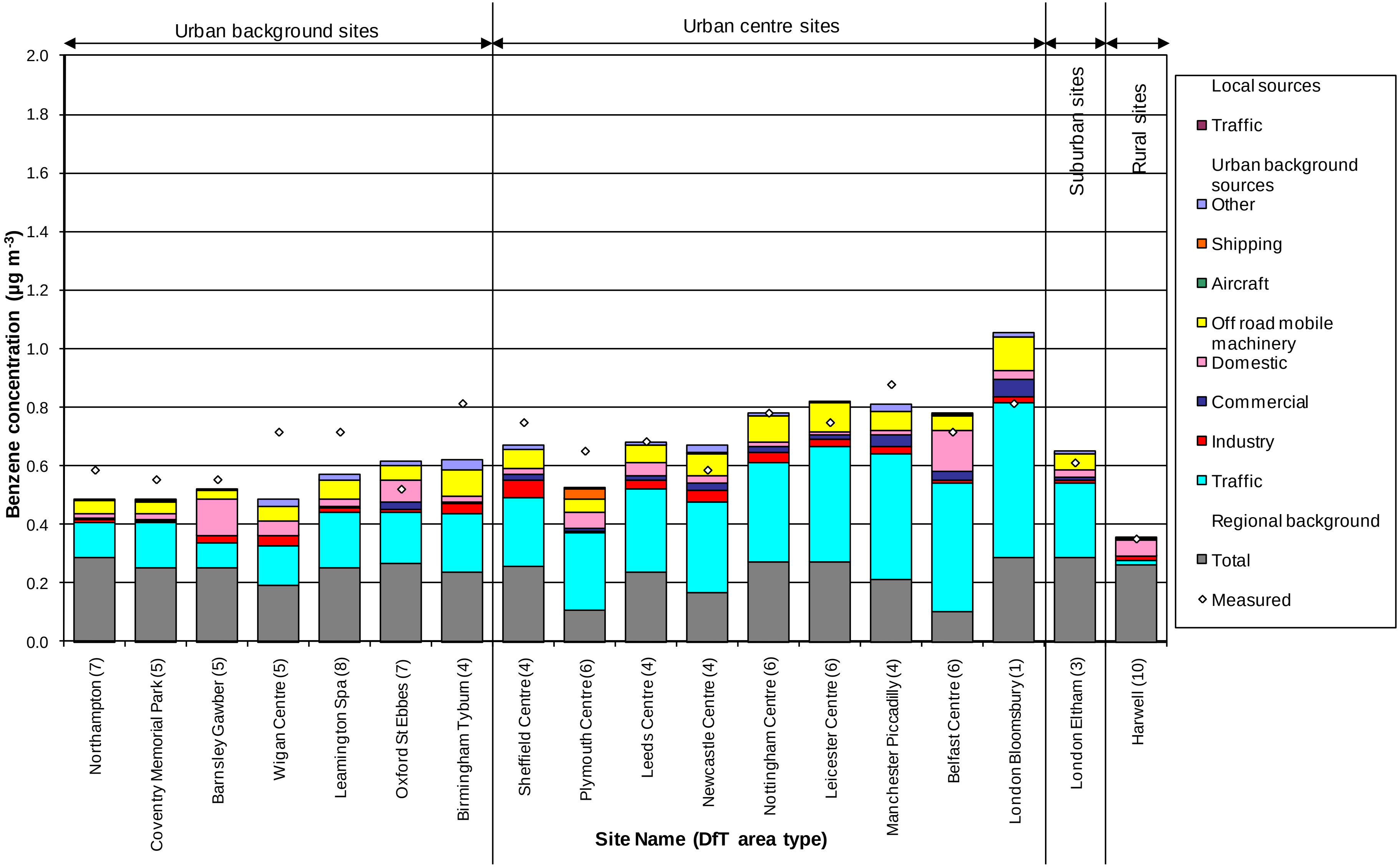
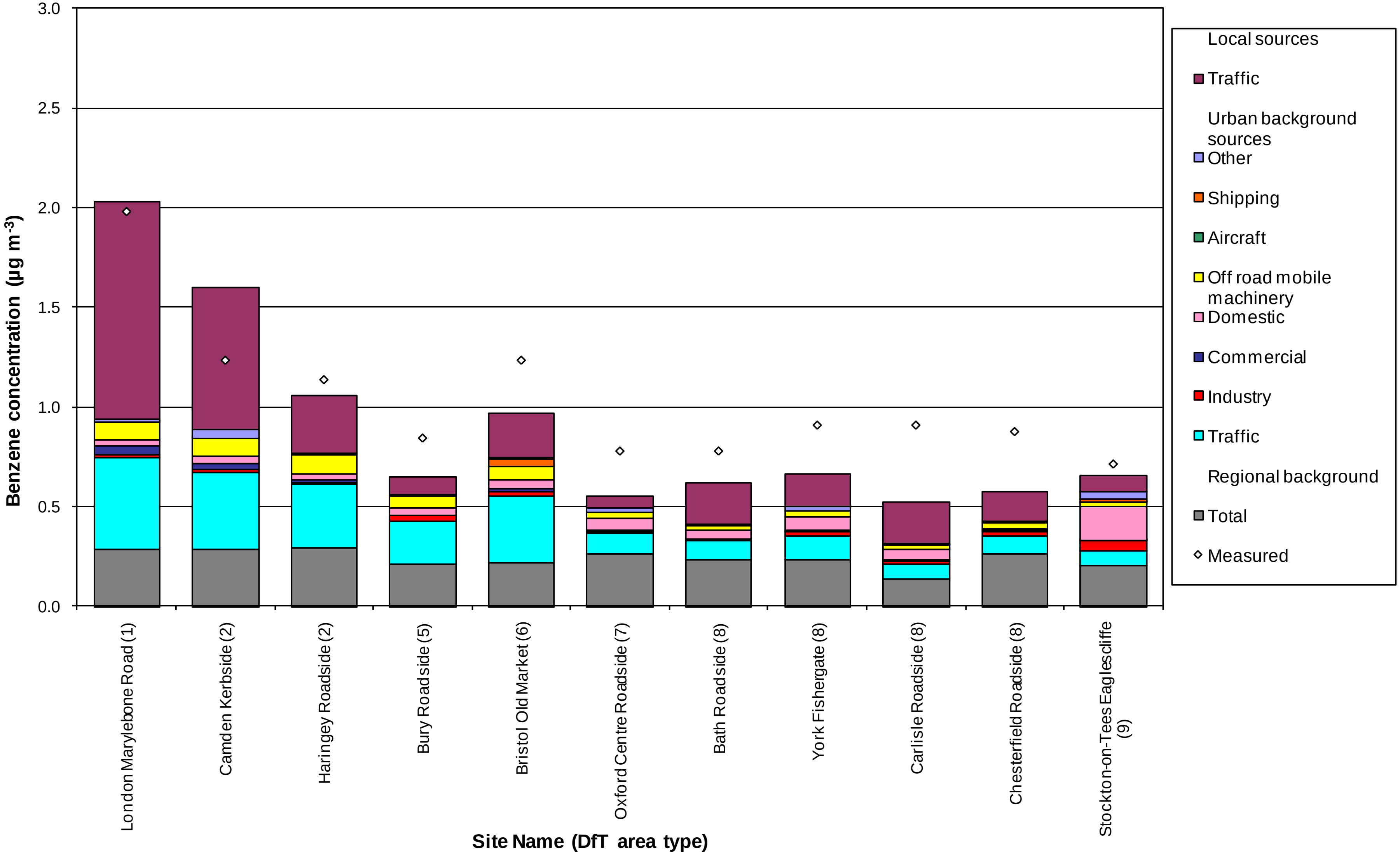


Figure 7.10 - Annual mean benzene source apportionment at roadside AURN monitoring sites (the area type of each site is shown in parenthesis after its name)



8 CO

8.1 Introduction

8.1.1 Limit values

A single limit value for ambient CO concentrations is set out in the Air Quality Directive (AQD). This limit value has been specified for the protection of human health and came into force from 01/01/2005. The limit value is a maximum daily 8-hour mean concentration of 10 mg m^{-3}.

8.1.2 Annual mean model and modelling the maximum 8 hour mean metric

Maps of the modelled maximum 8-hour mean CO concentrations at background and roadside locations in 2009 are presented in Figure 8.1 and Figure 8.2 respectively.

Background and roadside maps of annual mean CO concentration were calculated in the process of modelling the maximum 8-hour mean metric. Maps of the maximum 8-hour mean were calculated from these maps using relationships between measured annual mean concentrations and measured maximum 8-hour mean concentrations from the national network. Only the maximum 8-hour mean maps are required for comparison with the AQD 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 mean metric.

CO concentrations have been calculated using a similar approach to that adopted for NO_X but without the inclusion of a mapped regional component because regional 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 very local road traffic sources.

Figure 8.1 - Maximum 8-hour mean background CO concentration, 2009 (mg m^{-3})

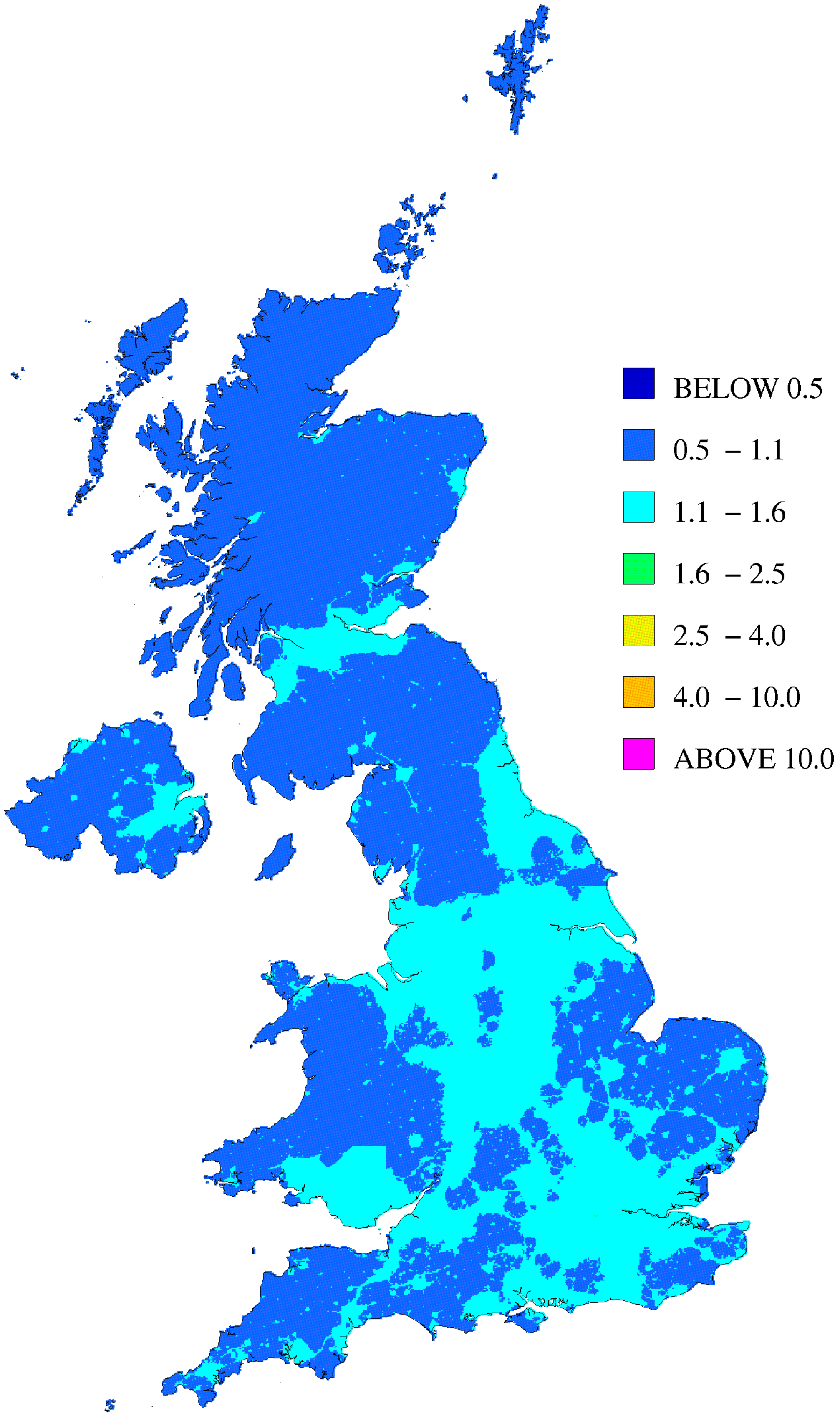
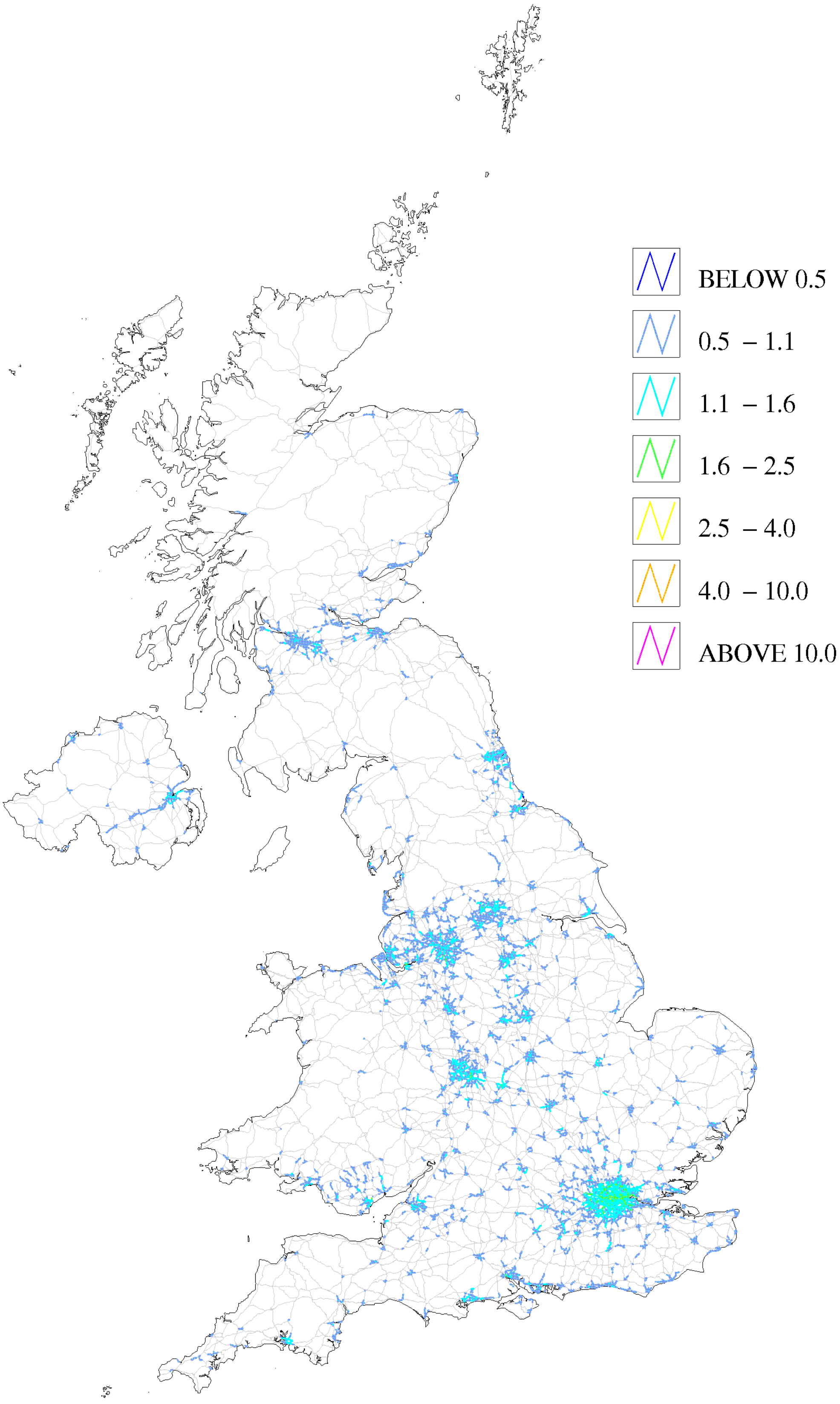


Figure 8.2 - Urban major roads, maximum 8-hour mean roadside CO concentration, 2008 (mg m^{-3})



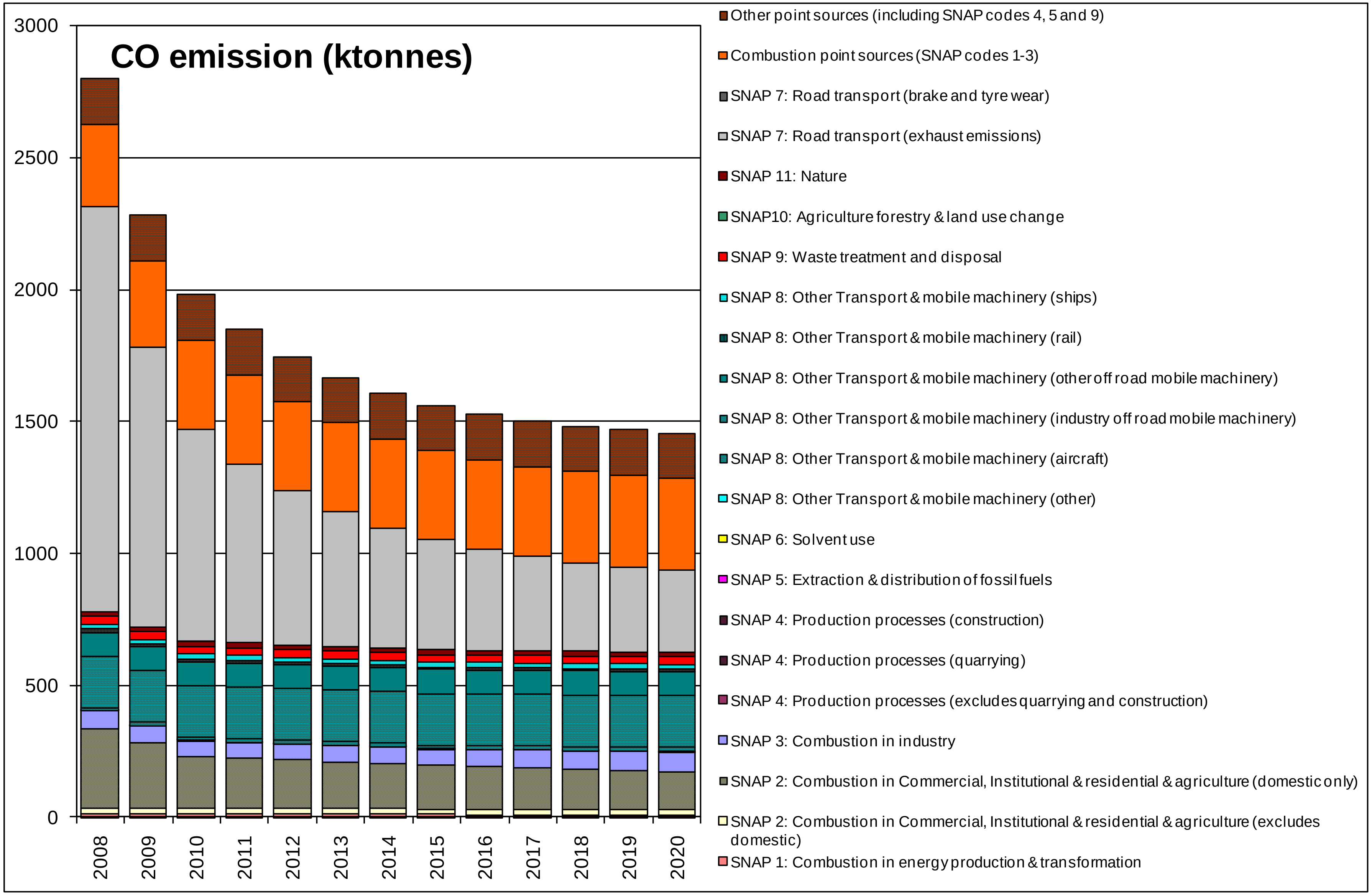
8.1.3 Chapter structure

This chapter describes modelling work carried out for 2009 to assess compliance with the CO maximum 8-hour mean limit value described above. Emission estimates for CO are described in Section 8.2, Section 8.3 describes the CO modelling methods, and the modelling results are presented in Section 8.4.

8.2 CO emissions

Figure 8.3 shows the total UK CO emissions for each year from 2008 to 2020 with the emissions broken down by SNAP code for area sources and into combustion and other for point sources. The emissions are dominated by road transport exhaust emissions and it is the projected reductions in these emissions that dominate the overall trend in emissions over the period 2008 to 2020. Combustion point sources (SNAP codes 1-3) become progressively more important as these emissions are projected to remain relatively constant while road transport exhaust emissions decrease.

Figure 8.3 - Total UK CO emissions for 2008 and emissions projections up to 2020 by SNAP code from NAEI 2008



8.3 CO modelling

8.3.1 Contributions from large point sources

Following a similar methodology as for NO_x (Section 2.2.2), point sources in the 2008 NAEI have been classified as large if they fulfil either of the following criteria:

- CO emissions in the 2008 NAEI are greater than 3 ktonnes for any given plant
- Stack parameters are already available for any given plant in the PCM stack parameters database (described in more detail in Section 2.2.2)

Contributions to ground level annual mean CO concentrations from large point sources in the 2008 NAEI were estimated by modelling each source explicitly using an atmospheric dispersion model (ADMS 4.2) and sequential meteorological data for 2009 from Waddington. A total of 391 large point sources were modelled. Surface roughness was assumed to be 0.1 m at the dispersion site and 0.02 m at the meteorological site. 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 the PCM stack parameters database.

There are some point sources in the 2008 NAEI which closed before the start of 2009. Hence, these point sources were removed from the modelling for 2009.

8.3.2 Contributions from small point sources

Contributions from CO point sources with less than 3 ktonnes per annum release and without stack parameters were modelled using the small points model described in Appendix 2.

8.3.3 Contributions from area sources

Figure 8.4 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 (Figure 8.4).

The 2009 area source CO emissions maps have been calculated following the method applied for NO_X described in Section 2.2.5. An ADMS derived dispersion kernel has been used to calculate the contribution to ambient concentrations at a central receptor location from the area source emissions within a 33 km x 33 km square surrounding each monitoring site. Hourly sequential meteorological data from Waddington in 2009 has been used to construct the dispersion kernels, as described in Appendix 3.

A constant regional rural concentration of 0.1654 mg m^{-3} has been estimated from the intercept of the graph of measured annual mean concentration corrected for point source versus the uncalibrated modelled area source contribution (Figure 8.4), and the calibration coefficient from the slope.

As part of the calibration process concentration caps have been applied to certain sectors. This is because the use of surrogate statistics for mapping area source emissions sometimes results in unrealistically large concentration in some grid squares for a given sector. The concentration caps applied are given in Table 8.1.

Table 8.1 - Concentration caps applied to CO sector grids

SNAP code	Description	Cap applied (mg m^{-3})*
SNAP 8 (industrial off road machinery only)	Other Transport & Mobile Machinery	0.01

*Caps listed are for calibrated concentrations

The modelled area source contribution was multiplied by the empirical calibration 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.

8.3.4 Roadside annual mean CO concentrations

Calibration of the CO annual mean roadside increment model is shown in Figure 8.5. The annual mean concentration of CO at a roadside location has been considered to be 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 2008 (Murrells et al., 2010) and these have been adjusted to provide estimates of emissions in 2009. 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 8.5. The traffic flow adjustment factors used were the same as those applied in the roadside NO_X modelling (Section 2.2.6) and are presented in Figure 2.9.

Figure 8.4 - Calibration of area source annual mean CO model, 2009 (mg m^{-3})

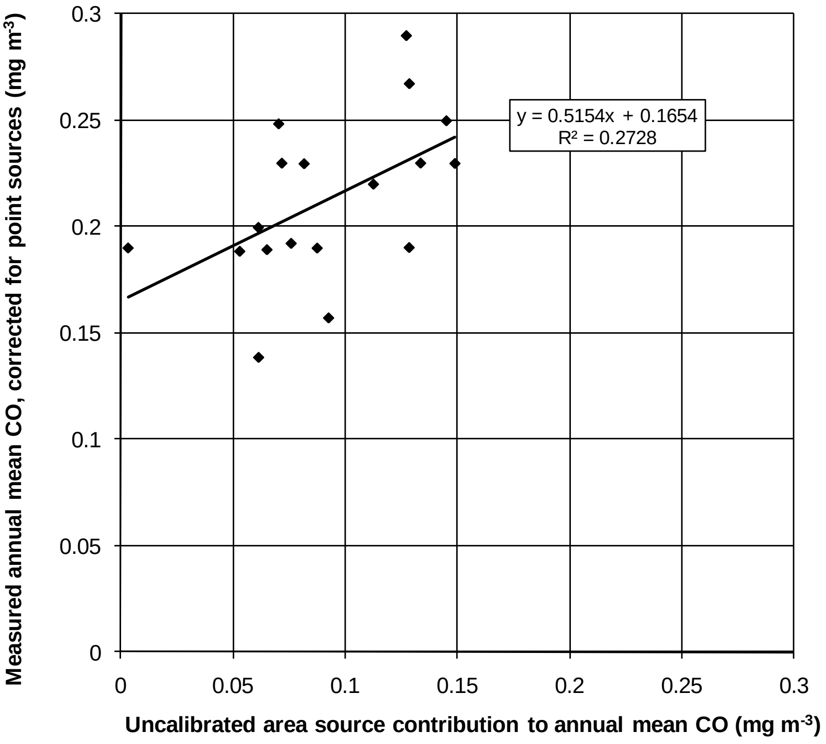
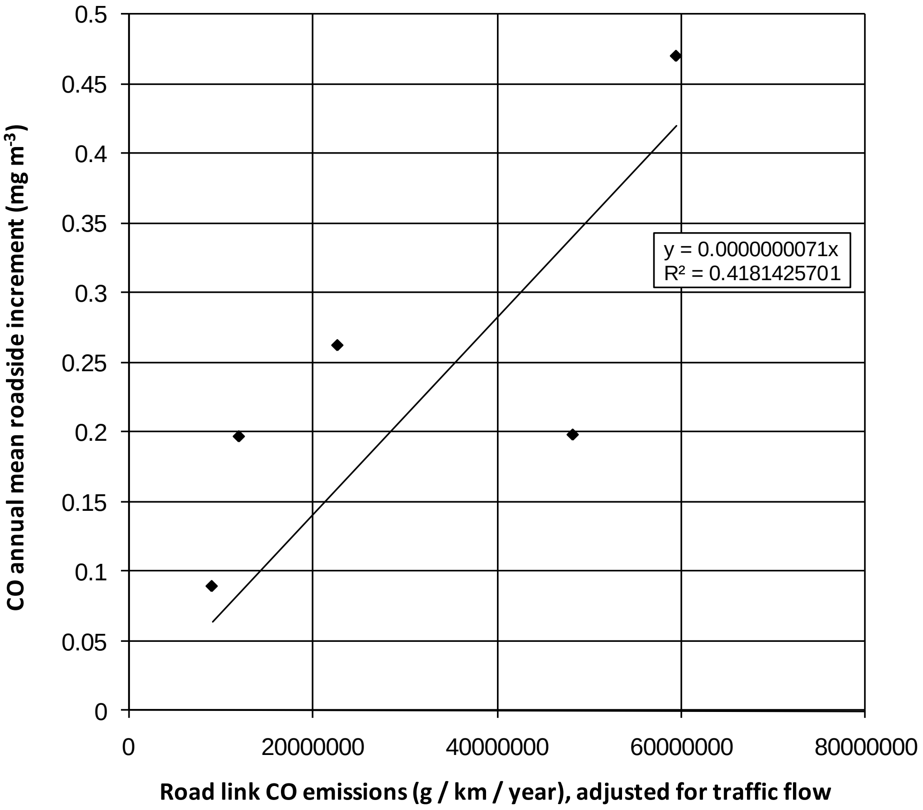


Figure 8.5 - Calibration of annual mean CO roadside increment model, 2009 (mg m^{-3})



8.3.5 Modelling the maximum 8 hour mean CO concentration

The map of maximum 8-hour mean CO concentrations at background locations shown in Figure 8.1 was calculated from a map of background annual mean CO concentrations. The relationship between measured maximum 8-hour concentration and the measured annual mean concentration from the national network has been used to scale the annual mean map. Figure 8.6 shows this relationship.

The map of maximum 8-hour mean CO concentrations at roadside locations shown in Figure 8.2 was calculated from the 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 8.7. This graph shows a composite of data from 2007 and 2009.

There was a reduction in the number of roadside monitoring sites where CO concentrations were measured between the year 2007 and 2008 from twelve to five. The 2007 monitoring data for the closed sites has been assessed for consistency with data from the sites that continue to operate (Figure 8.7). While few data points are available for 2009 it is clear that the relationship between the measured maximum 8-hour mean CO concentration and the annual mean remains consistent from 2007 to 2009. The empirical relationship used to scale the annual mean roadside map was therefore determined using a composite of the 2007 monitoring data from the closed sites with the 2009 monitoring data from the sites that continue to operate. Roadside concentrations for urban roads only are reported to the EU and included in this report.

Figure 8.6 - Calibration of maximum 8-hour mean CO area source model, 2009 (mg m^{-3})

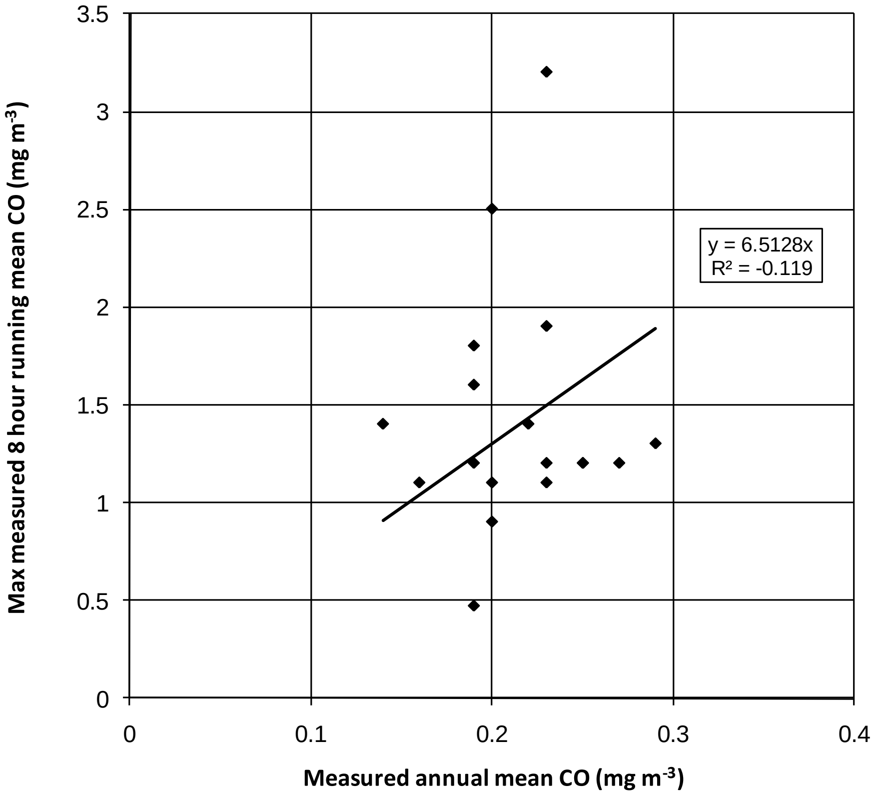
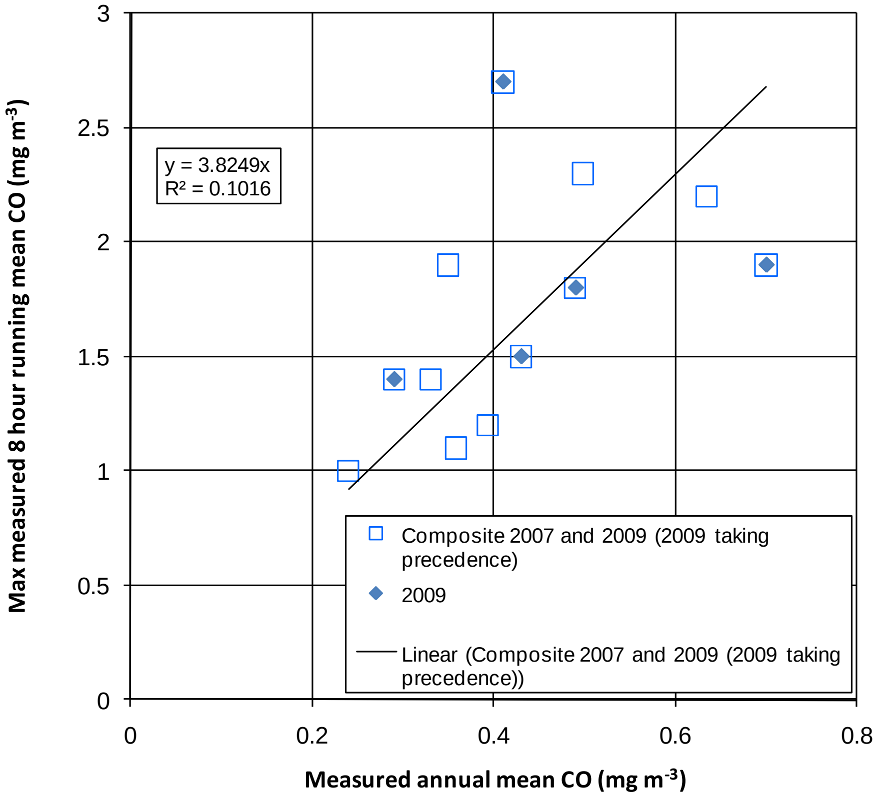


Figure 8.7 - Calibration of maximum 8-hour mean CO roadside increment model, 2009 (mg m^{-3})



8.4 Results

8.4.1 Verification of mapped values

Figure 8.8 to Figure 8.11 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 AQD data quality objective for modelled carbon monoxide concentrations – see Section 1.8. Summary statistics for the comparison between modelled and measured carbon monoxide concentrations are listed in Table 8.2 to Table 8.5.

Figure 8.8 - Verification of annual mean CO area source model 2009

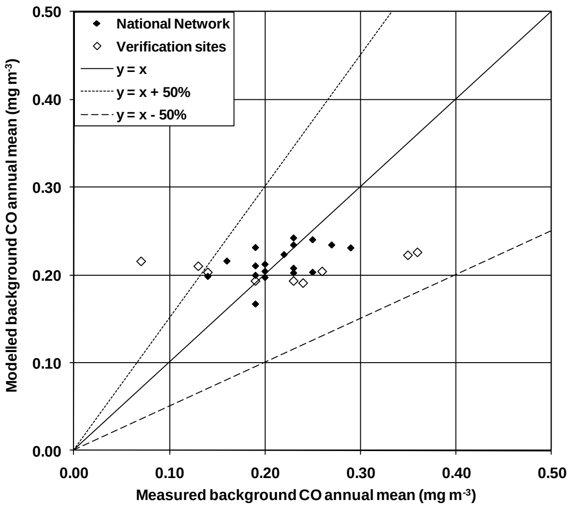


Figure 8.9 - Verification of maximum 8-hour mean CO area source model 2009

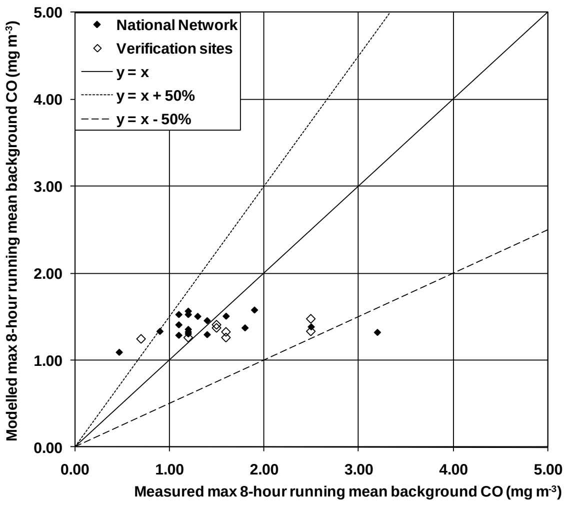


Figure 8.10 - Verification of annual mean CO roadside model 2009

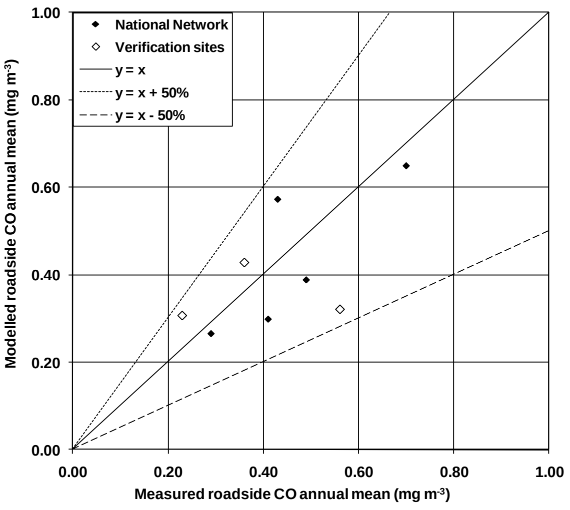


Figure 8.11 - Verification of maximum 8-hour mean CO roadside model 2009

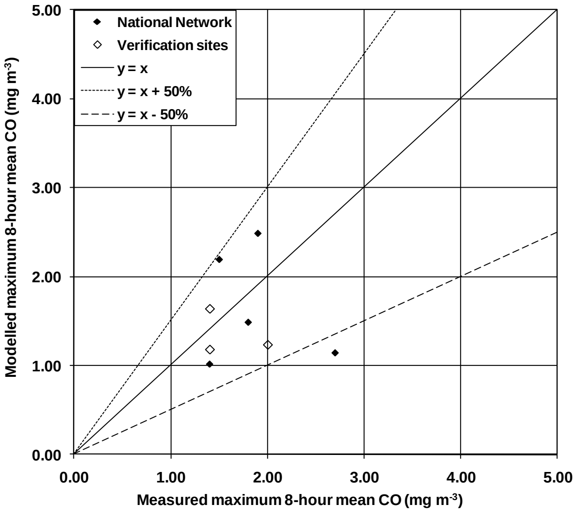


Table 8.2 - Summary statistics for comparison between modelled and measured annual mean CO concentrations at background sites (mg m^{-3})

	Mean of measurements (mg m^{-3})	Mean of modelled (mg m^{-3})	R^2	%outside data quality objectives	Number of sites
National Network Sites	0.21	0.21	0.25	0	18
Verification Sites	0.22	0.21	0.10	22	9

Table 8.3 - 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 modelled (mg m^{-3})	R^2	%outside data quality objectives	Number of sites
National Network Sites	1.43	1.40	0.03	11	18
Verification Sites	2.07	1.35	0.43	22	9

Table 8.4 - 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 modelled (mg m^{-3})	R^2	%outside data quality objectives	Number of sites
National Network Sites	0.47	0.43	0.64	0	5
Verification Sites	0.38	0.35	0.00	0	3

Table 8.5 - 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 modelled (mg m^{-3})	R^2	%outside data quality objectives	Number of sites
National Network Sites	1.86	1.66	0.05	20	5
Verification Sites	1.60	1.35	0.16	0	3

8.4.2 CO source apportionment at monitoring sites

Figure 8.12 and Figure 8.13 show the modelled annual mean CO source apportionment for 2009 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 (the estimated constant regional concentration), 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 everywhere are well below the limit values.

8.4.3 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 2009 are below the limit value for all zones.

Figure 8.12 - Annual mean CO source apportionment at background AURN monitoring sites (the area type of each site is shown in parenthesis after its name)

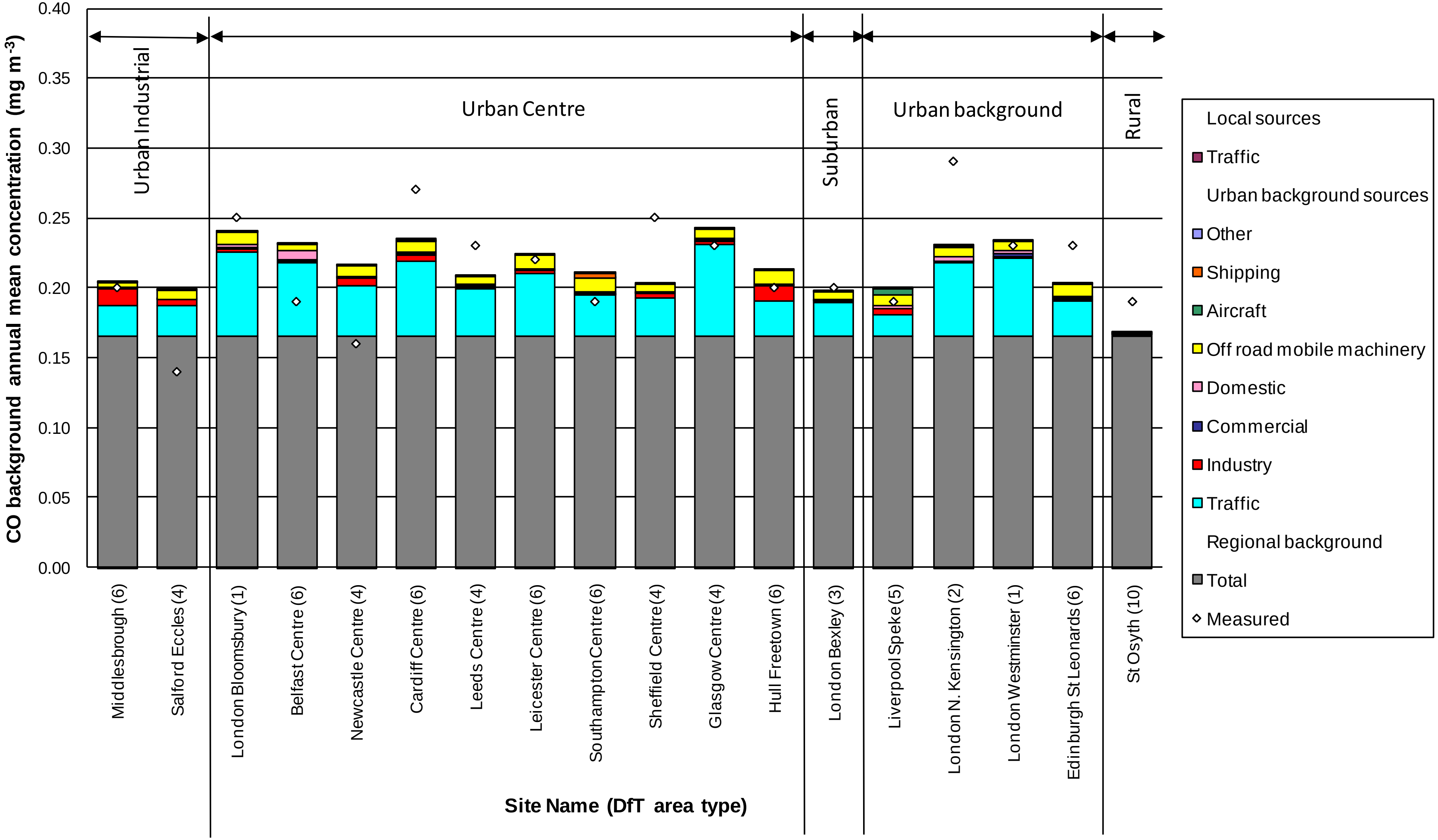
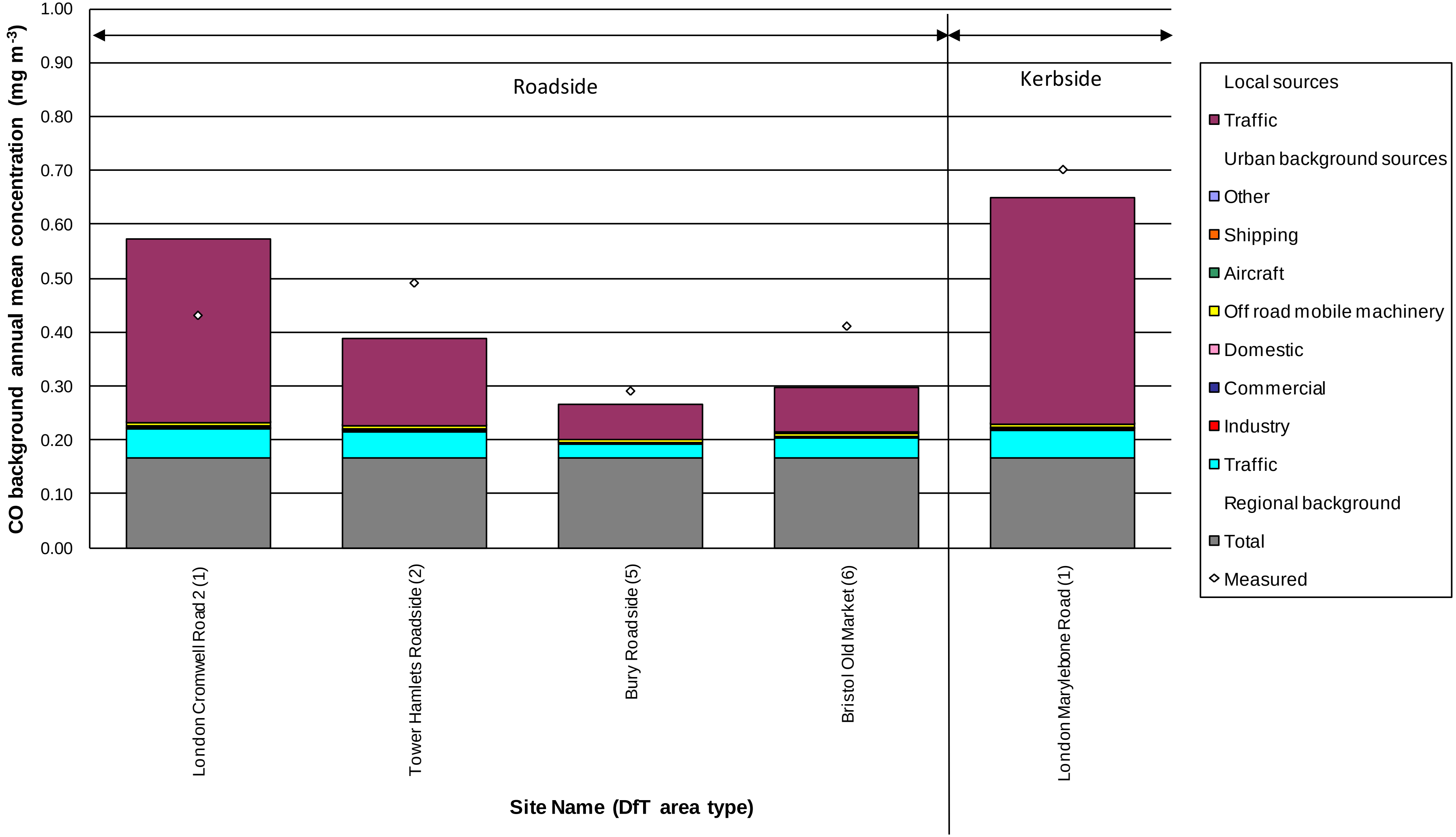


Figure 8.13 - Annual mean CO source apportionment at roadside AURN monitoring sites (the area type of each site is shown in parenthesis after its name)



9 Ozone

9.1 Introduction

9.1.1 Target values and long term objectives

Two target values (TV) for ambient ozone concentrations are set out in the Air Quality Directive (AQD), these are:

- A maximum daily 8-hour mean concentration of 120 µg m^{-3}, not to be exceeded on 25 days per calendar year averaged over 3 years
- AOT40[7] (calculated from 1-h values) 18000 µg m^{-3} h averaged (May to July) over five years

The TV's have been specified for the protection of human health and the protection of vegetation respectively, both came into force from 01/01/2010.

Two long term objectives (LTO) for ambient ozone concentrations are set out in the AQD, these are:

- A maximum daily 8-hour mean concentration of 120 µg m^{-3} within a calendar year
- AOT40 (calculated from 1-h values) 6000 µg m^{-3} h averaged (May to July)

The LTO's have been specified for the protection of human health and the protection of vegetation respectively. The date for compliance with the LTO's has not been defined.

9.1.2 Ozone modelling

Following recommendations made by a study comparing the relative performance of the available techniques for modelling ozone within the UK (Bush and Targa, 2005), an empirical mapping approach has been used for predicting ozone concentrations in 2009.

The empirical approach draws upon measurements from the 81 monitoring stations in the AURN during 2009 to produce functions describing ground-level ozone based upon wind velocity, topography and local emissions of NO_X. These functions are capable of predicting ozone levels at a resolution of 1 km x 1 km and the methods are briefly described in the following sections. Full details can be sourced from the cited references. The methods used here are based upon those presented by Coyle et al. (2002), NEGTAP (2001) and PORG (1998).

9.1.3 Chapter structure

This chapter describes modelling work carried out for 2009 to assess compliance with the ozone TV's and LTO's described above. Section 9.2 describes the modelling methods and results in relation to the number of days exceeding 120 µg m^{-3} metrics. Section 9.3 describes the modelling methods and results in relation to the AOT40 metrics.

---

[7] The definition of ATO40 has been given in the AQD and reproduced in this report within Section 1.6

9.2 Modelling the number of days exceeding 120 µg m^{-3} metric

9.2.1 Days greater than 120 µg m^{-3} methodology

Maps of the modelled number of days with maximum daily 8-hour mean ozone concentrations greater than 120 µg m^{-3}, for comparison with the LTO (2009) and TV (averaged 2007 to 2009) are presented in Figure 9.1 and Figure 9.2 respectively.

At rural locations in the UK exceedances of 120 µg m^{-3} as a maximum daily 8-hour mean are broadly consistent over wide spatial scales. As a result, measured exceedances from rural monitoring stations have been interpolated throughout the whole of the UK to represent the likely exceedances of this metric in the absence of any influence from local emissions of NO_X from combustion sources.

The resultant interpolated maps, however, will overestimate exceedances in urban areas, where nitric oxide emissions from combustion sources deplete ozone concentrations. This effect has been accounted for by adding an empirically derived urban ozone decrement, expressed as a percentage. The percentage decrement is defined as follows:

% decrement = 100((measured concentrations - rural interpolated concentration)/rural interpolated concentration)*

The derivation of a coefficient relating the percentage decrement to the modelled local NO_X concentration is shown in Figure 9.3 and Figure 9.4. The local NO_X component is calculated as follows:

Local NO_X = modelled background NO_X concentration – modelled rural NO_X concentration

The local NO_X concentration is hence the sum of contributions from local point and area sources of NO_X emissions, calculated as described in Section 2.2.

Figure 9.3 shows the decrement plot for days greater than 120 µg m^{-3} in 2009 (the LTO for human health metric) and Figure 9.4 shows the decrement plot for days greater than 120 µg m^{-3} between 2007 and 2009 (the TV for human health metric).

Figure 9.1 - Estimated number of days with an 8-hour mean ozone concentration above 120 µg m^{-3}, 2009

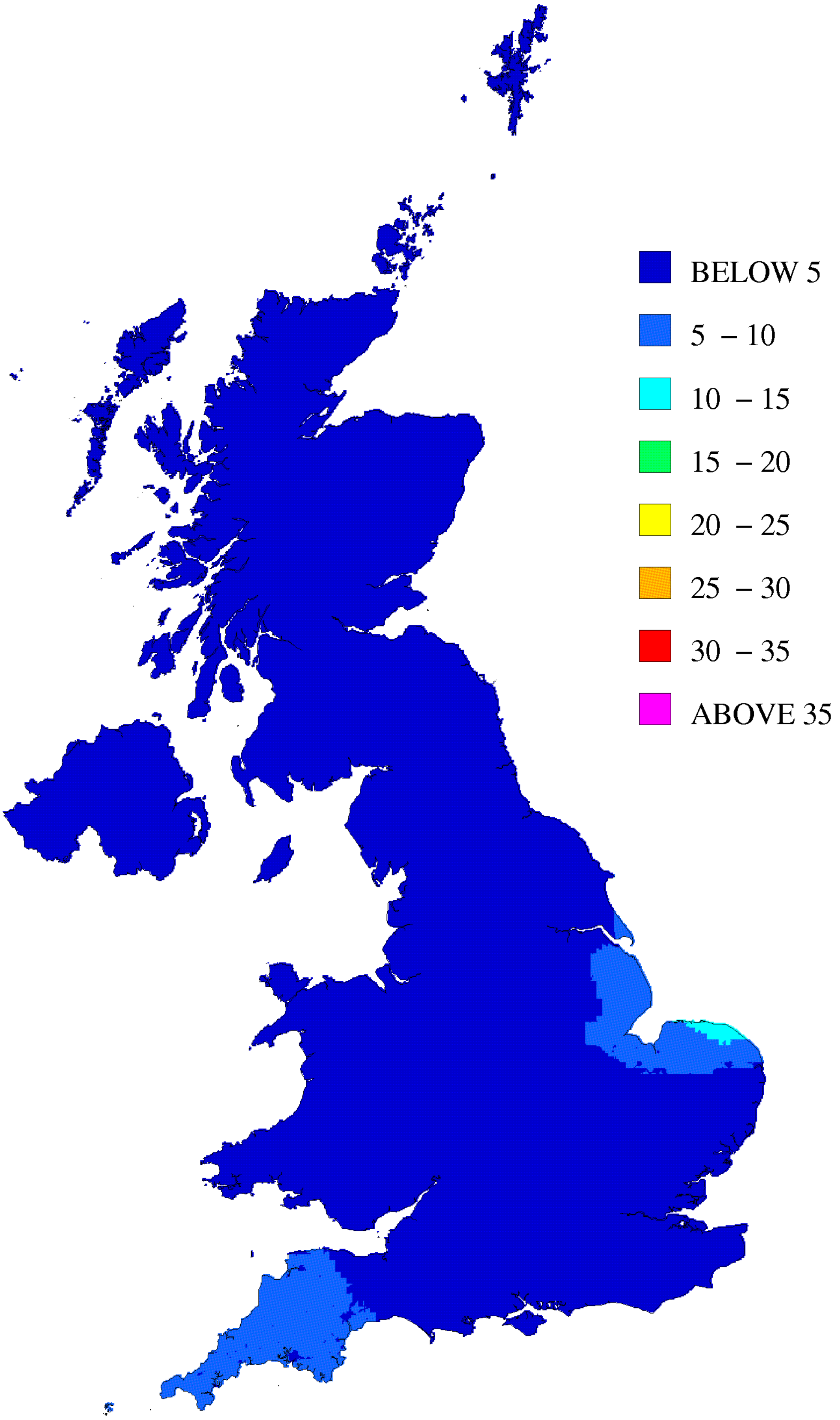


Figure 9.2 - Estimated average number of days with an 8-hour mean ozone concentration above 120 µg m^{-3}, 2007 to 2009

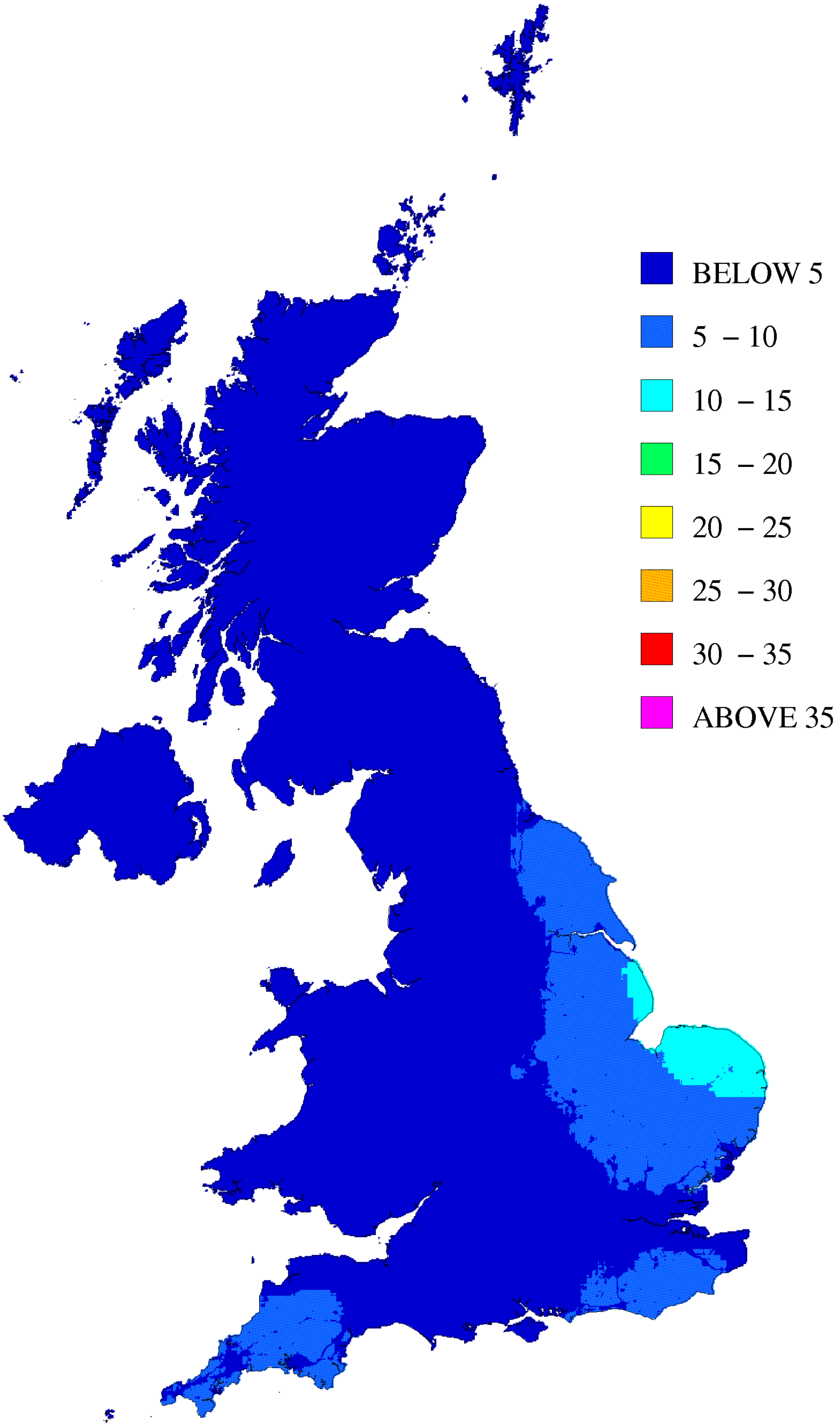


Figure 9.3 - Days greater than 120 µg m^{-3} percentage decrement in ozone concentrations, 2009

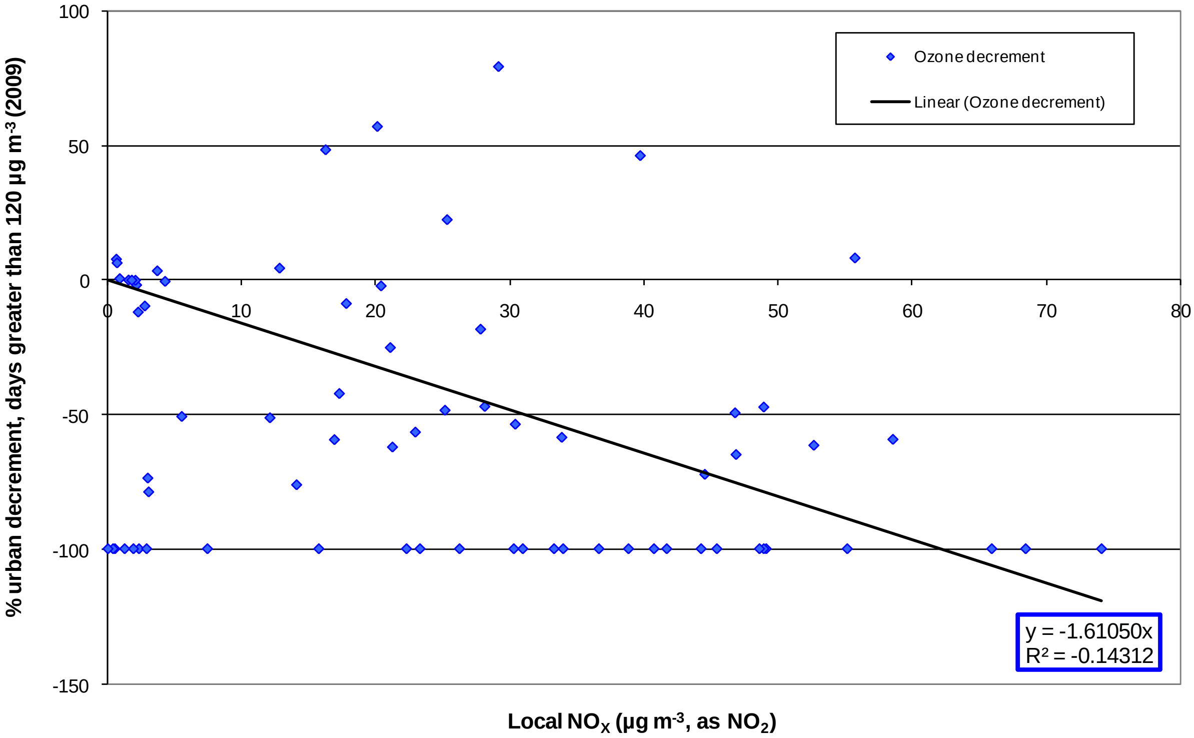


Figure 9.4 - Days greater than 120 µg m^{-3} percentage decrement in ozone concentrations, 2007-2009

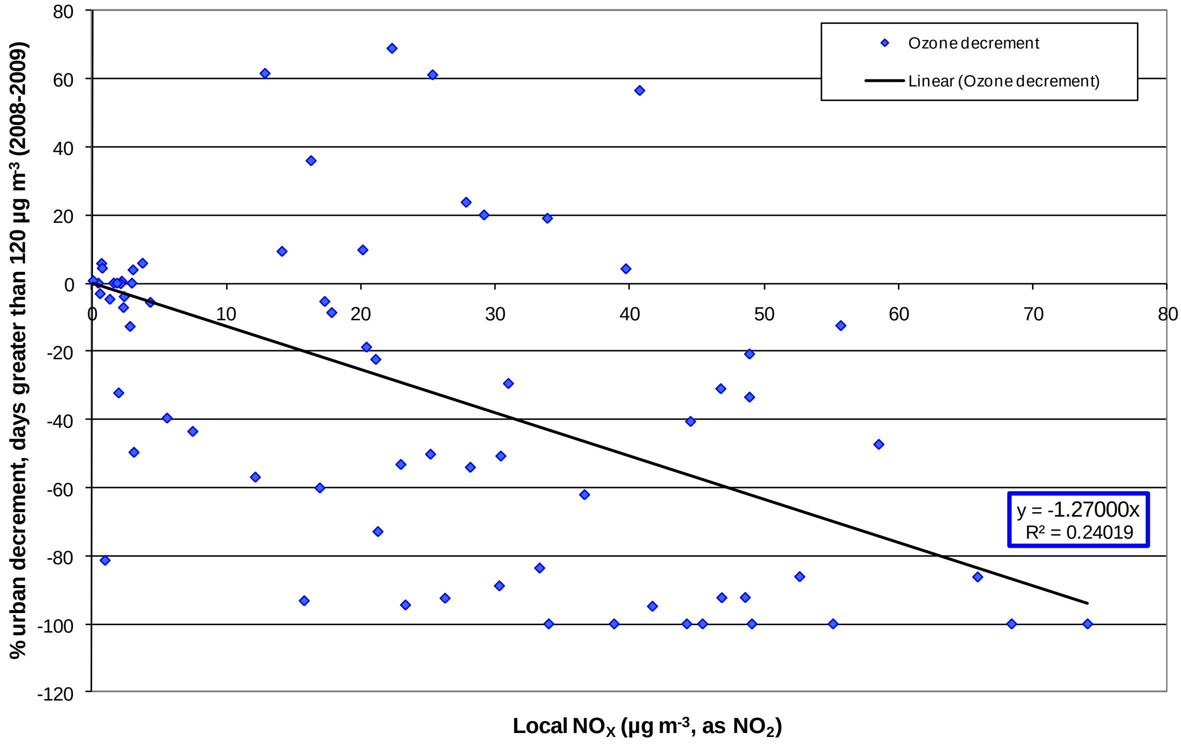


Figure 9.3 and Figure 9.4 show the relationship between the percentage urban decrement and local NO_X concentration. For some monitoring stations the decrement is positive, indicating that the measured number of days exceeding 120 µg m^{-3} is higher than the corresponding estimated rural value i.e. that the urban influence for these sites is not properly represented in the model. The cluster of low values close to the origin of these plots largely consists of the rural and remote sites, at which there will be little difference between

the rural estimated number of days exceeding 120 µg m^{-3} and the measured value. This helps to anchor the relationship to the origin. Percentage urban increments of -100% indicate that there were no measured exceedances of 120 µg m^{-3} at that monitoring site.

The calculated decrement is then used to correct the number of days where ozone concentrations are greater than 120 µg m^{-3} at rural sites, used for the interpolated maps:

Corrected days above 120 µg m^{-3} map = interpolated rural map + decrement

The decrement is a negative value and so reduces the concentration presented in the interpolated rural map to account for the reduction in ozone concentrations due to reaction with NO. Where the results of the expression predict a number of days less than 1, the predicted value is rounded to the nearest integer.

9.2.2 Verification of the number of mapped days > 120 µg m^{-3} values

Figure 9.5 and Figure 9.6 compare the number of modelled and measured days with maximum daily 8-hour mean ozone concentrations greater than 120 µg m^{-3} in 2009 and averaged 2007-2009 at background locations, respectively. Both the national network sites used to calibrate the models and the verification sites are shown. Lines representing y = x – 50 % and y = x + 50% are also shown, as this is the AQD data quality objective for modelled ozone concentrations – see Section 1.8.

Figure 9.5 - Verification of background number of days > 120 µg m^{-3} model 2009

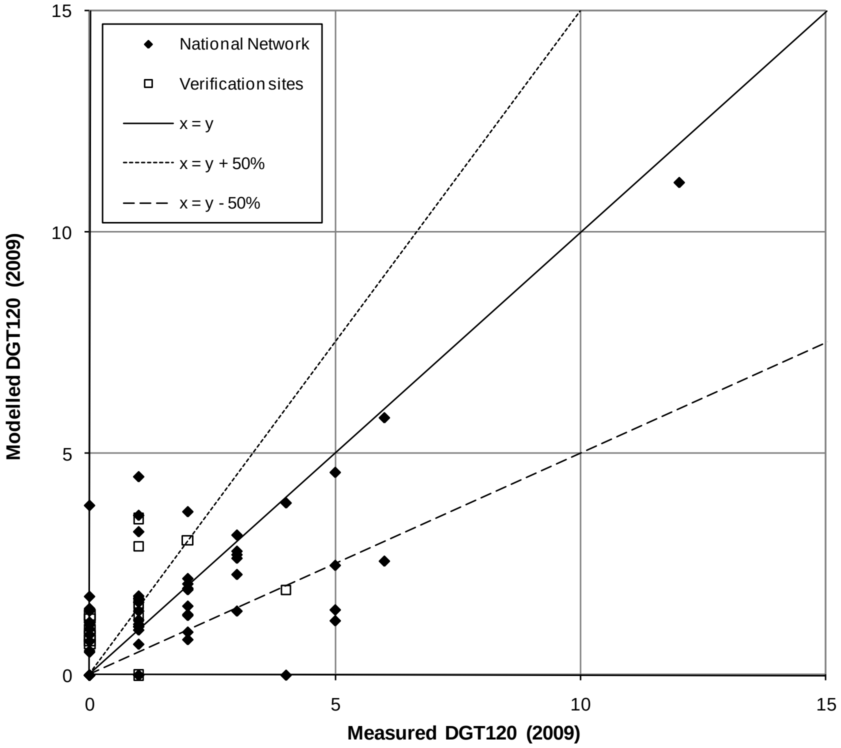


Figure 9.6 - Verification of background number of days > 120 µg m^{-3} model 2007-2009

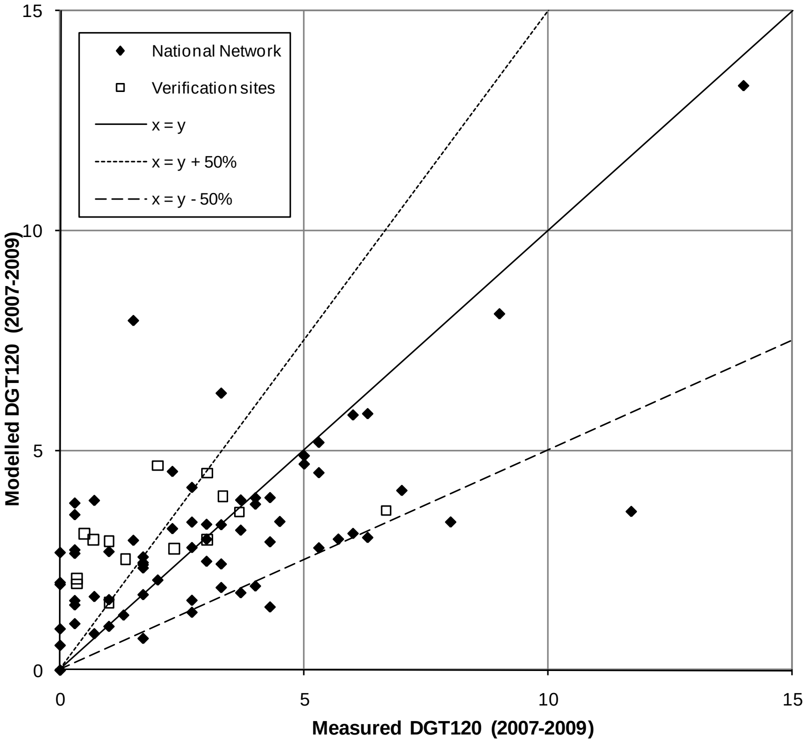


Figure 9.5 indicates that the verification sites were neither systematically over- or under-estimated for 2009, however the R^2 value, shown in Table 9.1, is low at 0.17. In general the model performs well for the national network, particularly at higher concentrations. The R^2 value of 0.58 indicates the improved relationship.

Figure 9.6 shows the model performance for the years 2007-2009. For the verification sites, this demonstrates an improvement of the multi-year (TV) model over the 2009 (LTO) model. Again, the model results for the national network sites are shown to closely match the corresponding measured value as these sites were used to generate the relationships used in the model, though the R^2 value is lower than that for the 2009 model (Figure 9.5, Table 9.1).

Table 9.1 - Summary statistics for comparison between modelled and measured number of days exceeding 120 µg m^{-3} as a maximum daily 8-hour mean

		Mean of measurements (days)	Mean of model estimates (days)	R^2	% outside data quality objectives	No. sites
National Network	2009	1.5	1.5	0.58	60%	70
Verification Sites	2009	0.9	1.6	0.17	72%	18
National Network	2007-2009	3.0	3.0	0.46	57%	70
Verification Sites	2007-2009	2.1	3.1	0.30	57%	14

9.2.3 Detailed comparison of model results with Target Values and Long-term Objectives

Table 9.2 gives a summary of the comparison of modelled concentrations with the TV and LTO by zone. These data are also presented in Form 19g of the questionnaire. 'Method A' in the table refers to the modelling methodology described in this report.

Table 9.2 - Tabular results of and methods used for supplementary assessment of ozone – for health

Zone	Zone code	Above TV for health				Above LTO for health			
		Area		Population exposed		Area		Population exposed	
		km^2	Method	Number	Method	km^2	Method	Number	Method
Greater London Urban Area	UK0001	0	A	0	A	1486	A	6611669	A
West Midlands Urban Area	UK0002	0	A	0	A	558	A	2000089	A
Greater Manchester Urban Area	UK0003	0	A	0	A	553	A	1834868	A
West Yorkshire Urban Area	UK0004	0	A	0	A	356	A	1138859	A
Tyneside	UK0005	0	A	0	A	201	A	672500	A
Liverpool Urban Area	UK0006	0	A	0	A	189	A	697951	A
Sheffield Urban Area	UK0007	0	A	0	A	158	A	517715	A
Nottingham Urban Area	UK0008	0	A	0	A	168	A	557911	A
Bristol Urban Area	UK0009	0	A	0	A	141	A	488145	A
Brighton/Worthing/Littlehampton	UK0010	0	A	0	A	103	A	388893	A
Leicester Urban Area	UK0011	0	A	0	A	102	A	374314	A
Portsmouth Urban Area	UK0012	0	A	0	A	102	A	358696	A
Teesside Urban Area	UK0013	0	A	0	A	79	A	252374	A
The Potteries	UK0014	0	A	0	A	91	A	266188	A
Bournemouth Urban Area	UK0015	0	A	0	A	123	A	340957	A
Reading/Wokingham Urban Area	UK0016	0	A	0	A	97	A	305786	A
Coventry/Bedworth	UK0017	0	A	0	A	76	A	277475	A
Kingston upon Hull	UK0018	0	A	0	A	81	A	259895	A
Southampton Urban Area	UK0019	0	A	0	A	75	A	243457	A
Birkenhead Urban Area	UK0020	0	A	0	A	92	A	266360	A
Southend Urban Area	UK0021	0	A	0	A	69	A	220761	A
Blackpool Urban Area	UK0022	0	A	0	A	70	A	218162	A
Preston Urban Area	UK0023	0	A	0	A	56	A	177579	A
Glasgow Urban Area	UK0024	0	A	0	A	0	A	0	A
Edinburgh Urban Area	UK0025	0	A	0	A	0	A	0	A
Cardiff Urban Area	UK0026	0	A	0	A	76	A	264395	A
Swansea Urban Area	UK0027	0	A	0	A	88	A	191717	A
Belfast Metropolitan Urban Area	UK0028	0	A	0	A	0	A	0	A
Eastern	UK0029	0	A	0	A	19501	A	4948618	A
South West	UK0030	0	A	0	A	24328	A	4105254	A

Zone	Zone code	Above TV for health				Above LTO for health			
		Area		Population exposed		Area		Population exposed	
		km^2	Method	Number	Method	km^2	Method	Number	Method
South East	UK0031	0	A	0	A	19067	A	6208241	A
East Midlands	UK0032	0	A	0	A	15559	A	3251315	A
North West & Merseyside	UK0033	0	A	0	A	10487	A	3212753	A
Yorkshire & Humberside	UK0034	0	A	0	A	14992	A	3014091	A
West Midlands	UK0035	0	A	0	A	12183	A	2614542	A
North East	UK0036	0	A	0	A	7291	A	1413126	A
Central Scotland	UK0037	0	A	0	A	7	A	100	A
North East Scotland	UK0038	0	A	0	A	1354	A	63838	A
Highland	UK0039	0	A	0	A	0	A	0	A
Scottish Borders	UK0040	0	A	0	A	866	A	19300	A
South Wales	UK0041	0	A	0	A	12623	A	1716464	A
North Wales	UK0042	0	A	0	A	8709	A	716784	A
Northern Ireland	UK0043	0	A	0	A	24	A	1154	A
Total		0	A	0	A	152181	A	50212296	A

9.3 Modelling the AOT40 vegetation metric

9.3.1 AOT40 methodology

Maps of modelled AOT40 for comparison with the LTO (2009) and TV (averaged 2005 to 2009) are presented in Figure 9.7 and Figure 9.8 respectively.

The AOT40 vegetation metrics for 2009 and the averaged metric for 2005-2009 were calculated from measured data at rural monitoring stations in the AURN during the 'well-mixed' period of the day (hours 12:00 UTC to 18:00 UTC). These data were interpolated to produce a 'rural well-mixed' map at 5 km x 5 km resolution.

Topographic effects are important for some ozone metrics, such as the AOT40 at lowland locations because of the disconnection of a shallow boundary layer from air aloft at times other than during the middle of the day. Surface ozone concentrations are lower in these locations at times other than during the middle of the day due to a combination of dry deposition and reactions with local NO. This effect is much less marked at higher altitudes and at coastal locations, where wind is generally stronger and a shallow boundary layer does not form. As a result of the influence of altitude on this metric, it is necessary to calculate the metric between these well-mixed hours to allow an appropriate correction to be applied to the interpolated well-mixed rural map. This correction accounts for the diurnal variation in ozone, thereby converting the mapped 'well-mixed' AOT40 to an 08:00 to 20:00 AOT40 for comparison with the Directive. The correction uses a variable ΔO_3, where ΔO_3 describes the difference between the AOT40 'well-mixed' and that between 08:00 UTC and 20:00 UTC (Coyle et al., 2002). For the purposes of this study, the components of ΔO_3 are described as follows, and were derived from measured values at rural sites in 2009 for the single year metric and years 2005-2009 for the multi-year metric:

$$\Delta O_{3\ 2009} = 0.0002.altitude + 1.3688$$

$$\Delta O_{3\ 2005\text{-}9} = 0.0002.altitude + 1.3667$$

An urban decrement term was subsequently defined for those monitoring stations in the AURN and the rural map so as to correct for the depletion of ozone in areas close to sources of NO. As for the days above 120 µg m^{-3} metric, the decrement is closely related to the annual mean NO_X concentration, and has been defined in a similar fashion, using a percentage decrement in ozone concentrations associated with local NO_X concentrations.

Using the same methodology discussed in Section 9.2.1 for the days greater than 120 µg m^{-3} maps, the decrement was then used to correct the final AOT40 maps:

Corrected AOT40 map = interpolated rural map + decrement

The relationships between the decrement and modelled NO_X concentrations for 2009 and 2005-2009 averaged metrics are presented in Figure 9.9 and Figure 9.10 respectively.

Figure 9.7 - Estimated AOT40 vegetation metric, 2009 (µg m^{-3} hours)

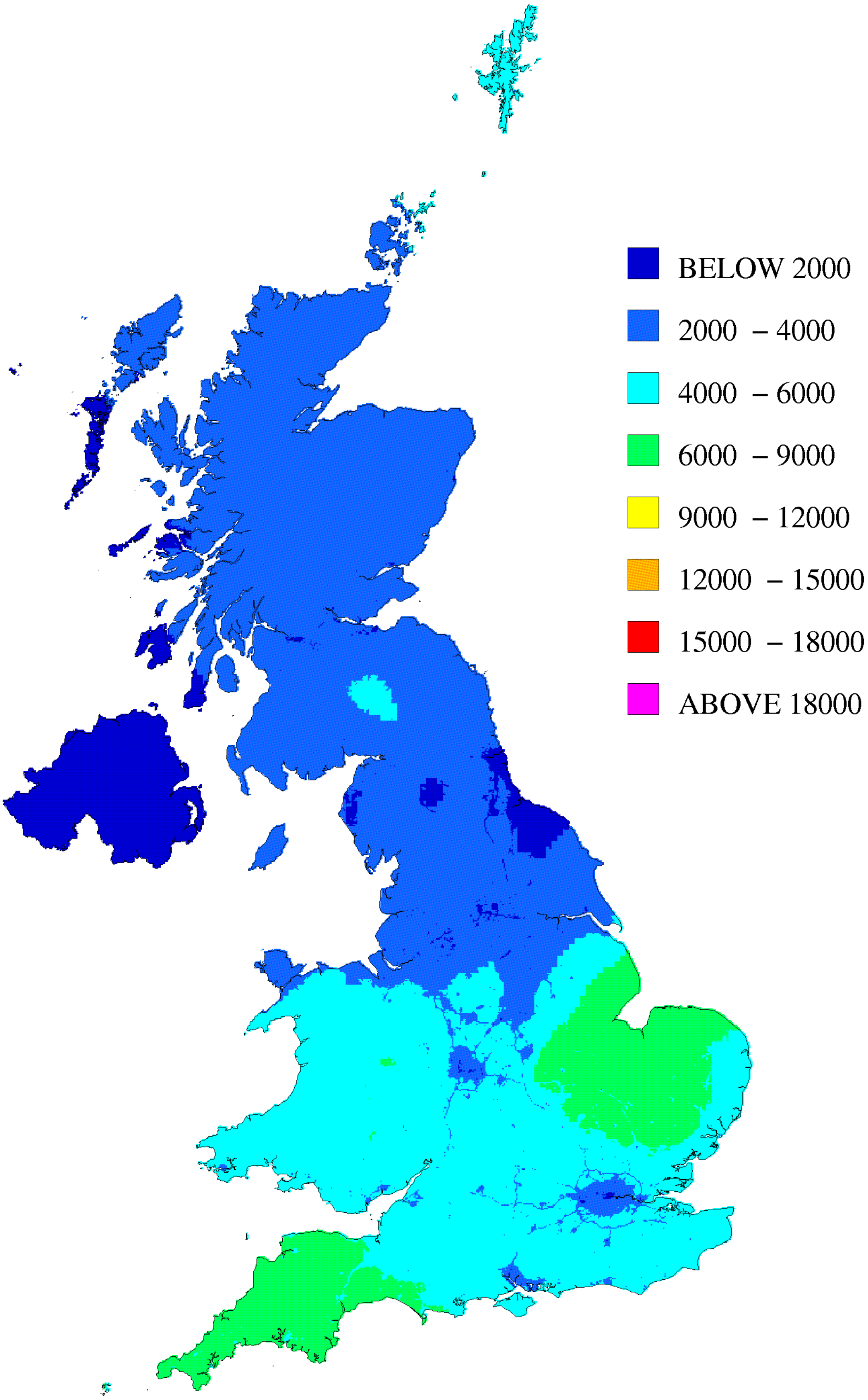


Figure 9.8 - Estimated AOT40 vegetation metric, averaged 2005-2009 (µg m^{-3} hours)

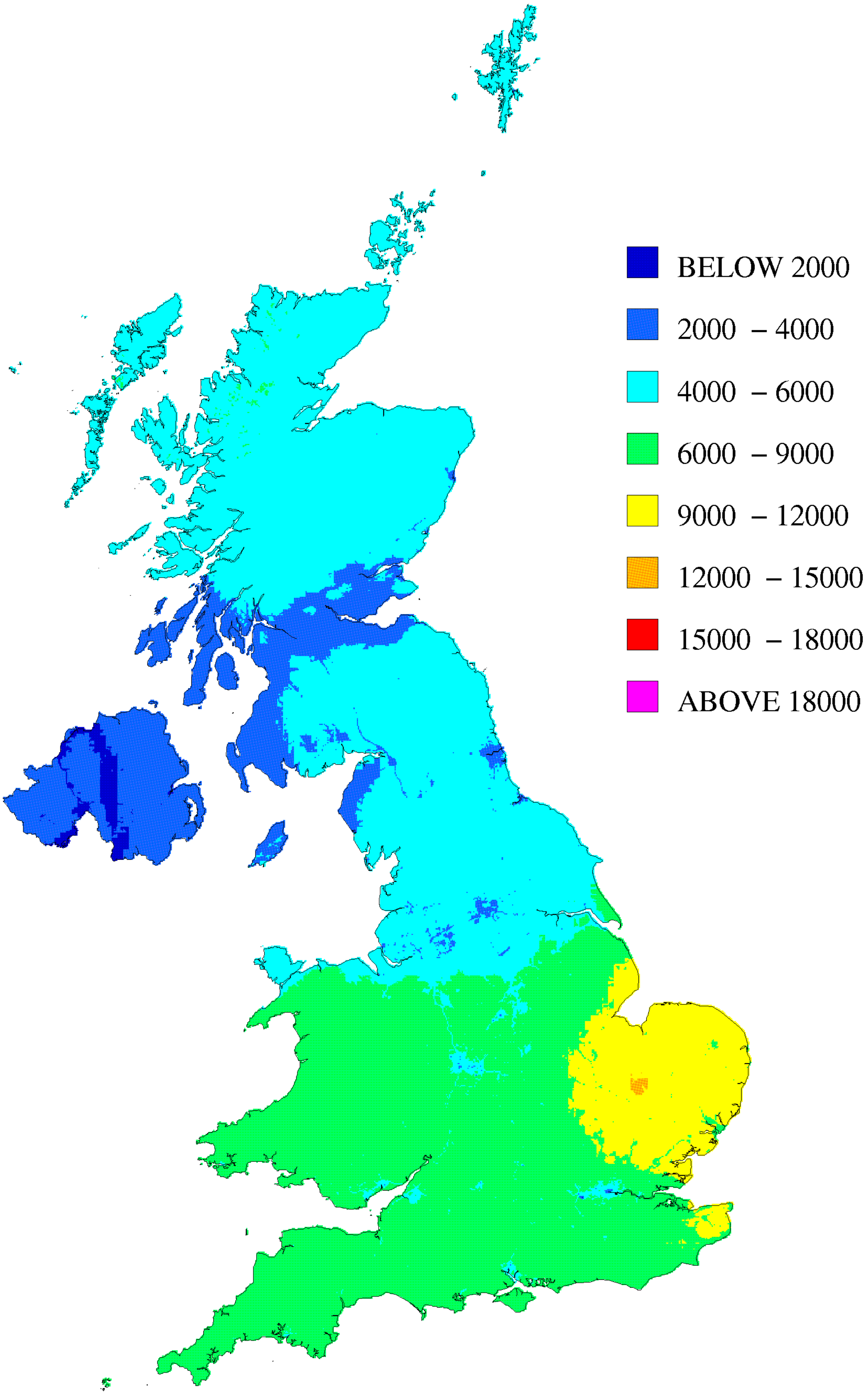


Figure 9.9 - AOT40 percentage decrement in ozone concentrations, 2009

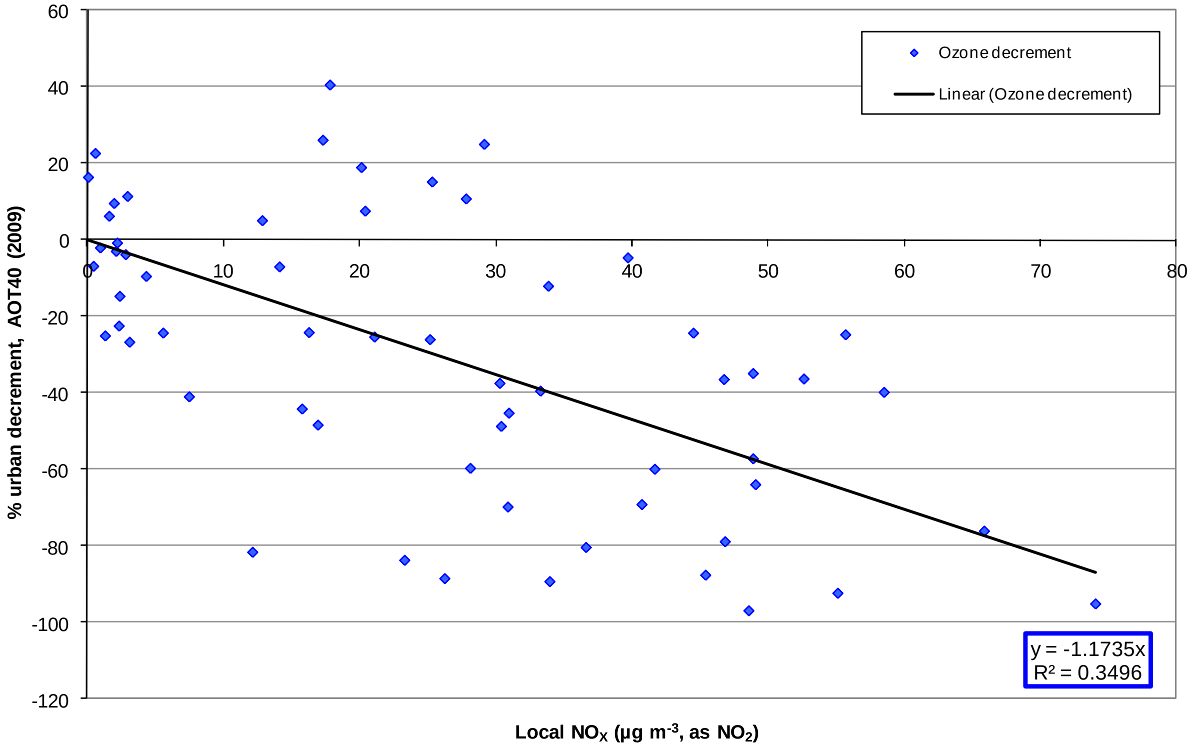
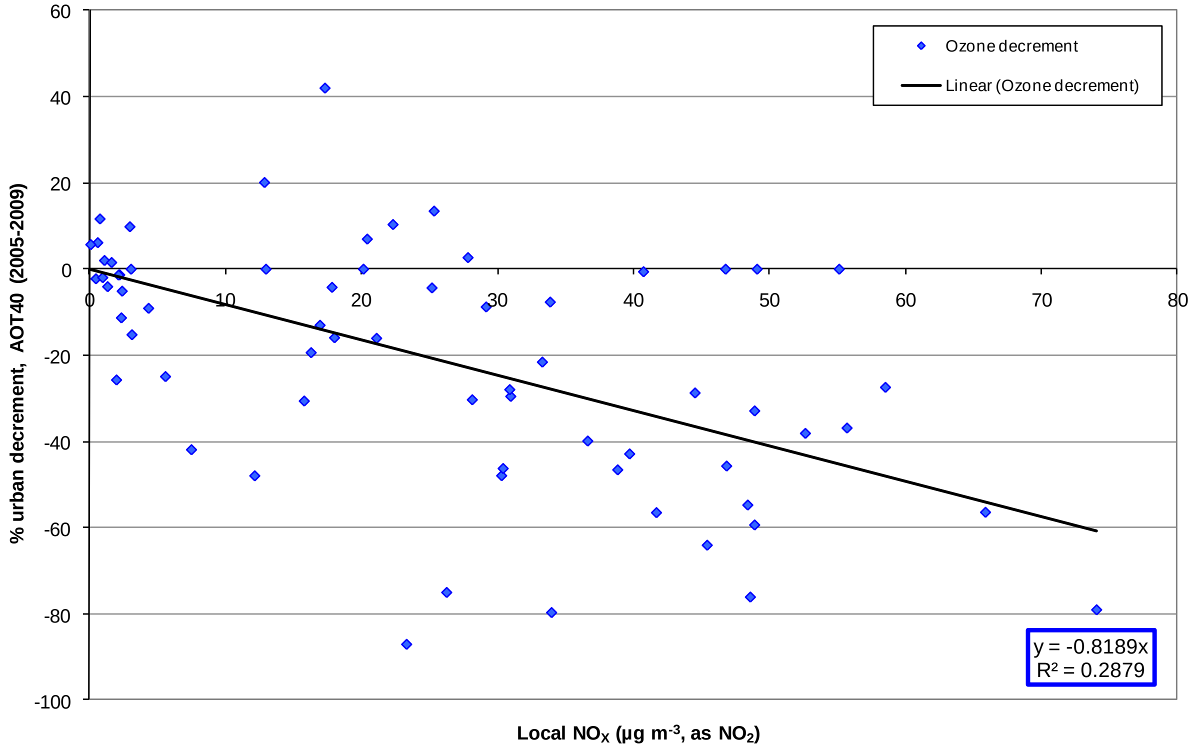


Figure 9.10 - AOT40 percentage decrement in ozone concentrations, 2005-2009



9.3.2 Verification of mapped AOT40 values

Figure 9.11 and Figure 9.12 show a comparison of modelled and measured AOT40 metrics in 2009 and averaged 2005-2009 at background locations. Both the national network sites used to calibrate the models and the verification sites are shown. Lines representing y = x – 50 % and y = x + 50% are also shown, as this is the AQD data quality objective for modelled ozone concentrations – see Section 1.8.

Figure 9.11 - Verification of background AOT40 vegetation model, 2009

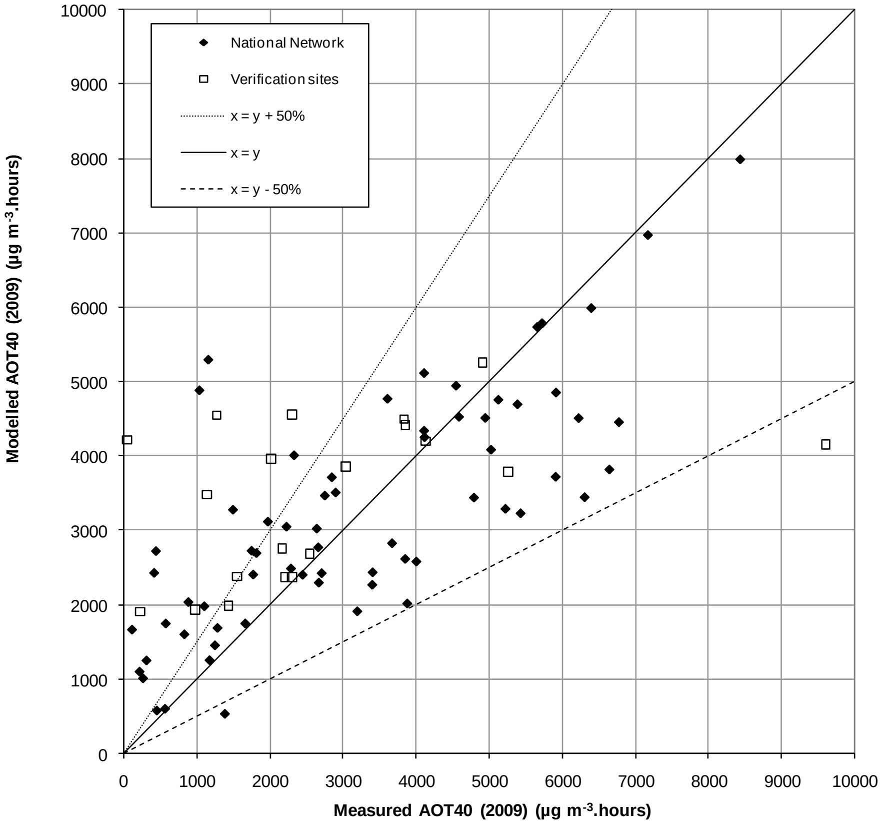
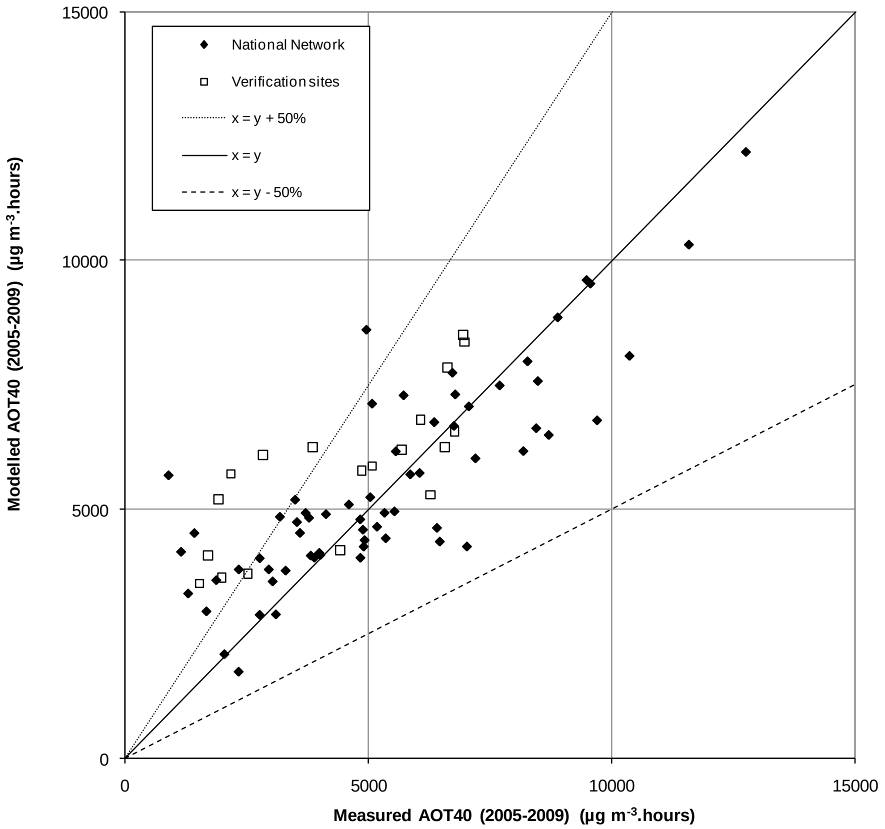


Figure 9.12 - Verification of background AOT40 vegetation model, 2005-2009



The verification sites generally suggested a slight over estimation by the model for 2009. This is also reflected in Table 9.3 which presents the summary statistics for the comparison between modelled and measured ozone concentrations. However, the results for the AOT40 metric are more encouraging than those for the number of days greater than 120 µg m^{-3} and just 25% of national network data points outside the +/- 50% DQO range.

The multi-year metric (TV) shows improved results when compared with the single year model (LTO), as shown in Figure 9.12 and Table 9.3 below. However, a slight overestimation of the measured results can still be seen in the Figure.

Table 9.3 - Summary statistics for comparison between modelled and measured AOT40 vegetation metric

		Mean of measurements (days)	Mean of model estimates (days)	R^2	% outside data quality objectives	No. sites
National network	2009	3219.5	3236.4	0.59	25%	67
Verification sites	2009	2737.9	3463.1	0.21	45%	20
National network	2005-2009	5335.2	5497.6	0.70	14%	66
Verification sites	2005-2009	4465.7	5774.6	0.61	37%	19

9.3.3 Detailed comparison of modelling results with Target Values and Long-term Objectives

Table 9.4 gives a summary of the comparison of modelled concentrations with the TV and LTO by zone. These data are also presented in Form 19g of the questionnaire. 'Method A' in the table refers to the modelling methodology described in this report. There are no ecosystem areas in the agglomeration zones (indicated by 'n'). Estimates of area and population exposed have been derived from the background maps only.

Table 9.4 - Tabular results of and methods used for supplementary assessment of ozone – for vegetation

Zone	Zone code	Above TV for vegetation				Above LTO for vegetation			
		Area		Vegetation area exposed		Area		Vegetation area exposed	
		km^2	Method	Number	Method	km^2	Method	Number	Method
Greater London Urban Area	UK0001	0	A	n	A	0	A	n	A
West Midlands Urban Area	UK0002	0	A	n	A	0	A	n	A
Greater Manchester Urban Area	UK0003	0	A	n	A	0	A	n	A
West Yorkshire Urban Area	UK0004	0	A	n	A	0	A	n	A
Tyneside	UK0005	0	A	n	A	0	A	n	A
Liverpool Urban Area	UK0006	0	A	n	A	0	A	n	A
Sheffield Urban Area	UK0007	0	A	n	A	0	A	n	A
Nottingham Urban Area	UK0008	0	A	n	A	0	A	n	A
Bristol Urban Area	UK0009	0	A	n	A	0	A	n	A
Brighton/Worthing/Littlehampton	UK0010	0	A	n	A	0	A	n	A
Leicester Urban Area	UK0011	0	A	n	A	0	A	n	A
Portsmouth Urban Area	UK0012	0	A	n	A	0	A	n	A
Teesside Urban Area	UK0013	0	A	n	A	0	A	n	A
The Potteries	UK0014	0	A	n	A	0	A	n	A
Bournemouth Urban Area	UK0015	0	A	n	A	0	A	n	A
Reading/Wokingham Urban Area	UK0016	0	A	n	A	0	A	n	A
Coventry/Bedworth	UK0017	0	A	n	A	0	A	n	A
Kingston upon Hull	UK0018	0	A	n	A	0	A	n	A
Southampton Urban Area	UK0019	0	A	n	A	0	A	n	A
Birkenhead Urban Area	UK0020	0	A	n	A	0	A	n	A
Southend Urban Area	UK0021	0	A	n	A	0	A	n	A
Blackpool Urban Area	UK0022	0	A	n	A	0	A	n	A
Preston Urban Area	UK0023	0	A	n	A	0	A	n	A
Glasgow Urban Area	UK0024	0	A	n	A	0	A	n	A
Edinburgh Urban Area	UK0025	0	A	n	A	0	A	n	A

Zone	Zone code	Above TV for vegetation				Above LTO for vegetation			
		Area		Vegetation area exposed		Area		Vegetation area exposed	
		km^2	Method	Number	Method	km^2	Method	Number	Method
Cardiff Urban Area	UK0026	0	A	n	A	0	A	n	A
Swansea Urban Area	UK0027	0	A	n	A	0	A	n	A
Belfast Metropolitan Urban Area	UK0028	0	A	n	A	0	A	n	A
Eastern	UK0029	0	A	0	A	11563	A	11563	A
South West	UK0030	0	A	0	A	12222	A	12222	A
South East	UK0031	0	A	0	A	10	A	10	A
East Midlands	UK0032	0	A	0	A	5185	A	5185	A
North West & Merseyside	UK0033	0	A	0	A	0	A	0	A
Yorkshire & Humberside	UK0034	0	A	0	A	0	A	0	A
West Midlands	UK0035	0	A	0	A	67	A	67	A
North East	UK0036	0	A	0	A	0	A	0	A
Central Scotland	UK0037	0	A	0	A	0	A	0	A
North East Scotland	UK0038	0	A	0	A	0	A	0	A
Highland	UK0039	0	A	0	A	0	A	0	A
Scottish Borders	UK0040	0	A	0	A	0	A	0	A
South Wales	UK0041	0	A	0	A	20	A	20	A
North Wales	UK0042	0	A	0	A	5	A	5	A
Northern Ireland	UK0043	0	A	0	A	0	A	0	A
Total		0	A	0	A	29072	A	29072	A

10 Results of air quality assessments

10.1 Results of the air quality assessment for 2009

The results of the air quality assessments for SO_2, NO_2 and NO_X, PM_{10}, $PM_{2.5}$, Pb, C_6H_6, CO and O_3 are listed in Table 10.1 to Table 10.5. The tables present information for SO_2, NO_2 and NO_X, PM_{10}, Pb, C_6H_6 and CO from Form 8 of the questionnaire. $PM_{2.5}$ is reported against a target value (TV) and a list of zones in relation to the TV is given in Form 9c of the questionnaire, this information is summarised in Table 10.3 alongside the information for PM_{10}. O_3 is reported against TV's and long term objectives (LTO's) and a list of zones in relation to these is given in Form 9a of the questionnaire, this information is summarised in Table 10.5.

The tables have been completed as follows:

- Where all measurements were within the relevant critical levels (CL's), LV's, (or LV's with margins of tolerance (MOT) where applicable) in 2009, the table shows this as "OK".
- Where compliance was determined by modelling, this is shown as "OK (m)".
- Where locations were identified as exceeding a LV, CL, or a LV + MOT where applicable, this is identified as ">MOT" or ">LV" as applicable.
- Where an exceedance was determined by modelling, this is indicated by (m), as above.

A similar approach has also been used to compare concentrations with TV's and LTO's.

"n/a" means that an assessment is not relevant for a zone, such as for the vegetation limit value in agglomeration zones. Zones that complied with the relevant CL's, LV's, TV's or LTO's are shaded blue, while those that did not are shaded red.

If both measurements and model estimates show that a threshold has been exceeded then the measurements are regarded as the primary basis for the compliance status. Where locations have been identified as exceeding from modelling this 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 concentrations 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. Compliance can be determined by modelling where measurements are not available for a zone.

Table 10.1 - List of zones and agglomerations in relation to limit value and critical level exceedances for SO_2

Zone	Zone code	SO_2 LV for health (1hr mean)	SO_2 LV for health (24hr mean)	SO_2 CL for vegetation (annual mean)	SO_2 LV for vegetation (winter mean)
Greater London Urban Area	UK0001	OK	OK	n/a	n/a
West Midlands Urban Area	UK0002	OK	OK	n/a	n/a
Greater Manchester Urban Area	UK0003	OK	OK	n/a	n/a
West Yorkshire Urban Area	UK0004	OK	OK	n/a	n/a
Tyneside	UK0005	OK	OK	n/a	n/a
Liverpool Urban Area	UK0006	OK	OK	n/a	n/a
Sheffield Urban Area	UK0007	OK	OK	n/a	n/a
Nottingham Urban Area	UK0008	OK	OK	n/a	n/a
Bristol Urban Area	UK0009	OK	OK	n/a	n/a
Brighton/Worthing/Littlehampton	UK0010	OK (m)	OK (m)	n/a	n/a
Leicester Urban Area	UK0011	OK	OK	n/a	n/a
Portsmouth Urban Area	UK0012	OK (m)	OK (m)	n/a	n/a
Teesside Urban Area	UK0013	OK	OK	n/a	n/a
The Potteries	UK0014	OK (m)	OK (m)	n/a	n/a
Bournemouth Urban Area	UK0015	OK (m)	OK (m)	n/a	n/a
Reading/Wokingham Urban Area	UK0016	OK (m)	OK (m)	n/a	n/a
Coventry/Bedworth	UK0017	OK (m)	OK (m)	n/a	n/a
Kingston upon Hull	UK0018	OK	OK	n/a	n/a
Southampton Urban Area	UK0019	OK	OK	n/a	n/a
Birkenhead Urban Area	UK0020	OK (m)	OK (m)	n/a	n/a
Southend Urban Area	UK0021	OK (m)	OK (m)	n/a	n/a
Blackpool Urban Area	UK0022	OK (m)	OK (m)	n/a	n/a
Preston Urban Area	UK0023	OK (m)	OK (m)	n/a	n/a
Glasgow Urban Area	UK0024	OK	OK	n/a	n/a
Edinburgh Urban Area	UK0025	OK	OK	n/a	n/a
Cardiff Urban Area	UK0026	OK	OK	n/a	n/a
Swansea Urban Area	UK0027	OK	OK	n/a	n/a

Zone	Zone code	SO_2 LV for health (1hr mean)	SO_2 LV for health (24hr mean)	SO_2 CL for vegetation (annual mean)	SO_2 LV for vegetation (winter mean)
Belfast Urban Area	UK0028	OK	OK	n/a	n/a
Eastern	UK0029	OK	OK	OK	OK
South West	UK0030	OK (m)	OK (m)	OK (m)	OK (m)
South East	UK0031	OK	OK	OK	OK
East Midlands	UK0032	OK	OK	OK	OK
North West & Merseyside	UK0033	OK (m)	OK (m)	OK (m)	OK (m)
Yorkshire & Humberside	UK0034	OK	OK	OK (m)	OK (m)
West Midlands	UK0035	OK	OK	OK (m)	OK (m)
North East	UK0036	OK (m)	OK (m)	OK (m)	OK (m)
Central Scotland	UK0037	OK	OK	OK (m)	OK (m)
North East Scotland	UK0038	OK (m)	OK (m)	OK (m)	OK (m)
Highland	UK0039	OK (m)	OK (m)	OK (m)	OK (m)
Scottish Borders	UK0040	OK (m)	OK (m)	OK (m)	OK (m)
South Wales	UK0041	OK	OK	OK	OK
North Wales	UK0042	OK	OK	OK (m)	OK (m)
Northern Ireland	UK0043	OK	OK	OK (m)	OK (m)

Table 10.2 - List of zones and agglomerations in relation to limit value and critical level exceedances for NO_2 and NO_X

Zone	Zone code	NO_2 LV for health (1-hr mean)	NO_2 LV for health (annual mean)	NO_x CL for vegetation (annual mean)
Greater London Urban Area	UK0001	> MOT	> MOT	n/a
West Midlands Urban Area	UK0002	OK	> MOT	n/a
Greater Manchester Urban Area	UK0003	OK	> MOT	n/a
West Yorkshire Urban Area	UK0004	OK	> MOT	n/a
Tyneside	UK0005	OK	> MOT (m)	n/a
Liverpool Urban Area	UK0006	OK	> MOT (m)	n/a
Sheffield Urban Area	UK0007	OK	> MOT (m)	n/a
Nottingham Urban Area	UK0008	OK	> MOT (m)	n/a
Bristol Urban Area	UK0009	OK	> MOT	n/a
Brighton/Worthing/Littlehampton	UK0010	OK	> MOT (m)	n/a
Leicester Urban Area	UK0011	OK	> MOT (m)	n/a
Portsmouth Urban Area	UK0012	OK	> MOT (m)	n/a
Teesside Urban Area	UK0013	OK	> MOT (m)	n/a
The Potteries	UK0014	OK	> MOT (m)	n/a
Bournemouth Urban Area	UK0015	OK	> MOT (m)	n/a
Reading/Wokingham Urban Area	UK0016	OK (m)	> MOT (m)	n/a
Coventry/Bedworth	UK0017	OK	> MOT (m)	n/a
Kingston upon Hull	UK0018	OK	> MOT (m)	n/a
Southampton Urban Area	UK0019	OK	> MOT (m)	n/a
Birkenhead Urban Area	UK0020	OK	> MOT (m)	n/a
Southend Urban Area	UK0021	OK (m)	> MOT (m)	n/a
Blackpool Urban Area	UK0022	OK (m)	OK (m)	n/a
Preston Urban Area	UK0023	OK	> MOT (m)	n/a
Glasgow Urban Area	UK0024	> MOT	> MOT	n/a
Edinburgh Urban Area	UK0025	OK	> MOT (m)	n/a
Cardiff Urban Area	UK0026	OK	> MOT (m)	n/a
Swansea Urban Area	UK0027	OK	> MOT (m)	n/a
Belfast Urban Area	UK0028	OK	> MOT (m)	n/a
Eastern	UK0029	OK	> MOT	OK
South West	UK0030	OK	> MOT	OK
South East	UK0031	OK	> MOT	OK
East Midlands	UK0032	OK	> MOT (m)	OK
North West & Merseyside	UK0033	OK	> MOT (m)	OK (m)
Yorkshire & Humberside	UK0034	OK	> MOT (m)	OK (m)
West Midlands	UK0035	OK	> MOT (m)	OK (m)
North East	UK0036	OK	> MOT (m)	OK (m)
Central Scotland	UK0037	OK	> MOT (m)	OK
North East Scotland	UK0038	OK	> MOT (m)	OK (m)
Highland	UK0039	OK	OK	OK (m)
Scottish Borders	UK0040	OK	OK	OK
South Wales	UK0041	OK	> MOT (m)	OK
North Wales	UK0042	OK	> MOT (m)	OK
Northern Ireland	UK0043	OK	> MOT (m)	OK (m)

Table 10.3 - List of zones and agglomerations in relation to limit value exceedances for PM_{10} and target value exceedances for $PM_{2.5}$

Zone	Zone code	PM_{10} LV for health (24-hr mean)	PM_{10} LV for health (annual mean)	$PM_{2.5}$ TV for health (annual mean)
Greater London Urban Area	UK0001	> LV	OK	OK
West Midlands Urban Area	UK0002	OK	OK	OK
Greater Manchester Urban Area	UK0003	OK	OK	OK
West Yorkshire Urban Area	UK0004	OK	OK	OK
Tyneside	UK0005	OK	OK	OK
Liverpool Urban Area	UK0006	OK	OK	OK
Sheffield Urban Area	UK0007	OK (m)	OK (m)	OK
Nottingham Urban Area	UK0008	OK (m)	OK (m)	OK
Bristol Urban Area	UK0009	OK	OK	OK
Brighton/Worthing/Littlehampton	UK0010	OK (m)	OK (m)	OK
Leicester Urban Area	UK0011	OK	OK	OK (m)
Portsmouth Urban Area	UK0012	OK (m)	OK (m)	OK
Teesside Urban Area	UK0013	OK (m)	OK (m)	OK (m)
The Potteries	UK0014	OK	OK	OK
Bournemouth Urban Area	UK0015	OK (m)	OK (m)	OK
Reading/Wokingham Urban Area	UK0016	OK	OK	OK
Coventry/Bedworth	UK0017	OK (m)	OK (m)	OK
Kingston upon Hull	UK0018	OK	OK	OK
Southampton Urban Area	UK0019	> LV (m)	OK	OK
Birkenhead Urban Area	UK0020	OK (m)	OK (m)	OK
Southend Urban Area	UK0021	OK (m)	OK (m)	OK
Blackpool Urban Area	UK0022	OK (m)	OK (m)	OK
Preston Urban Area	UK0023	OK (m)	OK (m)	OK
Glasgow Urban Area	UK0024	OK	OK	OK
Edinburgh Urban Area	UK0025	OK (m)	OK (m)	OK
Cardiff Urban Area	UK0026	OK	OK	OK
Swansea Urban Area	UK0027	OK	OK	OK
Belfast Urban Area	UK0028	OK	OK	OK
Eastern	UK0029	> LV (m)	OK	OK
South West	UK0030	OK	OK	OK (m)
South East	UK0031	OK	OK	OK
East Midlands	UK0032	OK	OK	OK
North West & Merseyside	UK0033	OK	OK	OK
Yorkshire & Humberside	UK0034	OK	OK	OK
West Midlands	UK0035	OK	OK	OK
North East	UK0036	OK	OK	OK
Central Scotland	UK0037	OK	OK	OK
North East Scotland	UK0038	OK	OK	OK (m)
Highland	UK0039	OK	OK	OK
Scottish Borders	UK0040	OK (m)	OK (m)	OK (m)
South Wales	UK0041	OK	OK	OK
North Wales	UK0042	OK	OK	OK (m)
Northern Ireland	UK0043	OK	OK	OK (m)

Table 10.4 - List of zones and agglomerations in relation to limit value exceedances for lead, benzene and CO

Zone	Zone code	Lead LV for health (annual mean)	Benzene LV for health (annual mean)	CO LV for health (8-hr mean)
Greater London Urban Area	UK0001	OK	OK	OK
West Midlands Urban Area	UK0002	OK	OK	OK (m)
Greater Manchester Urban Area	UK0003	OK	OK	OK
West Yorkshire Urban Area	UK0004	OK (m)	OK	OK
Tyneside	UK0005	OK (m)	OK	OK
Liverpool Urban Area	UK0006	OK (m)	OK	OK
Sheffield Urban Area	UK0007	OK	OK	OK
Nottingham Urban Area	UK0008	OK (m)	OK	OK (m)
Bristol Urban Area	UK0009	OK	OK	OK
Brighton/Worthing/Littlehampton	UK0010	OK (m)	OK (m)	OK (m)
Leicester Urban Area	UK0011	OK (m)	OK	OK
Portsmouth Urban Area	UK0012	OK (m)	OK (m)	OK (m)
Teesside Urban Area	UK0013	OK	OK	OK
The Potteries	UK0014	OK (m)	OK	OK (m)
Bournemouth Urban Area	UK0015	OK (m)	OK (m)	OK (m)
Reading/Wokingham Urban Area	UK0016	OK (m)	OK (m)	OK (m)
Coventry/Bedworth	UK0017	OK (m)	OK	OK (m)
Kingston upon Hull	UK0018	OK (m)	OK (m)	OK
Southampton Urban Area	UK0019	OK (m)	OK	OK
Birkenhead Urban Area	UK0020	OK (m)	OK (m)	OK (m)
Southend Urban Area	UK0021	OK (m)	OK (m)	OK (m)
Blackpool Urban Area	UK0022	OK (m)	OK (m)	OK (m)
Preston Urban Area	UK0023	OK (m)	OK (m)	OK (m)
Glasgow Urban Area	UK0024	OK	OK	OK
Edinburgh Urban Area	UK0025	OK (m)	OK (m)	OK
Cardiff Urban Area	UK0026	OK	OK (m)	OK
Swansea Urban Area	UK0027	OK	OK (m)	OK
Belfast Urban Area	UK0028	OK	OK	OK
Eastern	UK0029	OK	OK	OK
South West	UK0030	OK	OK	OK (m)
South East	UK0031	OK	OK	OK (m)
East Midlands	UK0032	OK	OK	OK
North West & Merseyside	UK0033	OK	OK	OK (m)
Yorkshire & Humberside	UK0034	OK	OK	OK (m)
West Midlands	UK0035	OK (m)	OK	OK (m)
North East	UK0036	OK	OK	OK (m)
Central Scotland	UK0037	OK	OK	OK (m)
North East Scotland	UK0038	OK	OK (m)	OK (m)
Highland	UK0039	OK (m)	OK (m)	OK (m)
Scottish Borders	UK0040	OK	OK (m)	OK (m)
South Wales	UK0041	OK	OK (m)	OK (m)
North Wales	UK0042	OK (m)	OK (m)	OK (m)
Northern Ireland	UK0043	OK (m)	OK (m)	OK (m)

Table 10.5 - List of zones and agglomerations in relation to target value and long term objective exceedances for ozone

Zone	Zone code	O_3 TV and LTO for health (8-hr mean)	O_3 TV and LTO for vegetation (AOT40)
Greater London Urban Area	UK0001	Meets TV, >LTO	OK
West Midlands Urban Area	UK0002	Meets TV, >LTO	OK
Greater Manchester Urban Area	UK0003	Meets TV, >LTO (m)	OK
West Yorkshire Urban Area	UK0004	Meets TV, >LTO (m)	OK
Tyneside	UK0005	Meets TV, >LTO (m)	OK
Liverpool Urban Area	UK0006	Meets TV, >LTO	OK
Sheffield Urban Area	UK0007	Meets TV, >LTO (m)	OK
Nottingham Urban Area	UK0008	Meets TV, >LTO (m)	OK
Bristol Urban Area	UK0009	Meets TV, >LTO	OK
Brighton/Worthing/Littlehampton	UK0010	Meets TV, >LTO	Meets TV, >LTO
Leicester Urban Area	UK0011	Meets TV, >LTO	OK
Portsmouth Urban Area	UK0012	Meets TV, >LTO	OK
Teesside Urban Area	UK0013	Meets TV, >LTO (m)	OK
The Potteries	UK0014	Meets TV, >LTO	OK
Bournemouth Urban Area	UK0015	Meets TV, >LTO	OK
Reading/Wokingham Urban Area	UK0016	Meets TV, >LTO	Meets TV, >LTO
Coventry/Bedworth	UK0017	Meets TV, >LTO	OK
Kingston upon Hull	UK0018	Meets TV, >LTO (m)	OK
Southampton Urban Area	UK0019	Meets TV, >LTO (m)	OK
Birkenhead Urban Area	UK0020	Meets TV, >LTO	OK
Southend Urban Area	UK0021	Meets TV, >LTO	Meets TV, >LTO
Blackpool Urban Area	UK0022	Meets TV, >LTO	OK
Preston Urban Area	UK0023	Meets TV, >LTO	OK
Glasgow Urban Area	UK0024	OK	OK
Edinburgh Urban Area	UK0025	OK	OK
Cardiff Urban Area	UK0026	Meets TV, >LTO	OK
Swansea Urban Area	UK0027	Meets TV, >LTO	OK
Belfast Urban Area	UK0028	OK	OK
Eastern	UK0029	Meets TV, >LTO	Meets TV, >LTO
South West	UK0030	Meets TV, >LTO	Meets TV, >LTO
South East	UK0031	Meets TV, >LTO	Meets TV, >LTO (m)
East Midlands	UK0032	Meets TV, >LTO	Meets TV, >LTO
North West & Merseyside	UK0033	Meets TV, >LTO	OK
Yorkshire & Humberside	UK0034	Meets TV, >LTO (m)	OK
West Midlands	UK0035	Meets TV, >LTO	Meets TV, >LTO (m)
North East	UK0036	Meets TV, >LTO (m)	OK (m)
Central Scotland	UK0037	Meets TV, >LTO (m)	OK
North East Scotland	UK0038	Meets TV, >LTO (m)	OK
Highland	UK0039	OK	OK
Scottish Borders	UK0040	Meets TV, >LTO (m)	OK
South Wales	UK0041	Meets TV, >LTO	Meets TV, >LTO
North Wales	UK0042	Meets TV, >LTO	Meets TV, >LTO
Northern Ireland	UK0043	Meets TV, >LTO (m)	OK

10.2 Measured exceedances in 2009

Measured exceedances of limit values plus margins of tolerance are listed in Form 11 of the questionnaire (CDR, 2010). Exceedances of thresholds for O_3 are listed in Form 13. Summary statistics for the exceedances identified are provided in Table 10.6 – Table 10.11.

Table 10.6 - Exceedances of the NO_2 limit value plus margin of tolerance for health (1-hour mean)

Site name	Zone code	Number of 1-hour exceedances of MOT	Number of 1-hour exceedances of LV	Maximum 1-hour concentration ($\mu g\ m^{-3}$)
Glasgow Centre	UK0024	43	48	701
Glasgow Kerbside	UK0024	32	57	384
London Marylebone Road	UK0001	312	486	332

Table 10.7 - Exceedances of the NO_2 limit value plus margin of tolerance for health (annual mean)

Site name	Zone code	Annual mean concentration ($\mu g\ m^{-3}$)
Bath Roadside	UK0030	65
Birmingham Tyburn	UK0002	47
Bristol Old Market	UK0009	63
Bury Roadside	UK0003	72
Glasgow City Chambers	UK0024	46
Glasgow Kerbside	UK0024	78
Haringey Roadside	UK0001	43
Leeds Headingley Kerbside	UK0004	48
London Bloomsbury	UK0001	54
London Cromwell Road 2	UK0001	72
London Hillingdon	UK0001	54
London Marylebone Road	UK0001	107
London Westminster	UK0001	44
Oxford Centre Roadside	UK0031	50
Sandy Roadside	UK0029	46
Tower Hamlets Roadside	UK0001	61

Table 10.8 - Exceedances of the PM_{10} limit value (24-hour mean)

Site name	Zone code	Number of 24-hour exceedances of LV	Maximum 24-hour concentration ($\mu g\ m^{-3}$)
London Marylebone Road	UK0001	36	88

Note: Number of exceedances reduced to 25 after subtraction of the contribution from natural sources but a modelled exceedance of the 24-hour mean limit value remains in this zone after subtraction of the contribution from natural sources.

Table 10.9 - Exceedances of the ozone information threshold value (180 µg m^{-3} for 1-hour means)

Site name	Zone code	Number of 1-hour exceedances of information threshold	Maximum 1-hour concentration (µg m^{-3})
Brighton Preston Park	UK0010	1	184
Sibton	UK0029	3	200
Southend-on-Sea	UK0021	2	210
St Osyth	UK0029	5	258

Table 10.10 - Exceedances of the ozone alert threshold value (240 µg m^{-3} for 1-hour means)

Site name	Zone code	Number of 1-hour exceedances of alert threshold	Maximum 1-hour concentration (µg m^{-3})
St Osyth	UK0029	2	258

Table 10.11 - Exceedances of the ozone long term objective for health protection

Site name	Zone code	Number of days with exceedances	Maximum 8-hour concentration (µg m^{-3})
Aston Hill	UK0042	5	136
Birmingham Tyburn	UK0002	2	150
Birmingham Tyburn	UK0002	1	132
Blackpool Marton	UK0022	1	137
Bottesford	UK0032	1	121
Bournemouth	UK0015	3	131
Brighton Preston Park	UK0010	2	171
Bristol St Paul's	UK0009	5	128
Cardiff Centre	UK0026	2	125
Charlton Mackrell	UK0030	3	122
Coventry Memorial Park	UK0017	3	150
Cwmbran	UK0041	6	131
Glazebury	UK0033	1	124
Harwell	UK0031	3	157
Ladybower	UK0032	2	128
Leamington Spa	UK0035	2	148
Leicester Centre	UK0011	1	138
Leominster	UK0035	2	131
Liverpool Speke	UK0006	1	125
London Haringey	UK0001	1	151
London Harlington	UK0001	1	136
London N. Kensington	UK0001	1	128
London Teddington	UK0001	3	154
Lullington Heath	UK0031	2	145
Market Harborough	UK0032	1	128
Narberth	UK0041	4	134
Northampton	UK0032	5	163
Port Talbot Margam	UK0027	1	125
Portsmouth	UK0012	2	161
Preston	UK0023	1	124

Site name	Zone code	Number of days with exceedances	Maximum 8-hour concentration ($\mu g\ m^{-3}$)
Reading New Town	UK0016	5	164
Rochester Stoke	UK0031	1	124
Sandwell West Bromwich	UK0002	4	157
Sibton	UK0029	2	170
Southend-on-Sea	UK0021	2	152
St Osyth	UK0029	2	188
Stoke-on-Trent Centre	UK0014	1	122
Thurrock	UK0029	1	134
Weybourne	UK0029	12	144
Wicken Fen	UK0029	3	147
Wigan Centre	UK0033	1	124
Wirral Tranmere	UK0020	1	133
Yarner Wood	UK0030	6	133

10.3 Comparison with previous years

Table 10.12 and Table 10.13 provide a comparison of the monitoring and modelling results for 2009 with the results of the annual air quality assessments covering AQDD1 and AQDD2 pollutants reported to the EU from 2001 to 2008 (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, Grice et al., 2010).

Table 10.14 and

Table 10.15 provide a similar comparison of the monitoring and modelling results for 2009 with the results of the annual air quality assessments covering AQDD3 pollutants (O_3) reported to the EU from 2004 to 2008 (Bush et al., 2006; Bush et al., 2007; Kent and Stedman, 2007; Kent and Stedman, 2008; Kent and Stedman, 2010). 2009 is the first year for which the results of an air quality assessment for $PM_{2.5}$ have been reported to the EU and hence there are no years for comparison in

Table 10.16.

The listed numbers of zones exceeding the LV in Table 10.13 include the zones exceeding the LV + MOT. An exceedance of the LV can be determined by either measurements or modelling. Where an exceedance of the LV + MOT has been determined by modelling, exceedance of the LV in this zone may still be determined by either measurements or modelling but this distinction is not shown in Table 10.1 to Table 10.4.

No modelled exceedances of the 1-hour LV and 24-hour LV for SO_2 were reported for 2009 in common with 2007 and 2008. Modelled exceedances of the 1-hour LV and 24-hour LV for SO_2 were reported for 2006, 2005 and 2004. These exceedances 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 exceedances of the annual or winter mean limit values for SO_2 in vegetation areas.

An exceedance of the 1-hour LV + MOT for NO_2 was observed in London for 2009. The exceedance was initially reported in 2003 has been observed in all subsequent years (2004, 2005, 2006, 2007 and 2008) in London. The reason for this exceedance at the London Marylebone Road site appears to be related to an increase in primary NO_2 emissions (Abbott, 2005). An exceedance of the 1-hour LV + MOT for NO_2 has also been observed in Glasgow for 2008 and 2009, and is thought to be driven by traffic emissions of primary NO_2. The number of zones in which there were modelled exceedances of the annual mean LV + MOT in 2009 was similar to the number in previous years. In 2009 the number of zones with exceedances of the annual mean LV was also similar to the number in previous years. There were no reported exceedances of the annual mean LV for NO_X in vegetation areas.

A similar number of zones exceeded the LV for PM_{10} in 2009 as in 2008, with fewer exceedances than in previous years. This is partly a consequence of the lower secondary inorganic aerosol concentration experienced during 2008 and 2009. 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 have been no exceedances for Pb from 2001 to 2009.

There were no exceedances of the C_6H_6 LV reported in 2009. One exceedance of the C_6H_6 LV was modelled in 2006 but there were no modelled exceedances of the LV + MOT. These exceedances were modelled in close proximity to a large oil refinery at Killingholme.

There have been no exceedances for CO from 2001 to 2009.

There were no exceedances of the O_3 TV's in 2009. A measured exceedance of the TV for human health was reported for the Eastern zone in 2008 as a result of measurements at the Wicken Fen monitoring site. The number of zones exceeding the LTO for the protection of human health in 2009 remains similar to previous years, while the number of zones exceeding the LTO for the protection of vegetation varies significantly year to year from 2004 to 2009. The lack of exceedances of the TV's (which are less stringent and an average over a number of years) contrasts with the variability causing exceedance of the LTO's.

No exceedances of the TV for $PM_{2.5}$ were reported in 2009.

Exceedances of 'old' directives are listed in Table 10.17. Directive 85/203/EEC was exceeded at one monitoring site, Marylebone Road, in 2009 as in previous years.

Table 10.12 - Exceedances of limit values plus margins of tolerance for the Air Quality Directive

Pollutant	Averaging time	2009	2008	2007	2006	2005	2004	2003	2002	2001
SO_2	1-hour	n/a	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	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	n/a
SO_2	winter[2]	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a
NO_2	1-hour[3]	2 zones measured (London, Glasgow)	2 zones measured (London, Glasgow)	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 (9 measured + 31 modelled)	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	n/a
PM_{10}	24-hour[4] (Stage 1)	n/a	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	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)

Pollutant	Averaging time	2009	2008	2007	2006	2005	2004	2003	2002	2001
Lead	annual	n/a	n/a	n/a	n/a	n/a	none	none	none	none
Benzene	annual	none	none	none	none	none	none	none	not assessed	not assessed
CO	8-hour	n/a	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 10.13 - Exceedances of limit values for the Air Quality Directive

Pollut-ant	Averag-ing time	2009	2008	2007	2006	2005	2004	2003	2002	2001
SO_2	1-hour	none	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	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	none
SO_2	Winter[2]	none	none	none	none	none	none	none	none	not assessed
NO_2	1-hour[3]	2 zones measured (London, Glasgow)	3 zones measured (London, Glasgow, NE Scotland)	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

Pollut-ant	Averag-ing time	2009	2008	2007	2006	2005	2004	2003	2002	2001
NO_2	Annual	40 zones (9 measured + 31 modelled)	40 zones (10 measured + 30 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	None
PM_{10}	24-hour (Stage 1)	3 zones (1 measured + 2 modelled) *1 zone modelled after subtraction of natural contribution*	2 zones (1 measured + 1 modelled) *1 zone measured after subtraction of natural contribution*	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)	none	none	1 zone measured (Greater London Urban Area)	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	None
Benzene	Annual	none	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	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 10.14 - Exceedances of Air Quality Directive target values for ozone

Pollutant	Averaging time	2009	2008	2007	2006	2005	2004
O_3	8-hour	none	1 zone measured (Eastern)	none	none	none	none
O_3	AOT40	none	none	none	none	none	none

Table 10.15 - Exceedances of Air Quality Directive long term objectives for ozone

Pollutant	Averaging time	2009	2008	2007	2006	2005	2004
O_3	8-hour	39 zones (25 measured + 14 modelled)	43 zones (35 measured + 8 modelled)	41 zones (24 measured + 17 modelled)	43 zones (41 measured + 2 modelled)	37 zones (22 measured + 15 modelled)	43 zones (36 measured + 7 modelled)
O_3	AOT40	10 zones (8 measured + 2 modelled)	41 zones (25 measured + 16 modelled)	3 zones (1 measured + 2 modelled)	41 zones (32 measured + 9 modelled)	16 zones (9 measured + 7 modelled)	7 zones (5 measured + 2 modelled)

Table 10.16 - Exceedances of Air Quality Directive target value for $PM_{2.5}$

Pollutant	Averaging time	2009
$PM_{2.5}$	Annual	none

Table 10.17 - Exceedances of old Directives

Pollutant	Averaging time and limit value	2009 Concentration (μg m^{-3})	2008 Concentration (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 (200 µg m^{-3})	227 (measured at London Marylebone Road)	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)

11 Acknowledgements

This work was funded by the UK Department for Environment, Food and Rural Affairs, Welsh Assembly Government, the Scottish Government and the Department of the Environment in Northern Ireland. 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: 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.

12 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.

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.airquality.co.uk/reports/empire/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.

Air Pollution in the UK, 2009 (Edition A: Summary of the UK’s Annual Report to the EU Commission under Directives 2008/50/EC and 2004/107/EC). (September 2010). 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. http://www.airquality.co.uk/annualreport/annualreport2009.php

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

Air Quality Expert Group (AQEG, 2005). Particulate Matter in the United Kingdom. http://www.defra.gov.uk/environment/quality/air/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/quality/air/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.airquality.co.uk/reports/cat09/0502100920_Art5_v9commission2(final_draft).pdf

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

Bush, T. and Kent, A. (2003). Preliminary Assessment of ozone levels 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, Netcen report AEAT/ENV/R/1528/Issue 1. http://www.airquality.co.uk/archive/reports/cat09/0506130933_o3dd1_art5_rep2.pdf

Bush. T., Targa, J., (2005). Ozone Mapping Techniques for the 3rd Daughter Directive; OSRM vs Empirical modelling Comparison Report. A report to The Department for Environment, Food and Rural Affairs, Welsh Assembly Government, The Scottish Executive and the Department of the Environment for Northern Ireland. AEA Technology plc, Netcen, Harwell. Report AEAT/ENV/R/2053.

Bush, T., Targa, J., and Stedman, J. (2006). UK Air Quality modelling for annual reporting 2004 on ambient air quality assessment under Council Directives 96/62/EC and 2002/3/EC relating to ozone in ambient air. A report to the Department for Environment Food and Rural Affairs, Welsh Assembly Government, The Scottish Executive and the Department of the Environment for Northern Ireland. AEAT/ENV/R/2053. http://www.airquality.co.uk/reports/cat09/0602281040_DD3_mapsrep2004v1.doc

Bush, T., Xu, Y., Stedman, J., and Brophy, N. (2007). UK and Gibraltar air quality modelling for annual reporting 2005 on ambient air quality assessment under Council Directives 96/62/EC and 2002/3/EC relating to ozone in ambient air. Report to Department for Environment, Food and Rural Affairs, the Scottish Executive, Welsh Assembly Government, the Department of the Environment in Northern Ireland and the Government of Gibraltar. AEA/ENV/R/2403. http://www.airquality.co.uk/reports/cat09/0709111603_DD3_mapsrep2005_v3_FINAL.pdf

CDR (2010) Annual report (questionnaire) on air quality for 2008 (2004/461/EC). http://cdr.eionet.europa.eu/gb/eu/annualair

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

Coyle M., Smith R., Stedman J., Weston K. and Fowler D., (2002). Quantifying the spatial distribution of surface ozone concentration in the UK. Atmospheric Environment, 36, 1013-1024.

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 of Energy & Climate Change (DECC) (2009). UK Low Carbon Transition Plan Emissions Projections. http://www.decc.gov.uk/assets/decc/statistics/projections/1_20090812111709_e_@@_lctprojections.pdf

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

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

Green, D., Baker, T. and Fuller, G. (2007). The King's College London Volatile Correction Model for PM_{10} 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 PM_{10} Application to hourly time resolution and AURN FDMS purge measurements. Environmental Research Group, King's College London. http://www.airquality.co.uk/reports/cat13/0902231025_VCM_Application_to_Hourly_and_AURN_FDMS_Purge_Measurements.pdf

Personal communication from David Green, ERG (2010). Environmental Research Group, King's College London, London, UK.

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

Grice, S. E., Cooke, S. L., Stedman, J. R., Bush, T. J., Vincent, K. J., Hann, M., Abbott, J. and Kent, A. J. (2010). 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. AEA report. AEAT/ENV/R/2859 Issue 1. http://www.airquality.co.uk/reports/cat09/1007201636_dd122008mapsrep_v4.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

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. (2007). UK and Gibraltar air quality modelling for annual reporting 2006 on ambient air quality assessment under Council Directives 96/62/EC and 2002/3/EC relating to ozone in ambient air. Report to Department for Environment, Food and Rural Affairs, the Scottish Executive, Welsh Assembly Government, the Department of the Environment in Northern Ireland and the Government of Gibraltar. AEA/ENV/R/2499. http://www.airquality.co.uk/reports/cat09/0807301054_DD3_mapsrep2006_v2.pdf

Kent, A.J. and Stedman, J.R. (2008). UK and Gibraltar air quality modelling for annual reporting 2007 on ambient air quality assessment under Council Directives 96/62/EC and 2002/3/EC relating to ozone in ambient air. Report to Department for Environment, Food and Rural Affairs, the Scottish Executive, Welsh Assembly Government, the Department of the Environment in Northern Ireland and the Government of Gibraltar. AEA/ENV/R/2681. http://www.airquality.co.uk/reports/cat09/0905061015_DD3_mapsrep2007_v1.pdf

Kent, A.J. Stedman, J.R., Yap, F. W. (2010). 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. Report to Department for Environment, Food and Rural Affairs, the Scottish Executive, Welsh Assembly Government, the Department of the Environment in Northern Ireland and the Government of Gibraltar. AEA Technology Energy & Environment. AEA/ENV/R/ 3097.

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

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., Li, Y., Bush, T., et al. (2010). UK Emissions of Air Pollutants 1970 to 2008. National Atmospheric Emissions Inventory, AEA Technology. AEA Report AEAT/ENV/R/3036. http://www.naei.org.uk/reports.php

NEGTAP 2001, Transboundary Air Pollution: Acidification, Eutrophication and Ground-level ozone in the UK. Prepared by the National Expert Group on Transboundary Air Pollution (NEGTAP) on behalf of the Department for Environment, Food and Rural Affairs, the Scottish Executive, Welsh Assembly Government and the Department of the Environment in Northern Ireland. ISBN 1 870393 61 9.

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

Passant, N.R, AEA (2005). Personal communication. AEA Technology, Harwell, UK.

PORG (UK Photochemical Oxidants Review Group), 1998. Ozone in the UK. 4th report of the UK Photochemical Oxidants Review Group, 1st Edition. The Department of the Environment Transport and the Regions.

Stedman, J. R. and Bush, T. (2000). Mapping of nitrogen dioxide and PM_{10} in the UK for Article 5 Assessment. AEA Technology, National Environmental Technology Centre. Report AEAT/ENV/R/0707. http://www.airquality.co.uk/reports/empire/aeat-env-r0707.pdf

Stedman, J.R., Bush, T.J., Murrells, T.P. and King, K. (2001a). 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.airquality.co.uk/reports/empire/aeat-env-r-0726.pdf

Stedman, J.R., Goodwin, J.W.L., King, K., Murrells, T.P. and Bush, T.J. (2001b). 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. (2010). CEH Edinburgh, Centre for Ecology and Hydrology, Natural Environment Research Council. http://www.uk-pollutantdeposition.ceh.ac.uk/

Tsagatakis, I., Bush, T., Passant, N. & Brophy, N. (2010). UK Emission Mapping Methodology 2008. A report of the National Atmospheric Emissions Inventory, AEA group, London. In preparation. http://uk-air.defra.gov.uk/library/

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

Vincent, K. J. and Passant, N. (2008). Updated maps of ambient arsenic, cadmium and nickel concentrations in the United Kingdom for 2006. Report to The Department for Environment, Food and Rural Affairs, Welsh Assembly Government, the Scottish Executive and the Department of the Environment for Northern Ireland. AEA/ENV/R/2619.

Walker, H. L., Kent, A. J., Stedman, J. R., Grice, S. E., Vincent, K. J., Yap, F. W., Brookes, D. M. (2010). UK modelling under the Air Quality Framework Directive (96/62/EC) and Fourth Daughter Directive (2004/30/EC) for 2009 covering As, Cd, Ni and B(a)P. Report for 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/3070 Issue 1.

Personal communication from Anne Wagner, AEA (2010). AEA Technology, London, UK.

Personal communication from Paul Willis, AEA (2010). 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.

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 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	SO_2	NO_2	PM_{10}	$PM_{2.5}$	Lead	Benzene	CO	Ozone
Aberdeen Anderson Dr	ROADSIDE	Aberdeen City Council		Y	Y					
Aberdeen King Street	ROADSIDE	Aberdeen City Council		Y	Y					
Aberdeen Union St	ROADSIDE	Aberdeen City Council			Y					
Aberdeen Wellington Road	ROADSIDE	Aberdeen City Council		Y	Y					
Abingdon	URBAN BACKGROUND	Vale of White Horse DC								Y
Alloa	ROADSIDE	Clackmannanshire Council			Y					
Anglesey Brynteg	RURAL INDUSTRIAL	Isle of Anglesey County Council			Y	Y				
Angus Forfar	ROADSIDE	Angus Council			Y					
Antrim Greystone Estate	URBAN BACKGROUND	Antrim BC	Y							
Ards Leisure Centre	URBAN BACKGROUND	Ards BC	Y		Y					
Ascot Rural	RU	ERG		Y						
Ashford Background	URBAN BACKGROUND	Kent & Medway Air Quality Network		Y	Y					Y
Ballymena Ballykeel	URBAN BACKGROUND	Ballymena BC	Y		Y					

Site name	Site type	LA/Network	SO_2	NO_2	PM_{10}	$PM_{2.5}$	Lead	Benzene	CO	Ozone
Ballymena North Road	KERBSIDE	Ballymena BC		Y						
Ballymoney	URBAN BACKGROUND	Ballymoney BC			Y					
Barking and Dagenham 1 - Rush Green	S	ERG	Y	Y						
Barking and Dagenham 2 - Scrattons Farm	S	ERG		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						
Bedford - Prebend Street	R	ERG		Y						
Belfast Ormeau Road	KERBSIDE	Belfast City Council		Y						
Belfast Roadside	ROADSIDE	Belfast City Council		Y						
Belfast Stockman's Lane	ROADSIDE	Belfast City Council		Y						
Bentley Hall Farm	RU	ERG	Y	Y						
Bexley 1 - Slade Green AURN (PM2.5)	S	ERG				Y				
Bexley 2 - Belvedere	S	ERG		Y		Y				
Bexley 2 (FDMS) - Belvedere	S	ERG			Y					
Bexley 3 - Thamesmead	S	ERG				Y				
Bexley 4 - Erith	I	ERG		Y	Y					
Bexley 7 - Thames Rd North	R	ERG		Y	Y	Y				
Bexley 7 (FDMS) - Thames Rd North	R	ERG			Y					
Bexley 8 - Thames Rd South	R	ERG		Y	Y	Y				
Birmingham Airport 2	BACKGROUND	Birmingham International Airport	Y	Y	Y				Y	

Site name	Site type	LA/Network	SO_2	NO_2	PM_{10}	$PM_{2.5}$	Lead	Benzene	CO	Ozone
Bolton College	URBAN BACKGROUND	Bolton Council	Y	Y						Y
Brent 1 - Kingsbury	S	ERG	Y	Y	Y				Y	
Brent 4 - Ikea	R	ERG	Y	Y	Y	Y				
Brent 5 - Neasden Lane	I	ERG		Y	Y					
Brent 6 - John Keble Primary School	R	ERG	Y	Y	Y					
Brent 7 - St Marys Primary School	U	ERG		Y	Y					
Brentwood 1 - Town Hall	U	ERG		Y						
Bromley 7 - Central	R	ERG		Y					Y	
Caerphilly Blackwood High Street	ROADSIDE	Caerphilly County Borough Council		Y	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		Y				
Cambridge Parker Street	ROADSIDE	Cambridge City Council		Y	Y					
Camden - St Martins College (NOX 1)	U	ERG		Y						
Camden - St Martins College (NOX 2)	U	ERG		Y						
Camden 3 - Shaftesbury Avenue	R	ERG		Y	Y					
Canterbury Backgrnd - Chaucer TS	U	ERG		Y						
Canterbury PM10	ROADSIDE	Kent & Medway Air Quality Network			Y					
Cardiff Briardene	ROADSIDE	Cardiff Council								Y
Carr Lane	RU	ERG	Y							

Site name	Site type	LA/Network	SO_2	NO_2	PM_{10}	$PM_{2.5}$	Lead	Benzene	CO	Ozone
Castle Point 1 - Town Centre	U	ERG	Y	Y						
Castlereagh Dundonald	ROADSIDE	Castlereagh BC		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	Y
Chatham Roadside	ROADSIDE	Kent & Medway Air Quality Network		Y	Y					
Chichester 4 - Orchard Street	R	ERG		Y						
Chichester Roadside	R	ERG		Y	Y					
City of London - Upper Thames Street	R	ERG			Y					
City of London - Walbrook Wharf Indoor	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 3 - Thornton Heath	S	ERG			Y					
Croydon 4 - George Street	R	ERG		Y	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					

Site name	Site type	LA/Network	SO_2	NO_2	PM_{10}	$PM_{2.5}$	Lead	Benzene	CO	Ozone
Dartford Town Centre Roadside	ROADSIDE	Kent & Medway Air Quality Network		Y	Y					
Derry Brandywell	URBAN BACKGROUND	Derry City Council	Y							
Dover Centre Roadside	ROADSIDE	Kent & Medway Air Quality Network			Y					
Dover Docks	URBAN INDUSTRIAL	Kent & Medway Air Quality Network	Y	Y						
Dover Langdon Cliff	URBAN BACKGROUND	Kent & Medway Air Quality Network	Y							
Dover Old Town Hall Roadside	ROADSIDE	Kent & Medway Air Quality Network		Y						
Downes Ground	RU	ERG	Y	Y						
Dundee Broughty Ferry Road	ROADSIDE	Dundee City Council	Y		Y					
Dundee Lochee Road	ROADSIDE	Dundee City Council		Y						
Dundee Mains Loan	URBAN BACKGROUND	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						
E. Herts Sawbridgeworth (Roadside)	R	ERG		Y	Y					
Ealing 1 - Ealing Town Hall	U	ERG	Y	Y						
Ealing 2 - Acton Town Hall	R	ERG			Y	Y			Y	
Ealing 7 - Southall	U	ERG		Y	Y					
Ealing 8 - Horn Lane	I	ERG			Y					
East Ayrshire New Cumnock	URBAN BACKGROUND	East Ayrshire Council		Y	Y					

Site name	Site type	LA/Network	SO_2	NO_2	PM_{10}	$PM_{2.5}$	Lead	Benzene	CO	Ozone
East Dunbartonshire Bearsden	ROADSIDE	East Dunbartonshire Council		Y						
East Dunbartonshire Bishopbriggs	ROADSIDE	East Dunbartonshire Council		Y	Y					
East Dunbartonshire Kirkintilloch	ROADSIDE	East Dunbartonshire Council		Y	Y					
East Renfrewshire Sheddens	ROADSIDE	East Renfrewshire Council			Y					
Eastbourne Background	U	ERG		Y	Y					
Edinburgh Gorgie Road	ROADSIDE	City of Edinburgh Council		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 4 - Derby Road Upper Edmonton	R	ERG	Y	Y						
Enfield 5 - Bowes Road A406	R	ERG		Y	Y					
Falkirk Grangemouth MC	URBAN BACKGROUND	Falkirk Council	Y	Y	Y					
Falkirk Haggs	ROADSIDE	Falkirk Council		Y						
Falkirk Hope St	ROADSIDE	Falkirk Council	Y	Y	Y					
Falkirk Park St	ROADSIDE	Falkirk Council	Y	Y	Y					
Falkirk West Bridge Street	ROADSIDE	Falkirk Council		Y						
Farnborough - Medway Drive	R	ERG		Y	Y					
Fife Dunfermline	ROADSIDE	Fife Council		Y						
Fife Rosyth	ROADSIDE	Fife Council		Y	Y					
Folkestone Suburban	SUBURBAN	Kent & Medway Air Quality Network	Y	Y	Y					Y
Gainsborough Cemetery	RU	ERG	Y	Y						

Site name	Site type	LA/Network	SO_2	NO_2	PM_{10}	$PM_{2.5}$	Lead	Benzene	CO	Ozone
Gatwick LGW3	BACKGROUND	BAA		Y	Y				Y	
Glasgow Abercromby Street	ROADSIDE	Glasgow City Council			Y					
Glasgow Anderston	URBAN BACKGROUND	Glasgow City Council	Y	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 Centre	S	ERG			Y					
Glasgow Nithsdale Road	ROADSIDE	Glasgow City Council			Y					
Glasgow Queen Street Station	SPECIAL	Glasgow City Council			Y					
Glasgow Waulkmillglen Reservoir	RURAL	Glasgow City Council		Y	Y					Y
Grangemouth Moray Scot Gov	URBAN BACKGROUND	Falkirk Council	Y		Y					
Gravesham A2 Roadside	ROADSIDE	Kent & Medway Air Quality Network		Y	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	Y	Y				
Greenwich 13 - Plumstead High Street	R	ERG		Y	Y	Y				
Greenwich 5 - Trafalgar Road	R	ERG		Y	Y					
Greenwich 7 - Blackheath	R	ERG		Y	Y					
Greenwich 8 - Woolwich Flyover	R	ERG		Y	Y	Y				
Greenwich 9 - Westhorne Ave	R	ERG		Y	Y	Y				

Site name	Site type	LA/Network	SO_2	NO_2	PM_{10}	$PM_{2.5}$	Lead	Benzene	CO	Ozone
Greenwich and Bexley - Falconwood FDMS	R	ERG			Y					
Greenwich Bexley 6 - A2 Falconwood	R	ERG		Y						
Hackney 4 - Clapton	U	ERG		Y		Y			Y	
Hackney 6 - Old Street	R	ERG		Y	Y	Y				
Harrow 1 - Stanmore Background	U	ERG	Y	Y		Y				
Harrow 2 - North Harrow Roadside	R	ERG		Y	Y					
Hastings 2 - Fresh Fields	R	ERG		Y	Y					
Hastings Roadside	R	ERG		Y	Y					
Havering 1 - Rainham	R	ERG		Y						
Havering 3 - Romford	R	ERG		Y						
Heathrow Airport	U	ERG		Y						
Heathrow Green Gates	BACKGROUND	BAA		Y	Y	Y				
Heathrow LHR2	BACKGROUND	BAA		Y	Y					
Heathrow Oaks Road	BACKGROUND	BAA		Y	Y	Y				
Hemingbrough Landing	RU	ERG	Y	Y						
Henley Roadside	R	ERG		Y						
Hertsmere Borehamwood 2 (Background)	U	ERG		Y						
Hillingdon 1 - South Ruislip	R	ERG		Y	Y					
Hillingdon 2 - Hillingdon Hospital	R	ERG		Y						
Hillingdon 3 - Oxford Avenue	R	ERG		Y	Y					
Horsham Roadside (Park Way)	R	ERG			Y					

Site name	Site type	LA/Network	SO_2	NO_2	PM_{10}	$PM_{2.5}$	Lead	Benzene	CO	Ozone
Hounslow 4 - Chiswick High Rd	R	ERG		Y	Y					
Hounslow 5 - Brentford	R	ERG		Y	Y					
Hounslow 6 - Heston Road	R	ERG		Y	Y					
Hounslow 7 - Hatton Cross	U	ERG		Y						
Islington 2 - Holloway Road	R	ERG		Y	Y				Y	
Islington 6 - Arsenal	U	ERG		Y	Y					
Kens and Chelsea 2 - Cromwell Rd	R	ERG	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						
Kensington and Chelsea - North Ken FDMS	U	ERG			Y					
Lambeth 1 - Christchurch Road	R	ERG	Y	Y						
Lambeth 3 - Loughborough Junct	U	ERG	Y	Y						
Lambeth 5	R	ERG	Y	Y						
Larne Craigyhill	URBAN BACKGROUND	Larne BC	Y		Y					
Lerwick Staney Hill	URBAN BACKGROUND	Shetland Islands Council	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	Y				

Site name	Site type	LA/Network	SO_2	NO_2	PM_{10}	$PM_{2.5}$	Lead	Benzene	CO	Ozone
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 Hayes	ROADSIDE	London Borough of Hillingdon		Y	Y					
London Westminster	U	ERG	Y	Y						
Luton (Background)	U	ERG	Y	Y	Y				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					Y
Manchester Piccadilly LA	URBAN CENTRE	Manchester City Council							Y	
Manchester South SO2	SUBURBAN	Manchester City Council	Y							
Marchlyn Mawr	REMOTE	Welsh Air Quality Forum		Y						Y
Marchwood Power - Marchwood	I	ERG		Y						
Marchwood Power - Millbrook Rd Soton	I	ERG		Y						
Midlothian Dalkeith	KERBSIDE	Midlothian Council	Y	Y	Y					
Midlothian Pathhead	KERBSIDE	Midlothian Council	Y		Y					
Mole Valley 3 - Dorking	U	ERG		Y						
N Lanarkshire Chapelhall	ROADSIDE	North Lanarkshire Council		Y	Y					
N Lanarkshire Coatbridge Whifflet	URBAN BACKGROUND	North Lanarkshire Council		Y	Y					
N Lanarkshire Croy	ROADSIDE	North Lanarkshire Council	Y		Y					

Site name	Site type	LA/Network	SO_2	NO_2	PM_{10}	$PM_{2.5}$	Lead	Benzene	CO	Ozone
N Lanarkshire Moodiesburn	ROADSIDE	North Lanarkshire Council		Y						
N Lanarkshire Motherwell	ROADSIDE	North Lanarkshire Council			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	Y					
Newcastle Centre	U	ERG			Y					
Newham - Cam Road	R	ERG	Y	Y	Y				Y	
Newham - Wren Close	U	ERG	Y	Y	Y				Y	
Newham Cam Road	ROADSIDE	London Borough of Newham								Y
Newham Wren Close	URBAN BACKGROUND	London Borough of Newham								Y
Newport Malpas Depot	URBAN BACKGROUND	Newport County BC		Y						Y
Newry Monaghan Row	URBAN BACKGROUND	Newry and Mourne DC			Y					
Newry Trevor Hill	KERBSIDE	Newry and Mourne DC		Y	Y					
North Ayrshire Irvine High St	KERBSIDE	North Ayrshire Council			Y					
North Down Bangor	URBAN BACKGROUND	North Down BC	Y		Y					
North Down Holywood A2	ROADSIDE	North Down BC		Y	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	Y				

Site name	Site type	LA/Network	SO_2	NO_2	PM_{10}	$PM_{2.5}$	Lead	Benzene	CO	Ozone
Oldham West End House	URBAN BACKGROUND	Oldham Metropolitan BC								Y
Oxford High St	ROADSIDE	Oxford City Council		Y	Y					
Oxford St Ebbes (Cal Club)	URBAN BACKGROUND	Oxford City Council								Y
Paisley Central Road	ROADSIDE	Renfrewshire Council		Y						
Paisley Glasgow Airport	BACKGROUND	Renfrewshire Council		Y						
Paisley Gordon Street	ROADSIDE	Renfrewshire Council		Y	Y					
Park Farm	RU	ERG	Y							
Perth Atholl Street	ROADSIDE	Perth and Kinross Council		Y	Y					
Perth High Street	ROADSIDE	Perth and Kinross Council		Y	Y					
Port Talbot Fire Station	I	ERG		Y						
Reading - Caversham Road	R	ERG		Y						
Reading - Kings Road	R	ERG		Y						
Reading - Oxford Road	R	ERG		Y						
Redbridge 1 - Perth Terrace	U	ERG		Y						
Redbridge 3 - Fullwell Cross	K	ERG		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 - Upper Teddington Road	R	ERG		Y						

Site name	Site type	LA/Network	SO_2	NO_2	PM_{10}	$PM_{2.5}$	Lead	Benzene	CO	Ozone
Richmond 1 - Castelnau	R	ERG		Y						
Richmond 2 - Barnes Wetlands	S	ERG		Y	Y					
Rother 2 - De La Warr Road	R	ERG		Y	Y					
S Cambs Bar Hill	RURAL	South Cambridgeshire DC		Y	Y	Y				
S Cambs Impington	ROADSIDE	South Cambridgeshire DC		Y	Y					
Salford M60	ROADSIDE	Salford City Council								Y
Scunthorpe Allanby Street	ROADSIDE	North Lincolnshire Council			Y					
Scunthorpe East Common Lane	URBAN BACKGROUND	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	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	Y				
Slough Town Centre A4	URBAN BACKGROUND	Slough BC		Y	Y					
Smeathalls Farm	RU	ERG	Y	Y						
South Ayrshire Ayr High St	ROADSIDE	South Ayrshire Council		Y	Y					
South Ayrshire Tarbolton	ROADSIDE	South Ayrshire Council		Y	Y					
South Beds Dunstable (Background)	U	ERG		Y	Y					

Site name	Site type	LA/Network	SO_2	NO_2	PM_{10}	$PM_{2.5}$	Lead	Benzene	CO	Ozone
South Holland Westmere School	RURAL	South Holland DC		Y	Y					
South Lanarkshire East Kilbride	ROADSIDE	South Lanarkshire Council		Y	Y					
Southampton - Bitterne	U	ERG		Y	Y					
Southampton - Onslow Road	R	ERG		Y						
Southampton - Redbridge	R	ERG	Y	Y	Y					
Southend-on-Sea	U	ERG				Y				
St. Albans Fleetville (Background)	U	ERG		Y						
Stansted 3	BACKGROUND	BAA		Y	Y					
Stansted 4	BACKGROUND	BAA		Y						
Stevenage (Roadside)	R	ERG		Y	Y					
Stile Cop Cemetery	RU	ERG	Y	Y						
Stirling Craig's Roundabout	ROADSIDE	Stirling Council		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	Y					
Sutton 5 - Beddington Lane	I	ERG		Y	Y					
Sutton 6 - Worcester Park	K	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					

Site name	Site type	LA/Network	SO_2	NO_2	PM_{10}	$PM_{2.5}$	Lead	Benzene	CO	Ozone
Swansea Cwm Level Park	URBAN BACKGROUND	Welsh Air Quality Forum								Y
Swansea Hafod DOAS	ROADSIDE	Welsh Air Quality Forum						Y		Y
Swansea Morfa Roadside	ROADSIDE	Welsh Air Quality Forum	Y							
Swansea Morriston Roadside	ROADSIDE	Welsh Air Quality Forum	Y						Y	Y
T5 - Colnbrook	R	ERG		Y						
T5 - Green Gates	U	ERG		Y						
T5 - Oaks Road	R	ERG		Y						
Tameside Two Trees School	URBAN BACKGROUND	Tameside MBC		Y						Y
Telscombe Cliffs Roadside	R	ERG		Y						
Thanet Airport	URBAN BACKGROUND	Kent & Medway Air Quality Network		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					
Thurrock 8 - Purfleet B	R	ERG		Y						
Tonbridge Roadside 2	ROADSIDE	Kent & Medway Air Quality Network		Y						
Tower Hamlets 1 - Poplar	U	ERG	Y	Y	Y					
Tower Hamlets 3 - Bethnal Green	U	ERG	Y	Y						
Tower Hamlets 4 - Blackwall	R	ERG		Y	Y	Y				
Trafford	URBAN BACKGROUND	Trafford MBC	Y	Y						

Site name	Site type	LA/Network	SO_2	NO_2	PM_{10}	$PM_{2.5}$	Lead	Benzene	CO	Ozone
Trafford A56	ROADSIDE	Trafford MBC		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						
V Glamorgan Fonmon	RURAL	Vale of Glamorgan Council								Y
V Glamorgan Penarth	ROADSIDE	Vale of Glamorgan Council								Y
Waltham Forest 1 - Dawlish Road	U	ERG		Y	Y					
Waltham Forest 4 - Crooked Billet	K	ERG		Y	Y					
Waltham Forest 5 - Leyton	U	ERG		Y						
Wandsworth 2 - Town Hall	U	ERG	Y	Y					Y	
Watford (Roadside)	R	ERG		Y						
Watlington Roadside	R	ERG		Y						
Welwyn Hatfield WGC	U	ERG		Y						
West Bank	RU	ERG	Y	Y						
Westminster - Marylebone Road FDMS	K	ERG			Y					
Westminster 4 - Charing Cross Library	R	ERG		Y						
Windsor Roadside	R	ERG		Y						
Wrexham Isycoed	URBAN INDUSTRIAL	Welsh Air Quality Forum	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). Some of the monitoring data supplied by ERG was still provisional when supplied (19-23 July 2010).

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

Site	Data supplier
Bexleyheath	JEP (RWE-NPOWER)
Bowaters Farm	JEP (RWE-NPOWER)
Northfleet	JEP (RWE-NPOWER)
West Thurrock	JEP (RWE-NPOWER)
Rosehurst Farm	JEP (RWE-NPOWER)
Winaway Kennels	JEP (RWE-NPOWER)
Font-y-Gary	JEP (RWE-NPOWER)
Bottesford	JEP (RWE-NPOWER)
Gainsborough Cemetery	JEP (RWE-NPOWER)
Grove Reservoir	JEP (RWE-NPOWER)
Marton School	JEP (RWE-NPOWER)
Thorney	JEP (RWE-NPOWER)
Warrington	JEP (RWE-NPOWER)
Carr Lane	JEP (RWE-NPOWER)
Downes Ground	JEP (RWE-NPOWER)
Hemingbrough Landing	JEP (RWE-NPOWER)
Park Farm	JEP (RWE-NPOWER)
Smeathalls Farm	JEP (RWE-NPOWER)
West Bank	JEP (RWE-NPOWER)
Ruddington	JEP (RWE-NPOWER)
Weston On Trent	JEP (RWE-NPOWER)
Gillingham	JEP (RWE-NPOWER)
Bentley Hall Farm	JEP (RWE-NPOWER)
Stile Cop Cemetery	JEP (RWE-NPOWER)
Telford Aqueduct	JEP (RWE-NPOWER)
Telford School	JEP (RWE-NPOWER)
Blair Mains	JEP (RWE-NPOWER)
Longniddry West	JEP (RWE-NPOWER)

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. The approach adopted 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:

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

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

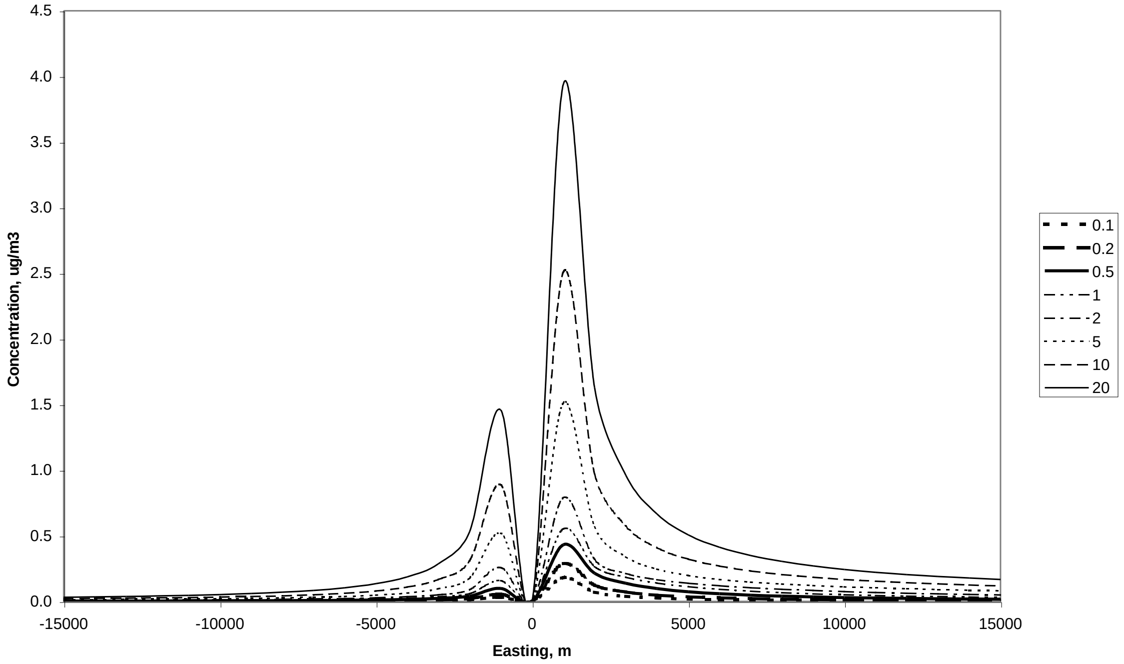
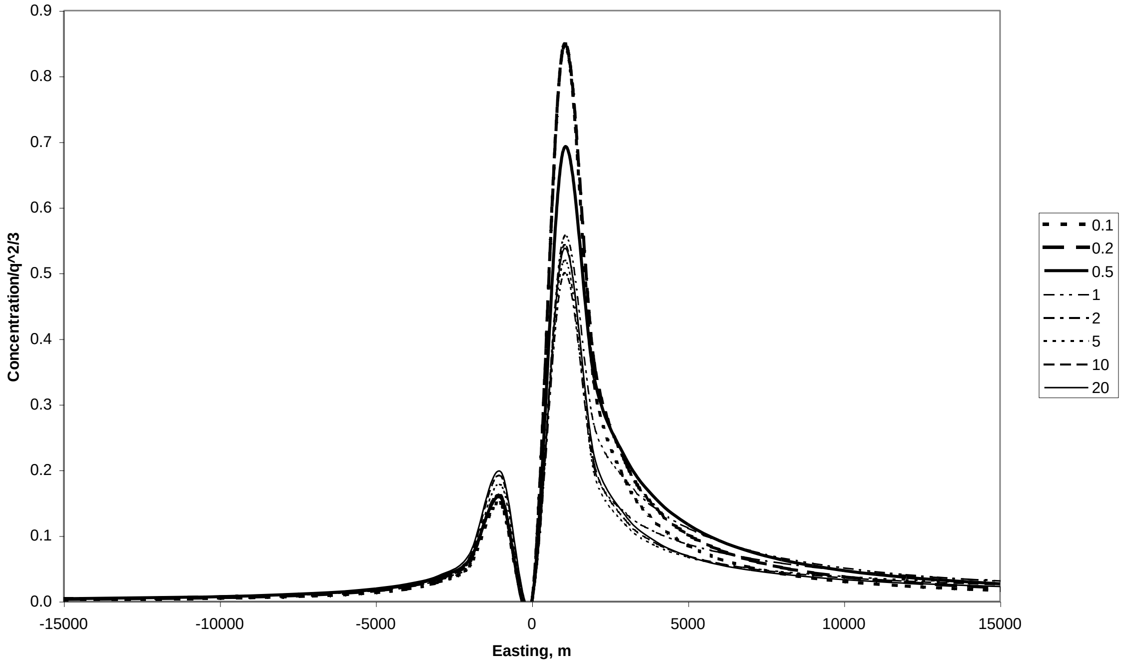


Figure A2.2 shows the same model results plotted as $C/q^{2/3}$. The spread of the model results is greatly reduced so that as a reasonable approximation all the model results may be reduced to a single line.

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, $\mu g\ m^{-3}$
0.1	0.464
0.2	0.764
0.5	1.37
1	1.97
2	2.6
5	3.31
10	3.58
20	4.34
50	3.745
100	4.3

The results shown in Table 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, $\mu g\ m^{-3}$ 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 $\mu g\ m^{-3}$.

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

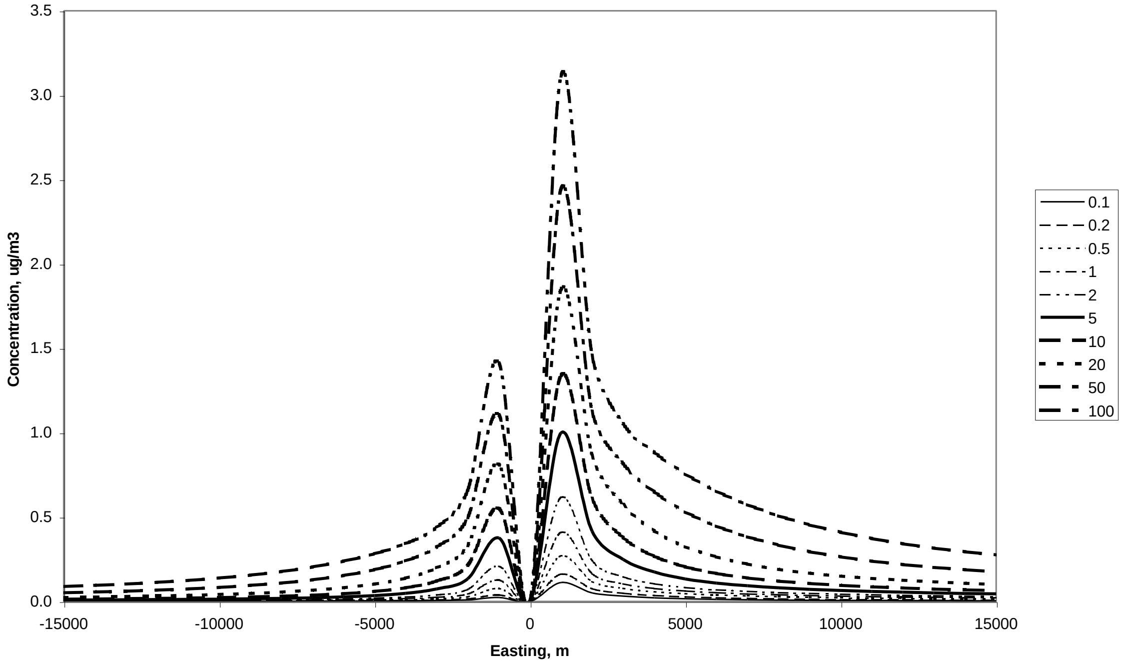
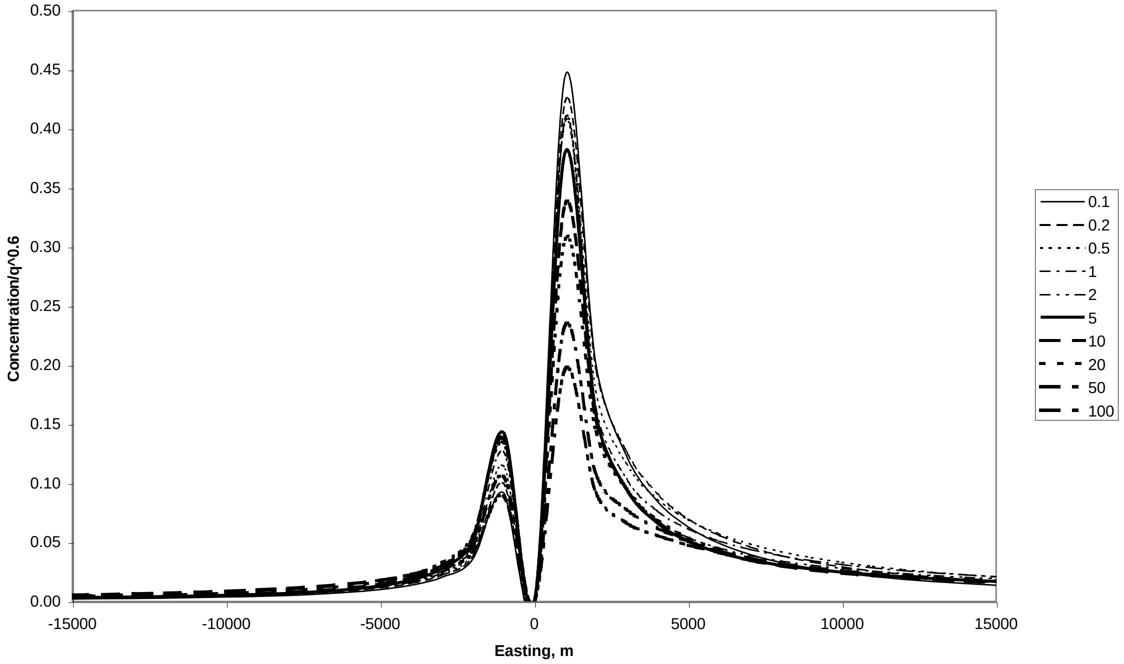


Figure A2.4 shows the same model results plotted as $C/q^{0.6}$. The spread of the model results is greatly reduced so that as a reasonable approximation all the model results may be reduced to a single line.

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, μg 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} and $PM_{2.5}$

The method for PM_{10} and $PM_{2.5}$ 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.

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 7.3.2.

CO

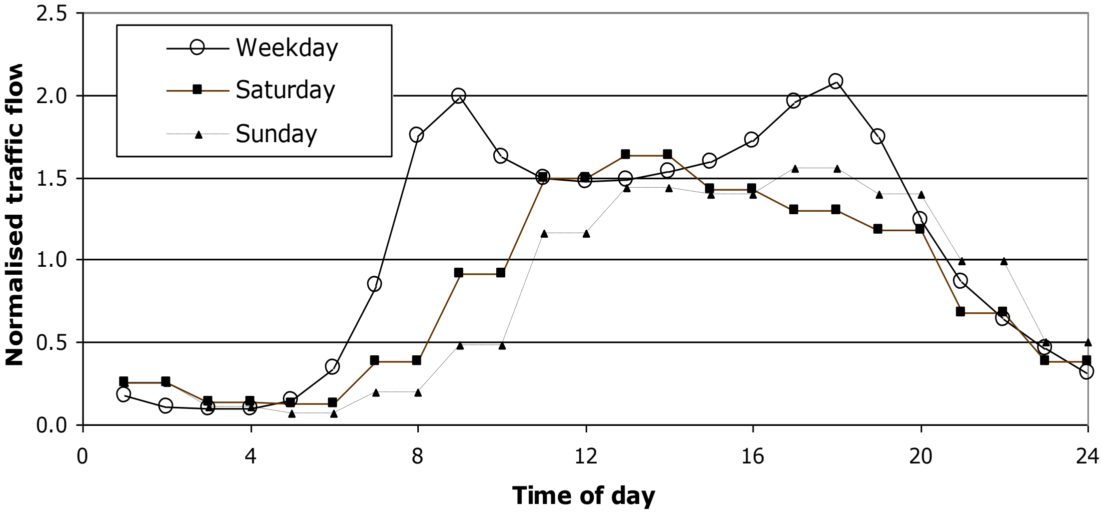
The method for CO was the same as for NO_x, except that point sources with emissions greater than or equal to 3000 tonnes per year (95.1 g s^{-1}) have been modelled explicitly using ADMS. Point sources with emissions less than 3000 tonnes per year have been modelled using the small points model.

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 calculated using ADMS 4.2. 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 2009 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 2009. 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 4.2 (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.

Table A3.1. Summary of inverted dispersion kernel parameters

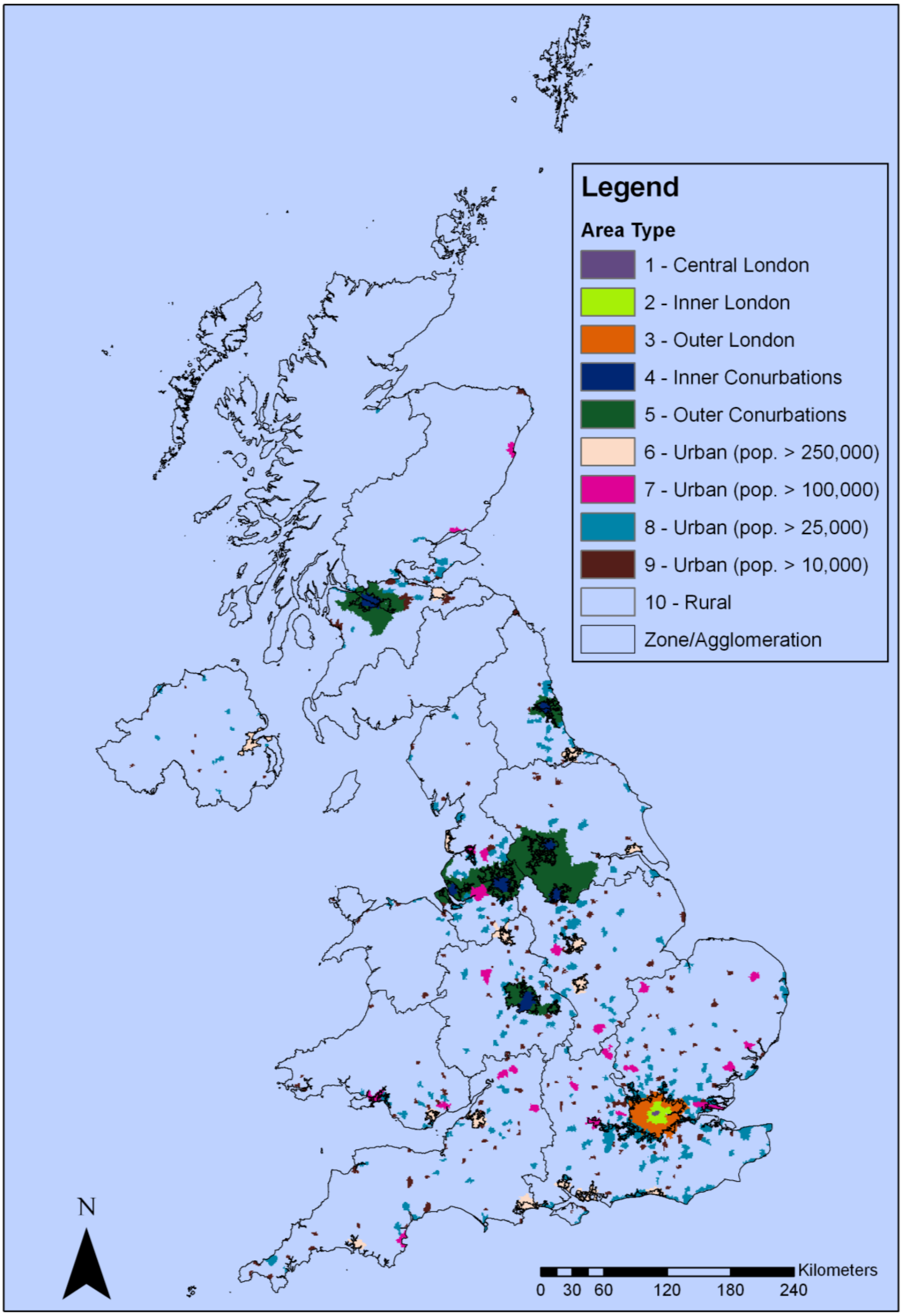
Kernel name	Area types	Type of location	LMO (m)	Surface roughness		Height (m) of volume source	Variable emission profile?	Emission rate (g m^{-3} s^{-1})
				Disp. site	Met. site			
Non road transport	1,2,4	Conurbation	25	0.5	0.02	30	N	3.33E-08
Non road transport	3,4,5,6,7,8	Smaller urban	20	0.5	0.02	30	N	3.33E-08
Non road transport	9,10	Rural	10	0.5	0.02	30	N	3.33E-08
Road transport	1,2,4	Conurbation	25	0.5	0.02	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 ($g\ m^{-3}\ s^{-1}$)**
				Disp. site	Met. site			
Road transport	3,4,5,6,7,8	Smaller urban	20	0.5	0.02	10	Y	1.0E-7
Road transport	9,10	Rural	10	0.5	0.02	10	Y	1.0E-7

ADMS 4.2 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 4.2.
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 7.3.2.

Figure A3.2. Map of UK area types



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

Introduction

As noted in Section 1.9, the method for calculating emissions from aircraft and ships was revised for the 2008 modelling. The same approach has been used in the 2009 modelling and the approach is described here.

Revised method for calculating and mapping emissions from aircraft

Aircraft emissions were calculated using data obtained from the NAEI (Murrells et al., 2010) 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 approach.

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

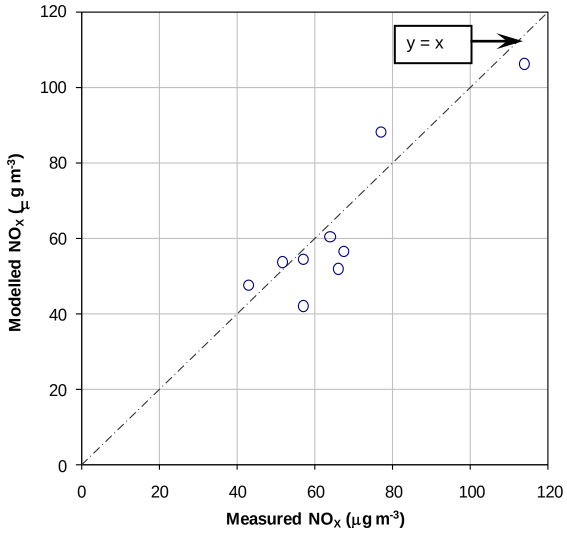
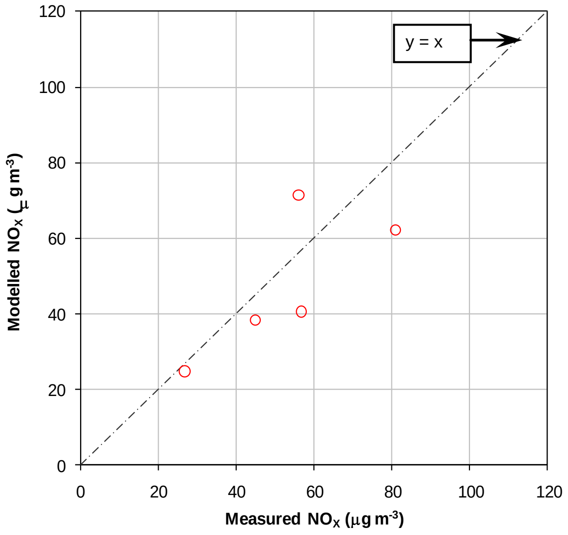


Figure A4.2. Comparison of the measured and modelled annual mean NO_X at Gatwick Airport for 2008



Revised method for calculating and mapping emissions from ships and shipping

ENTEC (2008) provided maps of shipping emissions for 2007 on a 5 km EMEP projection grid. The NAEI 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.

The ENTEC (2008) 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. The additional uncertainties associated with assigning the 5 km x 5 km grid emissions estimates to 1 km x 1 km grid squares is thought to cause the overestimates, particularly at port areas where the larger grid squares include a significant proportion of land area.

The available monitoring data for sites close to some of the largest predicted shipping emissions close to ports in 2007 was reviewed. 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 PM10 (method M3) monitoring data to account for the loss of volatile component. Prior to 2008 the UK used a factor of 1.3 to scale TEOM PM10 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/.

AEA

The Gemini Building
Fermi Avenue
Harwell
Didcot
Oxfordshire
OX11 0QR

Tel: 0870 190 1900
Fax: 0870 190 6318

www.aeat.co.uk