Baseline PM$_{10}$ and NO$_x$ projections for PM$_{10}$ objective analysis

A report produced for The Department for Environment, Food and Rural Affairs, The National Assembly for Wales, The Scottish Executive and the Department of the Environment in Northern Ireland

John R Stedman
Tony J Bush
Tim P Murrells
Katie King

July 2001

Title	Baseline PM_{10} and NO_x projections for PM10 objective analysis
Customer	The Department for Environment, Food and Rural Affairs, The National Assembly for Wales, The Scottish Executive and the Department of the Environment in Northern Ireland
Customer reference	EPG 1/3/146
Confidentiality, copyright and reproduction	
File reference	h:\baselinerep2.doc
Report number	
Report status	Issue 1

AEA Technology Environment
National Environmental Technology Centre
E5 Culham
Abingdon
OX14 3ED
Telephone 01235 463178
Facsimile 01235 463817

AEA Technology is the trading name of AEA Technology plc
AEA Technology is certificated to BS EN ISO9001:(1994)

	Name	Signature	Date
Author	John R Stedman Tony J Bush Tim P Murrells Katie King		
Reviewed by	John Stedman		
Approved by	John Stedman		

Executive Summary

The Air Quality Strategy for England, Wales, Scotland and Northern Ireland currently sets the following objectives for PM_{10} particles, to be achieved by 31 December 2004:

- 50 μgm^{-3} as a 24-hour mean, not to be exceeded more than 35 times a year
- 40 μgm^{-3} as an annual mean, not to be exceeded.

These objectives are consistent with the Stage 1 limit values for PM_{10} included in the first EU Daughter Directive (AQDD), which are to be achieved by 1 January 2005. Indicative Stage 2 limit values for PM_{10} are also included in the first AQDD at 20 μgm^{-3} as an annual mean and 50 μgm^{-3} as a 24-hour mean, not to be exceeded more than 7 times a year, to be achieved by 1 January 2010.

The Government and devolved administrations recognise that the possible health gains from reducing PM_{10} levels are thought to be greater than those for any other pollutant. They are concerned to set sights beyond the immediate need to comply with the AQDD Stage 1 limit values. The Government and devolved administrations have therefore undertaken to assess the prospects of whether the AQS objectives for PM_{10} can be strengthened.

An analysis of the costs and benefits of different measures to reduce ambient PM_{10} concentrations will form an important part of this PM_{10} objective analysis.

This report describes the assumptions used to define baseline emission inventory projections for 2010. It also describes the methods that have been used to calculate site specific projections of PM_{10} and NO_x and NO_2 concentrations in 2010 from measurements at automatic monitoring network sites for the period from 1996 to 1999. These site-specific projections provide a valuable tool for the rapid assessment of the impact of a range of policy measures on ambient PM_{10}, NO_x and NO_2 concentrations. The site-specific projections also have the advantage of excluding the uncertainties associated with the empirical or dispersion modelling of concentrations.

This report also describes the methods that have been used to calculate maps of PM_{10}, NO_x and NO_2 concentrations for the base years 1996 to 1999 and projections for 2010. Maps have been calculated of background concentrations for the whole of the UK at a 1 km x 1 km square resolution and for roadside concentrations at a total of 7180 individual built-up major road links (A roads and motorways). The maps of background concentrations are required for the assessment of the health and non-health benefits of policy measures to reduce PM_{10} concentrations. The maps of roadside concentrations can be used to assess the impact of policies on the number of road links with estimated concentrations exceeding threshold concentrations, such as existing or proposed AQS objectives or limit values.

Projections of NO_2 concentrations have been calculated alongside those of PM_{10} because these are the two pollutants for which the objectives set out within the AQS and in the AQDD are likely to be the most challenging. It will therefore be useful to assess the impact on ambient NO_2 concentrations of measures taken to reduce PM_{10} since many measures will reduce

concentrations of both pollutants. Projections have been calculated for the 2010, as this is the most likely year for which a more stringent AQS PM_{10} objective would apply.

The sensitivity of the predicted baseline and a possible additional measures scenario concentrations in 2010 to the likely upper bound of uncertainty in the more important input parameters in the model has also been examined and detailed results are presented.

Contents

7 Uncertainty and Sensitivity analyses for 2010 Baseline PM$_{10}$ projections 34

8 Acknowledgements 45

9 References 46

Appendices

1   Introduction

1.1   POLICY CONTEXT

The Air Quality Strategy for England, Wales, Scotland and Northern Ireland (AQS, DETR et al, 2000) currently sets the following objectives for PM_{10} particles, to be achieved by 31 December 2004:

- 50 μgm^{-3} as a 24-hour mean, not to be exceeded more than 35 times a year
- 40 μgm^{-3} as an annual mean, not to be exceeded.

These objectives are consistent with the Stage 1 limit values for PM_{10} included in the first EU Daughter Directive (AQDD), which are to be achieved by 1 January 2005. The 24-hour mean objective and limit value is expected to be the more stringent of the two. Indicative Stage 2 limit values for PM_{10} are also included in the first AQDD at 20 μgm^{-3} as an annual mean and 50 μgm^{-3} as a 24-hour mean, not to be exceeded more than 7 times a year, to be achieved by 1 January 2010.

The Government and devolved administrations recognise that the possible health gains from reducing PM_{10} levels are thought to be greater than those for any other pollutant. They are concerned to set sights beyond the immediate need to comply with the AQDD Stage 1 limit values. The Government and devolved administrations have therefore undertaken to assess the prospects of whether the AQS objectives for PM_{10} can be strengthened (DETR et al, 2000).

An analysis of the costs and benefits of different measures to reduce ambient PM_{10} concentrations will form an important part of this PM_{10} objective analysis.

1.2   THIS REPORT

This report describes the methods that have been used to calculate site specific projections of PM_{10} and NO_x and NO_2 concentrations in 2010 from measurements at automatic monitoring network sites for the period from 1996 to 1999. These site-specific projections provide a valuable tool for the rapid assessment of the impact of a range of policy measures on ambient PM_{10}, NO_x and NO_2 concentrations. The site-specific projections also have the advantage of not including the uncertainties associated with the empirical or dispersion modelling of concentrations.

This report also describes the methods that have been used to calculate maps of PM_{10}, NO_x and NO_2 concentrations for the base years 1996 to 1999 and projections for 2010. Maps have been calculated of background concentrations for the whole of the UK at a 1 km x 1 km square resolution and for roadside concentrations at a total of 7180 individual built-up major road links (A roads and motorways). The maps of background concentrations are required for the assessment of the health and non-health benefits of policy measures to reduce PM_{10} concentrations. The maps of roadside concentrations can be used to assess the impact of policies on the number of road links with estimated concentrations exceeding threshold concentrations, such as existing or proposed AQS objectives or limit values.

Projections of NO_2 concentrations have been calculated alongside those of PM_{10} because these are the two pollutants for which the objectives set out within the AQS and in the AQDD are likely to be the most challenging. It will therefore be useful to assess the impact on ambient NO_2 concentrations of measures taken to reduce PM_{10} since many measures will reduce concentrations of both pollutants.

Projections have been calculated for the 2010, as this is the most likely year for which a more stringent AQS PM_{10} objective would apply. The indicative stage 2 limit values for PM_{10} of the first AQDD are also to be achieved by 1 January 2010. 2010 is also the timeframe of the Ten Year Plan for Transport (DETR 2000a), which set out the Government's strategy to tackle congestion and pollution and deliver better integrated, high quality, transport systems over the next decade. Projections of PM_{10} concentrations for the years after 2010 will be calculated at a later date.

1.3   OTHER DOCUMENTS

The analyses of PM_{10} and NO_2 concentrations described here are based on the methods described in the AQS (DETR et al, 2000) and supporting technical reports (Stedman et al, 1998a, Stedman et al, 1998b). These methods have been updated to incorporate more recent ambient air monitoring results, understanding of atmospheric chemistry and emissions estimates and projections.

The proposals for a new PM_{10} objective are presented in the Air Quality Strategy consultation document "Proposals for air quality objectives for particles, benzene, carbon monoxide and polycyclic aromatic hydrocarbons" (DEFRA et al, 2001). The technical annex of the consultation document includes PM_{10} emission inventories and projections and a summary of ambient PM_{10} monitoring data in the UK. This report, along with the additional technical reports listed below provides full details of the modelling methods and results described in the technical annex.

This report only describes projections of PM_{10}, NO_x and NO_2 concentrations from the base years 1996 to 1999 to 2010 for a single 'baseline' scenario, which represents our best estimate of the impact of current national and international policies on concentrations of these pollutants. Projections for alternative scenarios incorporating the impact of additional policy measures to reduce PM_{10} are required to assess the costs and benefits of these measures in comparison with the baseline. Projections for these additional measures scenarios along with details of the packages of measures that they represent, will be published in a companion report (Stedman et al, 2001c). Analyses of the health benefits (Stedman et al, 2001d) and non-health benefits (Watkiss et al, 2001) of the additional measures will also be published. These analyses of health and non-health benefits contribute to "An Economic Analysis of the Air Quality Strategy Objectives for Particles" (DEFRA, 2001) along with an examination of the costs of possible measures to reduce PM_{10} emissions and concentrations (AEA Technology, 2001) A separate report describing the verification of the mapping results for the base years has been prepared (Stedman and Handley, 2001).

2   Baseline emissions projections

2.1   INTRODUCTION

Emission inventory maps for 1998 at a 1 km x 1 km from the National Atmospheric Emissions Inventory (NAEI) have been used throughout the work presented here (Goodwin et al, 2000). Maps of area emissions for the following sectors have been calculated:

- Domestic
- Services (emissions from heating plant in commercial and public buildings etc.)
- Industry
- Road Transport
- Off road vehicles
- Shipping
- Rail
- Other

UK totals for these sectors for 1996 and 1997 have been published by the NAEI (Goodwin et al, 2000) in addition to totals for 1998. Emissions maps for 1996 and 1997 have been calculated by scaling the 1998 maps by the changes in UK total emissions for each sector. Emissions maps for 1999 and 2010 have been calculated by scaling the 1998 emissions according to projections of emissions available from the NAEI. The emissions projections for road traffic and non-road traffic sources are described in this section. Projections of secondary PM_{10} concentrations are also described.

2.2   ROAD TRAFFIC EMISSIONS

Projections of emissions from road traffic sources are available from the NAEI. Information on methodology and emission factors is given in Goodwin et al (2000) and Murrells (2000) although the specific emissions projections used here have been calculated since the publication of these reports. These projections have been calculated from a combination of road traffic activity projections and knowledge of the expected emissions characteristics of the vehicle fleet in each year. Projections have been calculated from a base year of 1999 and appropriate scaling factors have been used to calculate maps of emissions for the years 1996 to 1999 and 2010 from a combination of these projections and a map of emissions for 1998. Emissions estimates for A-roads and motorways are available for individual road links for 1998 and the emissions projections have similarly been used to calculate individual road link emissions estimates for the other years.

The following projections of traffic activity (in terms of vehicle km travelled) were used:

- England: Traffic projections were provided by the DETR from the National Road Traffic Forecast (NRTF), incorporating the impact of the Ten Year Plan for Transport 'Plan' scenario (DETR, 2000b). The impact of the Plan on vehicle km is assumed to apply fully in 2010, with a linear increase in impact from zero in 2005.

- Scotland: Traffic projections were provided by the Scottish Executive from the Central Scotland Transport Model (CSTM3) and were extrapolated to the rest of Scotland. Projections were provided for a central growth, current policies scenario.
- Wales: Traffic projections were provided by the DETR from the NRTF (1997) The Ten Year Plan for transport has been assumed to also apply in Wales.
- Northern Ireland: Traffic projections were provided by the Northern Ireland Roads service.

For England and Wales the network model in the NRTF framework divides the country into 11 different 'area types' and these are listed in Table 2.1. Traffic data for road links in Scotland were also assigned to area types 4 to 11. In addition to projections of UK total emissions the NAEI can also provide projections of emissions for each individual area type in England, Scotland and Wales and these have been incorporated into the road link and area emissions maps for 2010.

Table 2.1 National Road Traffic Forecast area types for the Ten Year Plan for Transport

Area Type	Description
1	Central London
2	Inner London
3	Outer London
4	Inner Conurbantions
5	Outer Conurbations
6	Other urban areas > 25 km^2 area
7	Urban areas 15 - 25 km^2 area
8	Urban areas 10 - 15 km^2 area
9	Urban areas 5 - 10 km^2 area
10	Urban areas < 5 km^2 area
11	Rural areas

The following assumptions on a number of fleet, fuel and technology related policies were also made to calculate the baseline projections of emissions from the NAEI 1999 road traffic emissions inventory.

Future diesel penetration trends in the new car market

Diesel penetration in the new car market was around 14% in 1999. The trend in percentage of diesel car sales of total new car sales listed in Table 2.2 has been assumed in the baseline scenario. Diesel penetration is expected to increase over the next few years due to the introduction of better performing diesel models and improving consumer perception of diesels. Some increase in diesel penetration is also expected as a result of the EU CO_2 from Cars voluntary agreements.

Table 2.2 Diesel penetration of new car market (%)

Year	2001	2002	2003	2004	2005	2006	2007	2008+
Diesel penetration of new car market (%)	16	17	18	19	20	21	22	22

Early introduction of cleaner fuel specifications

The baseline takes into account the early introduction – as a result of fuel duty incentives - of Ultra Low Sulphur Diesel (ULSD) and Ultra Low Sulphur Petrol (ULSP), the maximum sulphur content of which is below 50ppm. In the case of ULSP, future market penetration is assumed to be 100% in 2001 and subsequent years. ULSD has accounted for around 100% of the diesel market since the end of 1999. These fuel standards will be mandatory from 1 January 2005.

Early introduction of petrol Euro IV standards

It is likely that there will be significant entry of vehicles meeting Euro IV standards into the fleet before 2005, especially for petrol cars. This is primarily due to the introduction by other European Member States of tax incentives for Euro IV vehicles. This development has already led to a wide range of Euro IV compliant models on the market in the UK – over 50 models, according to the January 2001 edition of the VCA's *New Car Fuel Consumption and emissions figures* booklet - as it is more often cost-effective to develop one single power-train for the entire European market. The proportion of new petrol cars meeting Euro IV standards is expected to increase gradually over the next five years, and the uptake listed in Table 2.3 has been assumed in the baseline. The baseline assumes no early introduction of Euro IV for petrol light goods vehicles.

Table 2.3 Proportion of Euro IV cars in the new petrol car market

Year	2000	2001	2002	2003	2004	2005
Proportion of Euro IV cars in the new petrol car market	0%	20%	40%	60%	80%	100%

Fitting of particulate traps to light duty diesel vehicles

Some new diesel light duty vehicles can be expected to meet Euro IV PM_{10} standards before 2005, especially through the fitting of a particulate trap. There are currently no diesel cars on sale which meet the required Euro IV standards. However, it is likely manufacturers will fit many Euro IV diesels with traps as standard before the mandatory date for Euro IV, in order to improve the emission performance of diesel vehicles. For example, Peugeot and Citroen have already fitted particulate traps to some of their new models. In view of this, the trend listed in Table 2.4 has been assumed. The baseline assumes that there is no uptake of particulate traps for diesel light goods vehicles.

Table 2.4 Proportion of new diesel cars with particulate traps

Year	2000	2001	2002	2003	2004	2005+
Proportion of new diesel cars with particulate traps	0%	5%	10%	15%	20%	25%

Fitting of particulate traps to heavy duty diesel vehicles

Particulate traps for heavy duty diesel vehicles have been feasible for at least the last five years, and their fitting has been encouraged since 1998 through the VED reduced pollution

concession. Several large commercial fleet operators such as London Transport have consequently voluntarily fitted particulate traps to their fleets, and the NAEI takes account of such developments based on discussions with the bus industry. Before 2000, the NAEI takes account of the fitting of oxidation cats on buses and the early use of ULSD - again based on discussions with the bus industry. There is no official data on the number of vehicles fitted with particulate traps, but trap manufacturers estimate that there are currently at least 4,000 heavy-duty vehicles fitted with traps in the UK.

The number of heavy duty vehicles fitted with particulate traps is expected to increase by 2005, although it is difficult to estimate the ingress of this technology into the fleet. Euro IV standards are not expected to mandate the use of particulate traps for heavy-duty vehicles. Most growth in heavy-duty vehicles fitted with particulate traps is therefore likely to be from retrofitting of nearly new vehicles. The emission modelling for the baseline assumes the number of heavy-duty vehicles fitted with particulate traps set out in Table 2.5 (split equally between buses and lorries).

Table 2.5 Number of heavy duty vehicles retrofitted with particulate traps

Year	2000	2001	2002	2003	2004	2005+
Cumulative number of heavy duty vehicles retrofitted with particulate traps	4000	6000	8000	10000	12000	14000
Cumulative % of the heavy duty vehicles in the fleet retrofitted with particle traps.	0.8%	1.2%	1.6%	2.0%	2.3%	2.7%
Proportion of these vehicles which would have met Euro II standards – the remainder complying as Euro III.	100%	90%	75%	60%	45%	30%

Emissions projections for road traffic sources are listed in Table 2.6.

Table 2.6. Projections UK total urban road traffic PM_{10} and NO_x emissions (ktonnes per year)

Year	PM_{10}	NO_x, as NO_2
1990	25.82	419.81
1991	25.96	419.72
1992	24.99	404.45
1993	24.26	390.28
1994	23.96	381.73
1995	21.99	360.11
1996	20.43	348.55
1997	17.80	321.85
1998	15.84	298.19
1999	14.10	271.80
2000	11.98	257.97
2001	11.48	237.35
2002	10.91	217.86
2003	10.38	200.59
2004	9.89	185.26
2005	9.43	171.86
2006	8.84	159.24
2007	8.16	146.46
2008	7.49	133.96
2009	6.88	122.30
2010	6.38	112.45
2015	5.06	85.44
2020	4.97	81.25

2.3   NON-ROAD TRAFFIC EMISSIONS

Projections of non-road transport emissions of PM_{10} have been calculated by the National Atmospheric Emissions Inventory based on the 1998 emissions estimates and activity drivers for the central growth/high fuel price scenario in Energy Paper 68, provided by the Department of Trade and Industry (DTI, 2000). These estimates therefore incorporate an assumed growth in economic activity of about 2.5% per year and the continuation of current trends towards greater use of natural gas and cleaner technologies (DTI, 2000). Emissions from the railways sector have been recalculated within the ambient concentration modelling to take into account the impact of the Ten Year Plan for Transport (DETR, 2000a).

Estimates of emissions for the years 1990 to 1998 for non-traffic sources are based on the NAEI emission inventory for the 1998 base year. This is the base year from which projections for future years have been calculated. Historical emission estimates are also available from the NAEI inventory for the 1999 base year but have not been incorporated into the models described in this report. This avoids any discontinuities in activity drivers caused by the use of 'real' activity data for 1999 and activity data for 2000 that has been projected from a 1998 base year. The historical emission data presented in the technical annex (DEFRA at al. 2001) are taken from

the 1999 NAEI inventory and are therefore not exactly the same as the data presented here. Projections for 2000 and beyond are identical. UK total emissions have been split into 9 sectors within the baseline models of ambient concentrations. A more detailed breakdown of emissions is given in the technical annex. Both historical and projected emission from road traffic sources listed in Table 2.6 have been calculated from a 1999 base year within the NAEI and are identical to the data included in the technical annex (DEFRA et al 2001).

Emissions projections for non-road traffic sources are listed in Table 2.7. Projected emissions are directly available for 2010; emissions for 1999 have been calculated by linear interpolation between 1998 and 2000. Emissions for the years 2001 to 2004 and 2006 to 2009 have been calculated by linear interpolation between 2000, 2005 and 2010.

Table 2.7a. Projections UK Total PM_{10} emissions for non-road traffic sources (ktonnes per year)

Year	Power Stations and refineries	Domestic	Services	Industry	Off road	Shipping	Aircraft	Rail	Other
1990	73.63	47.63	7.80	38.81	8.19	1.35	0.12	0.88	3.40
1991	73.41	50.98	7.72	39.91	8.19	1.41	0.12	0.88	3.19
1992	69.44	46.02	7.34	41.19	8.19	1.35	0.13	0.89	2.96
1993	58.78	47.26	6.99	40.18	8.19	1.33	0.13	0.90	2.45
1994	52.72	37.73	6.72	39.24	8.19	1.23	0.13	0.90	2.72
1995	41.13	27.65	6.14	36.35	8.19	1.19	0.14	0.91	2.08
1996	38.23	30.38	6.31	35.43	8.11	1.29	0.15	0.85	2.18
1997	26.52	27.86	6.17	32.83	8.03	1.24	0.15	0.79	1.71
1998	27.16	26.38	5.34	31.52	7.95	1.16	0.16	0.73	1.58
1999	20.14	21.96	5.67	29.10	7.71	1.17	0.17	0.75	1.68
2000	13.13	17.55	6.00	26.69	7.48	1.18	0.17	0.77	1.79
2001	13.46	16.74	5.94	26.79	7.21	1.18	0.18	0.79	1.81
2002	13.80	15.93	5.88	26.89	6.94	1.18	0.19	0.81	1.84
2003	14.13	15.12	5.82	27.00	6.58	1.18	0.19	0.82	1.87
2004	14.46	14.31	5.76	27.10	6.22	1.18	0.20	0.84	1.89
2005	14.79	13.50	5.70	27.20	5.81	1.18	0.20	0.85	1.92
2006	14.05	13.08	5.69	27.47	5.39	1.18	0.21	0.94	1.95
2007	13.30	12.66	5.68	27.73	5.02	1.17	0.22	1.03	1.98
2008	12.56	12.25	5.67	28.00	4.73	1.17	0.22	1.12	2.01
2009	11.82	11.83	5.65	28.27	4.52	1.17	0.23	1.21	2.04
2010	11.08	11.41	5.64	28.53	4.38	1.17	0.24	1.33	2.07
2015	9.17	10.17	5.58	30.00	4.38	1.16	0.27	0.95	2.22
2020	8.60	9.34	5.45	31.36	2.31	1.16	0.30	0.95	2.38

Table 2.7b. Projections UK Total NO$_x$ emissions for non-road traffic sources (ktonnes per year, as NO$_2$)

Year	Power Stations and refineries	Domestic	Services	Industry	Off road	Shipping	Aircraft	Rail	Other
1990	822.61	63.61	37.38	292.92	77.65	71.82	9.29	13.01	71.65
1991	727.10	70.62	40.06	282.53	78.59	75.13	8.79	13.44	63.10
1992	715.84	68.94	39.34	277.02	79.53	72.28	9.38	13.88	57.99
1993	614.83	71.72	37.79	276.04	80.46	71.31	9.55	14.32	50.94
1994	572.65	68.60	37.92	292.59	81.40	66.06	9.95	14.76	48.73
1995	541.69	65.89	37.05	249.75	82.34	63.61	10.32	15.19	48.33
1996	496.63	75.28	38.76	240.41	81.59	68.97	10.80	14.18	46.92
1997	418.32	69.53	36.14	238.56	80.83	66.18	11.24	13.17	43.55
1998	415.35	70.90	33.90	236.51	80.08	61.90	11.83	12.15	37.56
1999	389.65	69.68	36.29	230.38	77.97	62.54	12.36	12.35	39.89
2000	363.96	68.46	38.68	224.26	75.86	63.18	12.89	12.54	42.21
2001	373.36	68.69	38.60	224.39	73.48	63.12	13.35	12.93	41.92
2002	382.76	68.93	38.51	224.52	71.24	63.06	13.80	13.32	41.62
2003	392.16	69.16	38.42	224.65	68.58	63.00	14.25	13.71	41.32
2004	401.56	69.40	38.34	224.78	65.88	62.95	14.70	14.10	41.02
2005	410.96	69.63	38.25	224.91	62.78	62.89	15.15	14.48	40.72
2006	398.74	69.79	38.34	226.01	59.57	62.80	15.64	14.87	40.70
2007	386.53	69.94	38.43	227.10	56.84	62.72	16.13	15.26	40.68
2008	374.32	70.09	38.52	228.20	54.82	62.64	16.62	15.65	40.66
2009	362.10	70.24	38.61	229.29	53.46	62.56	17.10	16.04	40.64
2010	349.89	70.40	38.70	230.39	52.79	62.47	17.59	16.43	40.62
2015	298.47	72.25	39.34	237.47	52.79	61.71	19.86	16.43	40.44
2020	297.83	74.09	39.79	243.95	52.79	62.06	22.49	16.43	40.12

2.4   SECONDARY PARTICLES

Secondary particle concentrations for 2010 and other years have been predicted on the basis of a combination of measurements and modelling results. For simplicity secondary PM$_{10}$ has been assumed to consist of sulphates and nitrates. Secondary organic aerosol has not been considered in the baseline projections but has been considered in the sensitivity analyses presented in section 7. Measurements of sulphate at a network of eight rural sites have been made since 1987. Measurements of total inorganic nitrate (nitrate particles + nitric acid) were made at two rural sites between 1990 and 1999. The trend in nitrate particle concentrations over this period has been assumed to be the same as the trend in total inorganic nitrate concentrations.

Figure 2.1 shows the network mean of annual mean sulphate particle concentrations for the years 1987 to 1999. The overall decline in concentrations is clear and there is also considerable year to year variation in concentrations due to variations in meteorological conditions form. A best fit line has been calculated and we have assumed that this fit line represents an average trend in concentrations due to changes in UK, European and other sources of SO$_2$ contributing to

sulphate measured in the UK, with changes due to meteorological variability removed. Figure 2.2 shows a similar plot for nitrate.

Modelled sulphate and nitrate fields for the UK are available for 1997 and 2010 from both the EMEP model (at 150 x 150 km spatial resolution) and the HARM model (at 10 x 10 km spatial resolution) (Warren et al, 2000, Metcalfe et al, 2001). In both cases these models have been run using 10-year average meteorology for both 1997 and 2010. The calculated values for 2010 incorporate the emissions reductions set out within the 'Gothenburg Protocol' to Abate Acidification, Eutrophication and Ground-level Ozone and those proposed within the EU National Emission Ceilings Directive. Both of these models have been designed to predict acid deposition and are known to over-predict the absolute values of ambient sulphate and nitrate particle concentrations. We have therefore chosen to scale measured concentrations in the years 1996 to 1999 by the ratios of modelled concentrations in 1997 and 2010 from the EMEP model in order to predict sulphate and nitrate concentrations in 2010. The EMEP model results indicate a reduction in UK average sulphate by 2010 to 53% of 1997 levels and a reduction in nitrate to 67% of 1997 levels. These results are broadly confirmed by the results from HARM, which show a reduction of sulphate to 50% and nitrate to 70% of 1997 levels by 2010.

There are a number of ways in which the measured and modelled concentrations could be combined to provide estimates for 2010, particularly because the year to year variability in measured concentrations caused by variations in meteorology has been excluded from the modelled values by the use of average meteorology. Figures 2.1 and 2.2 illustrate the approach that we have adopted. We have used the ratios of the modelled concentrations in 2010 to those in 1997 to calculate a prediction for concentrations in 2010 from the best-fit line values for 1997. This prediction for 2010 therefore represents our best estimate of concentration in 2010 for average meteorology. We have also assumed a linear decline in concentrations from 1997 to 2010. Predictions of secondary particle concentrations for individual base years were then calculated by scaling the measured concentrations in that year according the ratio of the best fit concentration in that year and the average meteorology prediction for 2010. An alternative, more pessimistic interpretation of the possible trends from 1998 and 1999 to 2010 is discussed in section 7. In this way we have incorporated the individual base year meteorology into the prediction for 2010 for secondary particles. This is consistent with the method adopted for primary concentrations, where the incorporation of base year meteorology into the predictions for 2010 is implicit in the scaling of measured concentrations by changes in emissions. Secondary PM_{10} concentrations have been assumed to remain at 2010 levels in subsequent years.

3 Site-specific projections of NO_x and NO_2 concentrations

3.1 METHOD

The method used to calculate site-specific projections of future annual mean NO_2 concentrations were first described in the AQS (DETR et al, 2000) and in some detail by

Stedman et al (1998a) and Stedman (1999). The method was subsequently revised and updated to incorporate more up-to-date monitoring information and considerably more detailed emission inventory and projection information for the analyses carried out on the impact of the Ten Year Plan for Transport (Stedman et al, 2000).

The AQS sets the following provisional objectives for NO_2, to be achieved by 31 December 2005:

- Annual mean: 40 μgm^{-3}
- Hourly mean: 200 μgm^{-3}, not to be exceeded more than 18 times a year.

The first EU AQDD sets the same concentrations as limit values, to be achieved by 1 January 2010. The annual mean objective and limit value are expected to be the more stringent of the two and our analysis is therefore focussed on predicting annual mean NO_2 concentrations.

The projections are based on measurements carried out at sites within the national automatic monitoring networks (see www.aeat.co.uk/netcen/airqual for details of the site locations and an archive of monitoring results). The following steps were required to project these measured concentrations forwards:

1. The measured NO_x concentration was divided into component parts. A map of rural concentrations was subtracted from the measured concentration to determine the local source contribution to annual mean NO_x concentration. Emission inventory maps (Goodwin et al, 2000) for 1998 were used to split the local source contribution into emissions sectors. Local sources were summed within a 35 km x 35 km area centred on the monitoring site location. An ADMS based dispersion matrix was applied to weight emissions from individual grid cells according to distance and direction from the site location. This dispersion matrix approach was also used to calculate the maps and is described in sections 5 and 6.
2. An additional contribution from emissions on the road adjacent to the monitoring site was included for roadside monitoring sites. An annual mean background concentration for each roadside site was derived from the maps described in section 5.
3. Each component was then projected forwards from the measurement year to 2010 according to the projected change in emissions from each sector and added together to give an estimate of annual mean NO_x for 2010. Rural concentrations were projected on the basis of changes in UK total NO_x emissions.
4. Ambient NO_2 concentrations vary according to the availability of both NO and oxidant. The following non-linear relationships between annual mean NO_2 and NO_x concentrations were used to calculate estimates of NO_2 concentration (1 ppb NO_2 = 1.91 μgm^{-3} NO_2; similarly 1 ppb NO_x = 1.91 μgm^{-3} NO_x, as NO_2):

- Central London Background: $NO_2 \ (ppb) = 1.750.NO_x \ (ppb)^{0.7}$
- Elsewhere Background: $NO_2 \ (ppb) = 2.375.NO_x \ (ppb)^{0.6}$
- Roadside: $NO_2 \ (ppb) = 1.8767.NO_x \ (ppb)^{0.6}$

These relationships have been derived from monitoring data from 1990 to 1999 inclusive (Stedman et al 2000b) and graphs showing these relationships are reproduced in Appendix 1. They reflect the contrast between the behaviour of NO_x, which can be treated as a conserved pollutant and NO_2, for which the ambient concentration is dependent on the availability of

oxidant and distance from source. The majority of NO_x is present as NO_2 at rural locations because these areas are generally distant from sources and oxidant (ozone) is available in excess. Annual mean NO_2 concentrations in urban areas are more limited by the availability of oxidant. Measured NO_2 concentrations in Central London are found to be higher than in other urban areas (relative to corresponding levels of NO_x). It is thought that this is due to the large size of the urban area, which enables relatively aged NO_x from other parts of London to contribute to NO_2 in Central London. Pending further analysis, this relationship has been applied to locations forming a circle of approximate radius 3 km centred in the centre of London. Concentrations of NO_2 at the roadside are lower than at background locations with the same NO_x concentration due to the proximity to sources and the limited amount of available oxidant.

Figures 3.1 to 3.4 show examples of site-specific projections of NO_x and NO_2 concentrations for years between 1990 and 2010. Projected concentrations have been calculated from measured concentrations in 1996, 1997, 1998 and 1999. There is good agreement between the projections for the years in the early 1990s and the measured concentrations. This gives us confidence that the split into different sectors and the emissions estimates are reasonable. The inter-year changes in measured concentrations are also put into the context of changes in emissions, enabling the identification of years with unusually efficient or poor dispersion of primary pollutants. High concentrations due to poor dispersion conditions are evident at West London in 1997 and particularly in 1991, when there was a major episode of elevated concentrations. The projections also clearly illustrate the impact of emissions reductions on ambient NO_x concentrations and the correspondingly smaller changes in annual mean NO_2.

3.2 MEASURED CONCENTRATIONS 1996 – 1999

Measured annual mean NO_x and NO_2 concentrations for the base years 1996 to 1999 are listed in Table 3.1 for the sites for which site-specific projections have been calculated. Measured annual average NO_2 concentrations are listed along with the NO_2 concentrations that have been estimated from the measured NO_x concentrations using the relationships described above. There are some differences between the measured and estimated NO_2 concentrations but the non-linear relationships provide a good representation of ambient NO_2 concentrations at the majority of monitoring sites.

Table 3.1 Measured annual mean NO$_x$ and NO$_2$ concentrations 1996 to 1999 (μgm^{-3}, as NO$_2$)

	measured NO$_x$				measured NO$_2$				estimated NO$_2$			
Base year	1996	1997	1998	1999	1996	1997	1998	1999	1996	1997	1998	1999
London Bloomsbury	153	161	128	136	69	71	65	67	72	74	64	66
Birmingham Centre	82	80	74	63	44	44	42	38	43	43	41	37
Cardiff Centre	73	76	69	55	40	38	40	32	40	41	39	34
Edinburgh Centre	97	103	101	84	48	48	48	42	48	50	49	44
Belfast Centre	75	75	60	61	38	39	34	35	41	41	36	36
Liverpool Centre	99	103	92	97	48	44	38	42	49	50	46	48
Newcastle Centre	90	90	79	57	41	40	36	31	46	46	42	35
Manchester Piccadilly	112	100	87	86	54	41	40	43	52	49	45	45
Bristol Centre	113	124	92	80	48	44	40	38	52	56	46	43
West London	120	132	99	99	53	57	52	55	54	58	49	49
London Bridge Place	130	132	103	105	63	59	57	63	64	65	55	55
Manchester Town Hall	101	101	82	76	53	52	42	42	49	49	43	41
Leeds Centre	115	124	101	88	52	52	46	44	53	56	49	45
Hull Centre	101	90	84	76	42	40	38	38	49	46	44	41
Haringey Roadside	168	187	143	130	57	59	53	48	53	56	48	45
Glasgow Roadside		309	271	252		71	71	69		76	70	67
London Marylebone Road			374	390			92	92			85	87
Camden Roadside		277	243	208		70	64	66		71	66	60
Sutton Roadside	141	147	117	118	46	50	42	44	47	49	42	43
Bury Roadside		363	309	269		75	74	73		84	76	70
Tower Hamlets Roadside	313	298	246	239	65	71	65	67	76	74	66	65
London Cromwell Road	372		235	256	92		82	92	85		64	68

Measured annual mean NO$_2$ concentrations at most background monitoring sites were above or close to 40 μgm^{-3} during the period 1996 to 1999. Annual mean concentrations at roadside sites were consistently above 40 μgm^{-3}.

3.3   BASELINE PROJECTIONS FOR 2010

Projected annual mean NO$_x$ and NO$_2$ concentrations for 2010 for the base years 1996 to 1999 are listed in Table 3.2 for the baseline scenario for the sites for which site-specific projections have been calculated.

Table 3.2 Projected annual mean NO_x and NO_2 concentrations 2010 from base years 1996 to 1999 (μgm^{-3}, as NO_2) for the baseline scenario

Base year	projected NO_x 2010				projected NO_2 2010			
	1996	1997	1998	1999	1996	1997	1998	1999
London Bloomsbury	82.5	93.4	79.7	88.8	46.7	50.9	45.5	49.1
Birmingham Centre	39.8	42.0	41.8	38.0	28.1	29.0	28.9	27.3
Cardiff Centre	35.8	40.5	39.4	33.9	26.3	28.4	27.9	25.5
Edinburgh Centre	47.9	54.7	57.9	51.1	31.3	33.9	35.1	32.6
Belfast Centre	40.1	43.1	36.8	39.5	28.2	29.4	26.8	27.9
Liverpool Centre	54.1	60.2	57.4	64.2	33.7	36.0	34.9	37.4
Newcastle Centre	41.7	45.0	42.6	33.2	28.8	30.2	29.2	25.2
Manchester Piccadilly	51.7	50.0	47.0	49.7	32.8	32.2	31.0	32.0
Bristol Centre	53.6	63.5	50.9	47.6	33.5	37.1	32.5	31.2
West London	60.8	71.8	57.9	61.5	36.2	40.0	35.1	36.4
London Bridge Place	66.9	73.2	61.4	66.2	40.3	42.9	37.9	40.0
Manchester Town Hall	48.3	52.0	45.8	45.5	31.5	32.9	30.5	30.4
Leeds Centre	53.1	61.8	54.7	50.9	33.4	36.5	33.9	32.5
Hull Centre	45.2	43.4	44.5	43.2	30.3	29.6	30.0	29.5
Haringey Roadside	73.2	83.8	72.5	71.2	31.9	34.7	31.8	31.4
Glasgow Roadside		131.5	125.0	126.3		45.4	44.0	44.3
London Marylebone Road			181.5	200.4			55.1	58.5
Camden Roadside		117.6	112.0	105.4		42.5	41.3	39.8
Sutton Roadside	57.1	62.6	55.3	59.5	27.5	29.1	27.0	28.2
Bury Roadside		137.9	127.9	122.0		46.7	44.7	43.4
Tower Hamlets Roadside	125.3	128.3	116.6	121.0	44.1	44.7	42.2	43.2
London Cromwell Road	153.9		119.8	136.3	49.9		42.9	46.4

Of the background monitoring sites analysed, only the projections for London Bloomsbury show concentrations of NO_2 consistently above 40 μgm^{-3}. Projections for London Bridge Place exceed for all except the 1998 base year and projected concentrations at West London are above 40 μgm^{-3} for the 1997 base year. The projections for Glasgow Roadside, Bury Roadside, Tower Hamlets Roadside and London Cromwell Road are consistently above 40 μgm^{-3}. Projected concentrations at Marylebone Road are above 50 μgm^{-3}. Projections for the Camden Roadside site are higher than 40 μgm^{-3} for all except the 1998 base year. Projected concentrations of NO_2 in 2010 at Haringey Roadside and Sutton Roadside are well below 40 μgm^{-3}.

4   Site specific projections of PM$_{10}$ concentrations

4.1   TEOM AND GRAVIMETRIC MEASUREMENTS

The reference method for the AQDD limit values and AQS objectives for PM$_{10}$ is the use of a gravimetric instrument. The analyses presented here is based on TEOM (Tapered Element Oscillating Microbalance) instruments, which are currently widely used with in the UK national monitoring networks. We have applied a scaling factor of 1.3 to all data before comparing with the limit value, as suggested by APEG (1999), and recommended as an interim measure by the

EC Working Group set up to address the issue of scaling automatic PM measurements in advance of Member States undertaking their own detailed inter-comparisons with the Directive Reference Method.. All PM_{10} concentration data reported within this study are given in units of μgm^{-3}, gravimetric, meaning that TEOM data has been scaled to give a representation of concentrations as measured by a gravimentic, or equivalent instrument. In addition, a sensitivity analysis has been undertaken using a factor of 1.4 (see Section 7). This is at present the highest factor measured in the UK inter-comparison exercise between TEOM analysers and EC Directive Reference Method measurements.

4.2 THE APEG RECEPTOR MODEL

The site-specific projections presented here are based on the receptor modelling methods that we developed within the framework of the Airborne Particles Expert Group (APEG, 1999, Stedman et al, 1998). A regression analysis has been carried out to divide measured daily average PM_{10} concentrations (as measured by TEOM or equivalent monitor) into three components:

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

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

$$[\text{measured } PM_{10} \text{ } (\text{mg } m^{-3})] = A.[\text{measured } NO_x \text{ } (\text{mg } m^{-3})] + B.[\text{measured sulphate } (\text{mg } m^{-3})] + C \text{ } (\text{mg } m^{-3})$$

These coefficients can then be used to divide the measured concentration into the three components and the contributions from each component to the annual mean concentration can be calculated. This analysis has been completed for the years 1996 to 1999 inclusive at a range of UK national network monitoring sites. Two key outputs from the model are a UK average concentration of 'other' particles and the coefficient, B, relating measured sulphate concentrations to secondary PM_{10} concentrations. Values of this coefficient are listed in Table 4.1 for the base years that have been studied.

Table 4.1 Empirically derived factors relating measured sulphate to secondary PM_{10} concentrations

1996	2.66
1997	2.03
1998	2.60
1999	2.91

If all of the measured secondary PM_{10} were ammonium sulphate, then this coefficient would be approximately 1.3. The remaining secondary PM_{10} was assumed to be nitrate. The increase in the value of this coefficient from 1996 to 1999 illustrates a more rapid decline in sulphate concentrations in recent years, compared with nitrate concentrations.

4.3   PROJECTING CONCENTRATIONS

Each component of the annual mean PM_{10} concentration was then projected from the measurements in 1996, 1997, 1998 and 1999 to provide estimates of concentrations in 2010.

Maps of primary PM_{10} emissions for 1998 from the NAEI (Goodwin et al, 2000) were used to determine the sectors contributing to local primary combustion PM_{10} at each monitoring site location. Local sources were summed within a 35 km x 35 km area centred on the monitoring site location. An ADMS based dispersion matrix was applied to weight emissions from individual grid cells according to distance and direction from the site location. This dispersion matrix approach was also used to calculate the maps and is described in sections 5 and 6.

Secondary particle concentrations in the base years 1996 to 1999 were derived from maps of rural measurements of sulphate (at 8 sites) using the factors listed in Table 4.x. Concentrations of sulphate and nitrate in future years were derived as described in section 2.3. We assumed that there will be no change in coarse ('other') particle concentrations.

Figure 4.1 and 4.2 show examples of site-specific projections of annual mean PM_{10} concentrations for the London Bloomsbury and Belfast Centre sites. It is clear that there is good agreement between the projections for the years 1992 to 1999 and the measured values for these years. The projections track both the year to year variability in concentrations due to changes in the meteorology that influences secondary particle concentrations and the changes in concentrations due to reductions in emissions. The projections based on 1996 and 1997 monitoring data are higher than the projections based on 1998 and 1999 data. Secondary particle episodes made an important contribution to the high concentrations measured in 1996 (Stedman 1997, 1998) and primary pollutant concentrations were higher in 1997 than in 1996, 1998 and 1999, as discussed above for NO_x.

4.4   PROJECTIONS FOR ROADSIDE MONITORING SITES

Site-specific projections for roadside monitoring sites have also been calculated. Daily averages of measured PM_{10} at a nearby background monitoring site have been subtracted from the concentrations measured at roadside monitoring sites in order to determine the roadside increment of daily PM_{10}. The annual mean of the roadside increment was then calculated from these daily values. It is not possible to determine the split of the roadside increment between traffic exhaust emissions and re-suspended dusts from current network measurements. Analyses of PM_{10} and $PM_{2.5}$ monitoring data presented in the APEG report (APEG 1999) suggested that re-suspended component could be 50% of the total. It is likely that this is an overestimate because exhaust emission may include some particles of diameter greater than 2.5 μm. We have assumed that re-suspended dust does not contribute to the roadside increment of PM_{10} concentrations in our baseline projections. An alternative scenario in which 25% of the roadside increment in 1997 is assumed to be from re-suspended dust has been examined as a sensitivity analysis.

Figures 4.3 and 4.4 show projections for the Bury Roadside and Sutton Roadside monitoring sites.

4.5 ANNUAL MEAN CONCENTRATIONS AND THE NUMBER OF DAYS WITH CONCENTRATIONS ABOVE 50 μgm^{-3}

The analysis described in this report, has focussed on the prediction of annual mean values. Equivalent values of numbers of days exceeding 50 μgm^{-3} (gravimetric) can be calculated. Figure 4.5 illustrates that there is a reasonably robust relationship between annual mean concentrations and number of days per year with concentrations greater than or equal to 50 μgm^{-3}, although it should be noted that there are few data points in the 20 – 25 μgm^{-3} (gravimetric) range. Measured values of the number of days with concentrations greater than or equal to 50 μgm^{-3}, gravimetric are also subject to greater influence from local events such as bonfires, road or other contruction work or more wide spread events such as Saharan dust events than are annual means. Such events are especially important if the number of exceedences due to elevated concentrations from better characterised and controlled sources are relatively infrequent, as is anticipated for much of the country by 2010. The figure also illustrates that the EU Stage 2 annual mean limit value of 20 μgm^{-3} is likely to be more stringent than the 24 hour limit value of 50 μgm^{-3}, not to be exceeded more than 7 times a year. The approximate annual mean equivalents of different numbers of days above 50 μgm^{-3} are listed in Table 4.2 along with the equivalent annual mean concentrations for raw TEOM measurement data.

Table 4.2 The relationship between annual mean and number of days per year with concentrations greater than or equal to 50 μgm^{-3}, gravimetric

Annual mean equivalent μgm^{-3}, gravimentric	Annual mean equivalent μgm^{-3}, TEOM	Number of days with concentration greater than 50μgm^{-3}, gravimetric
28.0	21.5	23
25.0	19.2	14
23.0	17.7	9
*20.0	15.4	3

* EU AQDD indicative stage 2 annual mean limit value for PM$_{10}$

4.6 MEASURED CONCENTRATIONS 1996 – 1999

Measured annual mean PM$_{10}$ concentrations for the years 1996 to 1999 are listed in Table 4.3 for the sites for which site-specific projections have been calculated. Data from TEOM instruments has been multiplied by a factor of 1.3, as discussed above.

Table 4.3 Measured annual mean PM$_{10}$ concentrations 1996 to 1999 (μgm^{-3}, gravimetric)

	measured PM$_{10}$			
Base year	1996	1997	1998	1999
London Bloomsbury	39.0	35.1	29.9	28.6
Birmingham Centre	32.5	28.6	24.7	23.4
Cardiff Centre	32.5	33.8	28.6	27.3
Edinburgh Centre	24.7	23.4	19.5	19.5
Belfast Centre	31.2	32.5	27.3	26.0
Liverpool Centre	32.5	32.5	28.6	26.0
Rochester	31.2	26.0	22.1	20.8
Newcastle Centre	31.2	27.3	23.4	20.8
Manchester Piccadilly	33.8	31.2	27.3	26.0
Bristol Centre	32.5	31.2	27.3	26.0
Haringey Roadside		33.8	28.6	28.6
Glasgow Roadside		40.3	35.1	27.3
Marylebone Road		50.7	41.6	45.5
Camden Roadside		41.6	32.5	33.8
Sutton Roadide		31.2	27.3	26.0
Bury Roadside		39.0	33.8	31.2

The measured annual mean PM$_{10}$ concentrations show a considerable decline in values from 1996 to 1999. Concentrations at most sites background sites ranged from 30 to 33 μgm^{-3}, gravimetric in 1996 (the concentration at London Bloomsbury was 39 μgm^{-3}, gravimetric) and had declined to between 20 and 26 μgm^{-3}, gravimetric by 1999 (the concentration at London Bloomsbury was 29 μgm^{-3}, gravimetric). The roadside increment in PM$_{10}$ is less in comparison with background values than for NO$_x$. The site with the highest measured concentrations was London Marylebone Road.

4.7   BASELINE PROJECTIONS FOR 2010, 2015 AND 2020

Projected annual mean PM$_{10}$ concentrations for 2010, 2015 and 2020 for the base years 1996 to 1999 are listed in Tables 4.4, 4.5 and 4.6 for the baseline scenario for the sites for which site-specific projections have been calculated.

Table 4.4 Projected annual mean PM$_{10}$ concentrations 2010 from base years 1996 to 1999 (mgm^{-3}, gravimetric) for the baseline scenario

	projected PM$_{10}$ 2010			
Base year	1996	1997	1998	1999
London Bloomsbury	24.4	22.7	21.3	21.6
Birmingham Centre	21.3	19.5	18.4	18.5
Cardiff Centre	21.9	23.1	21.3	21.4
Edinburgh Centre	17.5	17.0	15.6	16.1
Belfast Centre	20.8	22.0	20.2	20.4
Liverpool Centre	21.8	22.3	21.2	20.5
Rochester	21.6	18.9	17.5	17.2
Newcastle Centre	20.3	18.6	17.5	16.8
Manchester Piccadilly	21.5	20.4	19.6	19.7
Bristol Centre	21.5	21.2	20.1	20.3
Haringey Roadside		21.3	20.0	20.9
Glasgow Roadside		22.1	21.5	18.6
Marylebone Road		26.3	24.5	27.7
Camden Roadside		24.3	21.5	23.3
Sutton Roadide		20.1	19.4	19.6
Bury Roadside		22.2	21.7	21.3

Table 4.5 Projected annual mean PM$_{10}$ concentrations 2015 from base years 1996 to 1999 (mgm^{-3}, gravimetric) for the baseline scenario

	projected PM$_{10}$ 2015			
Base year	1996	1997	1998	1999
London Bloomsbury	23.8	21.9	20.7	21.0
Birmingham Centre	20.8	18.9	18.0	18.1
Cardiff Centre	21.5	22.5	20.8	20.9
Edinburgh Centre	17.2	16.6	15.4	15.9
Belfast Centre	20.4	21.3	19.7	19.8
Liverpool Centre	21.3	21.5	20.6	19.9
Rochester	21.4	18.7	17.4	17.2
Newcastle Centre	19.8	18.6	17.1	16.5
Manchester Piccadilly	20.9	19.6	18.9	19.1
Bristol Centre	21.1	20.5	19.6	19.8
Haringey Roadside		20.5	19.3	20.2
Glasgow Roadside		20.1	19.7	17.3
Marylebone Road		24.2	22.8	25.4
Camden Roadside		22.9	20.5	22.1
Sutton Roadide		19.4	18.9	19.1
Bury Roadside		20.8	20.5	20.1

Table 4.6 Projected annual mean PM$_{10}$ concentrations 2020 from base years 1996 to 1999 (mgm^{-3}, gravimetric) for the baseline scenario

	projected PM$_{10}$ 2020			
Base year	1996	1997	1998	1999
London Bloomsbury	23.7	21.8	20.6	20.9
Birmingham Centre	20.7	18.8	17.9	18.0
Cardiff Centre	21.4	22.4	20.7	20.9
Edinburgh Centre	17.2	16.5	15.3	15.8
Belfast Centre	20.3	21.3	19.6	19.8
Liverpool Centre	21.2	21.4	20.4	19.8
Rochester	21.4	18.7	17.4	17.2
Newcastle Centre	19.7	17.9	17.0	16.4
Manchester Piccadilly	20.8	19.5	18.8	19.0
Bristol Centre	21.0	20.4	19.6	19.7
Haringey Roadside		20.4	19.2	20.1
Glasgow Roadside		19.8	19.5	17.1
Marylebone Road		23.9	22.5	25.0
Camden Roadside		22.7	20.4	21.9
Sutton Roadide		19.3	18.8	19.1
Bury Roadside		20.6	20.4	20.0

By 2010, under 1999 meteorology, the baseline scenario suggests that 9 of the 16 sites analysed would exceed the indicative Stage 2 limit value of 20 μgm^{-3} as an annual mean. The analysis also shows the impact of years characterised by a high secondary particle contribution. In 2010, with 1996 meteorology, 9 out of 10 sites are predicted to exceed under the baseline scenario.

By 2015 further reductions occur beyond that delivered in 2010. In this year, for the baseline scenario, for 1999 meteorology, 6 sites are predicted to exceed the EC Stage 2 indicative limit value. By 2020 very small additional reductions are expected beyond that already delivered by 2015. In 2020, for 1999 meteorology, 5 sites are predicted to exceed the EC Stage 2 annual mean indicative limit value.

5 Maps of NO$_x$ and NO$_2$ concentrations

5.1 METHOD FOR MAPS OF BACKGROUND CONCENTRATIONS

The methods used to calculate maps background NO$_2$ concentrations have been developed by AEA Technology Environment over a number of years and are described in detail in a number of reports and papers including Stedman et al (1997), Stedman (1998), Stedman et al (2001a) and Stedman and Bush (2000). These methods have been continually revised and updated to incorporate more up-to-date monitoring information and considerably more detailed emission inventory and projection information.

Measured annual mean background NO$_x$ (the sum of NO and NO$_2$) concentrations have been assumed to consist of two parts:

- A contribution from relatively distant major point and area sources such as power stations or large conurbations. Measurements from monitoring sites well away from local sources, from rural sites within the UK Acid Deposition Secondary Network, for example, provide good indications of the spatial variation of concentrations due to distant sources.
- A contribution from more local emissions.

The difference, *diff*, between measured ambient NO$_x$ concentrations at urban automatic monitoring sites (not roadside, industrial sites or urban or suburban sites that are significantly influenced by emissions from a nearby road) and the underlying rural concentration field is calculated at automatic monitoring site locations.

diff = measured annual mean urban NO$_x$ concentration - mapped rural NO$_x$ concentration

A regression analysis is then performed to find the coefficient, k_b, for the relationship between *diff* and estimated NO$_x$ emissions in the vicinity of the monitoring sites taken from the NAEI (Goodwin et al 2000):

diff = k_b.emissions

This coefficient, which is the equivalent of an empirical box model coefficient, can then be used to derive a map of annual mean concentrations from a combination of rural mapped concentrations and emissions inventory estimates. Thus, automatic monitoring data are used to calibrate the relationship between ambient air quality and emissions inventories.

In earlier work on the estimation of air pollutant concentrations from emission related parameters (Stedman et al, 1997) we have studied the spatial scale at which local emissions seem to influence ambient air quality. We found that estimates of emissions in an area of 25 km^2 centred on a background monitoring site provide the most robust relationships. In subsequent work incorporating improved spatially resolved emission inventories and more extensive

monitoring data it became clear that contributions from outside the 25 km^2 area should be included. This is particularly important for large urban areas such as London, where an empirically derived 'out of square' contribution was added for inner London (Stedman et al, 2001a, Stedman and Bush 2000). This has been addressed in the current work by including contributions to ambient concentrations from emissions in an area of 1225 km^2, with the contribution weighted by distance and direction from the central receptor. We have adapted an ADMS based approach described by Abbott and Vincent (1999) and others. The ADMS dispersion model was used to calculate the contribution to concentrations at a central receptor point from a 35 x 35 km hypothetical grid of 1 x 1 km cells of unit emissions, grouped into blocks of 5 x 5 km. This level of spatial resolution was chosen to retain consistency with earlier work and avoid discontinuities in predicted concentrations at the borders of 1 x 1 km cells. Long period average meteorological data from Heathrow was used. The weighted sum of emissions around each monitoring site location was calculated and compared with *diff* to derive the empirical dispersion coefficient k_b.

estimated background NO$_x$ concentration (μgm^{-3} as NO$_2$) = rural NO$_x$ map (μgm^{-3} as NO$_2$) + k_b. emissions (Tonnes NO$_x$ as NO$_2$ per year, weighted by distance and direction)

This revised method therefore implicitly includes a contribution from 'out of square' emissions but the calibration of dispersion coefficients by automatic monitoring data is retained.

Area emissions maps were calculated from each of the base years 1996 to 1999 as described in section 2 and empirical dispersion coefficients were calculated for each year by comparing these emissions with automatic monitoring results. The meteorological conditions of the base year are therefore included in the dispersion coefficients and this should be the only difference between the coefficients for different years because the year to year changes in emissions have been accounted for.

Coefficients are listed in Table 5.1 for the relationship between the weighted sum of emissions and the local source contribution to ambient annual mean NO$_x$ concentration. The highest coefficients were derived for the 1997 base year, which is consistent with the results of the site-specific projections described above. Monitoring sites were found to fall into two groups: those in the large urban centres of Greater London, the West Midlands and Greater Manchester and those in the rest of the UK. The empirical dispersion coefficients were found to be lower in the large urban areas, presumably due to a combination of urban influences on local meteorology. This result has been confirmed by dispersion modelling studies in London recently carried out by Abbott and Vincent (2001), who found considerable differences in modelled concentrations for results derived from meteorological data at Heathrow and London Weather Centre. Figure 5.1 shows the derivation of the regression coefficients for 1999.

Table 5.1 Coefficients used to calculate background annual mean NO$_x$ maps (sm^{-1})

Base year	1996	1997	1998	1999
Large urban areas	3.84	4.53	3.66	3.89
Elsewhere in the UK	8.05	8.61	7.39	7.18

Maps of estimated annual mean background NO$_2$ concentrations were then calculated from the maps of NO$_x$ using the following non-linear relationships: (which are consistent with those used

for the site-specific analysis; 1 ppb NO_2 = 1.91 ugm^{-3} NO_2; similarly 1 ppb NO_x = 1.91 μgm^{-3} NO_x, as NO_2).

- Rural Background: *NO_2 (ppb) = 0.833. NO_x (ppb)*
- Central London Background: *NO_2 (ppb) = 1.750.NO_x (ppb)$^{0.7}$*
- Elsewhere Background: *NO_2 (ppb) = 2.375.NO_x (ppb)$^{0.6}$*

5.2 METHOD FOR MAPS OF ROADSIDE CONCENTRATIONS

We have considered that the annual mean concentration of NO_x at a roadside location is made up of two parts: the background concentration (as described above) and a roadside increment (Stedman et al 1998a).

roadside concentration = background concentration + roadside increment

The NAEI provides estimates of NO_x emissions for a total of 14075 major road links in the UK for 1998 (Goodwin et al, 2000). Figure 5.2 shows a comparison of the roadside increment of annual mean NO_x concentrations at roadside or kerbside national automatic monitoring sites with NO_x emission estimates for the individual road links alongside which these sites are located. The background NO_x component at these roadside monitoring sites was derived from the map described above. The sites chosen for this analysis are those for which emission estimates are available that are in built-up areas. There is clearly a strong dependence of the roadside increment on NO_x emission at these sites.

roadside increment of annual mean NO_x (μgm^{-3} as NO_2) = k_r.NO_x emission from road link (kg NO_2 km^{-1} y^{-1})

The values of k_r for the different base years are listed in Table 5.2. It is likely that year to year variation in meteorology will not have much of an effect on this relationship and this is confirmed by the small range in coefficients (lowest is 92% of highest). It is not clear whether this variation in coefficient is meaningful or simply represents the uncertainties in the method. Since the year to year variation is small the values as listed in Table 5.2 were used.

Table 5.2 Coefficients used to calculate the roadside increment of annual mean NO_x concentration (sm^{-2})

Base year	1996	1997	1998	1999
Coefficient	0.243	0.234	0.224	0.233

Roadside NO_x monitoring sites at locations with a more open aspect, such as roads in rural areas, do not conform to this relationship. The NO_x emissions from vehicles travelling on these roads are generally more effectively dispersed than the emissions on built-up urban roads. We have therefore restricted our mapping to built-up major roads (7180 A-road and motorway road links), where the relationship is reliable. Built-up motorway road links with speed limits of less than 70 mph were treated in the same way as other built-up major road links. Built-up motorway road links with speed limits of 70 mph were treated separately and the roadside increment was set to 0.225 of the value for other built-up major road links. This factor is based

on the analysis of the limited monitoring data from sites close to motorways with fast moving traffic, which indicates considerably enhanced dispersion in comparison with other roads in the urban environment.

Roadside annual mean NO_2 concentration was calculated from the estimate of the roadside annual mean NO_x concentration using following relationship (Stedman et al 2000b):

- Roadside: NO_2 (ppb) = $1.8767.NO_x$ (ppb)$^{0.6}$

NO_2 concentrations at roadside monitoring sites are lower than at background locations with the same total NO_x concentration because these sites are very close to sources and NO_2 concentrations are limited by the availability of oxidant.

5.3   MAPS OF CONCENTRATIONS 1996 –1999

Maps of annual mean background NO_2 concentrations for the years 1996 to 1999 are shown in Figure 5.3. The highest estimated background concentrations are in the centres of the large cities. Areas strongly influenced by emissions from busy motorways are also evident. Scatter plots of estimated and measured concentrations are shown in Figure 5.4. Summary statistics for the comparison between mapped and measured background concentrations of NO_x and NO_2 are listed in Table 5.3. It is quite possible to obtain a sensible looking estimate of NO_2 from a combination of an inaccurate estimate of NO_x and an inappropriate NO_x to NO_2 conversion. It is therefore prudent to compare modelled and measured NO_x concentrations as well as those of NO_2. There is good agreement between the mapped and measured concentrations of both NO_x and NO_2. The measurement data presented in these comparisons is the same as was used to calibrate the relationships between measurements and emissions. A separate report describing the verification of the mapping results by comparison with an independent set of measurement data has also been published (Stedman and Handley, 2001).

Table 5.3 Summary statistics for comparison between estimated and measured concentrations of NO_x and NO_2 at background sites

	Mean of measurements (μgm^{-3}, as NO_2)	Mean of model estimates (μgm^{-3}, as NO_2)	r^2	Number of sites
NO_x, 1996	88.4	86.1	0.68	33
NO_x, 1997	86.3	83.9	0.76	46
NO_x, 1998	69.8	67.1	0.68	54
NO_x, 1999	64.6	63.4	0.76	55
NO_2, 1996	42.5	44.4	0.71	33
NO_2, 1997	39.7	43.3	0.79	46
NO_{2x} 1998	35.6	37.8	0.76	54
NO_2, 1999	34.6	36.5	0.76	55

Maps of annual mean NO_2 concentrations at the roadside of built-up major road links for the years 1996 to 1999 are shown in Figure 5.5. Scatter plots of estimated and measured concentrations are shown in Figure 5.6. Summary statistics for the comparison between mapped and measured background concentrations of NO_x and NO_2 are listed in Table 5.4. There is

generally good agreement between the mapped and measured concentrations of both NO_x and NO_2. The verification of these mapping results by comparison with an independent set of measurement data has also been published (Stedman and Handley, 2001).

Table 5.4 Summary statistics for comparison between estimated and measured concentrations of NO_x and NO_2 at roadside sites

	Mean of measurements (μgm^{-3}, as NO_2)	Mean of model estimates (μgm^{-3}, as NO_2)	r^2	Number of sites
NO_x, 1996	255.2	245.0	0.79	5
NO_x, 1997	213.1	179.9	0.61	7
NO_x, 1998	201.0	192.0	0.82	12
NO_x, 1999	192.2	182.4	0.83	11
NO_2, 1996	65.2	65.5	0.75	5
NO_2, 1997	56.3	54.0	0.83	7
NO_{2x} 1998	58.7	55.8	0.81	12
NO_2, 1999	59.6	54.0	0.84	11

Table 5.5 lists the number of road links with estimated roadside NO_2 concentrations greater than or equal to 40 μgm^{-3} for the base years for six geographical areas of the UK. 40 μgm^{-3} is the annual mean objective for 2005 with in the AQS and the annual mean limit values for 2010 within the AQDD.

Table 5.5 The number of built-up major road links with estimated NO_2 concentrations greater than or equal to 40 μgm^{-3} for the base years 1996 to 1999

Base year		1996	1997	1998	1999
Geographical area	Total				
Scotland	548	246	226	170	148
Wales	282	72	62	37	34
Northern Ireland	101	27	23	14	11
Inner London	760	760	760	760	759
Outer London	789	786	786	767	755
Rest of England	4700	3460	3242	2482	2218
Total	7180	5351	5099	4230	3925

The number of road links with concentrations greater than 40 μgm^{-3} declines across the UK between 1996 and 1999 in line with decreasing emissions of NO_x. This decline is dominated by roads in the rest of England. The majority of road links in London are predicted to have concentrations greater than 40 μgm^{-3} in all four base years.

5.4   BASELINE PROJECTIONS FOR 2010

Maps of annual mean background NO_2 concentrations for the 2010 for the baseline scenario for the base years 1996 to 1999 are shown in Figure 5.7. Maps of roadside NO_2 concentrations 2010 for the baseline scenario are shown in Figure 5.8. Table 5.6 lists the number of road links with estimated roadside concentrations NO_2 greater than or equal to 40 μgm^{-3} in 2010 for the

baseline scenario for the base four different base years. Baseline projections were calculated by the applying the empirical dispersion coefficients derived for each individual base year to the 2010 emission inventory for the baseline scenario.

Table 5.6 The number of built-up major road links with estimated NO$_2$ concentrations greater than or equal to 40 μgm^{-3} for the baseline scenario in 2010 for the base years 1996 to 1999

(Base year)		2010 (1996)	2010 (1997)	2010 (1998)	2010 (1999)
Geographical area	Total				
Scotland	548	8	8	7	7
Wales	282	0	0	0	0
Northern Ireland	101	1	1	1	1
Inner London	760	425	502	360	421
Outer London	789	41	51	31	38
Rest of England	4700	110	126	68	77
Total	7180	585	688	467	544

Roadside NO$_2$ concentrations are predicted to decline sharply from the base year values to those predicted for 2010. The majority of road links exceeding 40 μgm^{-3} in 2010 are in London.

6 Maps of PM$_{10}$ concentrations

6.1 METHOD FOR MAPS OF BACKGROUND CONCENTRATIONS

Mapping of PM$_{10}$ concentrations is more complex and subject to greater uncertainties than mapping of NO$_x$ and NO$_2$, due to the wide range of different sources and processes contributing to ambient particle concentrations. The knowledge derived from the results of the APEG receptor model studies has been applied to the calculation of maps of estimated annual mean concentrations by Abbott and Stedman (1999). These methods have since been revised and updated to incorporate more up-to-date monitoring information and considerably more detailed emission inventory and projection information (Stedman and Bush, 2000).

These mapping methods have now been developed further. The map of PM$_{10}$ concentrations presented here was calculated by adding together a number of different components:

1. Secondary PM$_{10}$ derived from maps of measured rural sulphate concentrations using the coefficients from the site specific receptor modelling analysis listed in Table 4.x.
2. European primary PM$_{10}$ has been modelled at Imperial College from a primary PM$_{10}$ emission inventory published by TNO (TNO, 1997).
3. The contribution from local primary PM$_{10}$ emissions has been estimated using 1 km primary PM$_{10}$ emission maps from the NAEI for 1998 and empirical dispersion coefficients calibrated using measurement data.

4. A constant regional coarse component 9.9 μgm^{-3},gravimetric has also been added. This value was derived from the site specific receptor modelling results as described in section 4.2 and this value is consistent with the intercept of the regression analyses to determine the empirical dispersion coefficients.

The difference, *diff*, between measured ambient PM_{10} concentrations at urban automatic monitoring sites (not roadside, industrial sites or urban or suburban sites that are significantly influenced by emissions from a nearby road) and the underlying concentration field (the sum secondary and European primary) is calculated where automatic monitoring data are available.

diff = measured annual mean urban PM$_{10}$ concentration – (secondary + European primary)

A regression analysis is then performed to find the coefficient, k_b, for the relationship between *diff* and estimated PM_{10} emissions in the vicinity of the monitoring sites taken from the NAEI (Goodwin et al 2000):

diff = k$_b$.emissions

This coefficient, which is the equivalent of an empirical box model coefficient, can then be used to derive a map of annual mean local primary PM_{10} concentrations, to which the other contributions can be added to calculate a map of total PM_{10}. The intercept of this regression analysis also provides confirmation of the constant concentration of coarse particles.

In earlier work on the estimation of air pollutant concentrations from emission related parameters (Stedman et al, 1997) we have studied the spatial scale at which local emissions seem to influence ambient air quality. We found that estimates of emissions in an area of 25 km^2 centred on a background monitoring site provide the most robust relationships. In subsequent work incorporating improved spatially resolved emission inventories and more extensive monitoring data it became clear that contributions from outside the 25 km^2 area should be included. This is particularly important for large urban areas such as London, where an empirically derived 'out of square' contribution was added for inner London (Stedman et al, 2001a, Stedman and Bush 2000). This has been addressed in the current work by including contributions to ambient concentrations from emissions in an area of 1225 km^2, with the contribution weighted by distance and direction from the central receptor. We have adapted an ADMS based approach described by Abbott and Vincent (1999) and others. The ADMS dispersion model was used to calculate the contribution to concentrations at a central receptor point from a 35 x 35 km hypothetical grid of 1 x 1 km cells of unit emissions, grouped into blocks of 5 x 5 km. This level of spatial resolution was chosen to retain consistency with earlier work and avoid discontinuities in predicted concentrations at the borders of 1 x 1 km cells. Long period average meteorological data from Heathrow was used. The weighted sum of emissions around each monitoring site location was calculated and compared with *diff* to derived the empirical dispersion coefficient k_b.

This revised method therefore implicitly includes a contribution from 'out of square' emissions but the calibration of dispersion coefficients by automatic monitoring data is retained.

Area emissions maps were calculated from each of the base years 1996 to 1999 as described in section 2 and empirical dispersion coefficients were calculated for each year by comparing these emissions with automatic monitoring results. The meteorological conditions of the base year are

therefore included in the dispersion coefficients and this should be the only difference between the coefficients for different years because the year to year changes in emissions have been accounted for.

Coefficients are listed in Table 6.1 for the relationship between the weighted sum of emissions and the local source contribution to ambient annual mean PM_{10} concentration. The highest coefficients were derived for the 1997 base year, which is consistent with the results of the site-specific projections described above. Monitoring sites were found to fall into two groups: those in the large urban centres of Greater London, the West Midlands and Greater Manchester and those in the rest of the UK. The empirical dispersion coefficients were found to be lower in the large urban areas, presumably due to a combination of urban influences on local meteorology. This result has been confirmed by dispersion modelling studies in London recently carried out by Abbott and Vincent (2001), who found considerable differences in modelled concentrations for results derived from meteorological data at Heathrow and London Weather Centre. Figure 6.1 shows the derivation of the regression coefficients for 1999.

Table 6.1 Coefficients used to calculate background annual mean PM_{10} maps (sm^{-1})

Base year	1996	1997	1998	1999
Large urban areas	4.37	6.01	3.66	3.60
Elsewhere in the UK	7.63	11.95	9.43	8.08

6.2   METHOD FOR MAPS OF ROADSIDE CONCENTRATIONS

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

roadside concentration = background concentration + roadside increment

The NAEI provides estimates of PM_{10} emissions for a total of 14075 major road links in the UK for 1998 (Goodwin et al, 2000). Figure 6.2 shows a comparison of the roadside increment of annual mean PM_{10} concentrations at roadside or kerbside national automatic monitoring sites with PM_{10} emission estimates for the individual road links alongside which these sites are located. The background PM_{10} component at these roadside monitoring sites was derived from the map described above and the roadside increments were found to be in good agreement with those derived from the results of the APEG receptor model for these sites. The sites chosen for this analysis are those for which emission estimates are available that are in built-up areas. The magnitude roadside increment of PM_{10} relative to background levels is much lower than for NO_x and the modelling of background concentrations is also subject to greater uncertainties for PM_{10}, as discussed above. The calibration of the relationship between the roadside increment for PM_{10} and road link emissions is therefore subject to greater uncertainties than for NO_x. There are also considerably fewer roadside monitoring sites for PM_{10}.

roadside increment of annual mean PM_{10} ($\mu g\ m^{-3}$) = k_r.PM_{10} emission from road link (kg PM_{10} $km^{-1}\ y^{-1}$)

A single value of the coefficient was applied for all base years. This value was derived for the 1999 base year and is given in Table 6.2

Table 6.2 Coefficients used to calculate the roadside increment of annual mean PM$_{10}$ concentration (sm^{-2})

Base year	1996	1997	1998	1999
Coefficient	0.167	0.167	0.167	0.167

Roadside monitoring sites at locations with a more open aspect, such as roads in rural areas, do not conform to this relationship. The PM$_{10}$ emissions from vehicles travelling on these roads are generally more effectively dispersed than the emissions on built-up urban roads. We have therefore restricted our mapping to built-up major roads (7180 A-road and motorway road links), where the relationship is reliable. Built-up motorway road links with speed limits of less than 70 mph were treated in the same as other built-up major road links. Built-up motorway road links with speed limits of 70 mph were treated separately and the roadside increment was set to 0.225 of the value for other built-up major road links. This factor is based on the analysis of the limited amount of monitoring data from sites close to motorways with fast moving traffic, which indicates considerably enhanced dispersion in comparison with other roads in the urban environment.

6.3   MAPS OF CONCENTRATIONS 1996 –1999

Maps of annual mean background PM$_{10}$ concentrations for the years 1996 to 1999 are shown in Figure 6.3. There is a clear south east to north west gradient in rural concentrations due to the reduction in secondary PM$_{10}$ concentrations with increasing distance from precursor source regions. The highest estimated background concentrations are in the centres of the large cities. Areas strongly influenced by emissions from busy motorways are also evident. Scatter plots of estimated and measured concentrations are shown in Figure 6.x. Summary statistics for the comparison between mapped and measured background concentrations of PM$_{10}$ are listed in Table 6.3. There is reasonably good agreement between the mapped and measured concentrations of PM$_{10}$, considering the complexities of mapping concentrations for this muti-source pollutant. The measurement data presented in these comparisons is the same as was used to calibrate the relationships between measurements and emissions. A separate report describing the verification of the mapping results by comparison with an independent set of measurement data has also been published (Stedman and Handley, 2001).

Table 6.3 Summary statistics for comparison between estimated and measured concentrations of PM$_{10}$ at background sites

	Mean of measurements (mgm^{-3}, garavimetric)	Mean of model estimates (mgm^{-3}, garavimetric)	r^2	Number of sites
PM$_{10}$, 1996	31.3	30.7	0.40	21
PM$_{10}$, 1997	28.3	27.3	0.51	34
PM$_{10}$, 1998	24.8	24.3	0.36	43
PM$_{10}$, 1999	23.3	23.2	0.41	40

Maps of annual mean PM_{10} concentrations at the roadside of built-up major road links for the years 1996 to 1999 are shown in Figure 6.4. Scatter plots of estimated and measured concentrations are shown in Figure 6.5 (full year annual means are not available for roadside monitoring sites for 1996). Summary statistics for the comparison between mapped and measured background concentrations of PM_{10} are listed in Table 6.4. There is generally good agreement between the mapped and few measured concentrations of PM_{10} at roadside sites but the mapped values are generally somewhat higher than the measured values. The verification of these mapping results by comparison with an independent set of measurement data has also been published (Stedman and Handley, 2001).

Table 6.4 Summary statistics for comparison between estimated and measured concentrations of PM_{10} at roadside sites

	Mean of measurements (μgm^{-3}, garavimetric)	Mean of model estimates (μgm^{-3}, garavimetric)	r^2	Number of sites
PM_{10}, 1996	-	-	-	0
PM_{10}, 1997	39.3	42.3	1.00	4
PM_{10}, 1998	32.5	36.1	0.97	4
PM_{10}, 1999	32.2	34.6	0.98	4

Table 6.5 lists the number of road links with estimated roadside concentrations PM_{10} greater than or equal to a range of annual mean thresholds for the base years for six geographical areas of the UK. The relationship between annual mean and number of days with concentrations above 50 μgm^{-3} has been described in section 4.5

The majority of the road links are predicted to have exceeded the illustrative threshold concentrations in the 1996 base year. A smaller proportion of the total number of urban road links exceeded the higher thresholds in Scotland, Wales and Northern Ireland. Roadside concentrations were lower in the 1999 base year, reflecting reductions in both primary and secondary particle concentrations. The modelling results indicate that almost all of the road links in London still had roadside PM_{10} concentrations in excess of 25 μgm^{-3}, gravimetric in 1999.

6.4   BASELINE PROJECTIONS FOR 2010

Maps of annual mean background PM_{10} concentrations for the 2010 for the baseline scenario for the base years 1996 to 1999 are shown in Figure 6.5. Maps of roadside PM_{10} concentrations 2010 for the baseline scenario are shown in Figure 6.6. Table 6.6 lists the number of road links with estimated roadside estimated roadside concentrations PM_{10} greater than or equal to a range of annual mean thresholds for six geographical areas of the UK in 2010 for the baseline scenario for the base four different base years. Baseline projections for primary PM_{10} were calculated by the applying the empirical dispersion coefficients derived for each individual base year to the 2010 emission inventory for the baseline scenario. Projections of secondary particle concentrations were calculated as described in section 2.3.

Roadside PM_{10} concentrations are predicted to be much lower in 2010 than in the base years. Exceedences of 20 μgm^{-3}, gravimetric are however still expected to be common at the roadside for the baseline scenario, especially for the 1996 base year in England. Fewer exceedences of 20 μgm^{-3}, gravimetric are expected in 2010 for the 1999 base year. Exceedences of 25 μgm^{-3}, gravimetric are largely confined to Inner London.

Table 6.5 The number of built-up major road links with estimated PM$_{10}$ concentrations greater than or equal to various thresholds for the base years 1996 to 1999

Base year		1996				1997				1998				1999			
Threshold (μgm^{-3}, gravimetric)		28	25	23	20	28	25	23	20	28	25	23	20	28	25	23	20
Geographical area	Total																
Scotland	548	113	265	380	499	63	171	252	384	12	71	164	329	7	39	110	302
Wales	282	77	216	275	279	20	58	133	239	5	27	66	215	1	12	39	177
Northern Ireland	101	29	49	77	99	23	32	46	79	18	27	32	61	10	17	26	49
Inner London	760	760	760	760	760	760	760	760	760	760	760	760	760	758	760	760	760
Outer London	789	787	787	787	787	787	787	787	787	714	787	787	787	554	786	787	787
Rest of England	4700	4189	4585	4652	4664	2109	3755	4313	4624	836	2689	3968	4590	354	1877	3497	4541
Total	7180	5955	6662	6931	7088	3762	5563	6291	6873	2345	4361	5777	6742	1684	3491	5219	6616

Table 6.6 The number of built-up major road links with estimated PM$_{10}$ concentrations greater than or equal to various thresholds for the for the baseline scenario in 2010 for the base years 1996 to 1999

Base year		1996				1997				1998				1999			
Threshold (μgm^{-3}, gravimetric)		28	25	23	20	28	25	23	20	28	25	23	20	28	25	23	20
Geographical area	Total																
Scotland	548	0	1	4	10	0	1	4	16	0	0	4	7	0	0	3	7
Wales	282	0	0	0	39	0	0	0	13	0	0	0	6	0	0	0	3
Northern Ireland	101	0	1	4	17	1	4	7	18	0	1	4	13	0	1	2	11
Inner London	760	136	691	760	760	48	373	687	760	8	75	360	760	9	107	428	760
Outer London	789	8	178	755	787	2	16	158	782	0	5	31	748	1	7	43	770
Rest of England	4700	1	24	396	3648	0	10	54	1264	0	3	25	903	0	2	23	892
Total	7180	145	895	1919	5261	51	404	910	2853	8	84	424	2437	10	117	499	2443

7 Uncertainty and Sensitivity analyses for 2010 Baseline PM$_{10}$ projections

7.1 INTRODUCTION

In assessing the results from any modelling, particularly that involving atmospheric phenomena, it is important to quantify as far as possible the uncertainties in the model output. This is separated into three components in the following discussion.

Firstly there is the possibility that various components of the input data are systematically wrong-for example the relationship between gravimetric and TEOM measurements has been taken as 1.3 (for the reasons discussed); but it may be some other factor (indeed a single factor may not even be appropriate, but there is insufficient evidence yet to analyse this possibility). We have therefore undertaken sensitivity analyses to investigate the likely upper bound of uncertainty in the more important input parameters in the model. Many of the uncertainties, such as the predictions of emission factors for new technologies and the political background to policy decisions are clearly beyond the scope of this report. There are, however, a number of areas where it is relatively easy to assess the sensitivity of the projections to the assumptions that we have made. This is particularly important in areas where the current scientific understanding of PM$_{10}$ is limited. This section presents the results of a number of sensitivity analyses carried out on the site-specific projections of PM$_{10}$ concentrations in 2010.

Secondly, the concentrations measured in 2010, or any future year, will be critically dependent on the prevailing meteorology. It is impossible to predict this, so we have used a range of 'base year' meteorologies to attempt to span the possible outcomes from this variability.

Thirdly there is the inherent unpredictability atmospheric properties-including air pollutant concentrations. This arise from a series of uncertainties including the stochastic nature of the atmosphere (although this is to some extent minimised by calculating annual average concentrations); the uncertainties in the emission rates and locations of the large number of sources; and the atmospheric processes which produce and remove particles in the atmosphere. An a priori 'bottom-up' analysis of these uncertainties is impossible in any practicable sense. We have attempted to assess this uncertainty by comparing the models predictions for 2000 (based on inputs from earlier years) with those which were actually measured.

7.2 THE USE OF TEOM MEASUREMENTS

A 1.4 conversion factor

A conversion factor of 1.3 has been applied to the baseline projections of PM$_{10}$ concentrations, as discussed in section 4.1. This factor is considered as a central estimate and is generally confirmed at locations where TEOM and gravimetric measurements of PM$_{10}$ are co-located. There are indications that the ratio could be closer to 1.4 at some locations and we have

therefore recalculated the site-specific projections using this factor. The results of this sensitivity analysis are listed in Table 7.1 and can be compared with the baseline projections listed in Table 4.4. The use of a 1.4 conversion factor leads to an change in projected annual mean PM_{10} concentrations of +1.5 μgm^{-3}, gravimetric at background sites and +1.7 μgm^{-3}, gravimetric at roadside sites.

Table 7.1 Projected annual mean PM_{10} concentrations 2010 from base years 1996 to 1999 (μgm^{-3}, gravimetric) for the baseline scenario and a 1.4 TEOM to gravimetric conversion factor

	projected PM_{10} 2010			
Base year	1996	1997	1998	1999
London Bloomsbury	26.2	24.5	23.0	23.3
Birmingham Centre	22.9	21.0	19.9	19.9
Cardiff Centre	23.5	24.9	22.9	23.1
Edinburgh Centre	18.8	18.3	16.8	17.3
Belfast Centre	22.4	23.7	21.7	21.9
Liverpool Centre	23.4	24.0	22.8	22.0
Rochester	23.2	20.4	18.8	18.6
Newcastle Centre	21.9	20.0	18.9	18.1
Manchester Piccadilly	23.2	22.0	21.1	21.2
Bristol Centre	23.1	22.8	21.7	21.8
Haringey Roadside		23.0	21.5	22.5
Glasgow Roadside		23.8	23.1	20.0
Marylebone Road		28.4	26.4	29.8
Camden Roadside		26.2	23.1	25.0
Sutton Roadide		21.7	20.9	21.1
Bury Roadside		23.9	23.4	23.0

7.3   PRIMARY PM10

2001 Draft emission factors for road traffic emissions

The Department of Transport, Local Government and the Regions will shortly be consulting on possible new emission factors for vehicles (Barlow et al 2001). These draft emission factors have been used in the model as a sensitivity analysis, in place of those used here and set out in the Technical Annexe of the Air Quality Strategy consultation document (DEFRA et al, 2001). The resulting site-specific projections of baseline PM_{10} concentration in 2010 and 2015 are listed in Tables 7.2 and 7.3 for comparison with the baseline projections listed calculated using the 1999 NAEI emission factors in Tables 4.4 and 4.5. The use of the draft new emission factors results in an increase in background concentrations in 2010 of about 0.4 μgm^{-3}, gravimetric and at roadside sites of about 0.8 μgm^{-3}, gravimetric for the baseline scenario. The impacts of the scenario incorporating the illustrative package of both traffic and stationary source measures (Stedman et al, 2001c, DEFRA at 2001) are estimated as being somewhat more effective using this factor, and so, overall result in a 0.2 μgm^{-3}, gravimetric increase in background concentrations and a 0.6 μgm^{-3}, gravimetric increase at roadsides. By 2015, use of the draft new emission factors leads to predictions of lower concentrations at both background and roadside sites for the illustrative package of measures scenario than for the current emission factors, while predictions for the baseline scenario remain higher. The impacts of the illustrative

package of measures on the site specific projections of PM_{10} concentrations in 2010 and 2015 are summarised in Tables 7,4 and 7.5 for the two alternative emission factors.

Table 7.2 Projected annual mean PM_{10} concentrations 2010 from base years 1996 to 1999 (mgm^{-3}, gravimetric) for the baseline scenario, 2001 draft emission factors

	projected PM_{10} 2010			
Base year	1996	1997	1998	1999
London Bloomsbury	24.9	23.3	21.7	21.8
Birmingham Centre	21.8	20.1	18.8	18.6
Cardiff Centre	22.4	23.9	21.8	21.7
Edinburgh Centre	17.8	17.3	15.7	16.2
Belfast Centre	21.2	22.6	20.5	20.6
Liverpool Centre	22.3	23.0	21.6	20.7
Rochester	21.8	19.2	17.6	17.3
Newcastle Centre	20.9	19.2	17.9	16.9
Manchester Piccadilly	22.2	21.2	20.1	20.0
Bristol Centre	22.0	21.9	20.6	20.5
Haringey Roadside		22.2	20.5	21.4
Glasgow Roadside		23.3	22.2	18.9
Marylebone Road		27.6	25.2	28.1
Camden Roadside		25.4	22.0	23.7
Sutton Roadide		20.9	19.9	20.0
Bury Roadside		24.0	22.9	22.2

Table 7.3 Projected annual mean PM_{10} concentrations 2015 from base years 1996 to 1999 (mgm^{-3}, gravimetric) for the baseline scenario, 2001 draft emission factors

	projected PM_{10} 2015			
Base year	1996	1997	1998	1999
London Bloomsbury	24.2	22.4	21.0	21.1
Birmingham Centre	21.2	19.3	18.2	18.1
Cardiff Centre	21.9	23.0	21.1	21.0
Edinburgh Centre	17.4	16.8	15.4	15.9
Belfast Centre	20.7	21.7	19.9	20.0
Liverpool Centre	21.6	22.0	20.8	20.0
Rochester	21.6	18.9	17.4	17.2
Newcastle Centre	20.2	19.2	17.3	16.5
Manchester Piccadilly	21.4	20.2	19.2	19.3
Bristol Centre	21.4	21.0	19.9	19.9
Haringey Roadside		21.0	19.7	20.4
Glasgow Roadside		20.8	20.1	17.3
Marylebone Road		25.0	23.2	25.6
Camden Roadside		23.6	20.9	22.3
Sutton Roadide		19.9	19.2	19.3
Bury Roadside		21.9	21.2	20.6

Table 7.4 Changes in 2010 PM$_{10}$ concentrations for the illustrative package of measures scenario, relative to the baseline (μgm^{-3}, gravimetric), ranges shown in brackets

	Background	Roadside
NAEI 1999 emission factors	-1.4 (-0.6 to -2.0)	-1.9 (-1.2 to -3.0)
2001 draft emission factors	-1.6 (-0.7 to –2.3)	-2.1 (-1.3 to -3.0)

Table 7.5 Changes in 2015 PM$_{10}$ concentrations for the illustrative package of measures scenario, relative to the baseline (μgm^{-3}, gravimetric), ranges shown in brackets

	Background	Roadside
NAEI 1999 emission factors	-1.5 (-0.6 to -2.1)	-2.0 (-1.2 to -3.1)
2001 draft emission factors	-1.9 (-0.8 to –2.7)	-2.6 (-1.5 to -3.4)

The impacts of the 2001 draft emission factors for NO$_x$ are illustrated in Table 7.6 for comparison with the baseline projections for the NAEI 1999 emission factors listed in Table 3.2. The mean change in annual mean NO$_2$ concentrations in 2010 at background sites is +2.1 μgm^{-3}. The mean change at roadside sites is +3.6 μgm^{-3}. As with PM$_{10}$, the reductions in annual mean NO$_2$ concentrations in 2010 implied by the illustrative package of measures is larger for the 2001 draft emission factors. But in contrast to PM$_{10}$ the increase in the implied increase in the effectiveness of the measures is of the order of a tenth of the increase in baseline concentration. This is not unexpected as the traffic measures within the illustrative scenario are targeted at reducing PM$_{10}$, rather than NO$_2$ concentrations.

Table 7.6 Projected annual mean NO_2 concentrations 2010 from base years 1996 to 1999 (mgm^{-3}, as NO_2) for the baseline scenario, 2001 emission factors

Base year	projected NO_x 2010				projected NO_2 2010			
	1996	1997	1998	1999	1996	1997	1998	1999
London Bloomsbury	91.8	102.5	85.8	94.3	50.3	54.3	47.9	51.2
Birmingham Centre	45.9	47.6	46.5	41.4	30.6	31.2	30.8	28.7
Cardiff Centre	42.1	46.7	44.3	37.1	29.0	30.9	29.9	26.9
Edinburgh Centre	57.3	64.1	66.2	57.1	34.9	37.3	38.1	34.8
Belfast Centre	45.5	48.1	40.3	42.7	30.4	31.4	28.3	29.3
Liverpool Centre	61.1	67.0	62.6	68.9	36.3	38.4	36.8	39.0
Newcastle Centre	49.5	52.4	48.3	36.7	32.0	33.1	31.5	26.7
Manchester Piccadilly	61.6	58.1	53.3	55.2	36.4	35.2	33.4	34.1
Bristol Centre	63.6	74.1	57.6	52.6	37.2	40.7	35.0	33.2
West London	68.7	80.1	63.1	66.1	38.9	42.7	37.0	38.1
London Bridge Place	75.1	81.0	66.4	70.7	43.7	46.0	40.1	41.9
Manchester Town Hall	56.8	60.1	51.4	50.1	34.7	35.9	32.7	32.2
Leeds Centre	62.9	72.0	61.9	56.2	36.9	40.0	36.6	34.5
Hull Centre	54.7	51.1	51.0	47.9	34.0	32.6	32.6	31.3
Haringey Roadside	87.0	99.9	83.0	80.1	35.4	38.5	34.5	33.7
Glasgow Roadside		161.9	149.3	147.4		51.5	49.0	48.6
London Marylebone Road			204.4	222.1			59.2	62.2
Camden Roadside		139.4	129.4	119.0		47.0	45.0	42.8
Sutton Roadside	69.7	75.9	64.6	68.8	31.0	32.6	29.6	30.8
Bury Roadside		180.1	161.6	149.7		54.8	51.4	49.1
Tower Hamlets Roadside	150.6	151.3	133.6	136.5	49.3	49.4	45.8	46.4
London Cromwell Road	181.6		133.7	150.4	55.1		45.9	49.2

Assumptions on re-suspended dusts and the roadside increment in concentrations

It is not possible to determine the split of the roadside increment in PM_{10} concentrations between traffic exhaust emissions and re-suspended dusts from current network measurements. The receptor model, can however, be used to determine the magnitude of the roadside increment. Analyses of PM_{10} and $PM_{2.5}$ monitoring data presented in the APEG report (APEG 1999) suggested that re-suspended component could be 50% of the total. It is likely that this is an overestimate because exhaust emission may include some particles of diameter greater than 2.5 µm. We have assumed that re-suspended dust does not contribute to the roadside increment of PM_{10} concentrations in our baseline projections. Projections for an alternative scenario in which 25% of the roadside increment in 1997 is assumed to be from re-suspended dust are listed in Table 7.7. This component of the roadside increment has been held constant from the base year to 2010. The average change in projected annual mean PM_{10} in 2010 at roadside sites is +1.6 µgm^{-3}, gravimetric as an average over projections for the three base years, compared with the 2010 baseline.

Table 7.7 Projected annual mean PM$_{10}$ concentrations 2010 from base years 1996 to 1999 (mgm^{-3}, gravimetric) for the baseline scenario and 25% of 1997 roadside increment assumed to be re-suspended dust

	projected PM$_{10}$ 2010			
Base year	1996	1997	1998	1999
Haringey Roadside		22.2	20.7	21.7
Glasgow Roadside		25.1	23.8	20.7
Marylebone Road		29.8	27.2	30.9
Camden Roadside		25.7	22.6	24.5
Sutton Roadide		20.9	19.9	20.1
Bury Roadside		24.3	23.0	22.7

Assumptions on emission height

Area emissions have been treated as a volume source of height 10m in both the mapping and site-specific projections (see section 4.3 and 6.1). This height is most appropriate for road traffic sources. A volume source of height 30m would be more appropriate for the majority of the other source sectors. Dispersion of the emissions would be expected to be somewhat more efficient for these higher level sources and it is therefore possible that we have overestimated the contribution from non-road traffic primary sources in our modelling. The site-specific projections listed in table 7.8 have been using a volume source of height 30m for non-traffic sources. This modification was found to have a very small impact on estimated concentrations. In future work, however, we will disperse non-traffic sources from a volume source of height 30m and traffic sources from a volume source of height 10m.

Table 7.8 Projected annual mean PM$_{10}$ concentrations 2010 from base years 1996 to 1999 (mgm^{-3}, gravimetric) for the baseline scenario and non-traffic primary PM$_{10}$ emissions height set to 30m

	projected PM$_{10}$ 2010			
Base year	1996	1997	1998	1999
London Bloomsbury	24.3	22.7	21.3	21.6
Birmingham Centre	21.3	19.5	18.4	18.5
Cardiff Centre	21.8	23.1	21.2	21.4
Edinburgh Centre	17.5	16.9	15.6	16.1
Belfast Centre	20.8	22.0	20.2	20.4
Liverpool Centre	21.7	22.2	21.1	20.4
Rochester	21.6	18.9	17.5	17.2
Newcastle Centre	20.3	18.6	17.5	16.8
Manchester Piccadilly	21.5	20.4	19.6	19.7
Bristol Centre	21.5	21.1	20.1	20.2
Haringey Roadside		21.3	20.0	20.9
Glasgow Roadside		22.1	21.5	18.6
Marylebone Road		26.3	24.5	27.6
Camden Roadside		24.3	21.5	23.3
Sutton Roadide		20.1	19.4	19.6
Bury Roadside		22.2	21.7	21.3

Treatment of European contribution to Primary PM$_{10}$

The treatment of contribution from European primary PM_{10} to ambient PM_{10} in the baseline projections is slightly different for the site-specific and mapped projections. It is considered as a separate component in the maps (and assumed to decline in line UK total emissions between the base year and 2010) but not specifically accounted for in the site-specific projections. It is likely, however, that this component will not show as steep a decline as UK emissions. It is reasonable to assume that this component will not be completely assigned to any of the primary, secondary or other components within the receptor model. We will not include a mapped component from European primary in future work and will assume that the majority is likely to be assigned as other in the receptor model and therefore held constant to 2010.

Alternative traffic projections for Northern Ireland

Two alternative projections are available for road traffic activity in Northern Ireland. The NRTF for 1997 implies a growth in vehicle km from 1997 to 2010 of about 25%. Projections provided by the Northern Ireland Roads Service suggest a growth in vehicle km over the same period of about 40%. This projection has been extrapolated from current trends and does not therefore include the impact of any specific policies or network constraints. In consultation with the Northern Ireland Roads Service we therefore used the NRTF projections to derive our baseline projections for Northern Ireland. Table 7.9 shows the effect of the higher traffic growth assumption. The average change in annual mean PM_{10} at Belfast Centre in 2010 for this scenario is 0.3 μgm^{-3}, gravimetric.

Table 7.9 Projected annual mean PM_{10} concentrations 2010 from base years 1996 to 1999 (μgm^{-3}, gravimetric) for the baseline scenario and higher traffic growth in Northern Ireland

	projected PM_{10} 2010			
Base year	1996	1997	1998	1999
Belfast Centre	21.1	22.4	20.5	20.7

7.4   SECONDARY PM10

More pessimistic projections of secondary PM_{10} from 1998 and 1999 base years

We have assumed a linear decline in concentrations secondary PM_{10} from 1997 to 2010 as discussed in section 2.3. Predictions of secondary particle concentrations for individual base years were calculated by scaling the measured concentrations in that year according the ratio of the best fit concentration in that year and the average meteorology prediction for 2010. The assumption in the baseline projections is that the low measured secondary PM_{10} concentrations in 1998 and 1999 were due to a combination of meteorological conditions leading to low concentrations and a long term trend due to reductions in precursor emissions. An alternative, more pessimistic interpretation of the possible trends from 1998 and 1999 to 2010 is that the low measured concentrations in 1998 and 1999 resulted from a combination of a steeper than expected reduction in emissions and more 'typical' meteorology. Such an assumption is more pessimistic than the baseline assumptions since it considers that the reduction in concentrations between 1998 and 1999 and 2010 will be less. The site-specific projections of PM_{10} presented in Table 7.10 have been calculated by extrapolating the measured sulphate and nitrate concentrations in 1998 and 1999 directly to the predicted concentrations in 2010 for average meteorology. The average change in projected annual mean PM_{10} in 2010 at background sites is

+0.3 μgm^{-3}, gravimetric as an average over projections for the four base years, compared with the 2010 baseline.

Table 7.10 Projected annual mean PM_{10} concentrations 2010 from base years 1996 to 1999 (ngm^{-3}, gravimetric) for the baseline scenario and a more pessimistic assumption for secondary PM_{10} in 1998 and 1999 base years

	projected PM_{10} 2010			
Base year	1996	1997	1998	1999
London Bloomsbury	24.4	22.7	21.9	22.3
Birmingham Centre	21.3	19.5	18.9	19.1
Cardiff Centre	21.9	23.1	21.7	22.0
Edinburgh Centre	17.5	17.0	15.9	16.5
Belfast Centre	20.8	22.0	20.5	20.8
Liverpool Centre	21.8	22.3	21.6	21.0
Rochester	21.6	18.9	18.1	18.0
Newcastle Centre	20.3	18.6	17.9	17.3
Manchester Piccadilly	21.5	20.4	20.0	20.3
Bristol Centre	21.5	21.2	20.5	20.8
Haringey Roadside		21.3	20.5	21.7
Glasgow Roadside		22.1	21.8	19.0
Marylebone Road		26.3	25.1	28.4
Camden Roadside		24.3	22.0	24.0
Sutton Roadide		20.1	20.0	20.4
Bury Roadside		22.2	22.1	21.9

More pessimistic assumption on secondary organic aerosol

We have assumed that the secondary component of PM_{10} consists of sulphates and nitrates only and have projected concentrations to 2010 on this basis in our baseline projections. Preliminary modelling work on the formation of secondary organic aerosol during photochemical episodes indicates that up to 15% of the total mass of secondary PM_{10}, could consist of secondary organic aerosol and that the bulk of this aerosol is of natural origin. This is likely to be an upper limit on the amount of secondary organic aerosol and would not be expected to show a significant decline between the base years and 2010. The projections listed in Table 7.11 have been calculated on the basis of 15% of the secondary PM_{10} in the base years being present as secondary organic aerosol. The average change in projected annual mean PM_{10} in 2010 at background sites is +0.2 μgm^{-3}, gravimetric as an average over projections for the four base years, compared with the 2010 baseline.

Table 7.11 Projected annual mean PM$_{10}$ concentrations 2010 from base years 1996 to 1999 (mgm^{-3}, gravimetric) for the baseline scenario and 15% of base year secondary PM$_{10}$ assumed to be secondary organic aerosol

	projected PM$_{10}$ 2010			
Base year	1996	1997	1998	1999
London Bloomsbury	24.8	23.0	21.6	21.8
Birmingham Centre	21.7	19.7	18.6	18.6
Cardiff Centre	22.2	23.3	21.5	21.6
Edinburgh Centre	17.8	17.1	15.7	16.2
Belfast Centre	21.1	22.2	20.3	20.5
Liverpool Centre	22.1	22.5	21.4	20.6
Rochester	22.1	19.2	17.7	17.5
Newcastle Centre	20.7	18.8	17.7	16.9
Manchester Piccadilly	21.9	20.6	19.7	19.9
Bristol Centre	21.8	21.4	20.3	20.4
Haringey Roadside		21.6	20.2	21.1
Glasgow Roadside		22.3	21.6	18.7
Marylebone Road		26.6	24.7	27.9
Camden Roadside		24.6	21.7	23.5
Sutton Roadide		20.4	19.7	19.8
Bury Roadside		22.4	21.9	21.5

Spatial variation in sulphate to nitrate base year ratios across the UK

A constant nitrate to sulphate ratio across the UK has been assumed in the baseline projections. This ratio has been derived as the average value from the receptor modelling. Measurements of both sulphate and nitrate at 12 rural sites during 2000 indicate that there is considerable spatial variation in this ratio, with the highest observed ratio in south east England (more nitrate). It is not clear at present to what extent this gradient in nitrate concentrations would be expected to be observed in the TEOM measurement of PM$_{10}$. This issue will be considered in future work.

Spatial variation in sulphate and nitrate temporal trends across the UK

Single, UK-wide values for the trends in sulphate and nitrate concentrations between 1997 and 2010 have been assumed in the baseline projections. The UK mean factor from HARM for sulphate in 2010 is a reduction to 50% of 1997 concentration, with extremes of 47% in the East Midlands and 53% in Scotland. The UK mean factor from HARM for nitrate in 2010 is a reduction to 70% of 1997 concentration, with extremes of 67% in the NI and 71% in South East. This small spatial variation in trends across the UK has not been considered in the baseline projections and will be considered alongside the spatial variation in nitrate to sulphate ratios in future work.

Alternative assumptions on the UK/other sources split in secondary PM$_{10}$

The UK contribution to sulphate concentrations has been assumed to be 44% in 1997, falling to 30% in 2010. The UK contribution to nitrate concentrations has been assumed to be 48% in 1997, falling to 45% in 2010. These percentages have been calculated as the UK average of EMEP modelling results and are broadly confirmed by the HARM model results of the UK contribution of sulphate declining from 42% to 29% and the UK contribution to nitrate declining from 44% to 42%. It is likely that these of Lagrangian models will overestimate the long-range transported component of secondary particle concentrations because mass cannot be

lost due to vertical transport. The split between UK and long-range transported sulphate and nitrate concentrations does not directly affect the baseline projected PM_{10} concentrations in 2010. The marginal impact of changes in sulphate and nitrate due to changes in UK emissions of SO_2 and NO_x would however be greater if the long-range transported component is assumed to be smaller. Site-specific projections for the illustrative package of measures in 2010 for the standard model have been compared with projections from an alternative model, in which a 75% UK contribution to sulphate and nitrate concentrations in 1997 has been assumed, declining to 60% in 2010. This change was found to increase the impact of the illustrative package of measures by 0.1 μgm^{-3}, gravimetric.

7.5   SUMMARY OF SENSITIVITY ANALYSES

Table 7.12 summarises the results of these sensitivity analyses in terms of impact on baseline concentration in 2010 and/or impact on the effectiveness of the illustrative package of measures (Stedman, et al 2001c, DEFRA et al 2001) (and therefore the implied health benefits in terms of changes in population-weighted mean background concentrations (see Stedman et al 2001d, DEFRA 2001)). The site-specific analysis is primarily based on city centre locations. Mean concentration in 2010 (averaged over the 4 base years) are about 20 μgm^{-3}, gravimetric at background sites and 22 μgm^{-3}, gravimetric at roadside sites. The population weighted mean background concentration in 2010 (averaged over the 4 base years) is 18 μgm^{-3}, so the impact of these sensitivity analyses on the population weighted mean background concentration will be somewhat smaller than listed in the table. No change means either no change at all or very small impact.

Table 7.12 Summary of sensitivity analyses (2010 site-specific projections)

Sensitivity analysis	Impact on baseline (μgm^{-3}, gravimetric)	Impact on effectiveness of measures (μgm^{-3}, gravimetric) for SA33
1.4 instead of 1.3 TEOM factor	+1.5	- 0.1 (measures more effective)
2001 draft emission factors	+0.4 background +0.8 roadside	-0.2 background measures more effective) -0.2 roadside (measures more effective) (in 2015 2001 emission factors indicate measures more effective by –0.4 background –0.6 roadside)
25% of roadside increment is re-suspended	No change background + 1.6 roadside	No effect on population weighted mean + 0.2 (out of total of 1.1) roadside (traffic measures less effective)
Assumption of emission height	No change	No change
Alternative traffic projections for NI	+0.3 (NI only)	Small increase in effectiveness in NI
More pessimistic secondary for 1998 and 1999 base years	+0.3	No change
More pessimistic secondary organic aerosol	+0.2	No change
UK/imported source split for secondary	No change	-0.1 population weighted mean (measures more effective)

We have examined the sensitivity of the predicted baseline concentrations in 2010 to the likely upper bound of uncertainty in the more important input parameters in the model. The parameter that causes the largest increase in predicted concentration is the TEOM to gravimetric conversion. The use of the draft 2001 emission factors would cause the second largest increase in background concentrations and a correspondingly larger increase in roadside concentrations. A more pessimistic assumption on the contribution to the roadside increment of concentrations from re-suspended dusts would also cause an increase in predicted roadside concentrations. The other sensitivity analyses lead to increases in concentrations in the range from 0 to 0.3 μgm^{-3}, gravimetric.

Several of the parameters have no influence on the effectiveness of the illustrative package of possible measures and others only have an effect on roadside concentrations. The 2001 emission factors, a 1.4 TEOM to gravimetric conversion factor and an assumption that UK emission contribute more to secondary concentrations than assumed in the baseline all lead to increases in effectiveness of the measures of between 0.1 and 0.2 μgm^{-3}, gravimetric for this site specific analysis. A more pessimistic assumption on the contribution to the roadside increment of concentrations from re-suspended dusts would cause a decrease in the predicted effectiveness of the illustrative package of measures.

7.6   DIFFERENT BASE YEAR METEOROLOGIES

As has already been noted the meteorological conditions can play an extremely important role in determining particle concentrations in the atmosphere, in three important ways. Firstly, extended periods of low wind speeds can reduce dispersion and lead to a build-up of high concentrations of all pollutants including particles, especially 'primary' particles from nearby sources. Secondly, in the UK, easterly air flows increase the contribution from secondary particles formed from sulphur and nitrogen emissions in Europe, so a year like 1996 when the incidence of such flows was much higher than normal, can lead to elevated particle levels in the UK. Thirdly low temperatures (or, increasingly, high temperatures) can lead to increased energy demand for heating (or for air conditioning) which increase emissions.

Table 4.4 for example shows the effect of different base year meteorologies on predicted concentrations in 2010 in the baseline and SA33 scenarios. The variation in predicted concentrations is, overall, greater than for the sensitivity analyses discussed in the previous section. This variation amounts to a spread of some 3 μgm^{-3}, gravimetric at the higher concentration sites. There is only a limited amount of data for roadside sites, but here the effect would be expected to be proportionally smaller, since the 'imported European' particles would make a proportionally smaller contribution than they would to a nearby urban background site.

7.7   OVERALL UNCERTAINTY

As noted above the overall uncertainty of the model has been assessed by calculating the concentrations for 2000 by using only the earlier years' data, and then comparing with the eventual measurements. The meteorological uncertainty discussed in the previous paragraph has also been incorporated in this process so that this should give a reasonably good estimate of the overall uncertainty of the model predictions. The plot of the modelled concentrations against those measured, for 2000, is shown in Figure 7.1 below. 60% of the predicted annual mean concentrations for 2000 are within 2 μgm^{-3} of the measured value and 90% are within 5 μgm^{-3}. The majority of the estimates showing the greatest difference from measured concentrations are due to known influences such as local construction emissions or unusual meteorological conditions leading to elevated secondary particle concentrations.

8   Acknowledgements

9   References

Abbott J and Vincent K (1999). Annual average sulphur dioxide concentration maps derived by dispersion modelling. AEA Technology, National Environmental Technology Centre. Report

Abbott and Vincent (2001). Further dispersion modelling studies of benzo[a]pyrene in the UK. AEA Technology, National Environmental Technology Centre. Report

AEA Technology (2001) The Cost of PM_{10} and NO_2 abatement. AEA Technology Report.

Air borne Particles Expert Group (APEG). Source Apportionment of Airborne Particulate Matter in the United Kingdom. ISBN 0-7058-1771-7, January 1999.

DEFRA et al (2001). Department for Environment, Food and Rural Affairs, The Scottish Executive, The National Assembly for Wales and The Department of the Environment Northern Ireland. Proposals for air quality objectives for particles, benzene, carbon monoxide and polycyclic aromatic hydrocarbons.

DEFRA (2001). Department for Environment, Food and Rural Affairs. An Economic Analysis to Inform the Review of the Air Quality Strategy Objectives for Particles. A Second Report of the Interdepartmental Group on Costs and Benefits.

Department of the Environment, Transport and the Regions, The Scottish Executive, The National Assembly for Wales and The Department of the Environment Northern Ireland. The Air Quality Strategy for England, Scotland, Wales and Northern Ireland. January 2000.

DETR (2000a). Transport 2010: The 10 Year Plan. Department of the Environment, Transport and the Regions. July 2000. www.detr.gov.uk/trans2010/index.htm

DETR (2000b). Transport 2010: The Background Analysis. Department of the Environment, Transport and the Regions. July 2000. www.detr.gov.uk/trans2010/index.htm

Barlow, TJ, Hickman AJ and Boulter P, (2001), Exhaust Emission factors 2001. Database and Emission Factors.

DTI (2000). Department of Trade and Industry. Energy Paper 68. Energy Projections for the UK. The Stationary Office.

Goodwin, J. W. L., Salway, A. G., Murrells, T. P., Dore C. J. Passant N. R.and Eggleston, H. S. (2000) UK Emissions of Air Pollutants 1970-1998. National Atmospheric Emissions Inventory, AEA Technology, National Environmental Technology Centre. Report AEAT/R/EN/0270.

Metcalfe, S.E., Whyatt, J.D., Broughton, R., Derwent, R.G., Finnegan, D., Hall, J., Mineter, M., O'Donoghue, M. and Sutton, M.A. (2001) Developing the Hull Acid Rain Model: its validation and implications for policy makers. *Environmental Science and Policy* **4**, 25-37.

Murrells T. P. (2000). UK Road Transport Emission Projections: The Assumptions Used and Results of the 1997 National Atmospheric Emissions Inventory Base Projection. AEA Technology Environment. Report AEAT-5953.

Stedman, J. R., Vincent, K. J., Campbell, G. W., Goodwin, J. W. L. and Downing, C. E. H. (1997). New High Resolution Maps of Estimated Background Ambient NO_x and NO_2 Concentrations in the UK. *Atmospheric Environment,* **31** 3591-3602.

Stedman, J. R. (1997). A UK-wide episode of elevated particle (PM_{10}) concentration in March 1996. *Atmospheric Environment* **31** 2379-2383.

Stedman, J R (1998). The secondary particle contribution to elevated PM_{10} concentrations in the UK. *Clean Air* **28** 87-93.

Stedman, JR (1998). Revised High Resolution Maps of Background Air Pollutant Concentrations in the UK: 1996. AEA Technology, National Environmental Technology Centre. Report 20008001/006. AEAT - 3133.

Stedman JR, Bush T and King K (1998a). An empirical model for estimating roadside nitrogen dioxide concentrations in the UK. AEA Technology Environment, National Environmental Technology Centre. Report AEAT-4291.

Stedman, JR, Linehan E, Espenhahn S, Conlan B, Bush T and Davies T (1998b). Predicting PM_{10} concentrations in the UK. AEA Technology Environment, National Environmental Technology Centre. Report AEAT-4630.

Stedman J R (1999) Site specific projections of NO_x and NO_2 concentrations for the UK. AEA Technology, National Environmental Technology Centre. Report AEAT – 5850. www.aeat.co.uk/netcen/airqual/reports/home.html

Stedman J R, Bush T J and Linehan E B (2000) The 10 Year Transport Plan. Site specific analyses of ambient NO_2 and PM_{10} concentrations. AEA Technology, National Environmental Technology Centre. Report AEAT/R/ENV/0166.

Stedman J R and Bush T (2000) Mapping of nitrogen dioxide and PM10 in the UK for Article 5 Assessment. AEA Technology, National Environmental Technology Centre. Report.

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

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

Stedman, J R, Bush, T J, Murrells, T P, Hobson, M and Handley C. (2001c). Projections of PM_{10} and NO_x concentrations in 2010 for additional measures scenarios. AEA Technology, National Environmental Technology Centre. Report AEAT/ENV/R/0727.

Stedman J R, King K and Holland M. (2001d) Quantification of the Health Effects of Air Pollution in the UK for PM_{10} Objective Analysis. AEA Technology Environment, National Environmental Technology Centre. Report AEAT/ENV/R/0728.

Stedman J R and Handley C (2001) A comparison of national maps of NO2 and PM10 concentrations with data from the NETCEN 'Calibration Club' AEA Technology, National Environmental Technology Centre. Report AEAT/ENV/R/0725.

TNO (1997) Particulate Matter Emissions (PM_{10}, $PM_{2.5}$, $PM_{<0.1}$) in Europe in 1990 and 1993, TNO Report TNO-MEP-R96/472, Netherlands, February 1997.

Warren, R.F., and ApSimon, H.M. (2000) The Role of Secondary Particulates in European Emission Abatement Strategies: Illustrations using the Abatement Strategies Assessment Model, ASAM, *Integrated Assessment*, **1**, 63-86

Watkiss, P, Pye, S, Holland, M, Forster, D and King, K (2001). Quantification of the non-health effects of air pollution in the UK for PM_{10} objective analysis. AEA Technology, National Environmental Technology Centre. Report

Figure 2.1. Comparison of trends in annual mean sulphate partcile concentrations
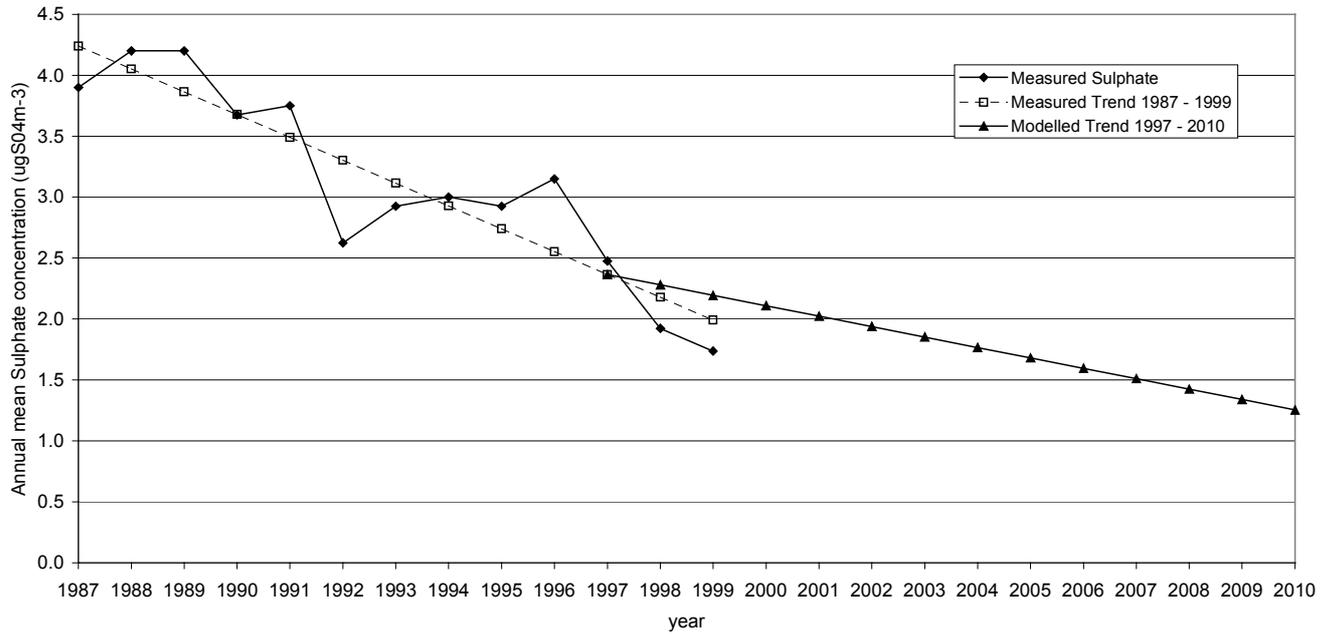
Figure 2.2. Comparison of trends in annual mean nitrate partcile concentrations
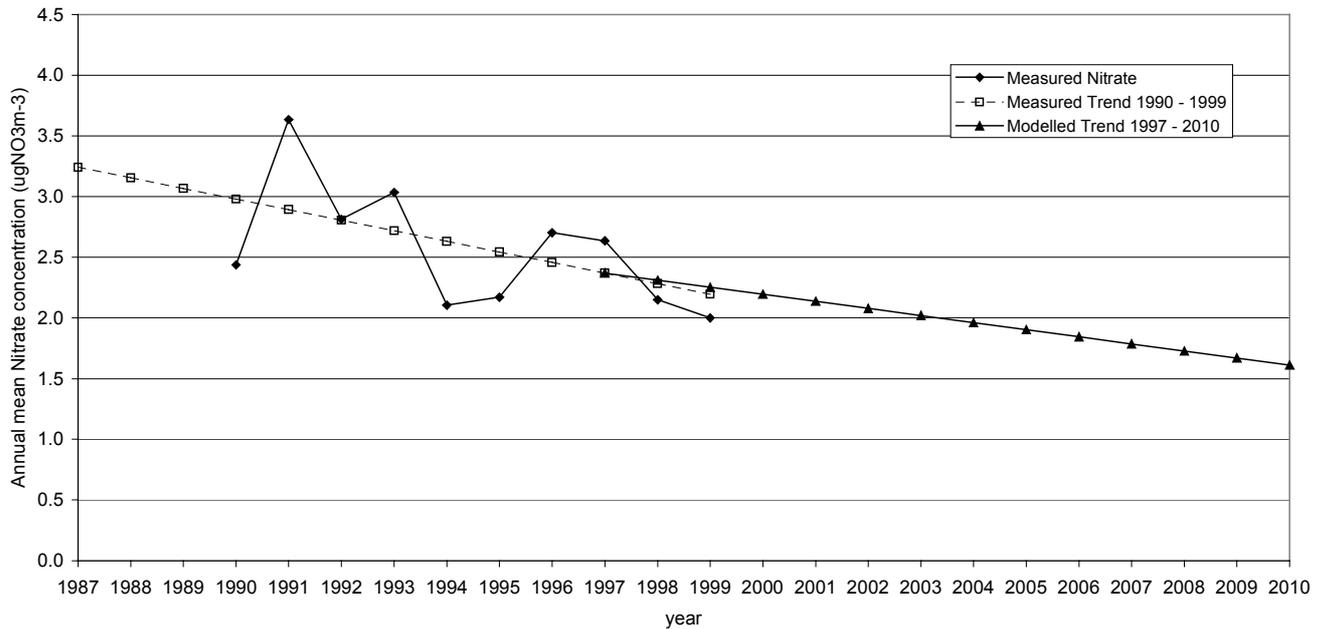
Figure 3.1 Site-specific projections of annual mean NOx and NO2 concentrations at West London
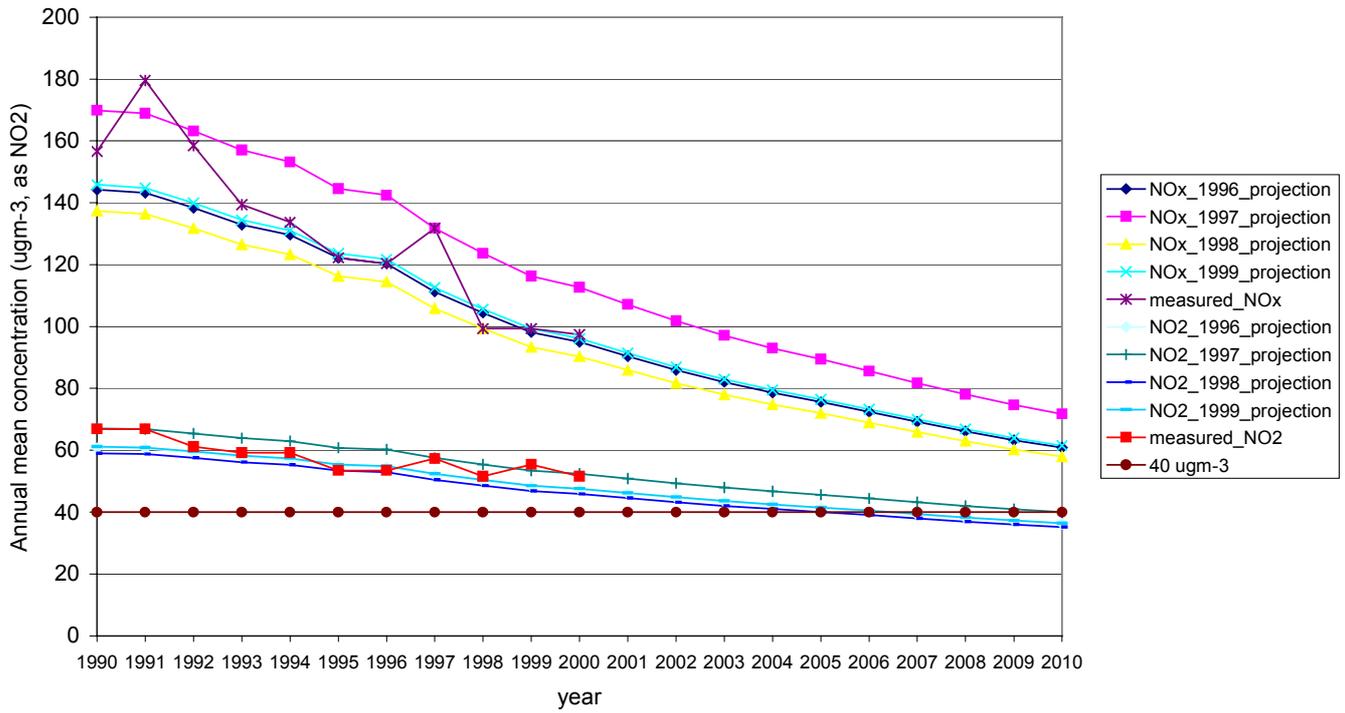
Figure 3.2 Site-specific projections of annual mean NOx and NO2 concentrations at Cardiff Centre
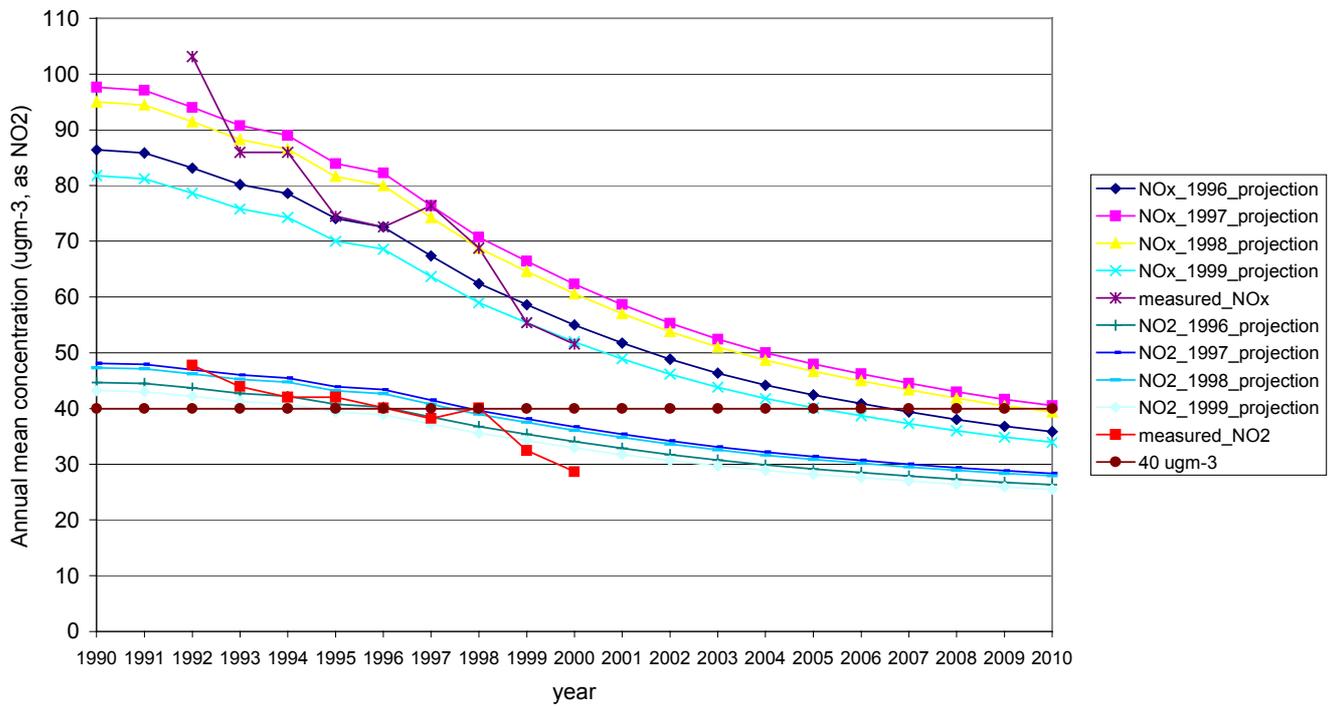
Figure 3.3 Site-specific projections of annual mean NOx and NO2 concentrations at Haringey Roadside
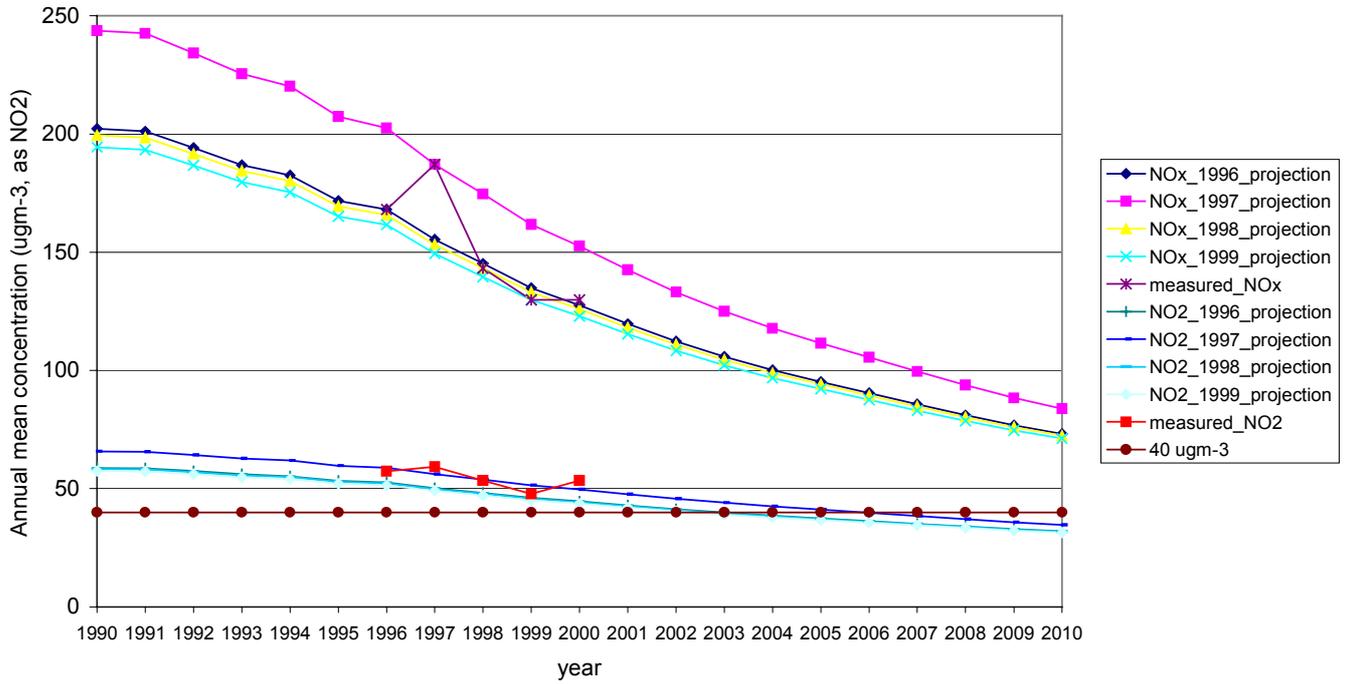
Figure 3.4 Site-specific projections of annual mean NOx and NO2 concentrations at Glasgow Roadside
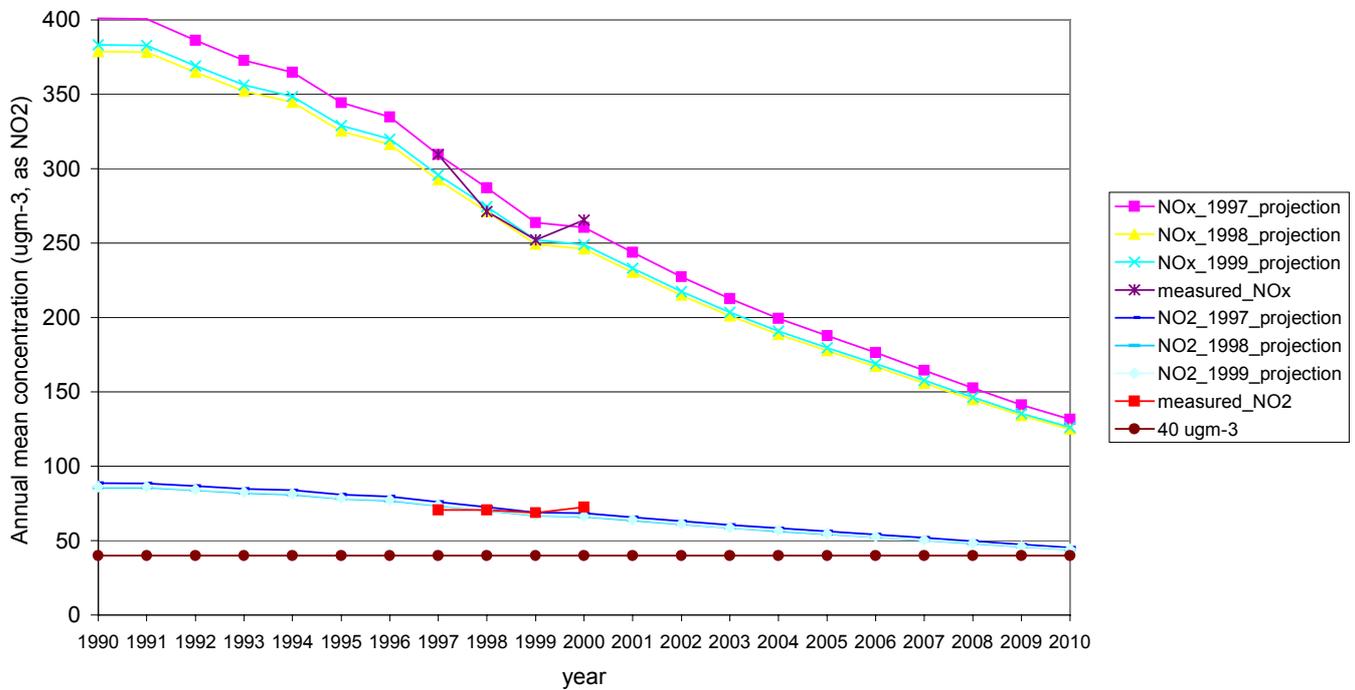
Figure 4.1 Site-specific projections of annual mean PM10 concentrations at London Bloomsbury
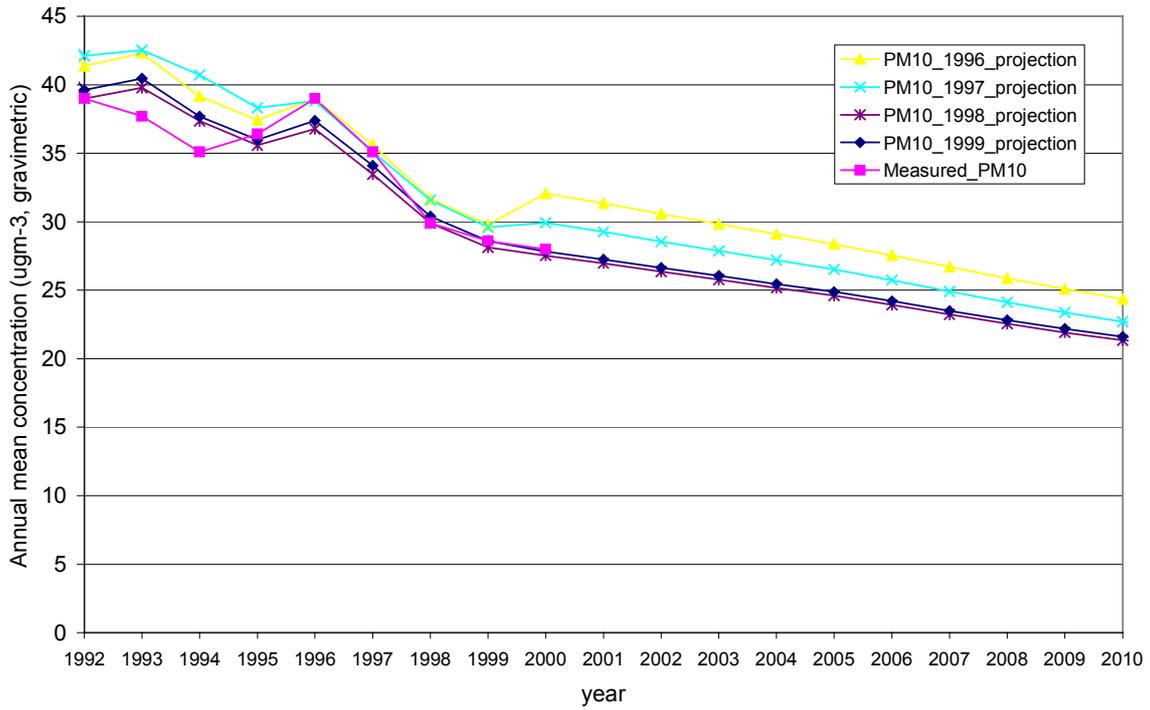
Figure 4.2 Site-specific projections of annual mean PM10 concentrations at Belfast Centre
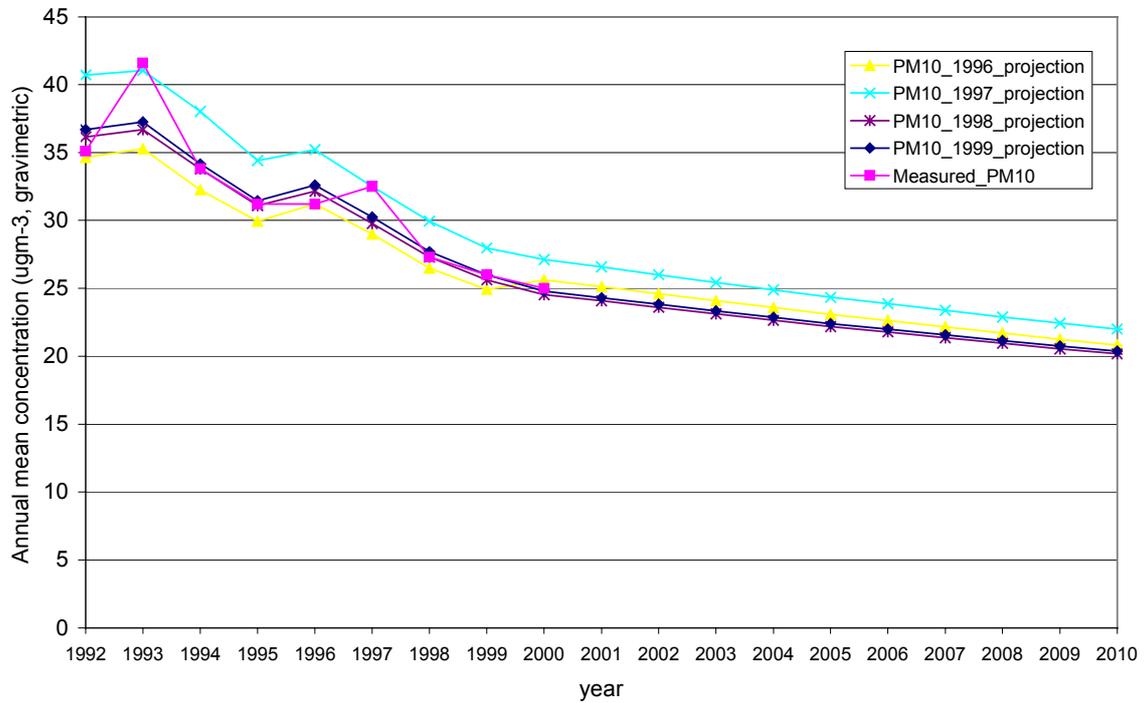
Figure 4.3 Site-specific projections of annual mean PM10 concentrations at Bury Roadside
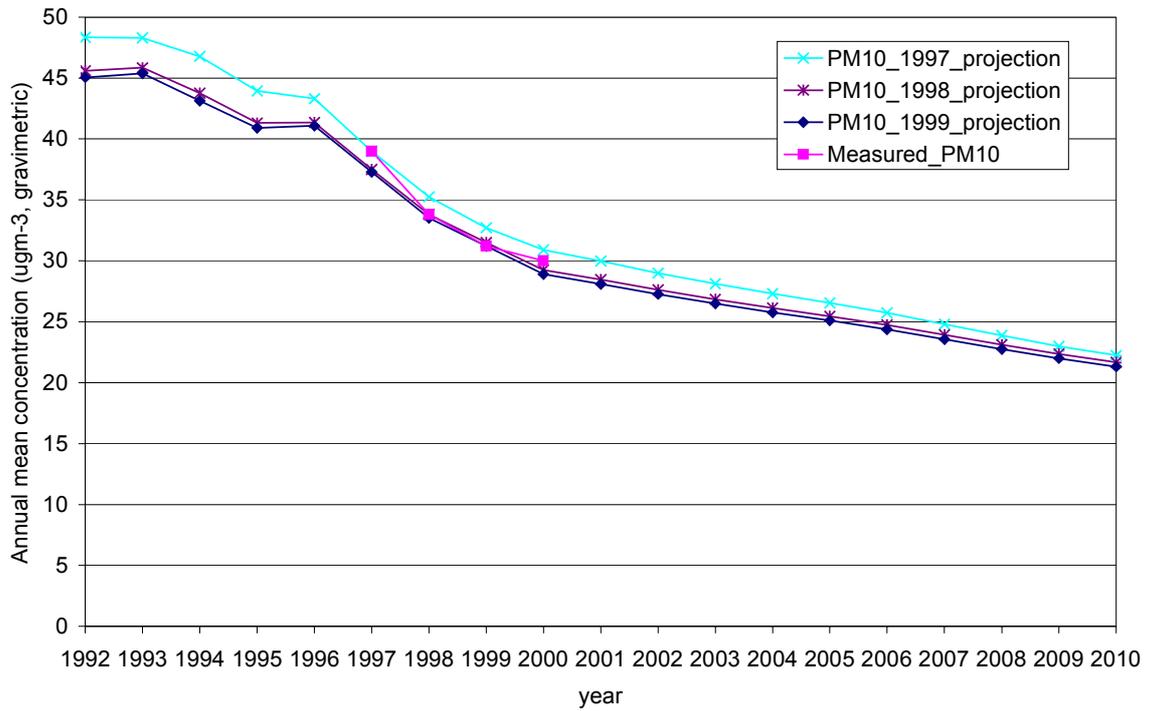
Figure 4.4 Site-specific projections of annual mean PM10 concentrations at Sutton Roadside
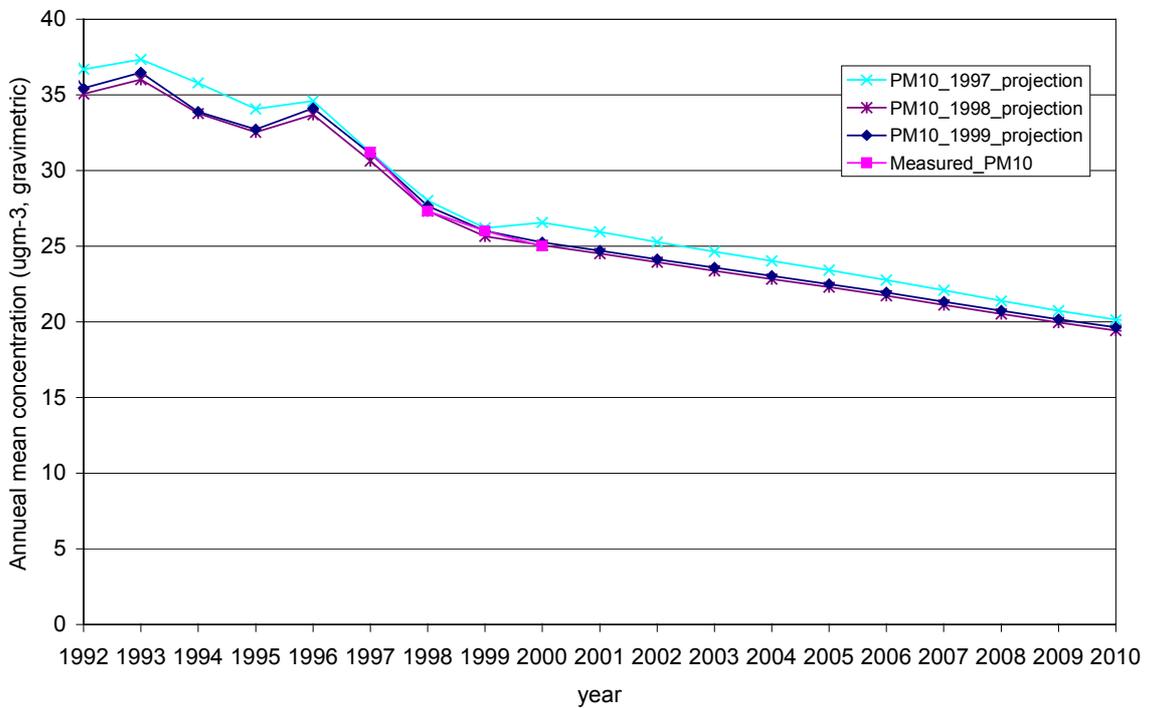
Figure 4.5 The relationship between the number of days with PM10 concentrations greater than or equal to 50 ugm-3 and annual mean (National network TEOM data 1992-1999)
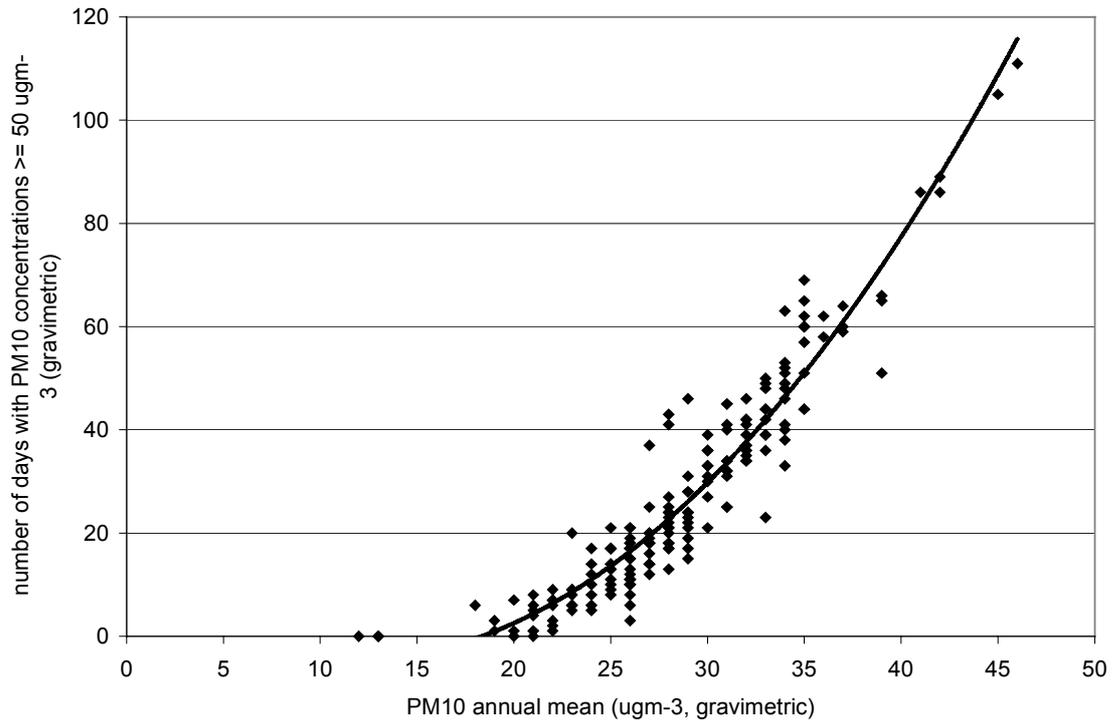
Figure 5.1 The relationship between ambient NOx concentrations and the weighted sum of local emissions
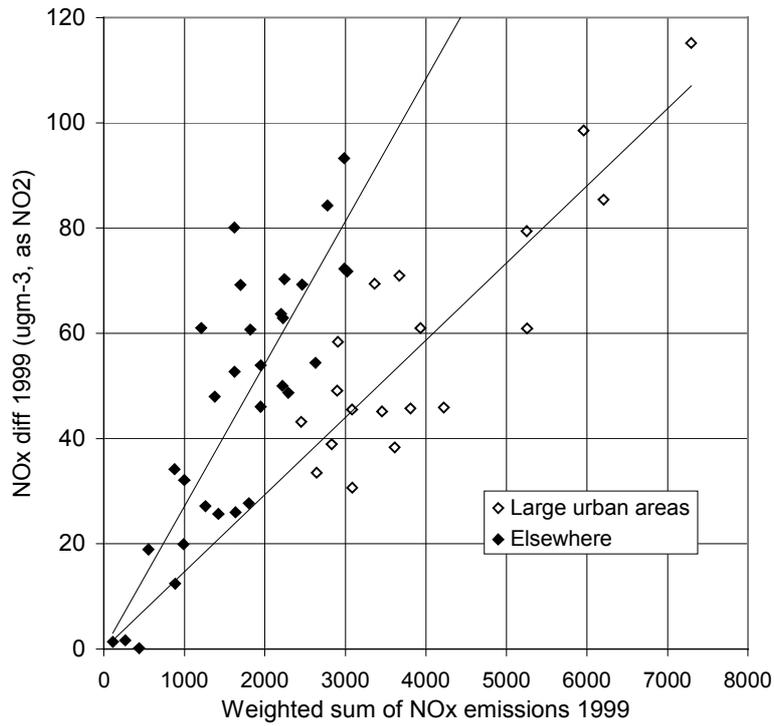
Figure 5.2 The relationship between the roadside increment of NOx and road link emissions
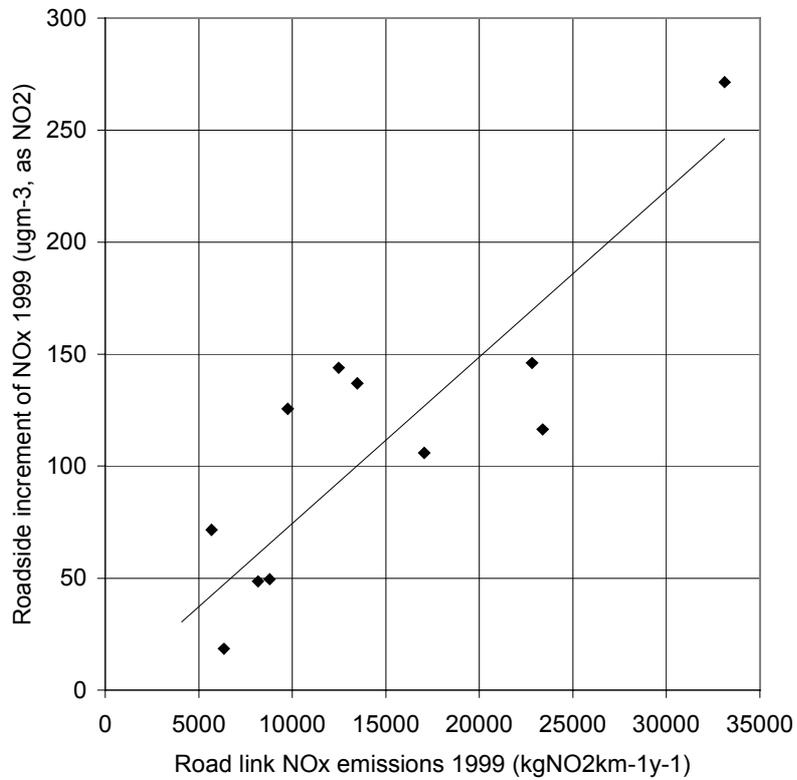
Figure 5.3
Estimated annual mean background nitrogen dioxide concentration, for base years
1996 to 1999 (ugm–3). Ref NETCEN 20/09/2000 /naqs3/nox1998naei/UK1NO219961

1996

1997

BELOW 5   10 – 15   20 – 30   40 – 50

5 – 10   15 – 20   30 – 40   ABOVE 50

1998

1999
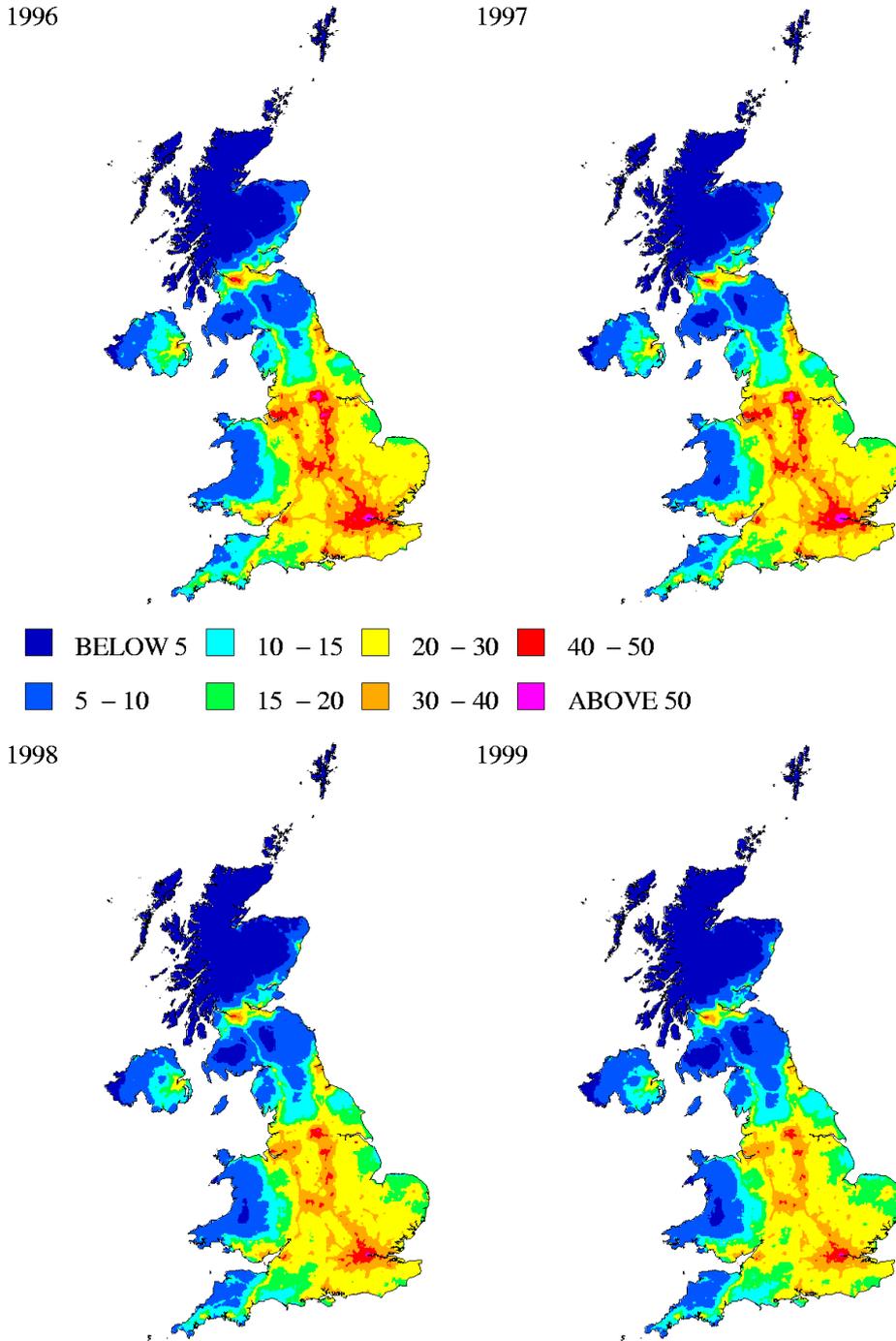
Figure 5.4a Measured and modelled annual mean NO2 at background sites 1996 (ugm-3)
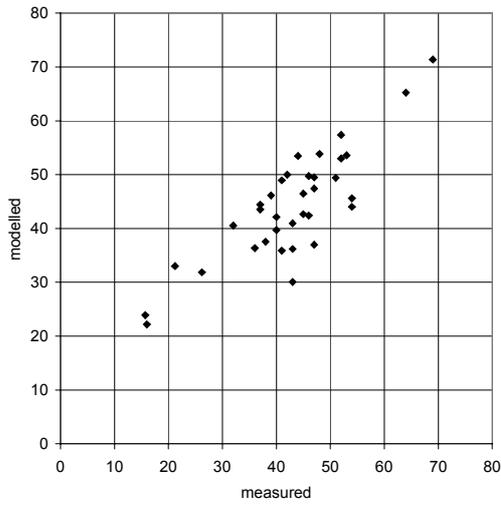
Figure 5.4b Measured and modelled annual mean NO2at background sites 1997 (ugm-3)
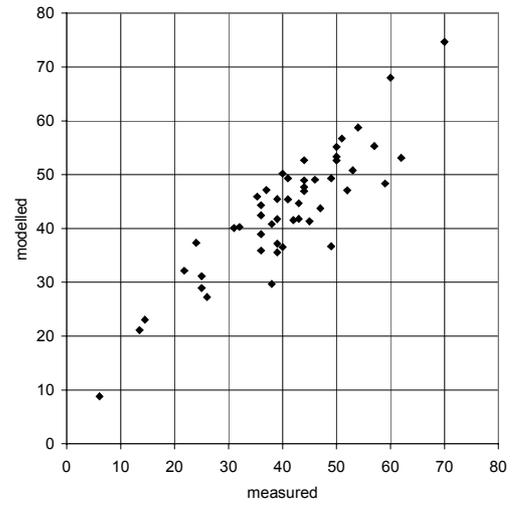
Figure 5.4c Measured and modelled annual mean NO2 at background sites 1998 (ugm-3)
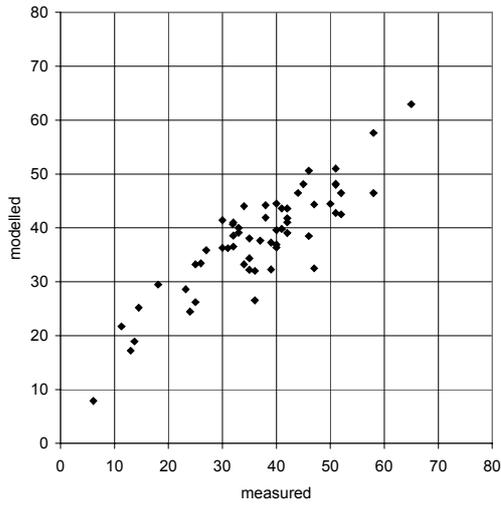
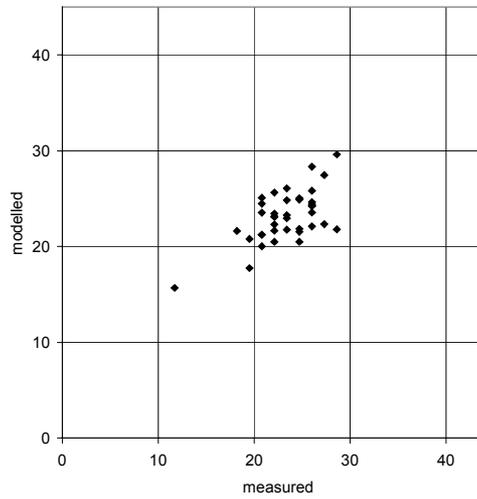**Figure 5.4d Measured and modelled annual mean NO2 at background sites 1999 (ugm-3)**
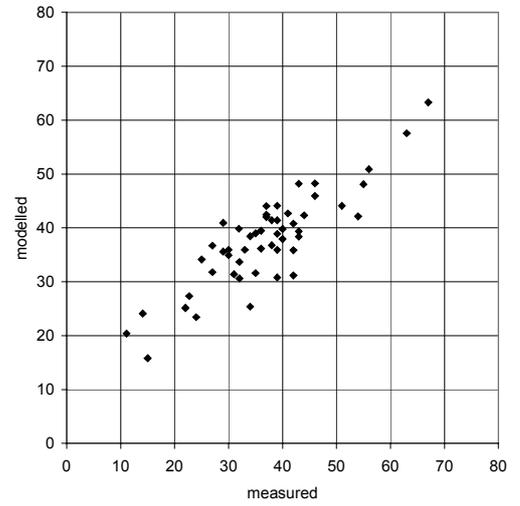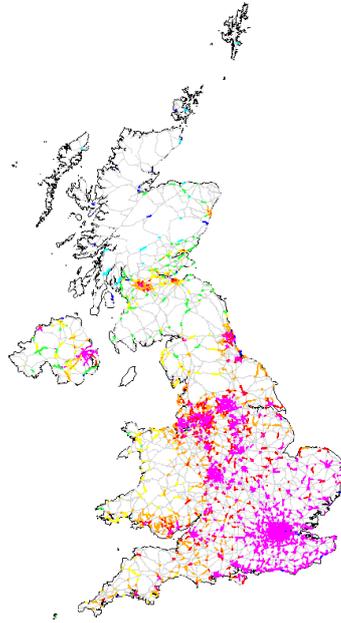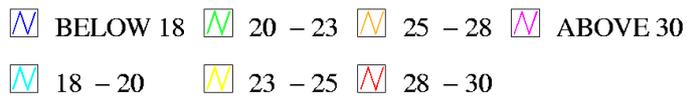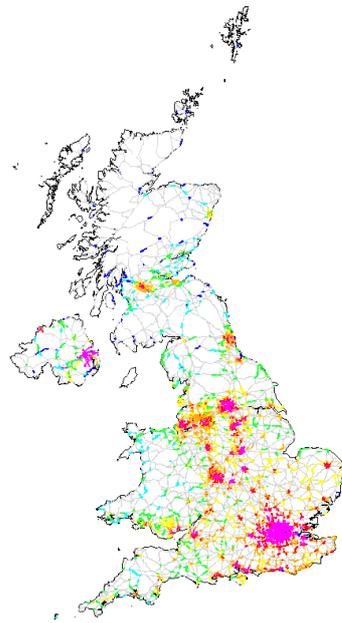
Figure 5.5.
Major urban roads, estimated annual mean roadside NO2 concentration,
for base years 1996 to 1999 (ugm-3), Ref NETCEN 28/09/2000 census_loca98

1996

1997

BELOW 20   30 – 40   50 – 60   ABOVE 70

20 – 30   40 – 50   60 – 70
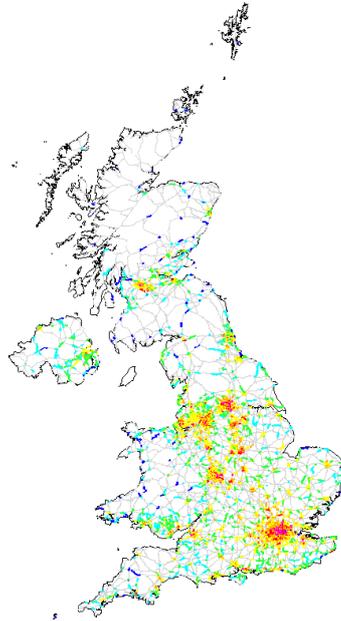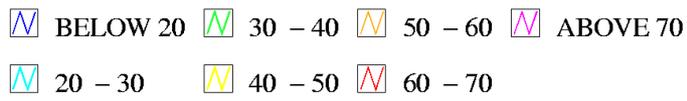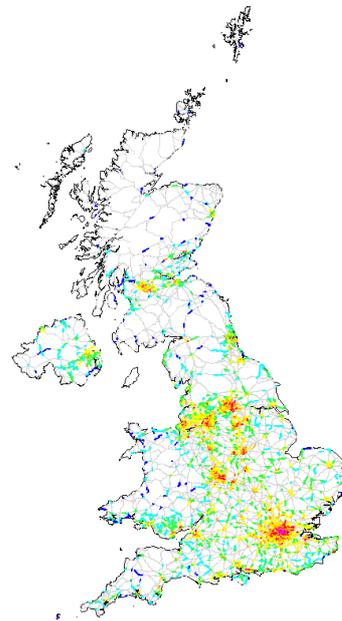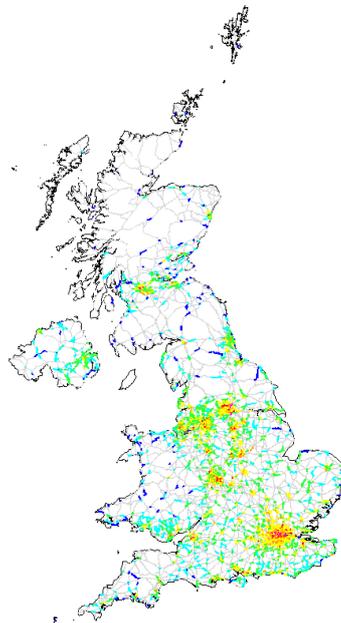
1998

1999
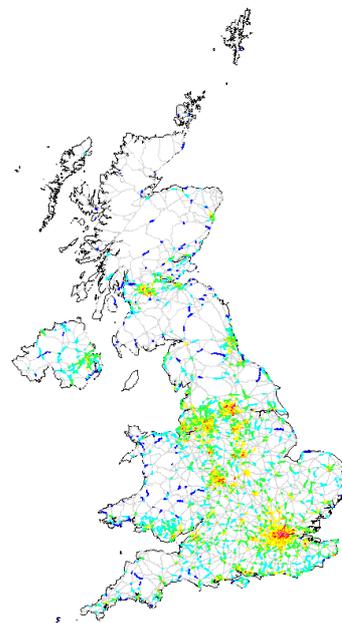
Figure 5.6a Measured and modelled annual mean NO2 at roadside sites 1996 (ugm-3)
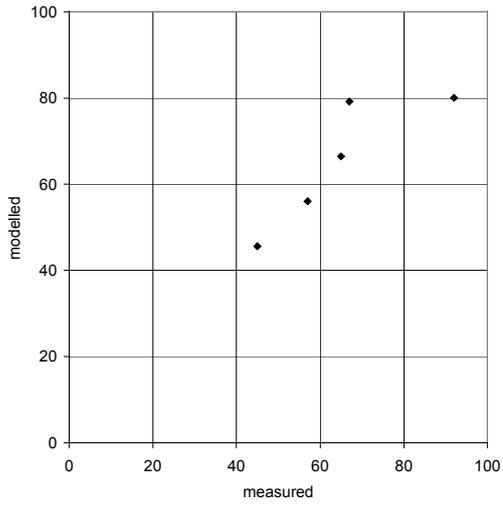
Figure 5.6b Measured and modelled annual mean NO2 at roadside sites 1997 (ugm-3)
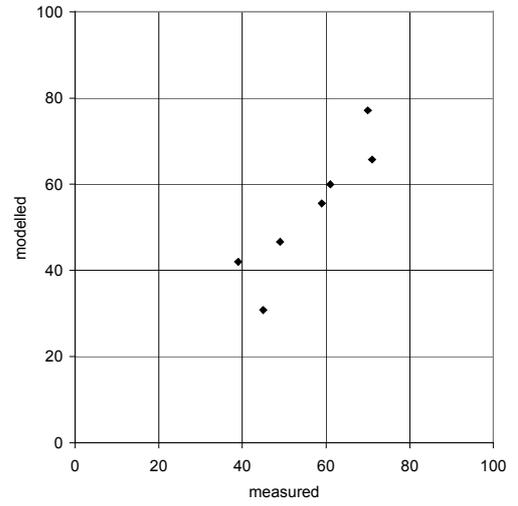
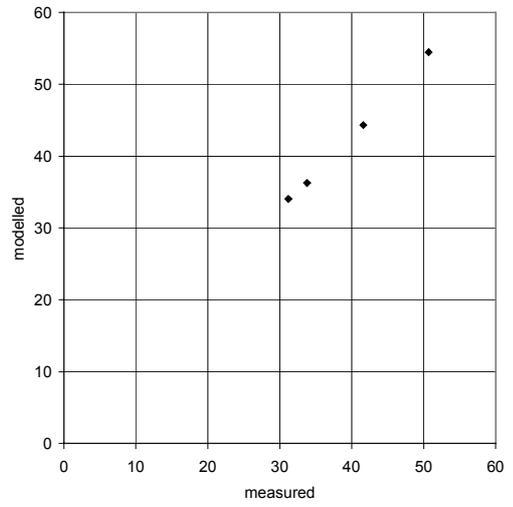**Figure 5.6c Measured and modelled annual mean NO2 at roadside sites 1998 (ugm-3)**
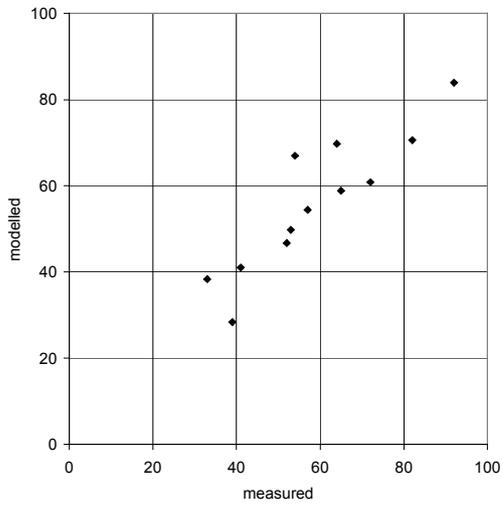
Figure 5.6d Measured and modelled annual mean NO2 at roadside sites 1999 (ugm-3)

AEA Technology
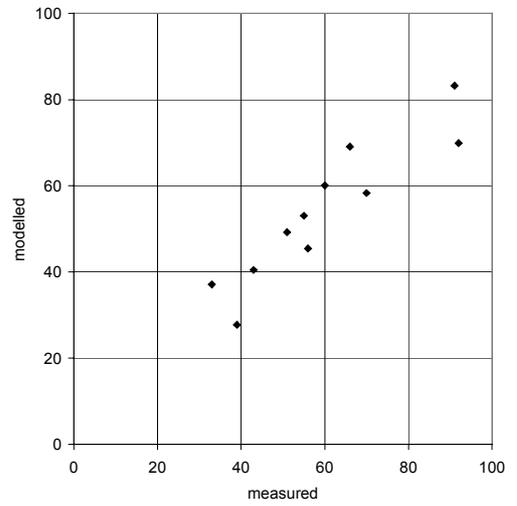
Figure 5.7
Estimated annual mean background nitrogen dioxide concentration, 2010 baseline
scenario (ugm-3). Ref NETCEN 07/03/2001 /naqs3/nox1998naei/

2010, base year 1996   2010, base year 1997

■	BELOW 5	■	10 − 15	■	20 − 30	■	40 − 50
■	5 − 10	■	15 − 20	■	30 − 40	■	ABOVE 50
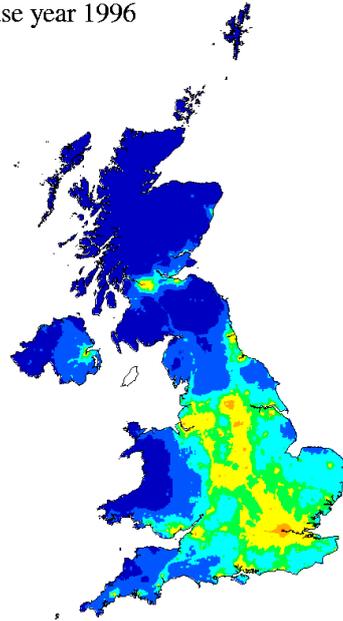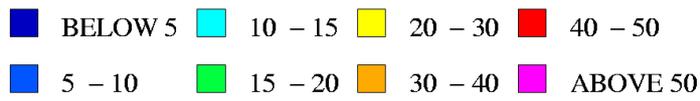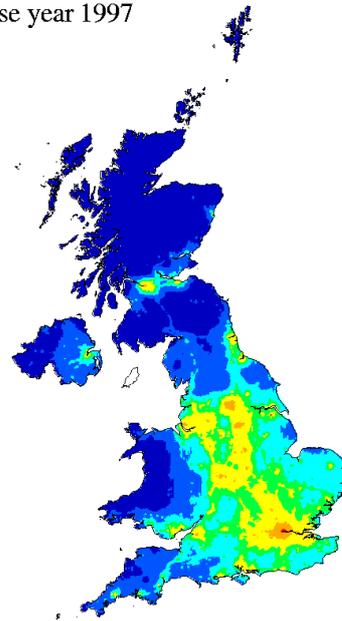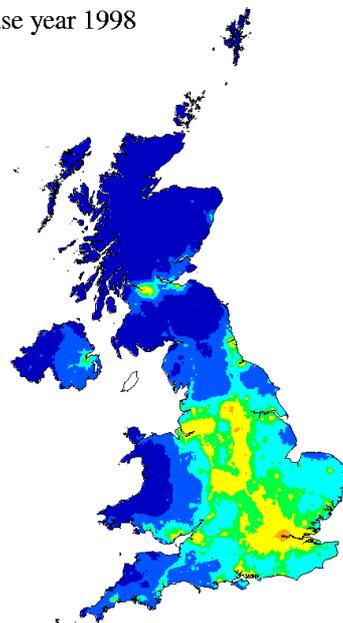
2010, base year 1998   2010, base year 1999
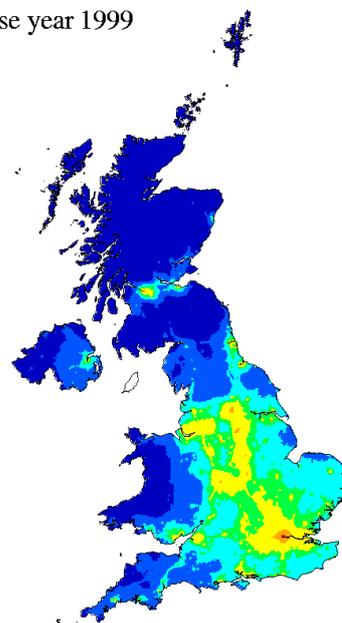
Figure 5.8.
Major urban roads, estimated annual mean roadside NO2 concentration,
for 2010 baseline scenario (ugm–3), Ref NETCEN 07/03/2001 census_locs98

2010, base year 1996

2010, base year 1997

BELOW 20   30 – 40   50 – 60   ABOVE 70

20 – 30   40 – 50   60 – 70
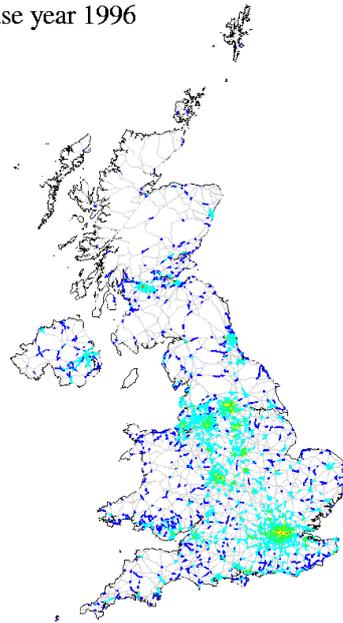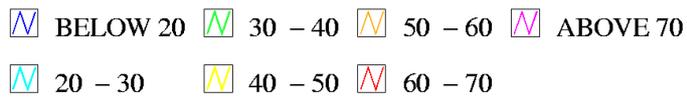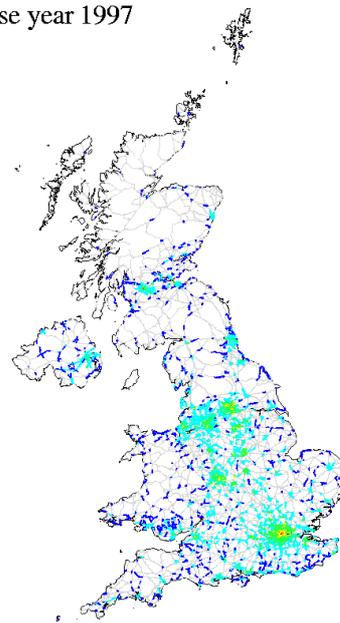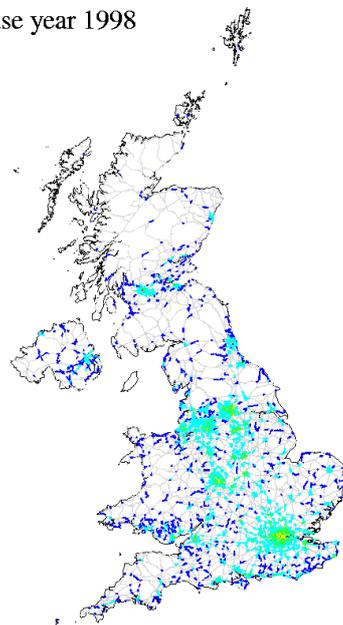
2010, base year 1998

2010, base year 1999
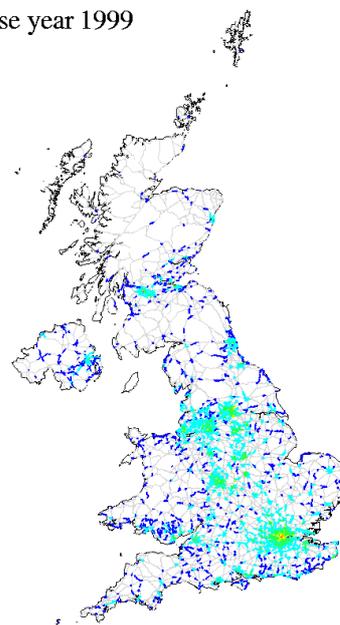
Figure 6.1 The relationship between ambient PM10 concentrations and the weighted sum of local emissions
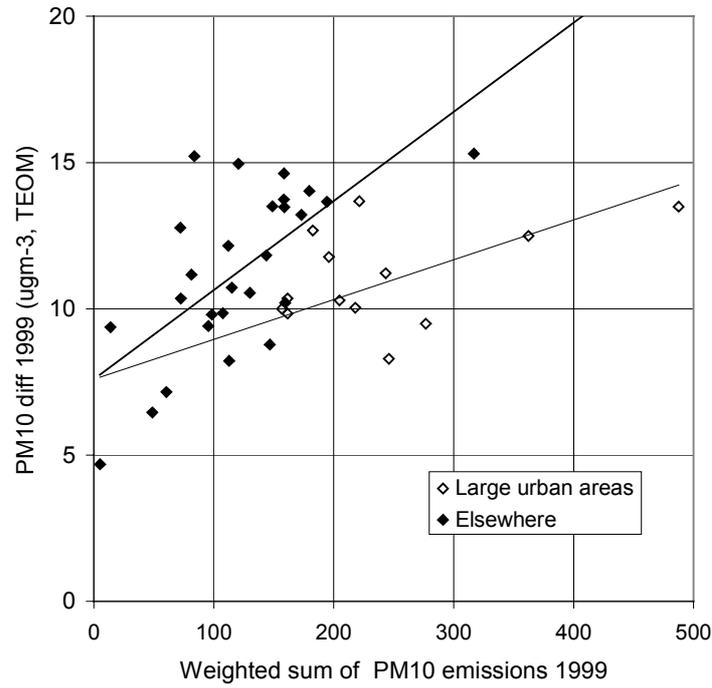
Figure 6.2 The relationship between the roadside increment of PM10 and road link emissions
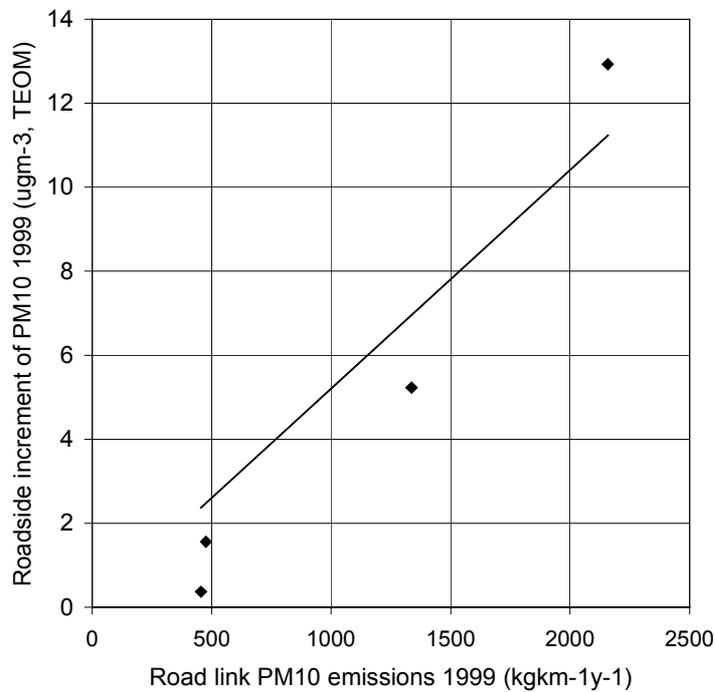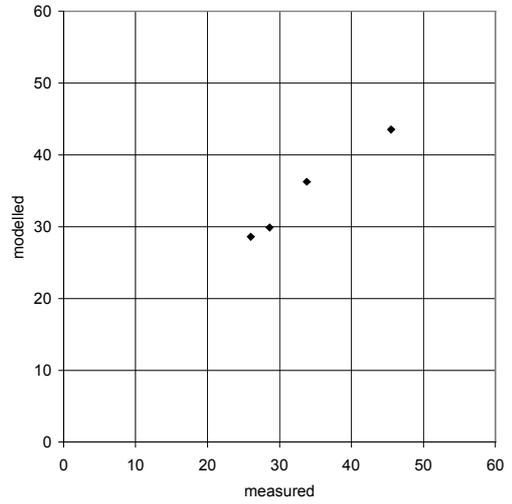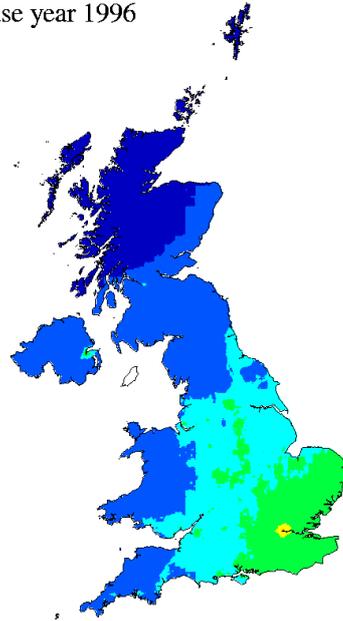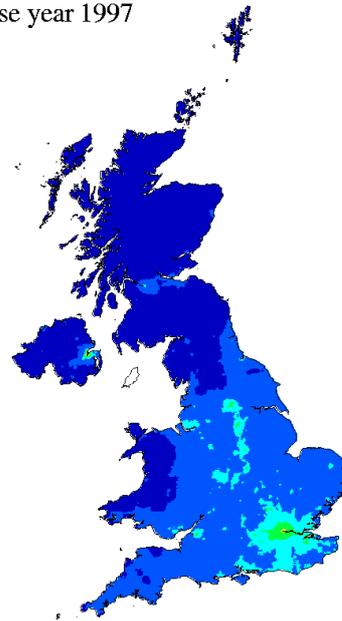
Figure 6.3
Estimated annual mean background PM10 concentration, for base years
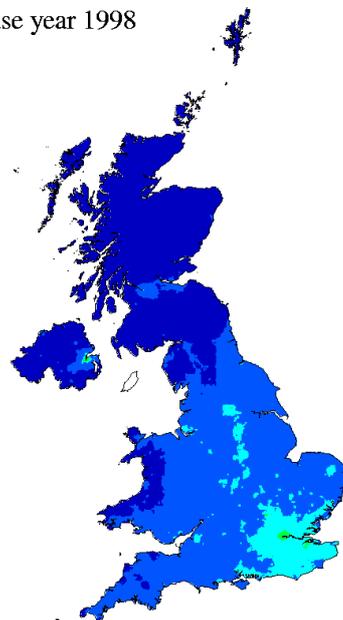1996 to 1999 (ugm–3, gravimetric). Ref NETCEN 25/09/2000 /naqs3/pm101998naei

1996

1997

■ (dark blue)	BELOW 15	■ (cyan)	18 – 20	■ (yellow)	23 – 25	■ (red)	28 – 30
■ (blue)	15 – 18	■ (green)	20 – 23	■ (orange)	25 – 28	■ (magenta)	ABOVE 30

1998

1999
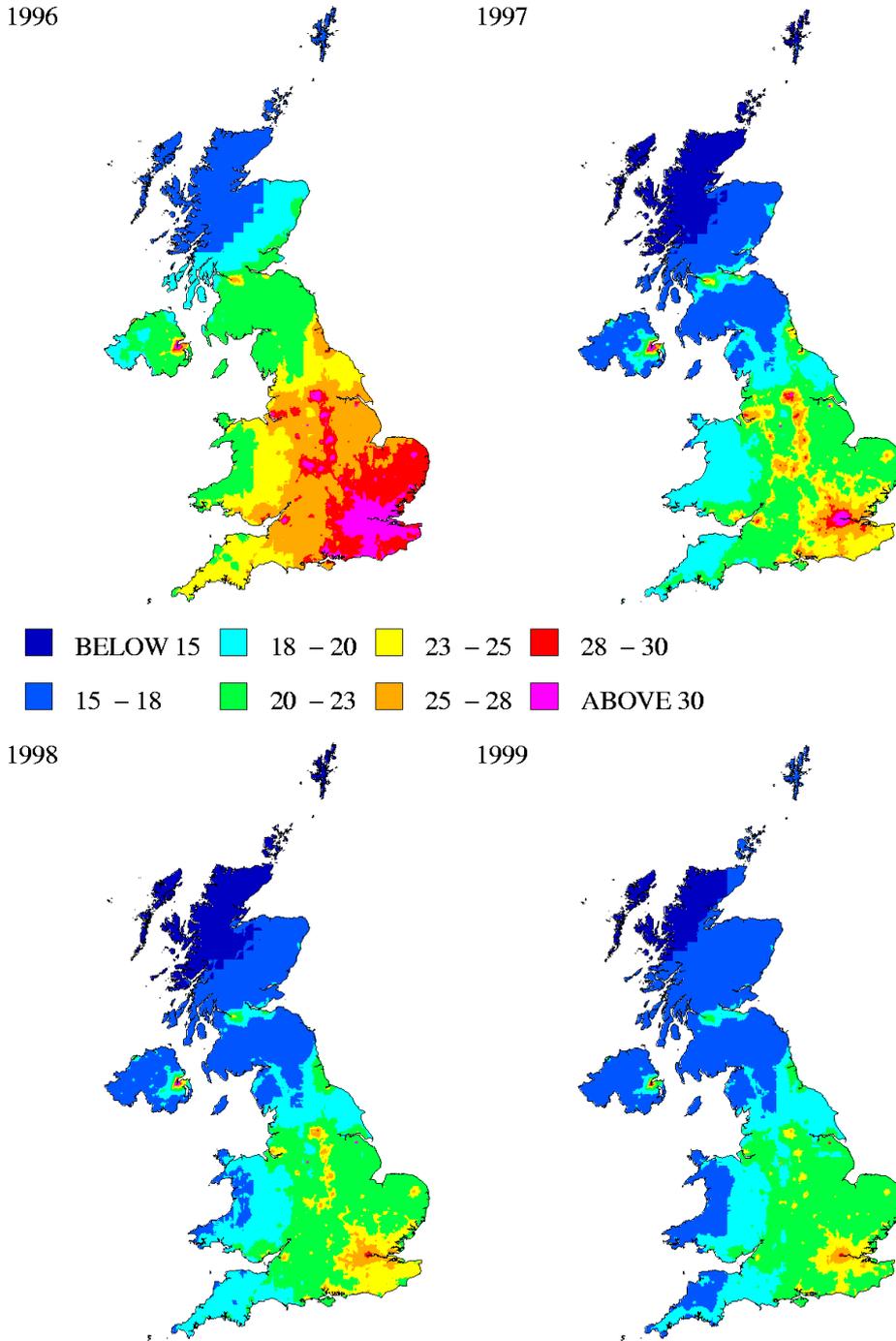
Figure 6.4a Measured and modelled annual mean PM10 at background sites 1996 (ugm-3, gravimetric)
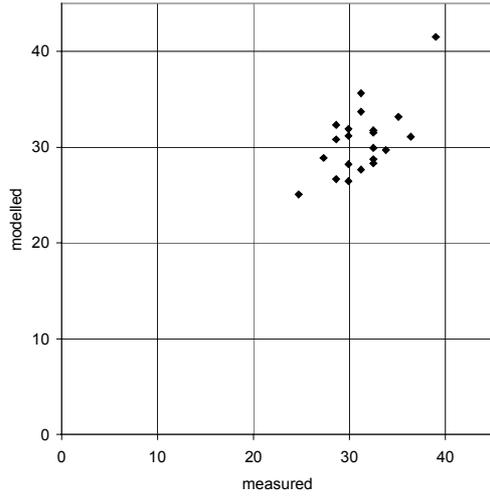
Figure 6.4b Measured and modelled annual mean PM10 at background sites 1997 (ugm-3, gravimetric)
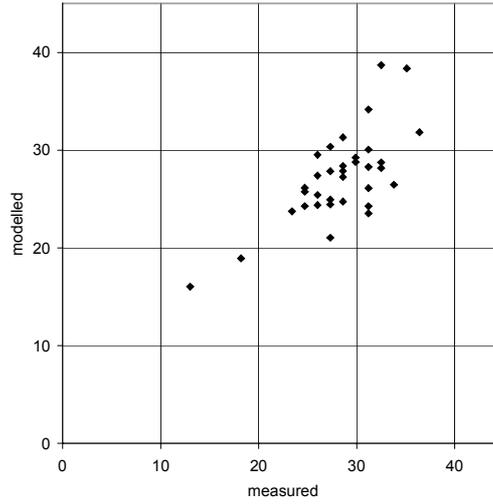
Figure 6.4c Measured and modelled annual mean PM10 at background sites 1998 (ugm-3, gravimetric)
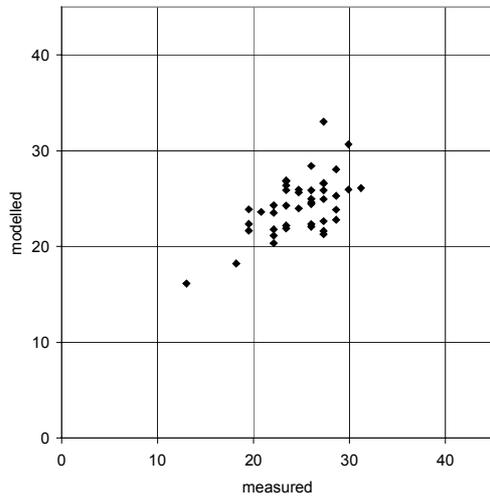
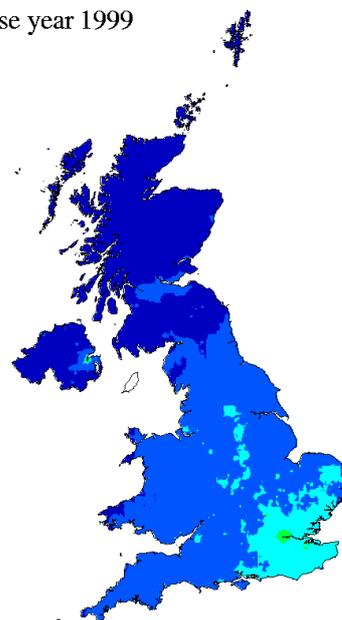**Figure 6.4d Measured and modelled annual mean PM10 at background sites 1999 (ugm-3, gravimetric)**
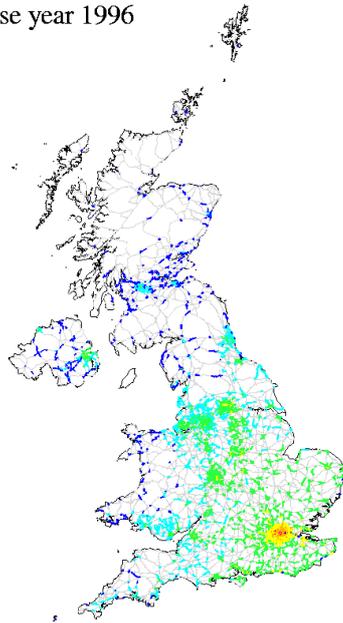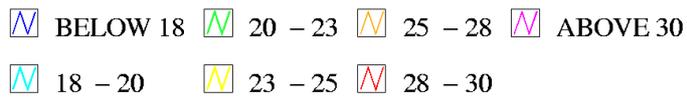
Figure 6.5.
Major urban roads, estimated annual mean roadside PM10 concentration,
for base years 1996 to 1999 (ugm-3, gravimetric), Ref NETCEN 28/09/2000 census_locs98

1996

1997

BELOW 18   20 – 23   25 – 28   ABOVE 30

18 – 20   23 – 25   28 – 30
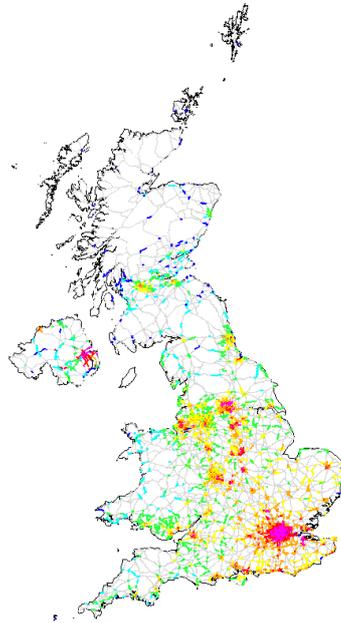
1998

1999
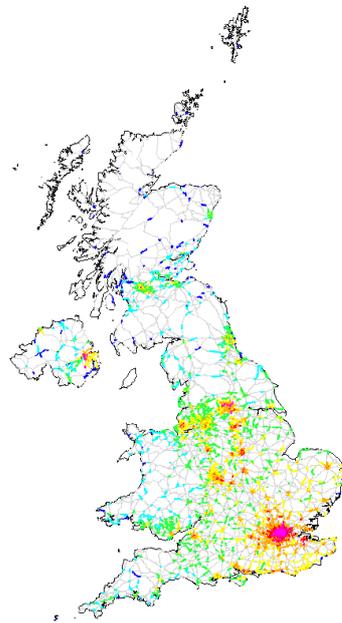
**Figure 6.6b Measured and modelled annual mean PM10
at roadside sites 1997 (ugm-3, gravimetric)**

**Figure 6.6c Measured and modelled annual mean PM10
at roadside sites 1998 (ugm-3, gravimetric)**
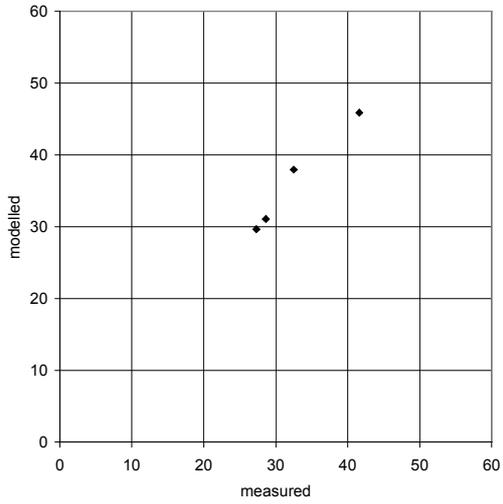
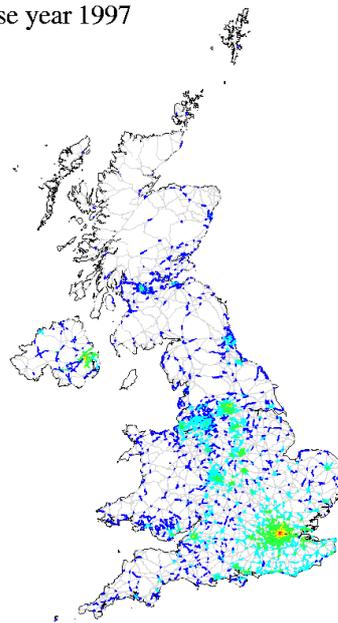**Figure 6.6d Measured and modelled annual mean PM10
at roadside sites 1999 (ugm-3, gravimetric)**

Figure 6.7
Estimated annual mean background PM10 concentration, for 2010 baseline scenario
(ugm–3, gravimetric). Ref NETCEN 07/03/2001 /naqs3/pm101998naei

2010, base year 1996   2010, base year 1997

BELOW 15   18 – 20   23 – 25   28 – 30
15 – 18   20 – 23   25 – 28   ABOVE 30

2010, base year 1998   2010, base year 1999

Figure 6.8.
Major urban roads, estimated annual mean roadside PM10 concentration,
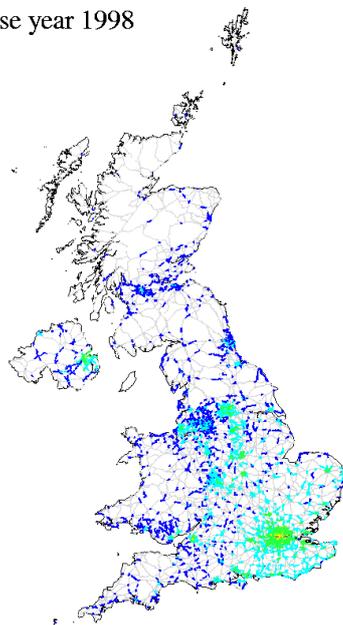for 2010 baseline scenario (ugm-3, gravimetric), Ref NETCEN 07/03/2001 census_locs98

2010, base year 1996

2010, base year 1997

| $\boxed{N}$ BELOW 18 | $\boxed{N}$ 20 – 23 | $\boxed{N}$ 25 – 28 | $\boxed{N}$ ABOVE 30 |
| $\boxed{N}$ 18 – 20 | $\boxed{N}$ 23 – 25 | $\boxed{N}$ 28 – 30 | |

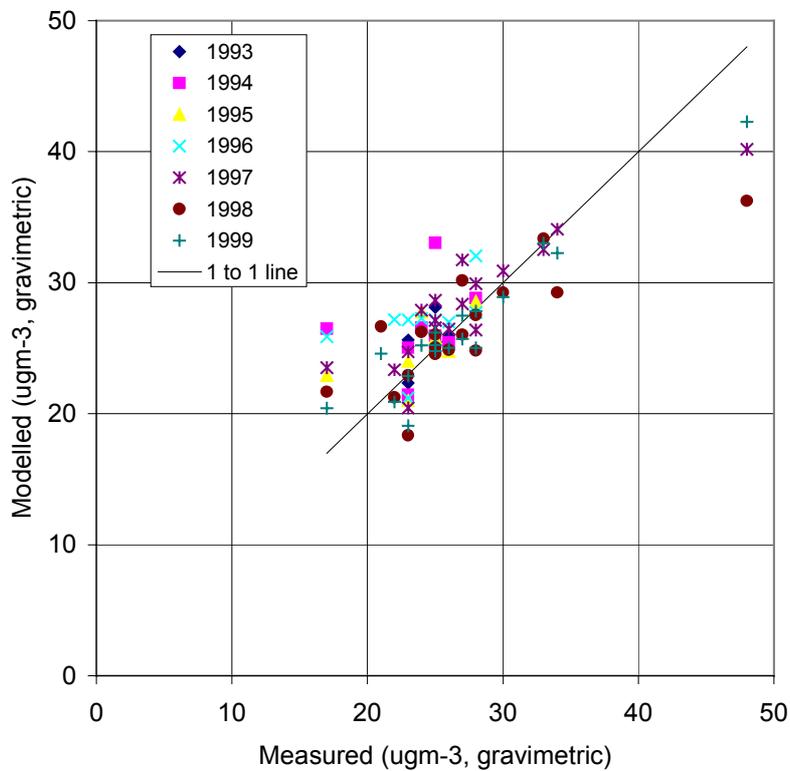2010, base year 1998

2010, base year 1999
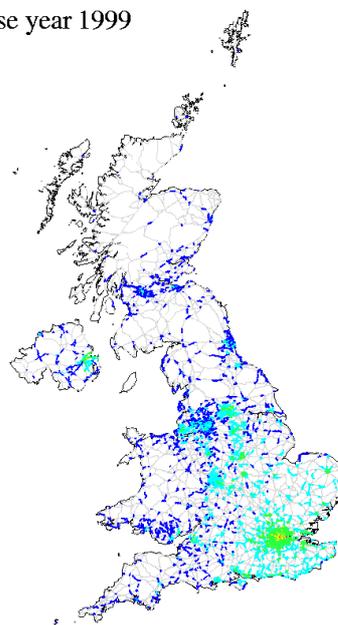
Figure 7.1 Comparison of modelled and measured annual mean PM10 concentrations for 2000 for a range of base years (1:1 line shown)

APPENDIX 1

THE RELATIONSHIPS BETWEEN ANNUAL MEAN NO_x AND NO_2 CONCENTRATIONS

Figure A1. Comparison of annual mean NOx and NO2 concentrations, for background sites with at least 3 years of data in 1998 (1990–1998)
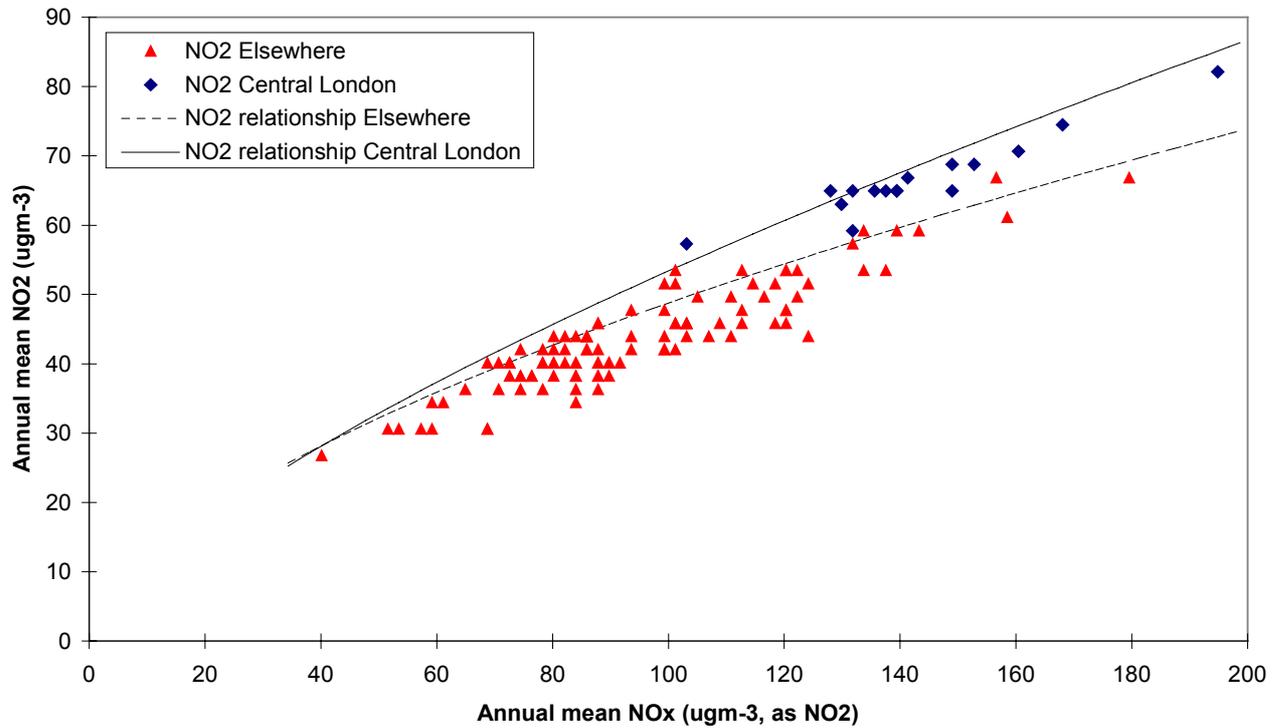

Figure A2. Comparison of annual mean NOx and NO2 concentrations, for roadside sites (1998–1999)

AEA Technology