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Air quality modelling for West London: Hillingdon, Hounslow, Spelthorne and Slough

Final Report

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C E R C

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Figures 8.3 to 8.4, 8.9 to 8.10	50m97...upl

Contents

1. Summary

An air quality modelling study has been carried out, using ADMS-Urban, for four boroughs in the West London area: the London Boroughs of Hillingdon and Hounslow and the Boroughs of Spelthorne and Slough. The study forms part of the Stage 4 Review and Assessment of Air Quality.

Current and future emissions data were taken from four different sources: the emissions inventory for Heathrow, 1998; the London Atmospheric Emissions Inventory (LAEI), supplied by the Greater London Authority (GLA), February 2002; the Surrey Traffic Model; and the February 2002 emissions inventory for Slough. Background concentration data, obtained from rural monitoring sites, and meteorological data from Heathrow were used in the modelling.

Comparisons of modelled and measured NO_2 and PM_{10} data for 1999 have been made at monitoring sites within the area and predicted future concentrations for 2004 for PM_{10} and 2005 for NO_2 have been calculated for comparison with Air Quality Strategy (AQS) objective values.

The comparison shows good agreement between modelled and measured data at the majority of monitoring sites, indicating that the modelling approach and emissions data are suitable for the current situation. Provided that the estimates of emissions for future years are accurate, the predicted future concentrations will therefore give a robust indication of whether or not the AQS objectives will be met by 2004 and 2005.

The AQS objective value for annual average NO_2 concentrations, 40µg/m³, is predicted to be exceeded over most of the southern part of Hillingdon and along major roads in the north. The objective value for the 99.79^{th} percentile of hourly average NO_2 concentrations, 200µg/m³, is predicted to be exceeded only along the M25 motorway.

Annual average PM_{10} concentrations are predicted not to exceed the AQS objective value of 40µg/m³ anywhere within Hillingdon. The AQS objective value for the 90.41^{st} percentile of 24-hour average PM_{10} concentrations, 50µg/m³, is predicted to be exceeded only along the M25 motorway.

2. Introduction

Cambridge Environmental Research Consultants Ltd (CERC) has been commissioned by the London Boroughs of Hillingdon and Hounslow and the Boroughs of Spelthorne and Slough to carry out air quality modelling using ADMS-Urban. The study forms part of the Stage 4 Review and Assessment of Air Quality.

A study for the Stage 3 Review and Assessment was carried out by CERC for Hillingdon, Hounslow and Spelthorne in 1999 and is reported in "*Air Quality Dispersion Modelling for the London Borough of Hillingdon for Current (1997) and Future (2005) Emissions*", dated 10th November 1999. In this study, NO_2 and PM_{10} concentrations were identified as being likely to exceed the Air Quality Strategy (AQS) objective values. In the study reported here, up-to-date emissions data taken from the GLA emissions inventory for London, dated February 2002, have been used to further investigate concentrations of NO_2 and PM_{10}. Modelling has also been carried out for the Borough of Slough.

Modelled NO_2 and PM_{10} concentrations were compared with monitoring data for 1999 in order to validate the model set-up and then, for the whole study area, high resolution concentration maps of NO_2 and PM_{10} were produced for 2005 and 2004, respectively, for comparison with the AQS objective values.

3. Emissions Data and Model Set-up

Emissions data for 1999, 2004 and 2005 have been used in the modelling for this study. These have been obtained from four different sources: the emissions inventory for Heathrow, 1998; the London Atmospheric Emissions Inventory (LAEI), supplied by the Greater London Authority (GLA), February 2002; the Surrey Traffic Model; and the emissions inventory for Slough.

A study for the Stage 3 Review and Assessment was carried out by CERC for Hillingdon, Hounslow and Spelthorne in 1999 and is reported in "*Air Quality Dispersion Modelling for the London Borough of Hillingdon for Current (1997) and Future (2005) Emissions*", dated 10th November 1999. In the Stage 4 study reported here, the following improvements have been made:

1. Up-to-date emissions data have been taken from the February 2002 GLA emissions inventory for London and the Heathrow emissions inventory;
2. Up-to-date traffic emission factors, dated February 2002, have been used;
3. An improved representation of aircraft emissions from Heathrow Airport data has been used, in which aircraft flight paths have been represented as volume sources to more accurately predict the impact of the airport; and
4. An updated version of ADMS-Urban (version 1.7) has been used, which contains many refinements.

3.1 Traffic data

The Heathrow emissions inventory contains a breakdown of Heathrow and non-Heathrow traffic, which was required for the subsequent source apportionment work. Therefore, where available, traffic data have been obtained from the Heathrow inventory. Where this was not possible, traffic data were taken from the GLA emissions inventory for London, and where neither of these covered the required area, data were taken either from the Surrey traffic model or the Slough emissions inventory, as appropriate. Figure 3.1 shows the source of traffic data used for each modelled road in the area.

In all cases, traffic flows and speeds were available for each road for the current situation and emissions of each pollutant were calculated using the DTLR emission factors released in February 2002. In the case of the Heathrow Emissions Inventory, traffic data were given for 1993 and 2003 and these were used together with traffic growth figures obtained from Tempro[1] to give flows for 1999.

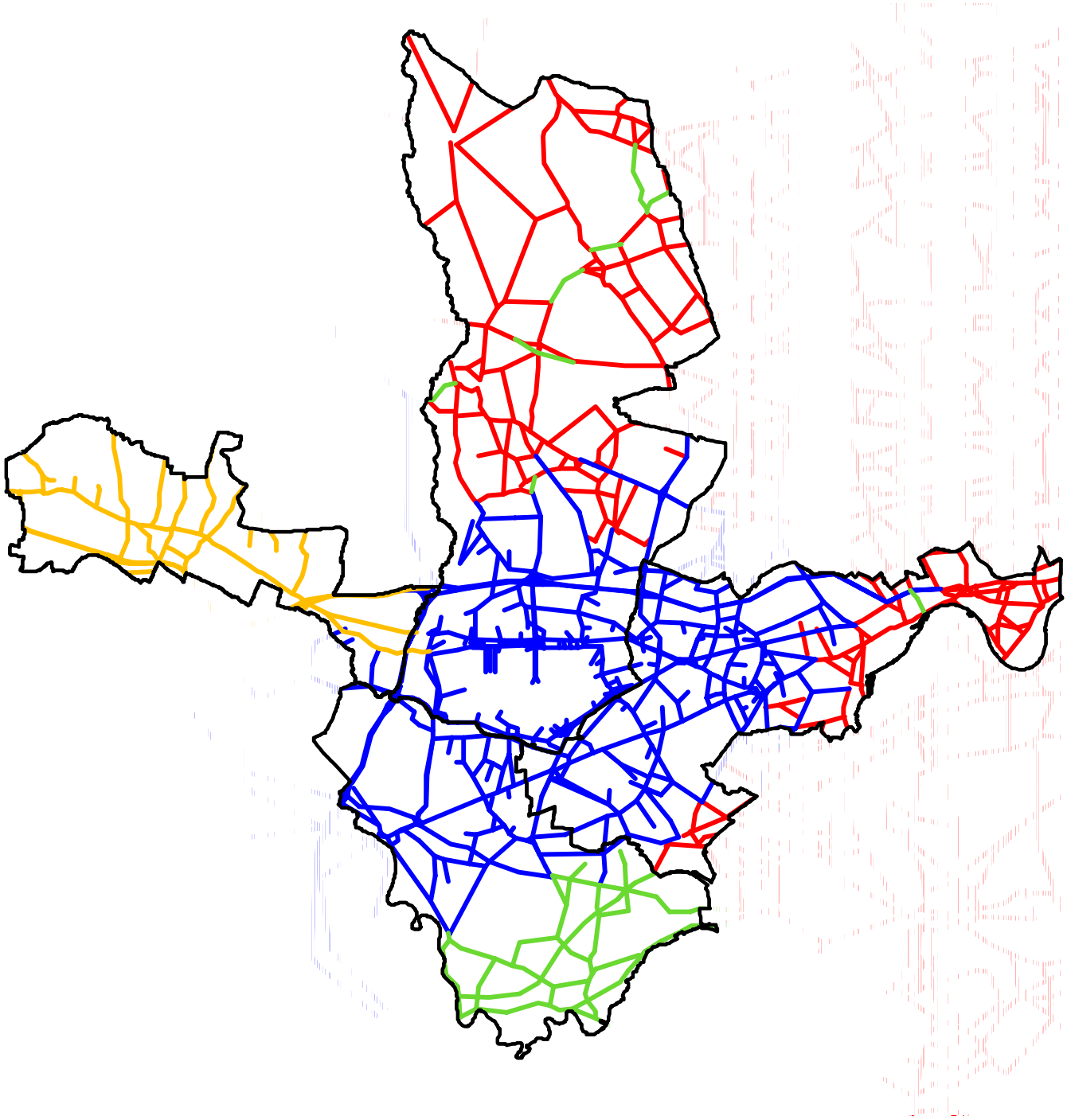
[1] TEMPRO 3.1 from http://www.roads.detr.gov.uk/roadnetwork/heta/hetatemp.htm

Traffic emissions are predicted to decrease between 1999 and 2005 due to the introduction of cleaner fuels and improved vehicle efficiency. Traffic emissions for 2004 and 2005 have been calculated using predicted flows for the relevant year and a fleet composition which represents the range of engine sizes and ages of the different vehicle types on the roads in that year. Traffic flows for the appropriate years were supplied as part of the GLA emissions inventory and also in the Surrey Traffic Model. For the Heathrow Emissions Inventory and the Slough Emissions Inventory traffic flows for 2005 were not available and, where this was the case, traffic growth figures from Tempro were applied to the 1999 flows.

Road widths were not supplied in the emissions inventories. For the purposes of the modelling all roads were assumed to be 20m wide unless they were motorways or dual carriageways. Motorways were assumed to be 50m wide and dual carriageways were assumed to be 30 or 40m wide.

All roads having a NO_x emission rate greater than 0.1g/km/s in 1999 were modelled explicitly, along with other road links which were used to join any isolated segments. Figure 3.2 shows the explicitly modelled roads for Hillingdon. The remainder of the roads was modelled, together with the other minor emission sources, as aggregated $1km^2$ grid sources. The grid sources were given a depth of 75 metres to represent the initial vertical spread of pollutants.

The variation of traffic flow during the day has been taken into account by applying a diurnal profile to the road emissions. This profile was taken from the GLA inventory and is shown in Figure 3.3.



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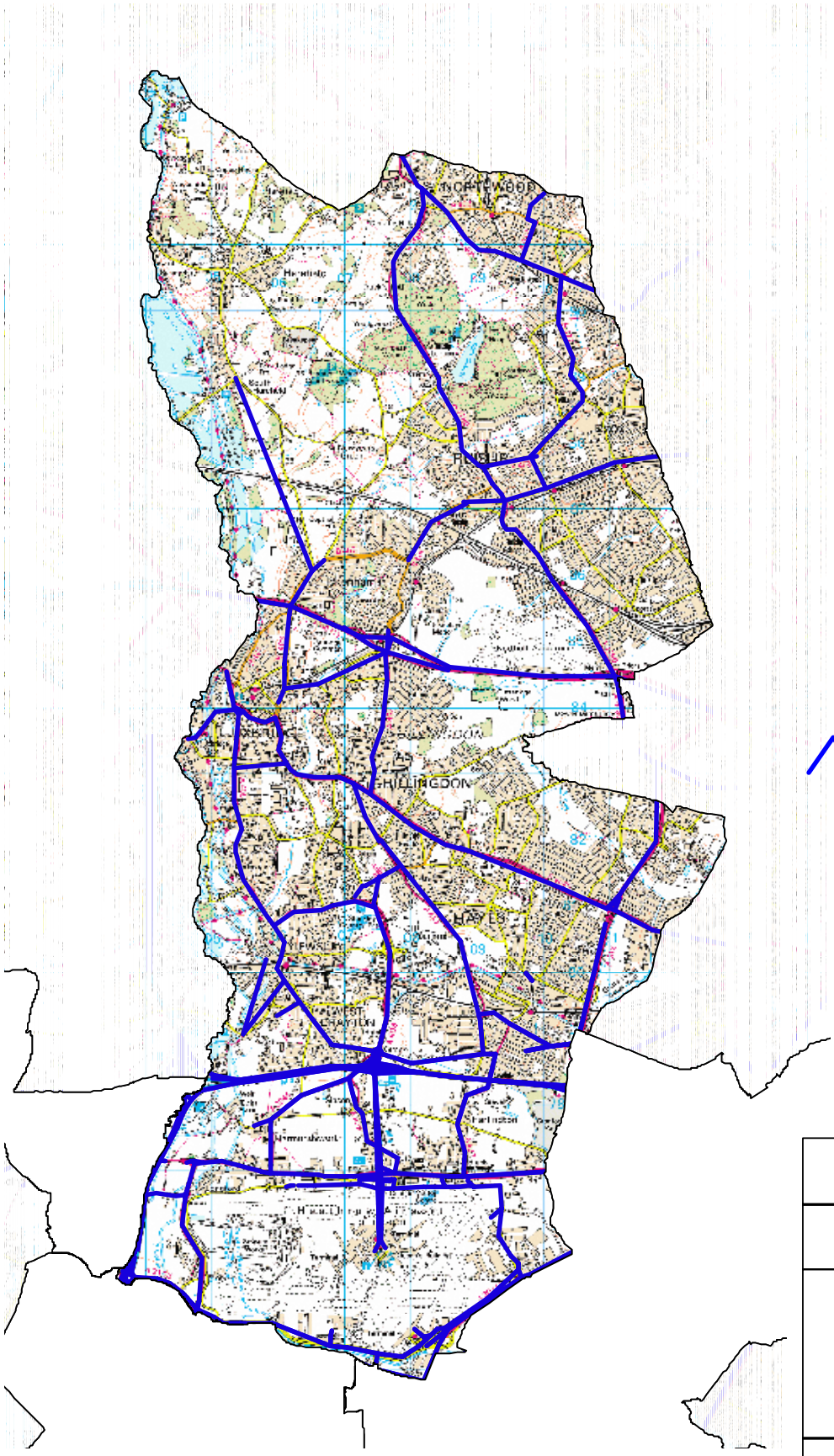
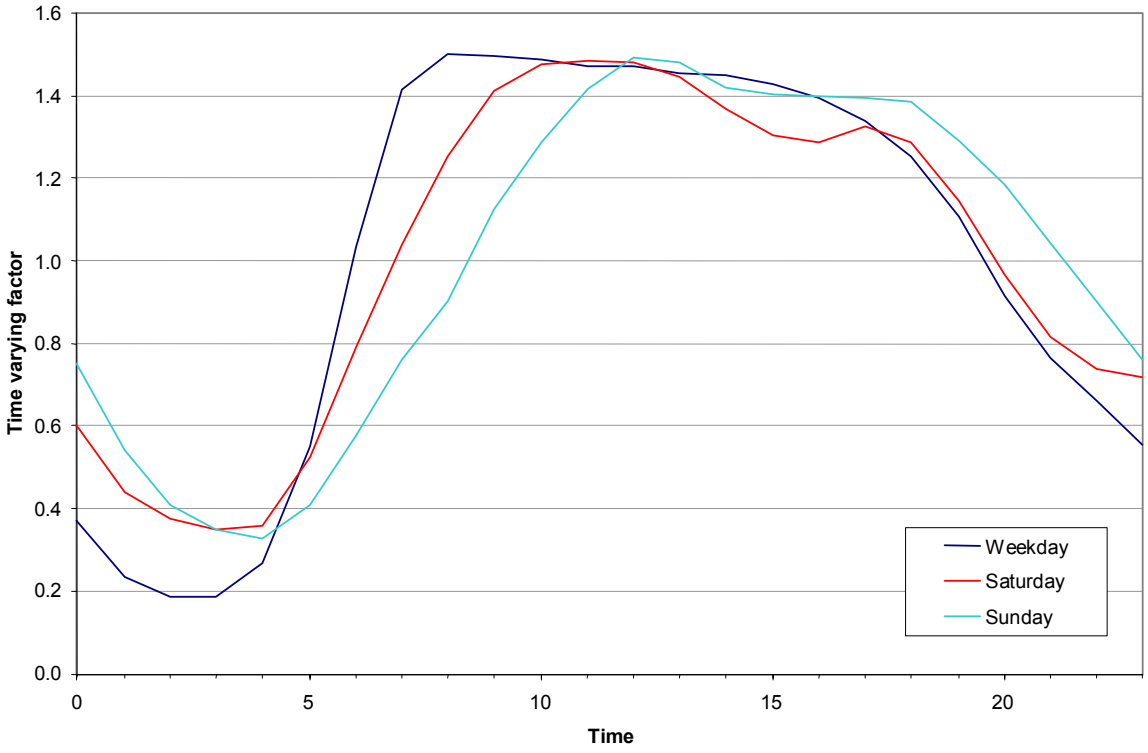
Sources of traffic data
Figure 3.1



CERC
Hillingdon
Explicitly modelled roads
Figure 3.2

Figure 3.3 Diurnal profiles for West London



3.2 Industrial Sources

Emissions data for industrial sources in Heathrow Airport were taken from the Heathrow emissions inventory. For sources elsewhere, data were taken from the GLA emissions inventory for London or the Slough emissions inventory, as appropriate. As for the roads, only the major industrial sources were modelled explicitly, while the remainder was included as aggregated grid sources. Table 3.1 shows the explicitly modelled sources; only those sources with an emission rate of over 1g/s for either NO_x or PM_{10} were modelled explicitly.

Table 3.1: Explicitly modelled industrial sources

	Location	NO_x emissions (t/yr)	PM_{10} emissions (t/yr)
Heathrow Airport sources			
Engine Testing, East Base	(509875, 176325)	127	5.8
Heating Plant	(506400, 174500)	309	9.2
Other sources			
Slough Heat & Power 1	(495300, 181500)	307	1.7
Slough Heat & Power 2	(495300, 181500)	307	1.7

3.3 Heathrow Airport emissions

All airport emissions were taken from the Heathrow emissions inventory. All aircraft emissions, except for taxiing emissions, have been modelled as a group of volume sources of varying heights and dimensions in order to model more accurately the location and spread of the emissions. Table 3.2 shows the dimensions and emission rates of the volume sources used in the modelling for 1999 and Figure 3.4 shows their locations. Aircraft movements are predicted to increase by 5% by 2005 and so for the future scenarios the aircraft emissions have been increased by 5%.

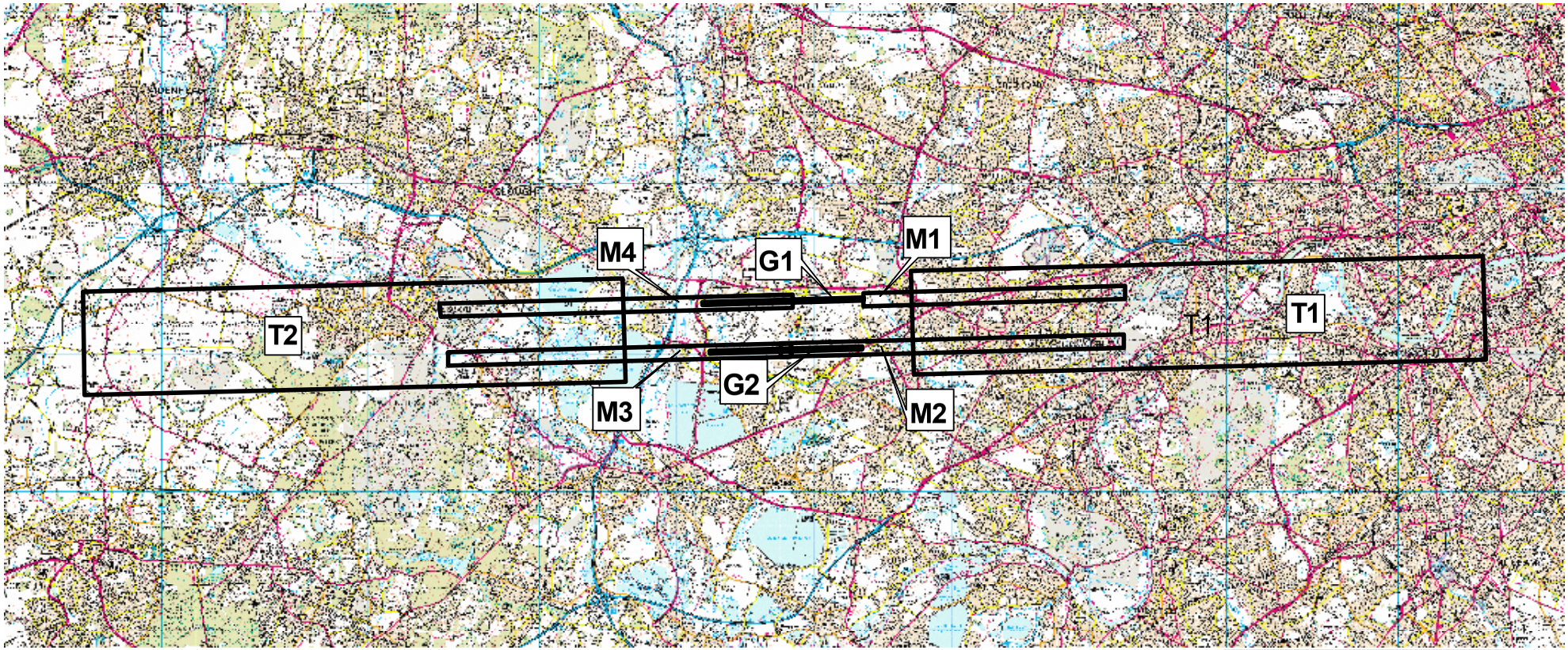
All other emissions from Heathrow Airport have been included in the grid sources.

Table 3.2: Explicitly modelled Heathrow Airport volume sources for 1999

Source	Base height (m)	Top height (m)	Length (m)	Width (m)	NO_x emission rate (T/yr)	NO_x emission rate ($g/m^3/s$)	PM_{10} emission rate (T/yr)	PM_{10} emission rate ($g/m^3/s$)
G1	0	50	4701	100	679	9.16×10^{-7}	3.1	4.03×10^{-9}
G2	0	50	4456	100	934	1.33×10^{-6}	3.6	4.92×10^{-9}
M1	50	450	7633	400	111	2.89×10^{-9}	2.1	5.14×10^{-11}
M2	50	450	9995	400	538	1.07×10^{-9}	3.4	6.48×10^{-11}
M3	50	450	10261	400	780	1.49×10^{-8}	3.3	4.43×10^{-11}
M4	50	450	10021	400	751	1.51×10^{-8}	2.3	6.03×10^{-11}
T1	450	1000	16695	3000	1058	1.22×10^{-9}	7.7	8.43×10^{-12}
T2	450	1000	15759	3000	2712	3.31×10^{-9}	8.7	1.02×10^{-11}
Total					**7563**		**34.2**	

3.4 Other emissions

Other emissions data, for example for domestic and industrial sources, have been taken directly from the GLA emissions inventory and modelled as a set of 1km^2 grid sources covering the whole of Greater London. The modelled emissions include those from minor roads, cold start and hot soaks, trains, shipping and domestic gas combustion.



0 5 10 15 20 Kilometers

N
W E
S

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Location of aircraft sources
Figure 3.4

3.5 Total Emissions

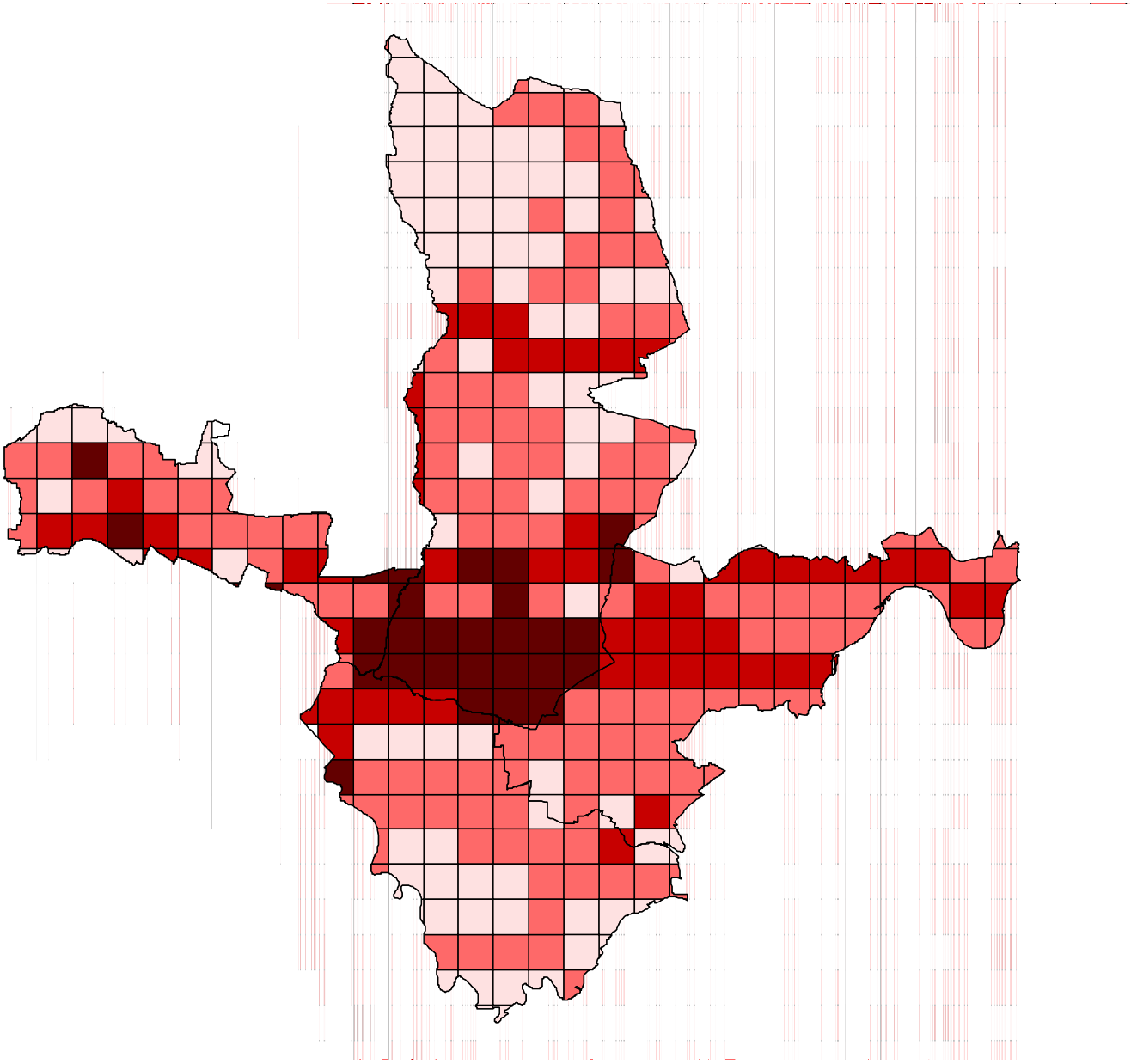
3.5.1 Total emissions for 1999

Table 3.3 shows the total emissions of NO_x and PM_{10} in West London from major roads, industrial sources and Heathrow Airport, as well as the total emissions from all sources for the year 1999. Also given for each pollutant are the major road, industrial source and Heathrow Airport emissions as percentages of the total emissions from all sources.

Table 3.3: Total emissions for 1999 (t/yr)

	NO_x		PM_{10}	
	t/yr	**% of total**	**t/yr**	**% of total**
Major roads	6841	51	570	68
Industrial sources	648	5	79	9
Heathrow Airport	3405	25	80	10
All sources	**13,457**	**100**	**837**	**100**

Figures 3.5 and 3.6 show the total emissions of each pollutant in West London on a $1km^2$ resolution grid.



0 5 10 15 Kilometers

NOx emissions (t/yr)
0 - 10
10 - 50
50 - 100
100 - 500

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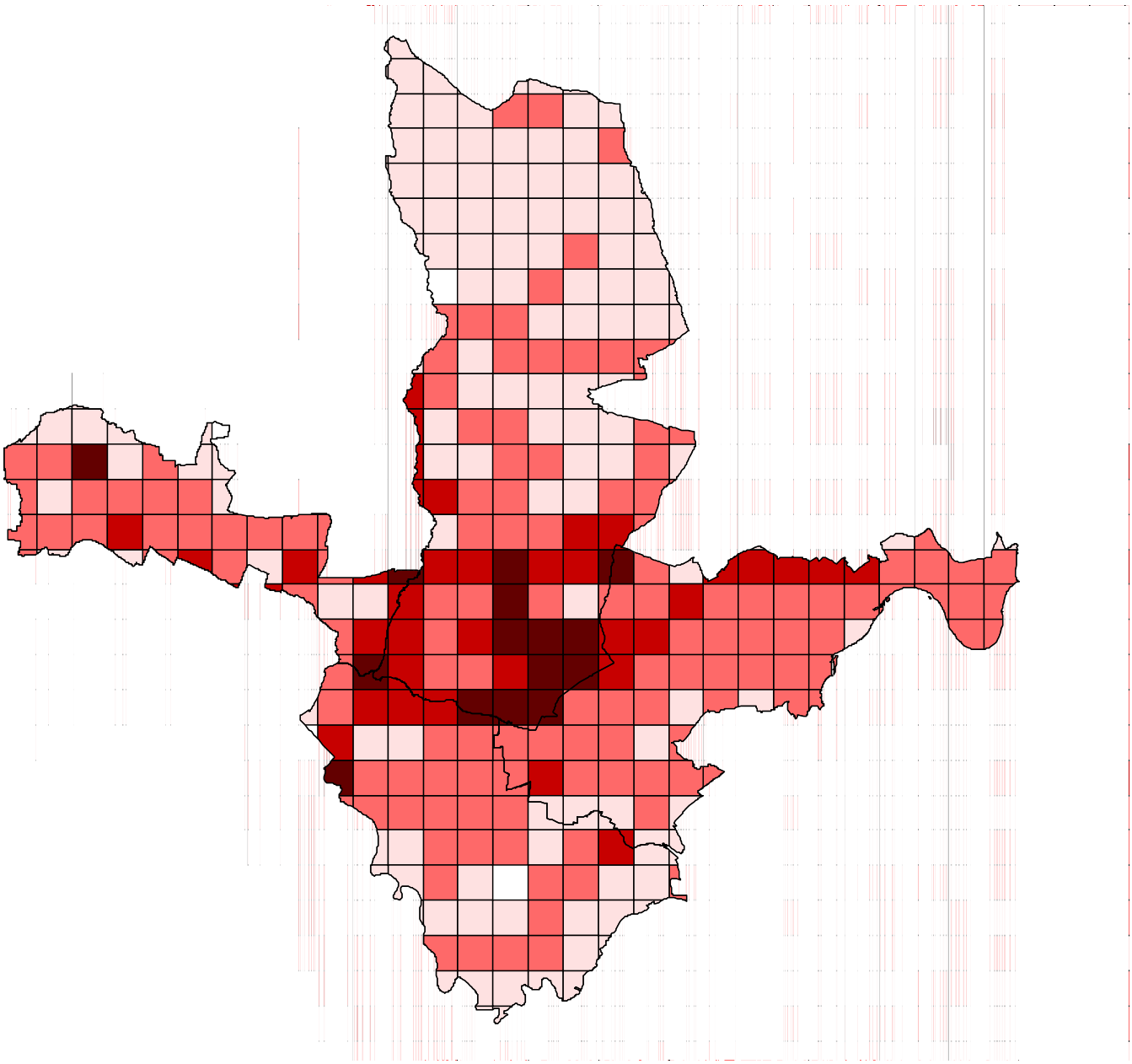
Total emissions of NOx (t/yr) for 1999
Figure 3.5



0 5 10 15 Kilometers

PM10 emissions (t/yr)
0 - 1
1 - 5
5 - 10
10 - 50

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Total emissions of PM10 (t/yr) for 1999
Figure 3.6

3.5.2 Total emissions for 2004/2005

Table 3.4 shows the total emissions in West London, and the emissions from major roads, industrial sources and Heathrow Airport, for the 2005 situation for NO_x and the 2004 situation for PM_{10}. Also given for each pollutant are the major road, industrial source, and Heathrow Airport emissions as percentages of the total emissions from all sources.

Table 3.4: Total emissions for 2004/2005 (t/yr)

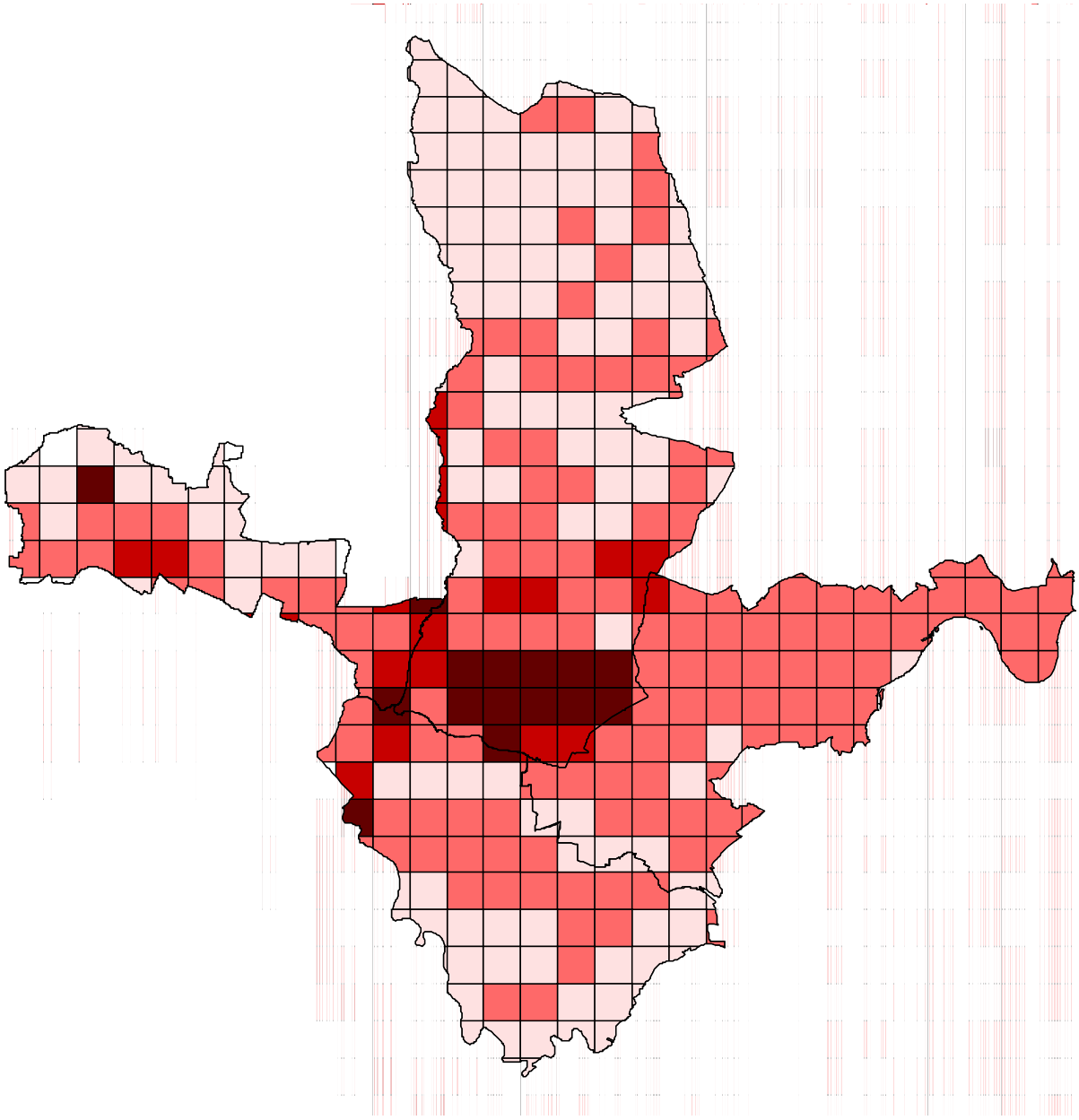
	NO_x		PM_{10}	
	t/yr	**% of total**	**t/yr**	**% of total**
Major roads	4175	42	240	50
Industrial sources	634	6	79	16
Heathrow Airport	3536	36	81	17
All sources	9864	100	483	100

Figures 3.7 and 3.8 show the total emissions for each pollutant for 2004 or 2005, as appropriate, on a $1km^2$ resolution grid.

Table 3.5 shows the percentage change in emissions from each category between 1999 and 2004/5. Road traffic emissions are predicted to decrease between 1999 and 2004/2005 due to the introduction of cleaner fuels and improved vehicle efficiency.

Table 3.5: Percentage change in emissions between 1999 and 2004/2005

	NO_x	PM_{10}
Major roads	-39	-58
Industrial sources	-2	0
Heathrow Airport	+4	+1
All sources	**-27**	**-42**



0 5 10 15 Kilometers

NOx emissions (t/yr)
- 0 - 10
- 10 - 50
- 50 - 100
- 100 - 500

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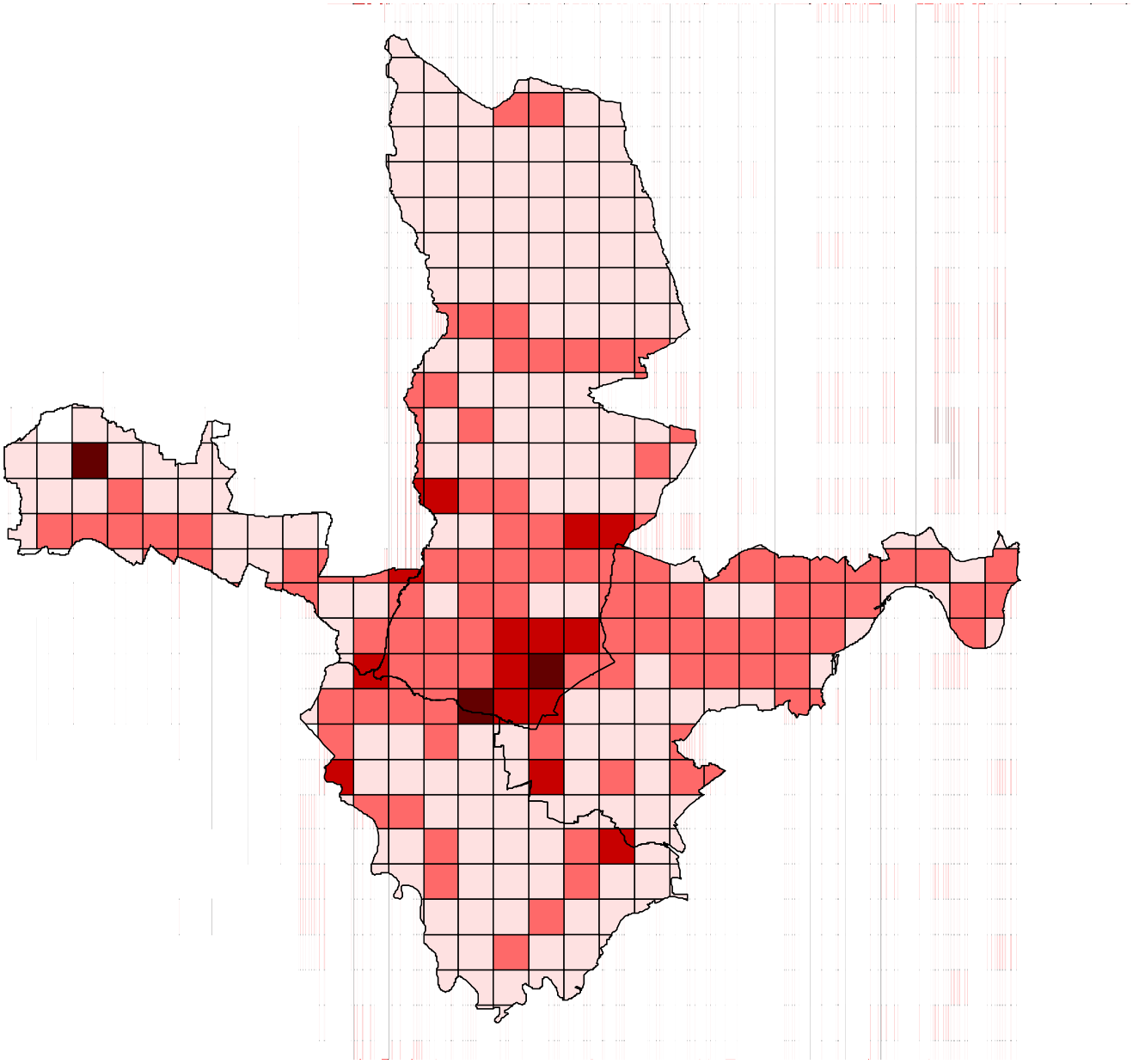
Total emissions of NOx (t/yr) for 2005
Figure 3.7



0 5 10 15 Kilometers

PM10 emissions (t/yr)
0 - 1
1 - 5
5 - 10
10 - 50

CERC
Hillingdon, Hounslow, Spelthorne and Slough
Total emissions of PM10 (t/yr) for 2004
Figure 3.8

3.6 Model Set-up

3.6.1 Surface Roughness

A length scale parameter called the surface roughness length is used in the model to characterise the study area in terms of the effects it will have on wind speed and turbulence, which are key factors in the modelling. Different surface roughness lengths were investigated and the most appropriate value of roughness length was found to be 1 metre; this value has been used in the modelling.

The difference in land use at Heathrow compared to the study area has been taken into account, by entering a different surface roughness for the meteorological site. See Section 4 for further details.

3.6.2 Monin-Obukhov Length

In urban and suburban areas there is a significant amount of heat emitted by buildings and traffic which warms the air within and above a city. This is known as the urban heat island and its effect is to prevent the atmosphere from becoming very stable. In general, the larger the area the more heat is generated and the stronger the effect becomes.

In the ADMS-Urban model, the stability of the atmosphere is represented by the Monin-Obukhov parameter, which also has the dimension of length. In very stable conditions it has a positive value of between 2 metres and 20 metres. In near neutral conditions its magnitude is very large, and it has either a positive or negative value depending on whether the surface is being heated or cooled by the air above it. In very convective conditions it would be negative with a magnitude of typically less than 20 metres.

The effect of the urban heat island is that, in stable conditions the Monin-Obukhov length will never fall below some minimum value; the larger the city, the larger the minimum value. Different Monin-Obukhov lengths were investigated and the most appropriate value of Monin-Obukhov length for the area was found to be 75m; this value has been used in the modelling.

3.6.3 NO_x Chemistry

The amount of emitted NO_x converted to NO_2 in the atmosphere has been calculated using the Generic Reaction Set (GRS) of equations. This requires the input of rural background concentrations of NO_x, NO_2 and ozone. Information on the background data used in the modelling is given in Section 5.

4. Meteorological Data

The modelling was carried out using hourly sequential meteorological data from Heathrow. For the validation stage of the modelling, data from the year 1999 were used in order to correspond to the available monitoring data. Data from the year 1999 were used for the predictions of future concentrations for NO_2 and PM_{10}. To account for the worst case meteorological conditions future concentrations of NO_2 were also predicted using data for the year 1997.

Table 4.1 shows a summary of the meteorological data for each year.

Table 4.1: Summary of meteorological data

	Minimum	Maximum	Mean
1997			
Temperature (°C)	-5.2	31.4	11.9
Wind speed (m/s)	0	12.9	2.9
Cloud cover (oktas)	0	8	5.4
1999			
Temperature (°C)	-4.6	32.7	11.8
Wind speed (m/s)	0	12.9	3.1
Cloud cover (oktas)	0	8	5.6

The ADMS meteorological pre-processor, written by the Meteorological Office, uses the data provided to calculate the parameters required by the program. Figures 4.1 and 4.2 show wind roses showing the frequency of occurrence of wind from different directions for a number of wind speed ranges.

The difference in land use at Heathrow compared to the study area has been taken into account by entering a different surface roughness for the meteorological site. The surface roughness for Heathrow has been set to 0.2m.

Figure 4.1 Wind rose for Heathrow, 1997

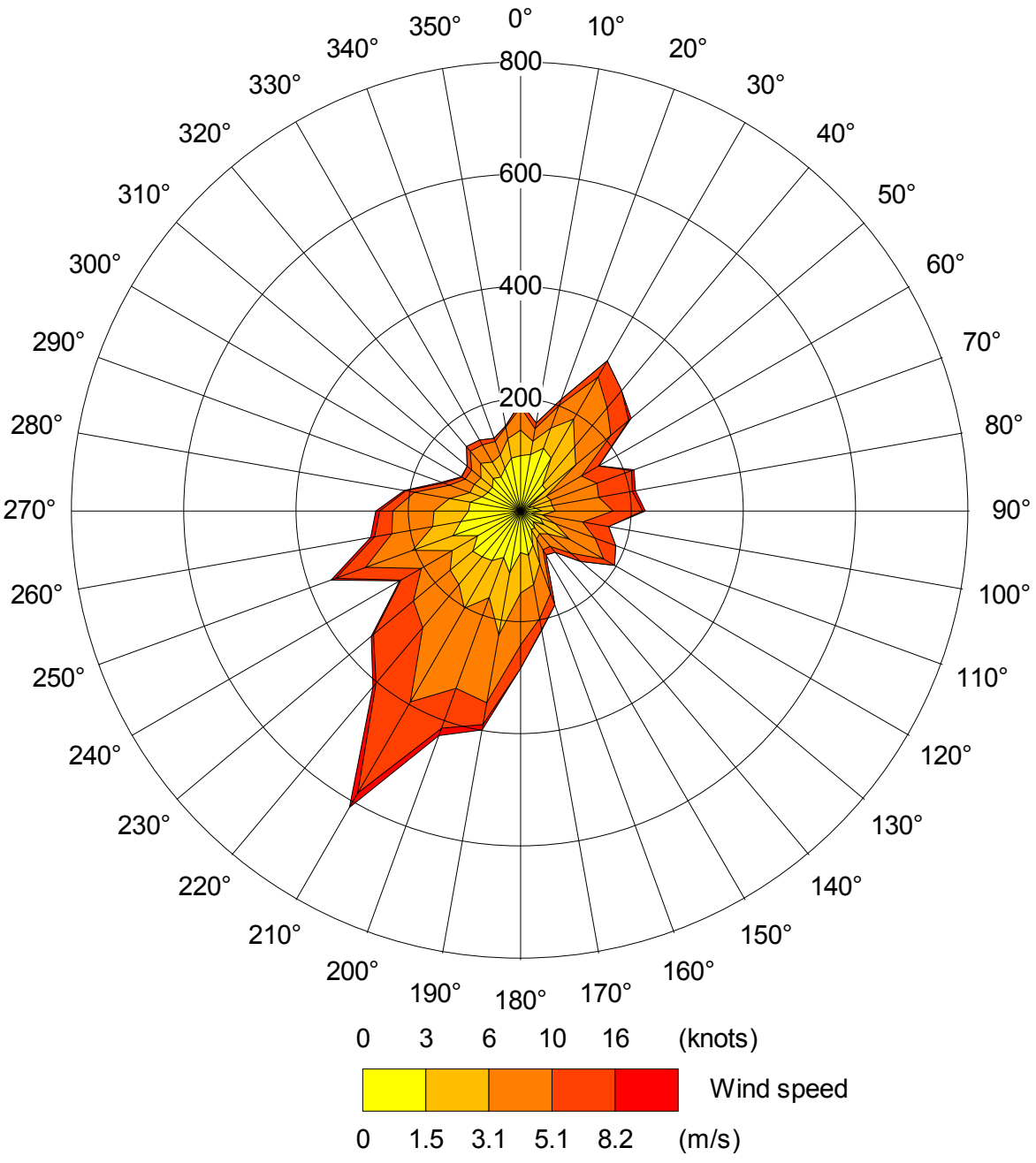
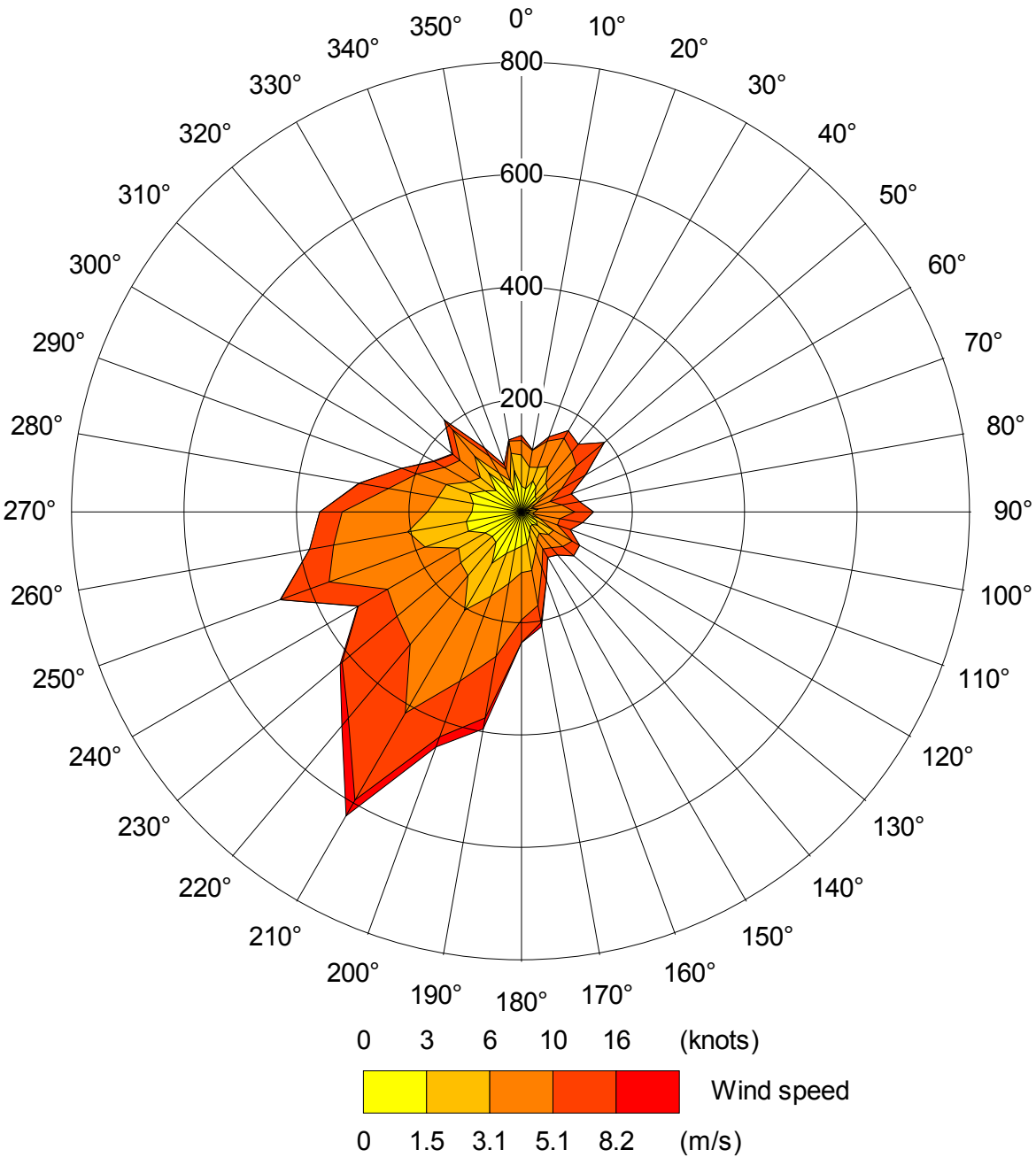


Figure 4.2 Wind rose for Heathrow, 1999



5. Background data

Hourly average background concentrations of NO_x, NO_2, ozone and PM_{10} are used in the modelling to represent the pollutant concentrations entering West London from outside the area. The background data year must always match the meteorological data year.

All emissions of NO_x and NO_2 from within the area are represented in the emissions inventory and so background data for these pollutants and ozone have been obtained from rural monitoring sites around the modelled area.

PM_{10} concentrations at any location can be thought of as being made up of a primary component (directly emitted), a secondary component (formed from primary particulates by subsequent reactions) and a coarse component (such as re-suspended dust). Only primary particulates are included in the emissions inventory, so all the other components must be represented by the background data.

The rural PM_{10} measurements take account of the entire secondary component and that part of the coarse component from rural sources. An additional 5µg/m^3 is added as an estimate of the coarse component from urban sources.

It was assumed that the total coarse contribution was 9.9µg/m^3, taken from the Air Quality Strategy[2]. The split between the rural and urban source contribution, 4.9µg/m^3 from rural sources and 5.0µg/m^3 from urban sources, was decided from the results of sensitivity studies.

5.1 Background data for 1999

NO_x, NO_2 and ozone concentrations from Rochester, Harwell, Lullington Heath and Wicken Fen were used, the monitored concentration used for a particular hour depending upon the wind direction for that hour.

Two sources of PM_{10} background data have been used for the 1999 validation modelling. For hours for which the wind direction is from the west, rural PM_{10} data from Harwell have been used and for hours for which the wind direction is from the east, rural PM_{10} measurements from Rochester have been used.

The PM_{10} background concentrations were calculated using data from Harwell and Rochester only, as these are the only rural sites which monitor hourly average PM_{10} in the south of England. The monitored concentrations were assumed to contain all the secondary particulates plus a proportion of the coarse particulates.

[2] The Air Quality Strategy for England, Scotland, Wales and Northern Ireland – A Consultation Document, DEFRA, September 2001, Paragraph A119, Technical Annexe, Section 1: Particles (PM_{10})

The total background PM_{10} concentration is therefore given by:

Background PM_{10} = (monitored PM_{10} concentration) $\times$ 1.3 + 5$\mu g/m^3$

Note that the factor of 1.3 is applied to change the monitored PM_{10} concentration from TEOM units to gravimetric units, which are the relevant units for the Air Quality Strategy (AQS).

Table 5.1 summarises the annual statistics of the resulting background concentrations used in the modelling for 1999.

Table 5.1: Background concentrations for 1999

	Annual average	**Maximum hourly average**	**99.79th percentile of hourly average**	**90.41st percentile of 24-hour average**
NO_x (ppb)	9.5	179	91	-
NO_2 (ppb)	7.2	49	35	-
O_3 (ppb)	28.8	111	87	-
PM_{10} ($\mu g/m^3$)	23.4	126	-	35

5.2 Background data for 2004/2005

Background concentrations of NO_x and PM_{10} for future years were obtained by projecting forward measured data from 1997 or 1999, as appropriate, using factors obtained from NETCEN[3]. The NETCEN factors are based on observed emissions data up to the current time and predicted emissions data for future years.

Concentrations of NO_2 for future years have been estimated by determining the relationship between NO_x and NO_2 for 1997 and 1999. This relationship was then applied to the future NO_x concentrations calculated using the NETCEN factor, to give corresponding NO_2 concentrations. Projected hourly ozone concentrations were calculated by conserving the potential to form NO_2. That is, if the hourly NO_2 concentration decreased by *x* ppb between 1997 and the future year being modelled, the corresponding hourly ozone concentration was assumed to *increase* by *x* ppb.

Table 5.2 gives a summary of the background NO_2 data for 2005 based on 1997 and 1999 met data, and the background PM_{10} data for 2004 based on 1999 met data.

[3] John Stedman, personal communication

Table 5.2: Background concentrations, adjusted to the years 2004/2005

	Year	Annual average	Maximum hourly average	99.79th percentile of hourly average	90.41st percentile of 24-hour average
NO_x	1997	9.9	134	94	-
(ppb)	1999	8.0	150	76	-
NO_2	1997	7.6	40	35	-
(ppb)	1999	6.2	28	26	-
O_3	1997	28.1	117	88	-
(ppb)	1999	29.8	115	86	-
PM_{10} ($\mu g/m^3$)	1999	21.9	113	-	34

6. Air Quality Standards

The air quality standards considered in this study are taken from The Air Quality Strategy for England, Scotland, Wales and Northern Ireland, Working Together for Clean Air, January 2000. They are presented in Table 6.1.

Table 6.1: AQS objectives

	Value	Description of standard
NO_2	200µg/m³	Maximum hourly average (not to be exceeded more than 18 times per year, assumed equivalent to a 99.79th percentile)
	40µg/m³	Annual average
PM_{10}	50µg/m^3	24 hour average (not to be exceeded more than 35 times per year, assumed equivalent to a 90.41st percentile)
	40µg/m^3	Annual average

7. Current situation

For the current situation, the model set-up has been validated by comparing predicted concentrations with measured values at monitoring sites with the modelled area. The monitoring sites considered in this study are shown in Figure 7.1.

Table 7.1 gives details of the monitoring sites and Table 7.2 shows the data availability for each pollutant at each of the sites.

Table 7.1: Monitoring site details

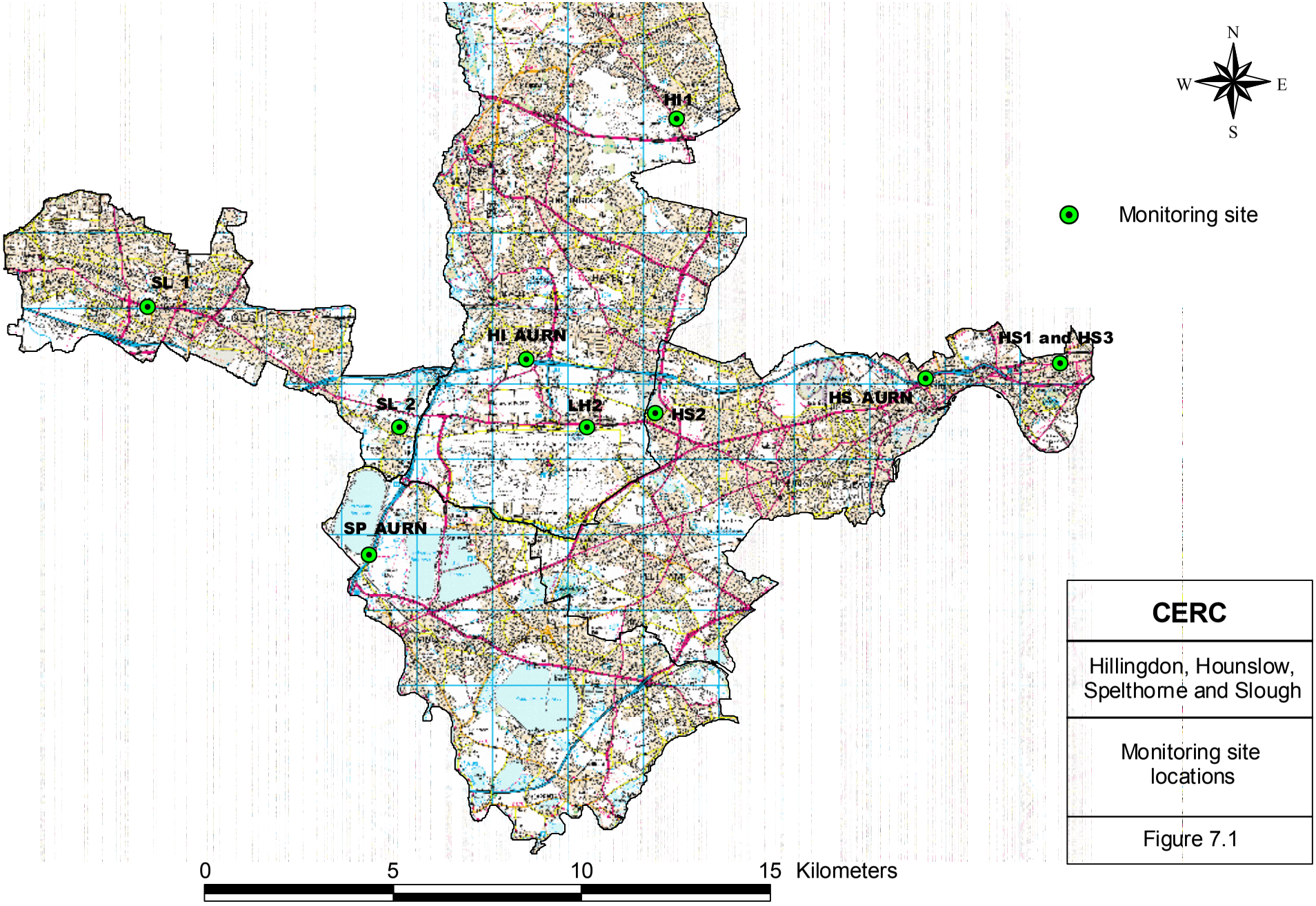
Monitoring site	Description	Pollutant	Coordinates		Height (m)	Borough
			northing	easting		
HI_AURN	London Hillingdon	NO_2, PM_{10}	506900	178620	3	Hillingdon
HI1	ERG[4]	NO_2, PM_{10}	510880	184970	2.5	Hillingdon
LH2	ERG	NO_2, PM_{10}	508500	176800	2.5	Hillingdon
HS_AURN	Hounslow Roadside	NO_2	517500	178110	2	Hounslow
HS1	ERG	NO_2	521070	178500	3	Hounslow
HS2	ERG	NO_2, PM_{10}	510300	177200	3	Hounslow
HS3	ERG	PM_{10}	521070	178500	1	Hounslow
SL_1	Town Hall	NO_2, PM_{10}	496860	179990	4	Slough
SL_2	School	NO_2	503546	176824	4	Slough
SP_AURN[5]	M25 motorway,	NO_2	502710	173420	1.5	Spelthorne
	Staines	PM_{10}	502710	173430	2.7	Spelthorne

Table 7.2: Monitoring sites - data capture

Monitoring site	Data capture (%)	
	NO_2	PM_{10}
HI_AURN	45	97
HI1	27	27
LH2	98	95
HS_AURN	92	-
HS1	92	-
HS2	94	93
HS3	-	73
SL_1	59	40
SL_2	56	-
SP_AURN	82	82

[4] Maintained by the Environmental Research Group, King's College London

[5] Note that the NO_x and PM_{10} monitors at this site are at different heights and distances from the M25



CERC
Hillingdon, Hounslow, Spelthorne and Slough
Monitoring site locations
Figure 7.1

The monitored and calculated concentrations of the modelled pollutants at each location have been presented in this section. In addition, they have been statistically processed, and the following statistics calculated in each case:

1. **Standard deviation**. This is a measure of the variability of the data sets. A small standard deviation implies the data are clustered closely around their mean, a large standard deviation implies that the data are much more scattered.
2. **Normalised mean square error (NMSE)**. This is a measure of how much the mean of the calculated concentrations differs from the observed mean. The NMSE would be zero if the two means were the same.
3. **Correlation**. When there is no similarity between the observed and calculated concentrations, the correlation will take a value close to zero. When there is strong correlation between the two values, the value will be near to 1.
4. **FA2**. This is the fraction of calculated concentrations within a factor of two of the observations.
5. **Fractional or normalised bias**. This is a measure of how the calculated mean differs from the observed mean. A value of zero indicates no difference, positive values indicate the underestimate in calculated concentrations and negative values indicate the overestimate.

7.1 NO_2 concentrations

Tables 7.3 and 7.4 show the measured and modelled annual average and 99.79th percentile of hourly average NO_x and NO_2 concentrations. Tables 7.5 and 7.6 show the calculated statistics for each monitoring location for NO_x and NO_2, respectively.

Figures 7.2 and 7.3 show the modelled annual average NO_x and NO_2 concentrations plotted against the measured values together with lines of equality and lines showing over- and under-prediction by a factor of two.

Table 7.3: Measured and modelled NO_x concentrations

Monitoring site	Annual average (ppb)		99.79th percentile (ppb)	
	Monitored	ADMS	Monitored	ADMS
HI_AURN	86.9	127.9	481.2	866.9
HI1	90.0	43.8	506.0	370.4
LH2	70.9	126.6	447.6	646.5
HS_AURN	99.0	117.8	564.9	752.9
HS1	98.8	52.4	564.6	433.6
HS2	43.8	52.3	457.8	396.4
SL_1	34.9	35.1	276.2	416.2
SL_2	33.0	36.0	290.0	495.9
SP_AURN	144.5	126.5	599.2	865.4

Table 7.4: Measured and modelled NO_2 concentrations

Monitoring site	Annual average (ppb)		99.79th percentile (ppb)	
	Monitored	ADMS	Monitored	ADMS
HI_AURN	26.3	35.9	71.0	147.7
HI1	24.5 / 4	23.4	70.3	75.4
LH2	29.0	39.1	97.5	120.0
HS_AURN	31.2	34.8	77.0	128.9
HS1	31.1	26.0	76.6	101.6
HS2	22.1	27.1	74.9	98.2
SL_1	18.2	21.1	66.5	107.3
SL_2	16.3	21.6	69.1	118.0
SP_AURN	24.3	34.6	87.2	196.3

Table 7.5: Monitored and calculated concentration statistics for NO_x (ppb)

Monitoring sites	Annual average		Standard deviation		NMSE (objective 0)	Correlation (objective 1)	FA2 (objective 1)	Normalised bias (objective 0)
	Monitored	Calculated	Monitored	Calculated				
HI_AURN	86.9	127.9	76.6	124.8	0.86	0.71	0.72	-0.38
HI1	90.0	43.8	80.9	47.7	1.50	0.65	0.45	0.69
LH2	70.9	126.6	62.5	104.3	1.27	0.50	0.46	-0.56
HS_AURN	99.0	117.8	117.8	125.6	0.74	0.69	0.65	-0.17
HS1	98.8	52.4	81.7	58.6	1.20	0.62	0.43	0.61
HS2	43.8	52.3	53.7	51.6	1.08	0.57	0.67	-0.18
SL_1	34.9	35.1	34.8	43.1	1.34	0.48	0.81	-0.01
SL_2	33.0	36.0	41.3	53.8	2.00	0.50	0.70	-0.09
SP_AURN	144.5	126.5	128.8	130.8	0.76	0.60	0.61	0.13

Table 7.6: Monitored and calculated concentration statistics for NO_2 (ppb)

Monitoring sites	Annual average		Standard deviation		NMSE (objective 0)	Correlation (objective 1)	FA2 (objective 1)	Normalised bias (objective 0)
	Monitored	Calculated	Monitored	Calculated				
HI_AURN	26.3	35.9	12.0	17.4	0.30	0.61	0.83	-0.31
HI1	24.5	23.4	11.0	11.4	0.17	0.61	0.87	0.04
LH2	29.0	39.1	14.8	14.7	0.35	0.31	0.73	-0.30
HS_AURN	31.2	34.8	13.0	17.8	0.19	0.63	0.90	-0.11
HS1	31.1	26.0	12.9	14.0	0.21	0.61	0.84	0.18
HS2	22.1	27.1	12.5	12.6	0.29	0.54	0.78	-0.21
SL_1	18.2	21.1	10.8	13.5	0.34	0.61	0.81	-0.15
SL_2	16.3	21.6	12.2	15.4	0.48	0.65	0.72	-0.28
SP_AURN	24.3	34.6	15.3	23.9	0.58	0.58	0.71	-0.35

The measured and modelled annual average NO_2 concentrations agree fairly well with the modelled results. All of the modelled values lie within a factor of two of the monitored values, with the majority of the modelled values being slightly higher than the measured values.

This indicates that, provided estimates of future emissions are accurate, the modelling of future emissions will give a good estimate of whether or not the air quality objectives for NO_2 are likely to be met.

Figure 7.2 Comparison of measured and modelled NO_x concentrations for 1999

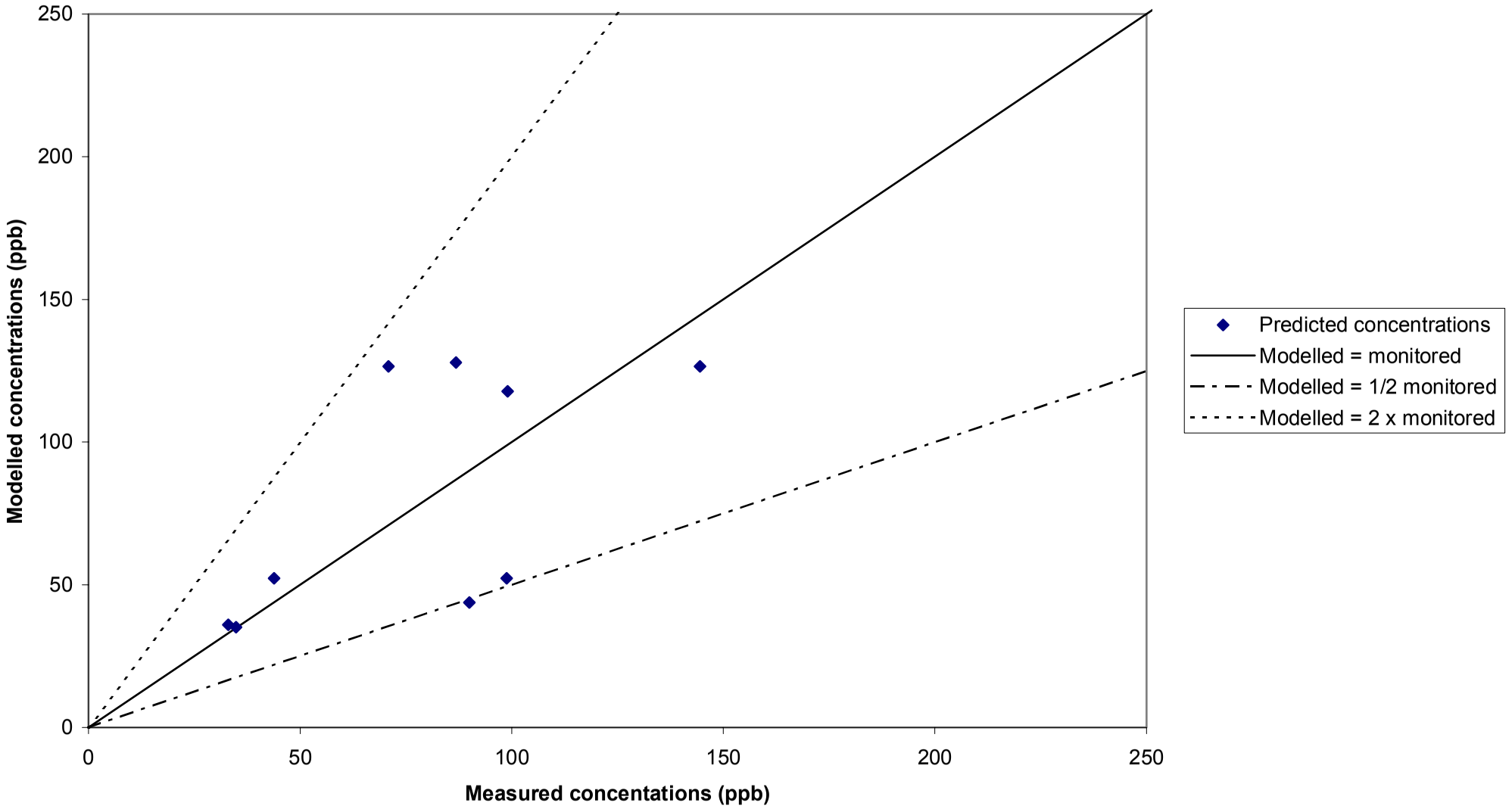
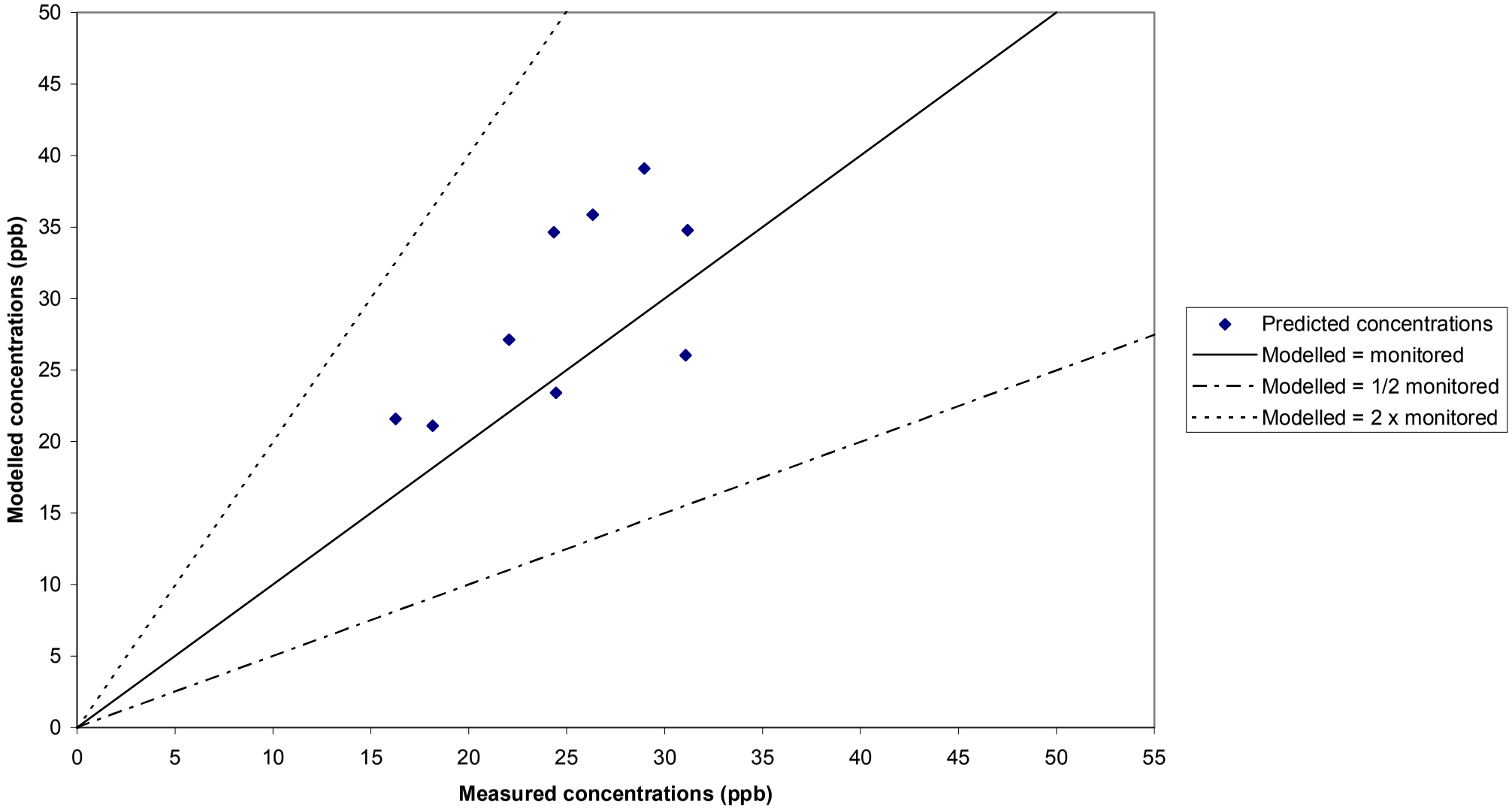


Figure 7.3 Comparison of measured and modelled NO_2 concentrations for 1999



7.2 PM_{10} concentrations

Table 7.7 shows the measured and modelled annual average and 90.41st percentile of 24-hour average PM_{10} concentrations. Table 7.8 shows the calculated statistics for each monitoring location for annual average concentrations of PM_{10}.

Figure 7.4 shows the modelled annual average PM_{10} concentrations plotted against the measured values with the line of equality and lines showing over- and under prediction by a factor of two.

Table 7.7: Measured and modelled PM_{10} concentrations

Monitoring site	**Annual average (µg/m³)**		**90.41st percentile (µg/m³)**	
	Monitored	**ADMS**	**Monitored**	**ADMS**
HI_AURN	26.7	35.0	41.8	49.6
HI1	24.0	23.7	38.3	33.1
LH2	29.2	33.3	48.3	46.7
HS2	22.7	27.5	37.8	39.2
HS3	33.7	28.0	48.1	40.4
SL_1	25.0	27.9	41.5	40.0
SP_AURN	28.9	36.0	47.8	53.7

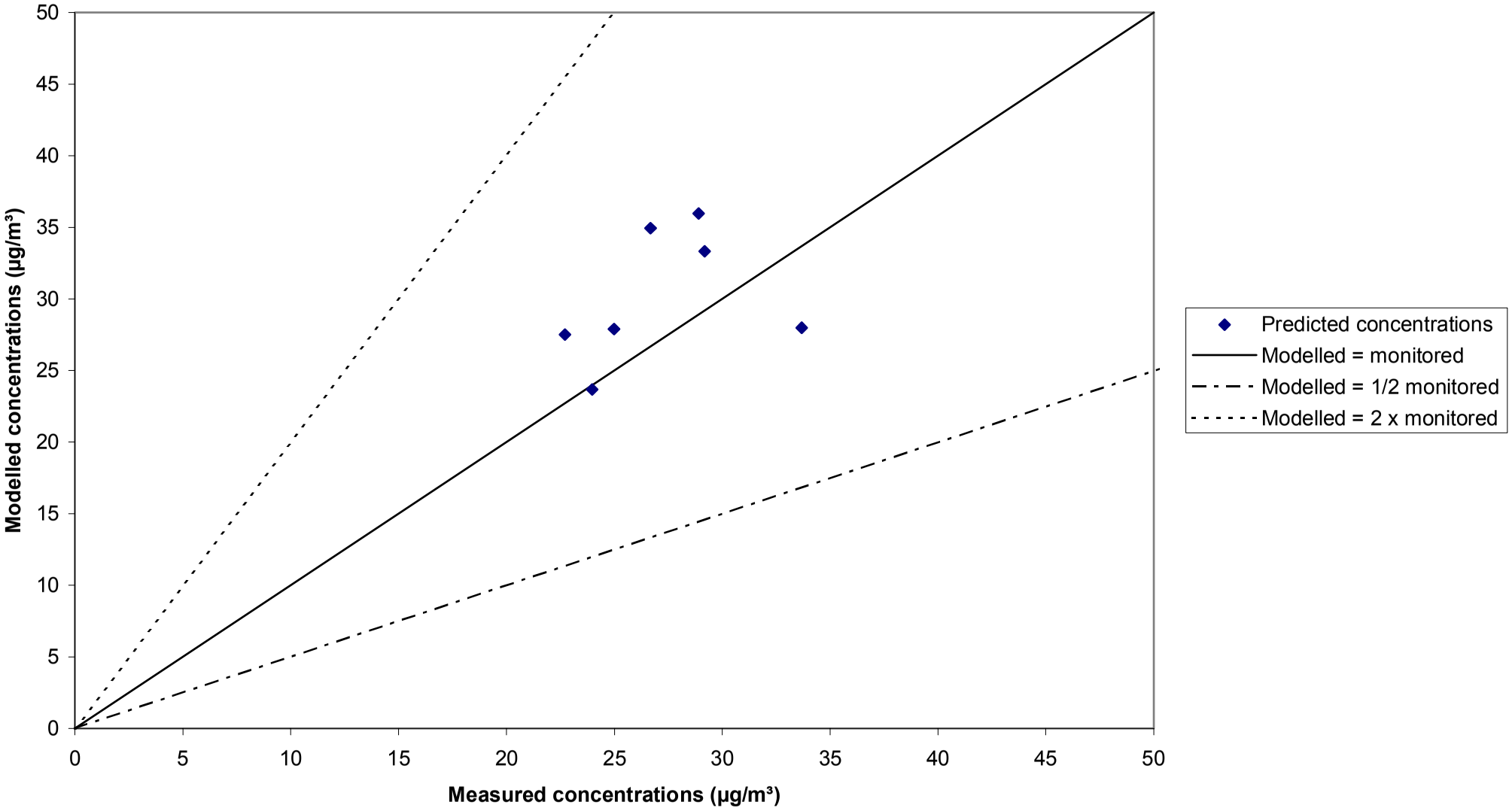
Table 7.8: Monitored and calculated concentration statistics for PM_{10} (µg/m³)

Monitoring sites	Annual average		Standard deviation		NMSE (objective 0)	Correlation (objective 1)	FA2 (objective 1)	Normalised bias (objective 0)
	Monitored	Calculated	Monitored	Calculated				
HI_AURN	26.7	35.0	16.6	16.7	0.29	0.63	0.81	-0.27
HI1	24.0	23.7	14.9	9.3	0.18	0.73	0.90	0.01
LH2	29.2	33.3	16.9	14.5	0.21	0.63	0.87	-0.13
HS2	22.7	27.5	13.8	12.0	0.22	0.66	0.89	-0.19
HS3	33.7	28.0	17.2	12.9	0.25	0.58	0.89	0.18
SL_1	25.0	27.9	13.9	13.5	0.20	0.66	0.88	-0.11
SP_AURN	28.9	36.0	17.2	19.4	0.23	0.73	0.86	-0.22

The modelled and measured concentrations agree well with all of the modelled concentrations, being well within a factor of two of the measured values. The predicted concentrations are generally slightly higher than the measured values.

This indicates that modelling of the future emissions will give a good indication of whether or not the air quality objectives for PM_{10} are likely to be met.

Figure 7.4 Comparison of measured and modelled PM_{10} concentrations for 1999



7.3 Model Uncertainty

The discussion of model uncertainty presented here provides an indication of the typical difference between the model predictions and actual levels of the pollutants considered over the study area. It is difficult to quantify the uncertainty in the model predictions because the relationship between the modelled and actual values is not straightforward. Any estimate of uncertainty must therefore be treated with caution.

The square root of the normalised mean square error is a measure of the variation between the measured values and those predicted by the model, and so gives an indication of the uncertainty in the model predictions. This statistic suggests an uncertainty for the annual average concentrations of NO_2 and PM_{10} of about 20%.

The normalised or fractional bias is a measure of the systematic error between the measured and modelled data, and so gives an indication of the tendency of the model to over- or under- predict. A negative bias indicates that the model is over-predicting. This statistic suggests that the annual average concentrations of NO_2 and PM_{10} are generally overestimated by about 15%.

The values of these two statistics indicate that the uncertainty in the modelling is dominated by the bias.

The prediction of percentile values requires the precise prediction of rare events, and so the uncertainty in these values will be greater.

The calculation of the statistics described above assumes that the measured data reliably represent the true pollution concentrations at the receptor point locations. However, there is also significant uncertainty in the measured concentrations due, for example, to the low percentage of data capture at some sites, variations in the calibration regime and errors associated with the instrumentation. In addition, the comparison between measured and modelled data has been carried out at a relatively small number of locations.

8. Predicted future concentrations

8.1 NO_2 concentrations

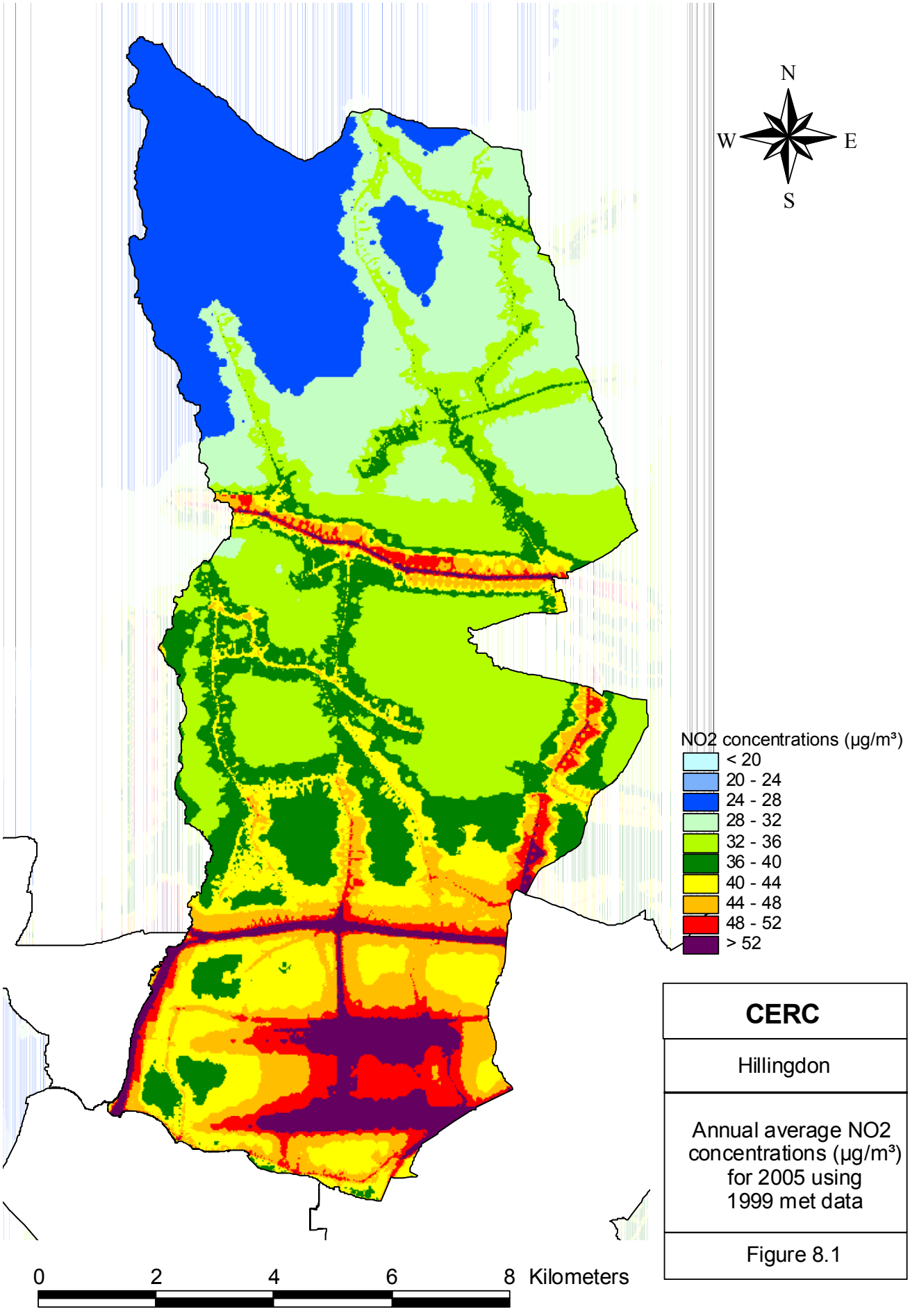
Figures 8.1 and 8.2, respectively, show the predicted annual average and 99.79th percentile of hourly average NO_2 concentrations for Hillingdon for 2005, using 1999 met data. Exceedences of the AQS objectives are shown in yellow and red.

Annual average concentrations of NO_2 are predicted to be highest in the south of the borough, reaching more than 26ppb around Heathrow Airport and along the two adjacent motorways. Concentrations are predicted to exceed the AQS objective value of 21ppb over most of the southern half of the borough and along the A40. In the north of the borough, concentrations are generally predicted to be below the AQS objective value, except in the immediate vicinity of the busiest roads and junctions.

The 99.79th percentiles of hourly average NO_2 concentrations are predicted to be below the AQS objective value of 105ppb over most of the borough, with the exception of the M25 motorway. Concentrations are predicted to be below 95ppb over most of the borough, except along the motorways, the A40 and at Heathrow Airport.

Figures 8.3 and 8.4 respectively show the predicted annual average and 99.79th percentile of hourly average NO_2 concentrations for Hillingdon for 2005 using 1997 met data.

Using 1997 meteorological data gives rise to greater predicted annual average NO_2 concentrations, with a greater predicted area of exceedence of the AQS objective value. The 99.79th percentiles of hourly average concentrations are predicted to be similar to those predicted using the 1999 meteorological data.

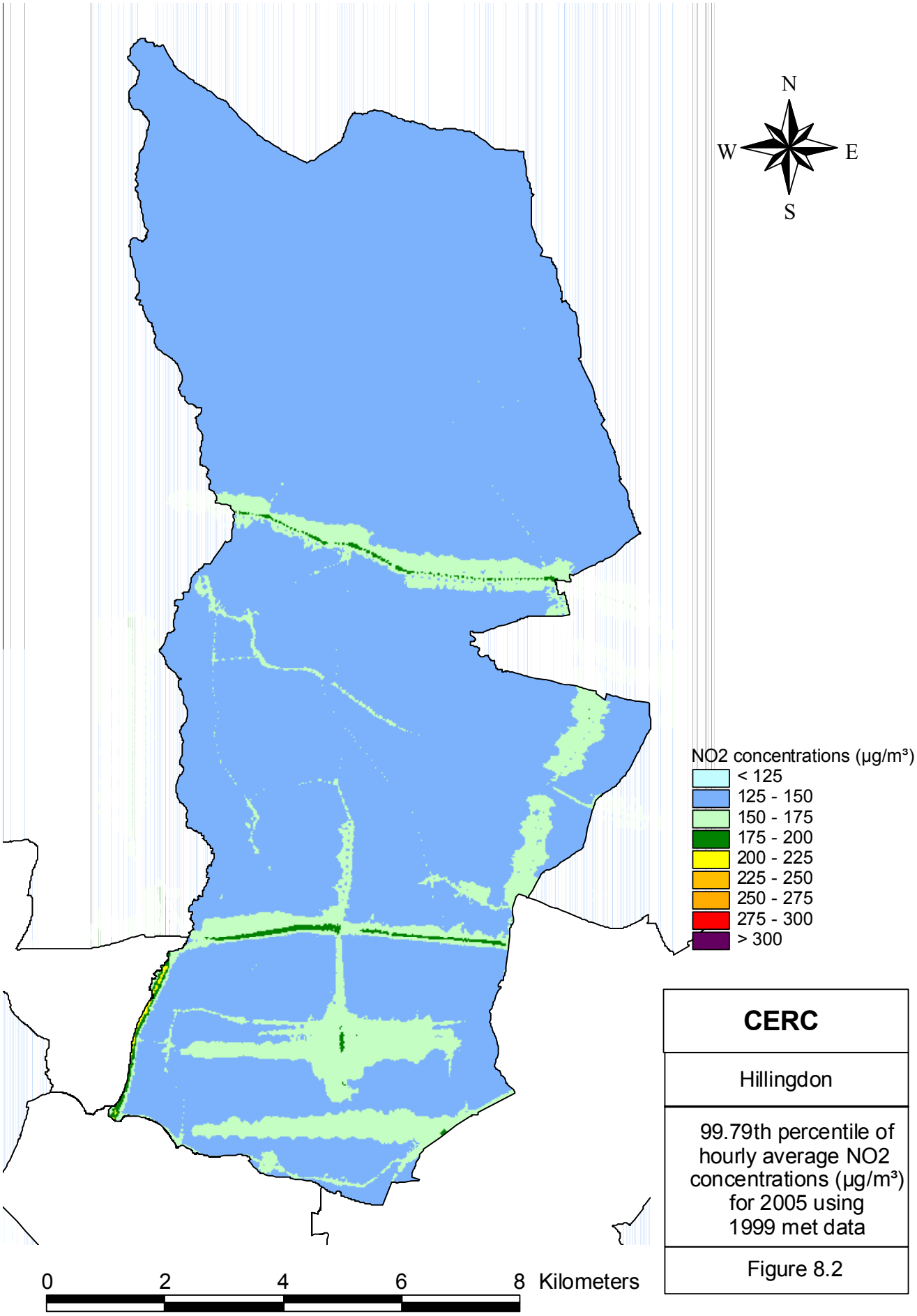


CERC

Hillingdon

Annual average NO2 concentrations (µg/m³) for 2005 using 1999 met data

Figure 8.1

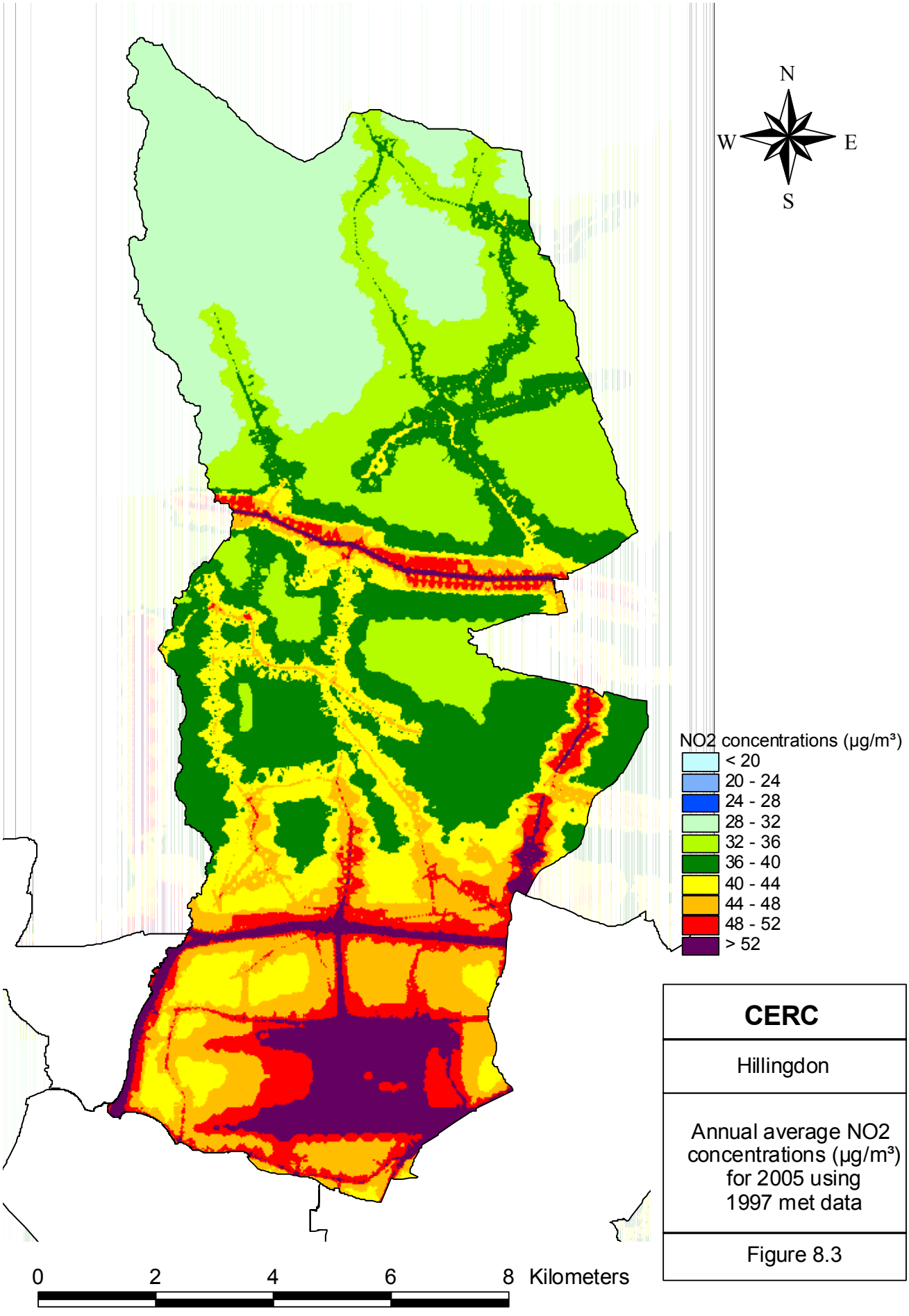


CERC

Hillingdon

99.79th percentile of hourly average NO2 concentrations (µg/m³) for 2005 using 1999 met data

Figure 8.2

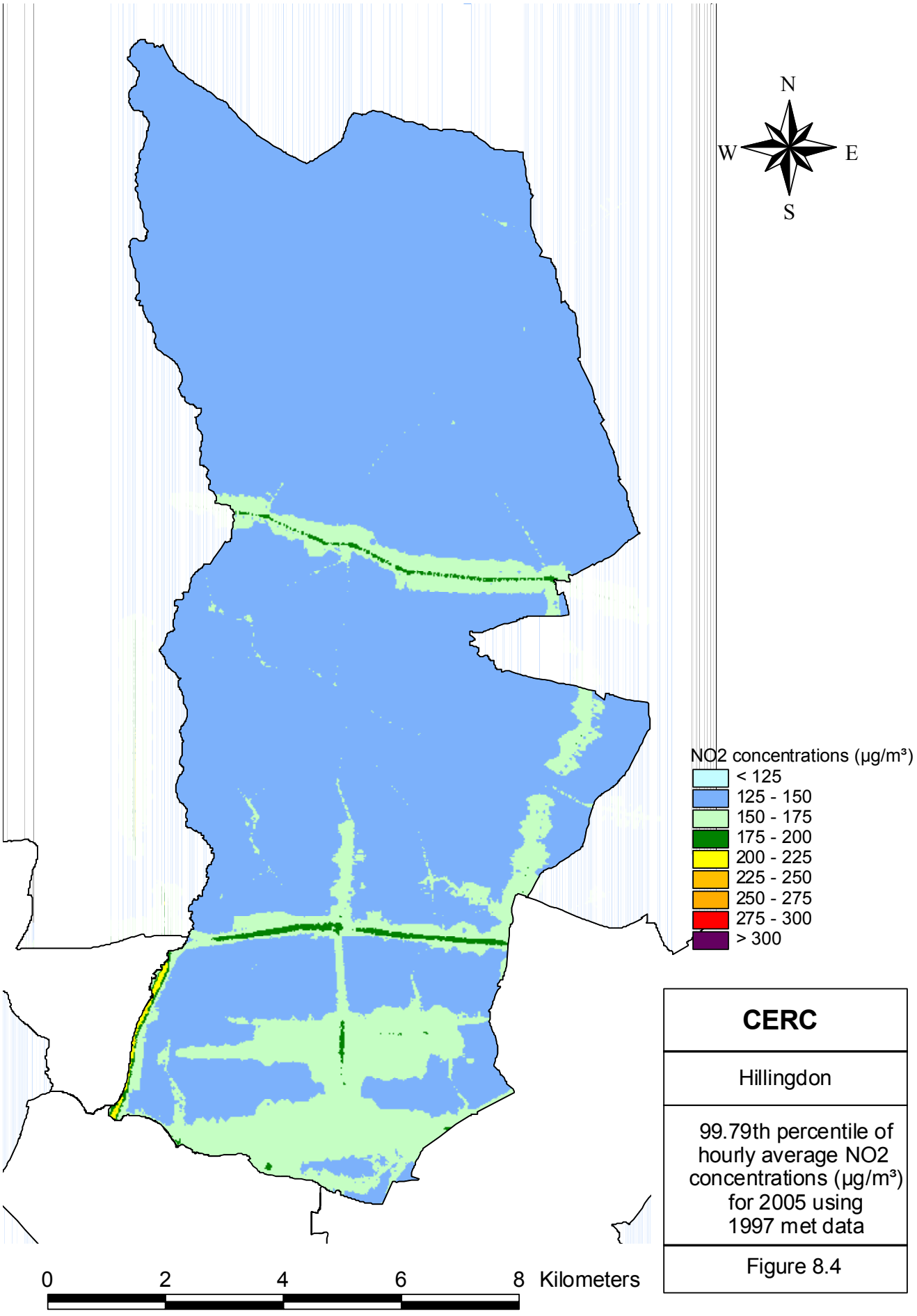


CERC

Hillingdon

Annual average NO2 concentrations (µg/m³) for 2005 using 1997 met data

Figure 8.3



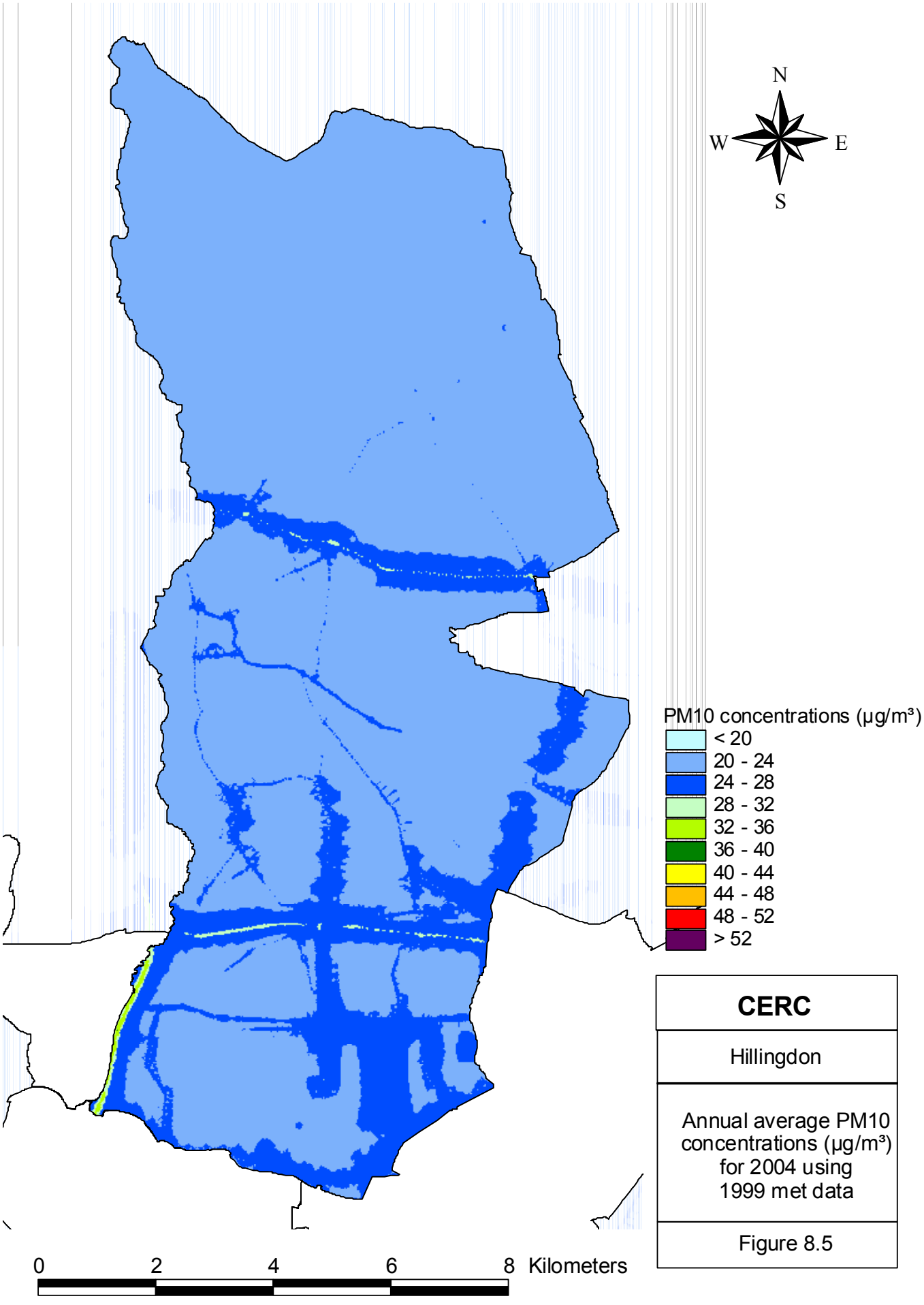
CERC
Hillingdon
99.79th percentile of hourly average NO2 concentrations (µg/m³) for 2005 using 1997 met data
Figure 8.4

8.2 PM_{10} concentrations

Figures 8.5 and 8.6, respectively, show the predicted annual average and 90.41st percentiles of 24-hour average PM_{10} concentrations for Hillingdon for 2004, using 1999 met data. Exceedences of the AQS objectives case are shown in yellow and red.

Annual average PM_{10} concentrations are predicted to be well below the AQS objective value of 40µg/m³ over the whole borough. Concentrations are predicted to be below 28µg/m³ over most of the borough, except along the motorways and the A40 where concentrations of up to 36µg/m³ are predicted.

The 90.41st percentiles of 24-hour average PM_{10} concentrations are predicted to exceed the AQS objective value of 50µg/m³ only over small areas on the M25. Away from the motorways, concentrations are predicted to be below 40µg/m³.

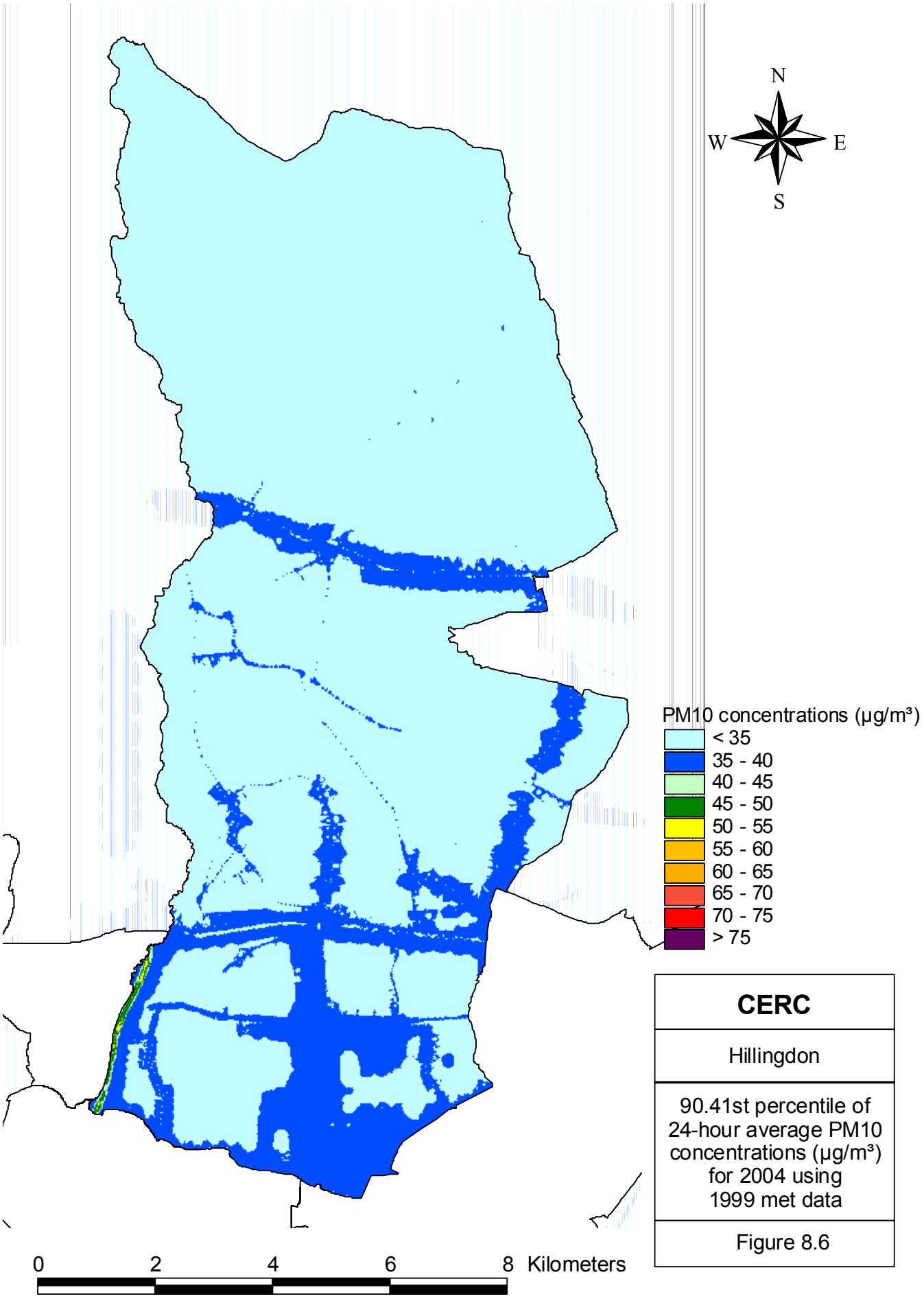


CERC

Hillingdon

Annual average PM10 concentrations (µg/m³) for 2004 using 1999 met data

Figure 8.5

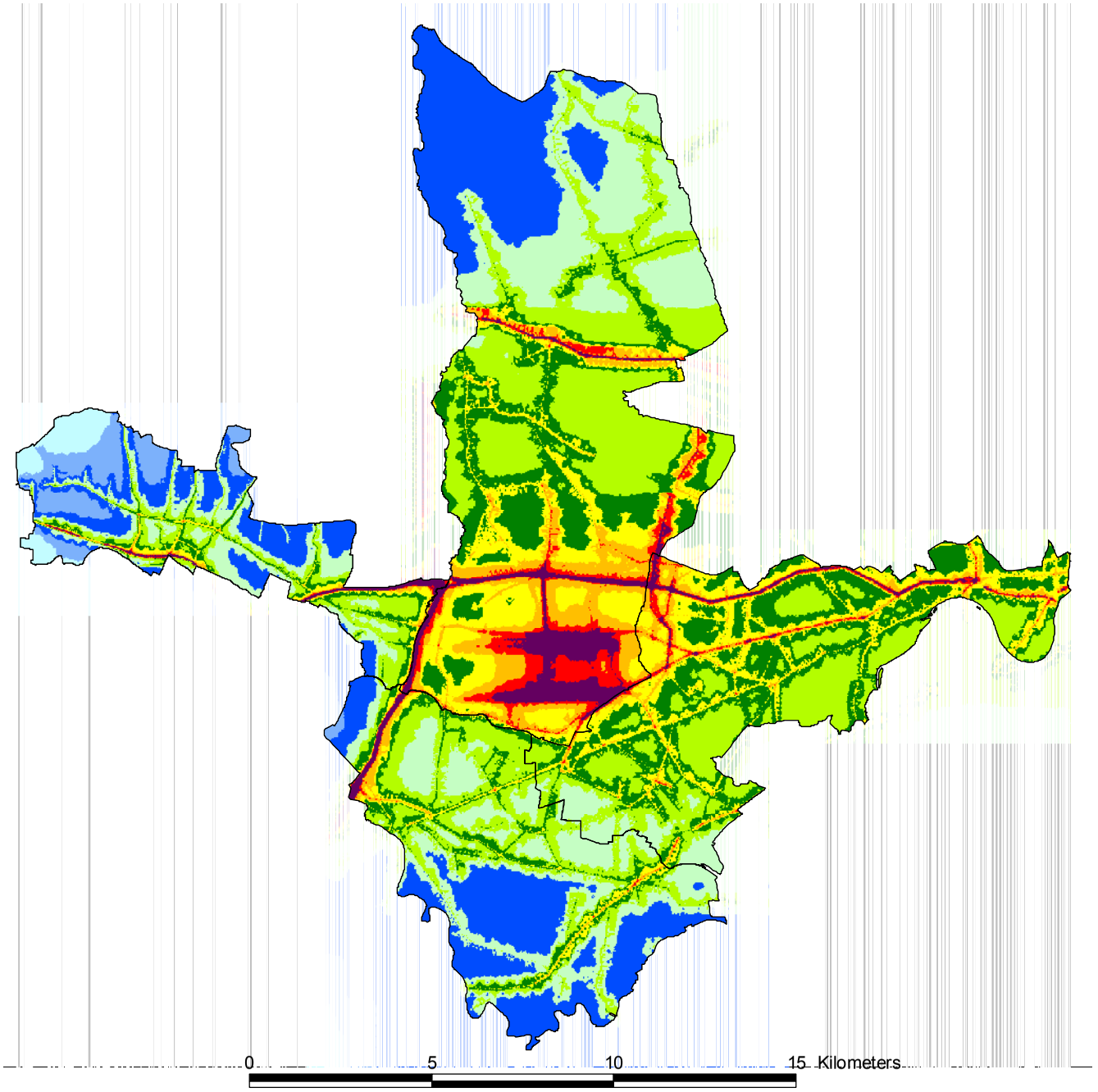


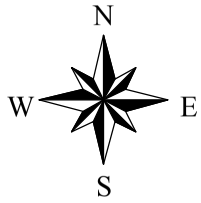
CERC
Hillingdon
90.41st percentile of 24-hour average PM10 concentrations (µg/m³) for 2004 using 1999 met data
Figure 8.6

8.3 Contour Maps of West London

Figures 8.7 and 8.8, respectively, show the predicted annual average and 99.79th percentiles of hourly average NO_2 concentrations for the whole of the West London area for 2005 using 1999 meteorological data. These maps correspond exactly to Figures 8.1 and 8.2 but for a larger area. Similarly, Figures 8.9 and 8.10 respectively show the corresponding NO_2 concentrations for Hillingdon and Hounslow only using 1997 meteorological data.

Figures 8.11 and 8.12, respectively, show the predicted annual average and 90.41st percentiles of 24-hour average PM_{10} concentrations for the whole of the West London area for 2004 using 1999 meteorological data.

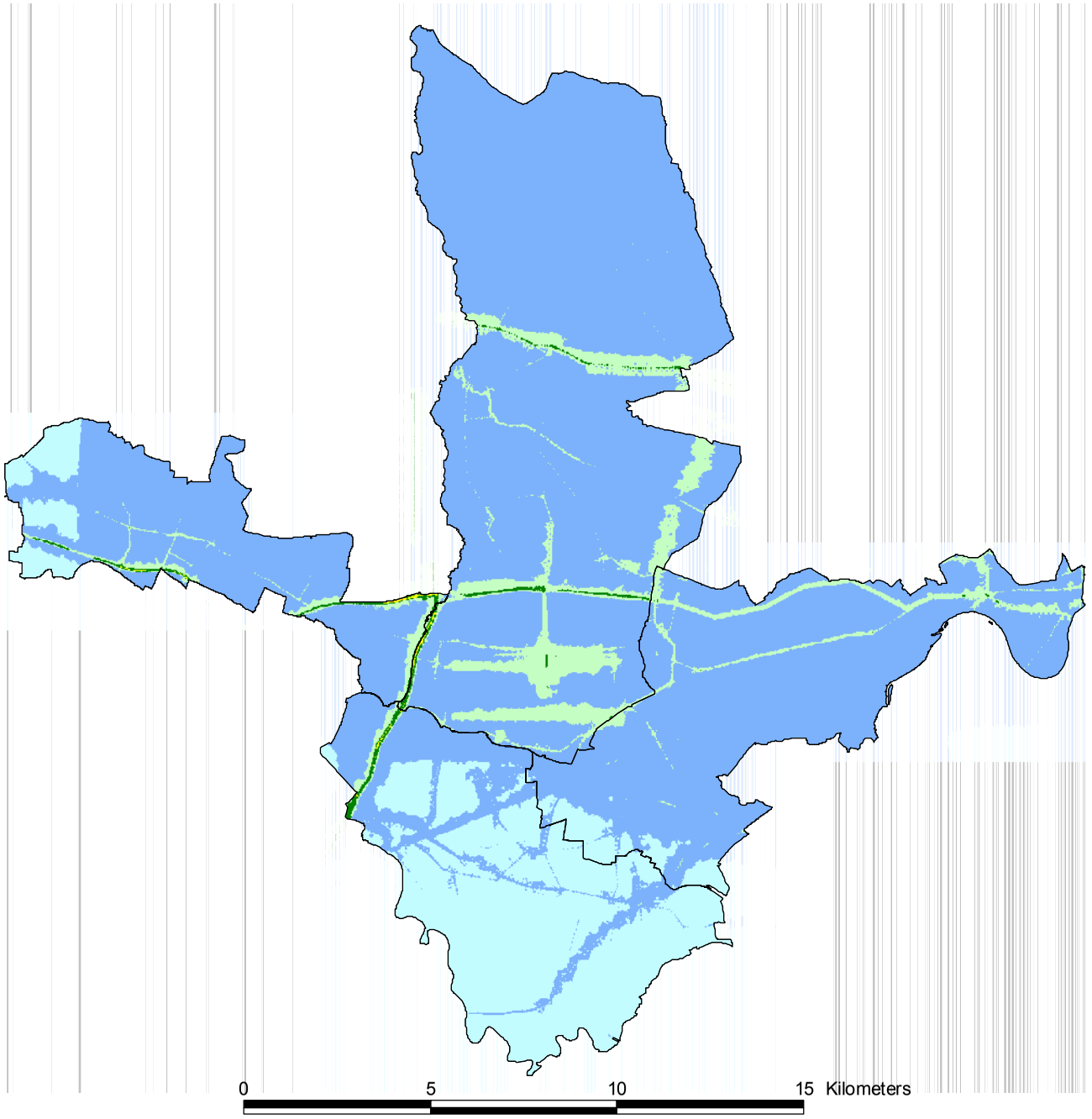




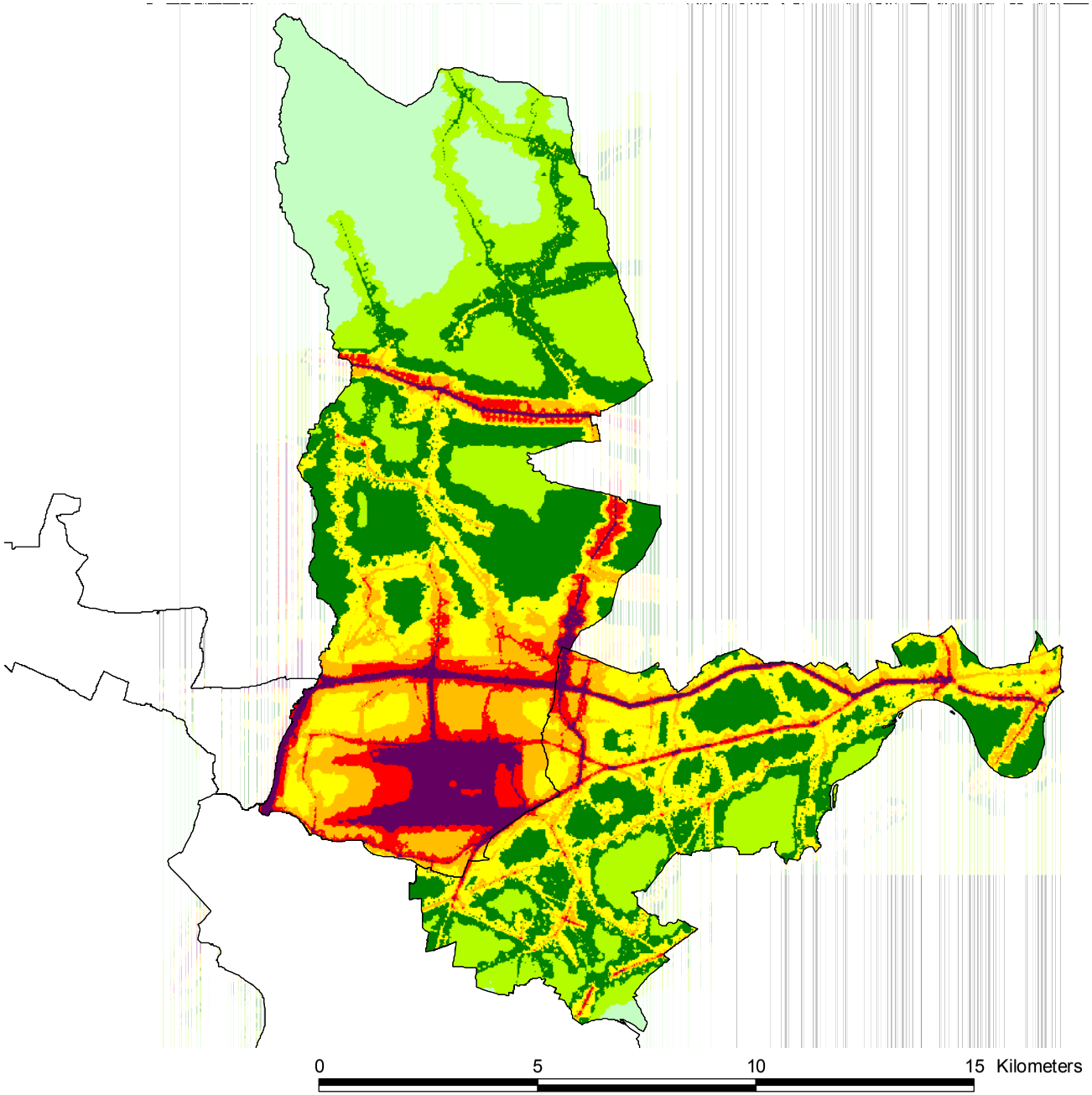
NO2 concentrations (µg/m³)

- < 20
- 20 - 24
- 24 - 28
- 28 - 32
- 32 - 36
- 36 - 40
- 40 - 44
- 44 - 48
- 48 - 52
- > 52

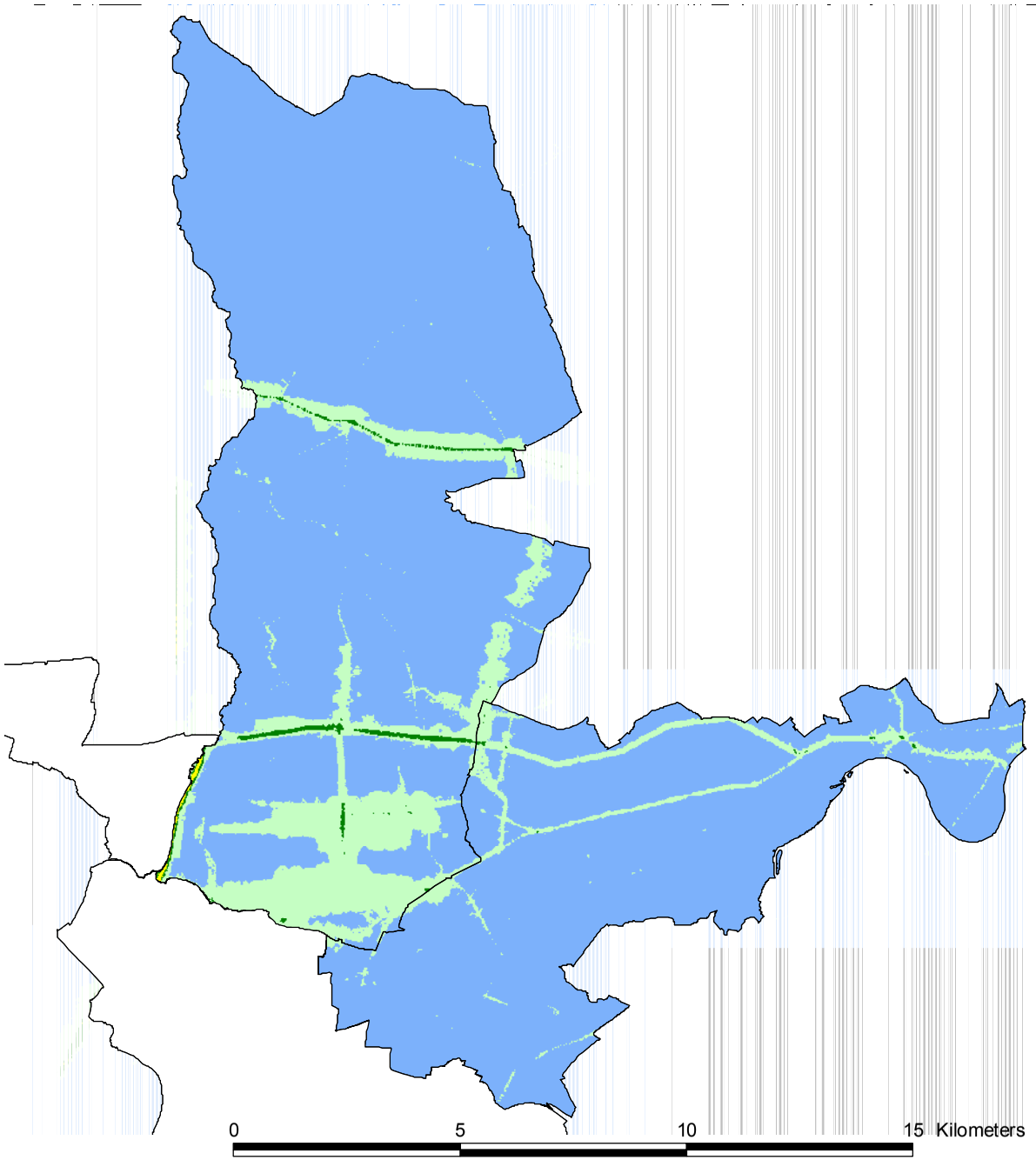
CERC
Hillingdon, Hounslow, Spelthorne and Slough
Annual average NO2 concentrations (µg/m³) for 2005 using 1999 met data
Figure 8.7



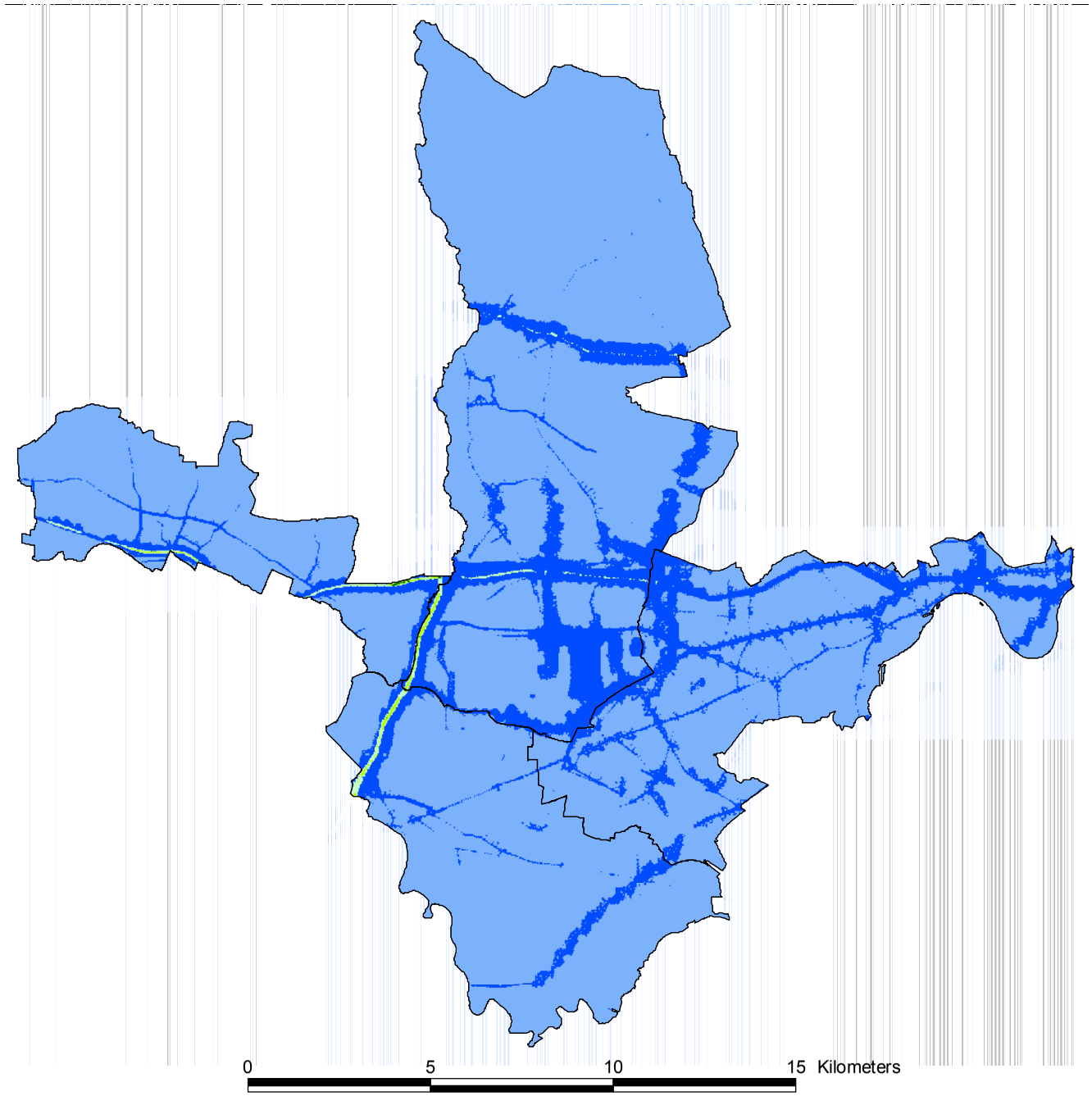
CERC
Hillingdon, Hounslow, Spelthorne and Slough
99.79th percentile of hourly average NO2 concentrations (µg/m³) for 2005 using 1999 met data
Figure 8.8



CERC
Hillingdon and Hounslow
Annual average NO2 concentrations (µg/m³) for 2005 using 1997 met data
Figure 8.9



CERC
Hillingdon and Hounslow
99.79th percentile of hourly average NO2 concentrations (µg/m³) for 2005 using 1997 met data
Figure 8.10

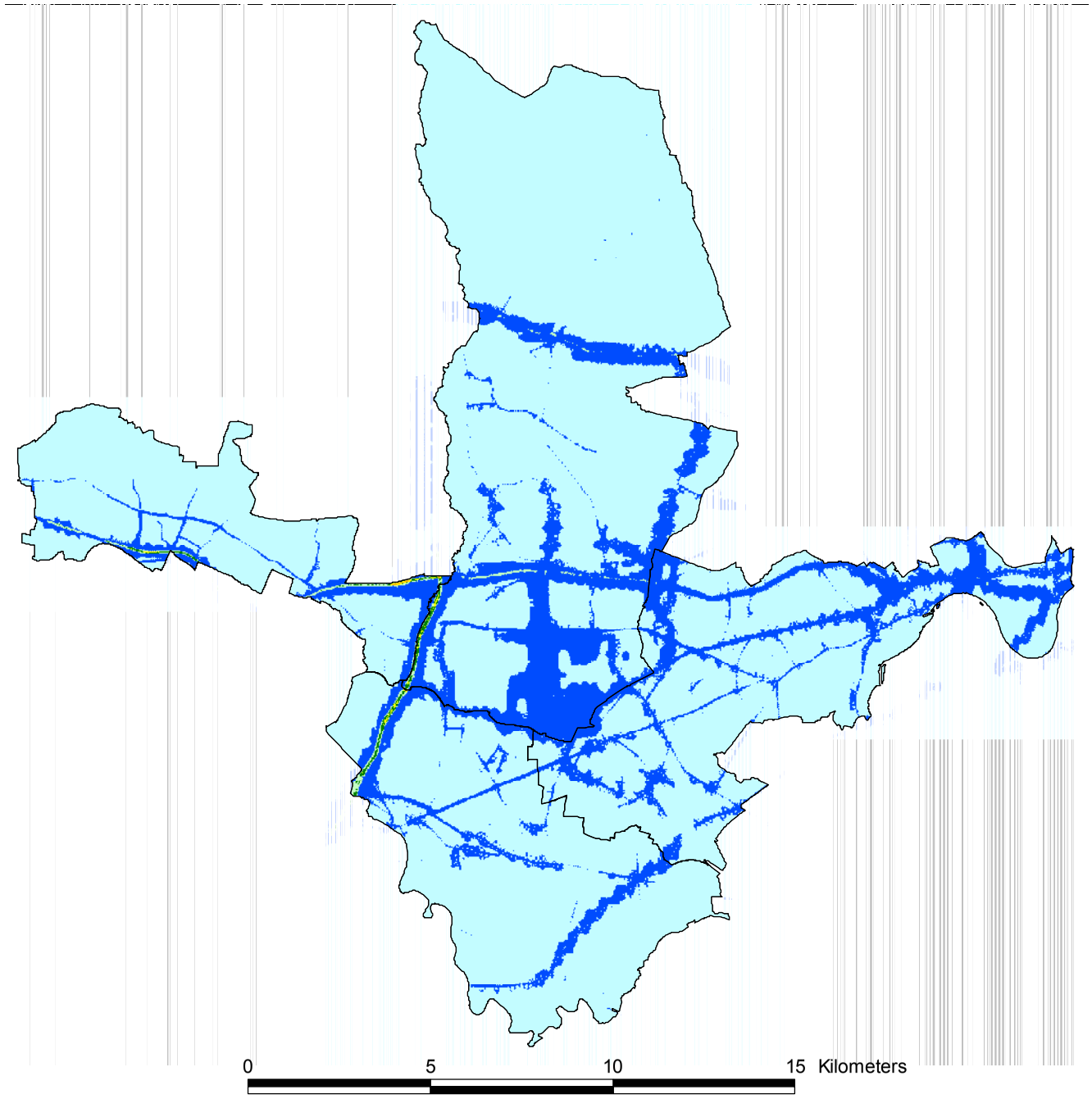


CERC

Hillingdon, Hounslow, Spelthorne and Slough

Annual average PM10 concentrations (µg/m³) for 2004 using 1999 met data

Figure 8.11



CERC
Hillingdon, Hounslow, Spelthorne and Slough
90.41st percentile of 24-hour average PM10 concentrations (µg/m³) for 2004 using 1999 met data
Figure 8.12

9. Discussion

Modelling of NO_2 and PM_{10} has been carried out for four Local Authorities in the West London area. Current and future emissions data were taken from four different sources: the emissions inventory for Heathrow, 1998; the London Atmospheric Emissions Inventory (LAEI), supplied by the Greater London Authority (GLA), February 2002; the Surrey Traffic Model; and the February 2002 emissions inventory for Slough.

Comparisons of modelled and measured NO_2 and PM_{10} data for 1999 have been made at monitoring sites within the area and predicted future concentrations for 2004 for PM_{10} and 2005 for NO_2 have been calculated for comparison with Air Quality Strategy (AQS) objective values.

The validation study for 1999 shows that the modelled concentrations agreed well with the measured values at the majority of monitoring locations. This indicates that the modelling approach and the emissions data are both suitable for the study area. Consequently, provided that the emissions estimates for the future years are accurate, the predicted future concentrations are likely to give a robust indication of whether or not the AQS objective values for NO_2 and PM_{10} will be exceeded.

The results for Hillingdon for 2004 and 2005 show that widespread exceedences of the AQS objective value for annual average NO_2 concentrations of 40μg/m³ are predicted. The AQS objective value for the 99.79^{th} percentile of hourly average concentrations is predicted to be exceeded only along the busiest roads and at major road junctions within the borough.

The AQS objective value for the annual average PM_{10} concentrations is predicted not to be exceeded anywhere within Hillingdon. However, exceedences of the AQS objective value for the 90.41^{st} percentile of 24-hour average concentrations are predicted to occur along the M25.

APPENDIX A: Summary of ADMS-Urban

ADMS-Urban is a practical air pollution modelling tool, which has been developed to provide detailed predictions of pollution concentrations for all sizes of study area. The model can be used to look at concentrations near a single road junction or over a region extending across the whole of a major city. ADMS-Urban has therefore been extensively used for Stage 3 of the Review and Assessment of Air Quality carried out by Local Authorities in the UK, and for the follow-up work required in Stage 4 and the development of Action Plans for improving air quality. The following is a summary of the capabilities and validation of ADMS-Urban. More details can be found on the CERC web site at www.cerc.co.uk.

ADMS-Urban is a development of the Atmospheric Dispersion Modelling System (ADMS) which has been developed to investigate the impacts of emissions from industrial facilities. ADMS-Urban allows full characterisation of the wide variety of emissions in urban areas, including an extensively validated road traffic emissions model. It also boasts a number of other features, which include consideration of:

- the effects of vehicle movement on the dispersion of traffic emissions;
- the behaviour of material released into street-canyons;
- the chemical reactions occurring between nitrogen oxides, ozone and Volatile Organic Compounds (VOCs);
- the pollution entering a study area from beyond its boundaries;
- the effects of complex terrain on the dispersion of pollutants; and
- the effects of a building on the dispersion of pollutants emitted nearby.

More details of these features are given below.

Studies of extensive urban areas are necessarily complex, requiring the manipulation of large amounts of data. To allow users to cope effectively with this requirement, ADMS-Urban has been designed to operate in the widely familiar PC environment, under Windows NT. The manipulation of data is further facilitated by the possible integration of ADMS-Urban with a Geographical Information System (GIS) such as MapInfo or ArcView, and with the CERC Emissions Inventory Toolkit, EMIT.

Dispersion Modelling

ADMS and ADMS-Urban use boundary layer similarity profiles to parameterise the variation of turbulence with height within the boundary layer, and the use of a skewed-Gaussian distribution to determine the vertical variation of pollutant concentrations in the plume under convective conditions.

The main dispersion modelling features of ADMS-Urban are as follows:

- ADMS-Urban is an **advanced dispersion model** in which the boundary layer structure is characterised by the height of the boundary layer and the Monin-Obukhov length, a length scale dependent on the friction velocity and the heat flux at the surface. This method supercedes methods based on Pasquill Stability Categories, as used in, for example, Caline and ISC. Concentrations are calculated hour by hour and are fully dependent on prevailing weather conditions.
- For convective conditions, a **non-Gaussian vertical profile of concentration** allows for the skewed nature of turbulence within the atmospheric boundary layer, which can lead to high concentrations near to the source.
- A **meteorological pre-processor** calculates boundary layer parameters from a variety of input data, typically including date and time, wind speed and direction, surface temperature and cloud cover. Meteorological data may be raw hourly averaged or statistically analysed data.

Emissions

Emissions into the atmosphere across an urban area typically come from a wide variety of sources. There are likely to be industrial emissions from chimneys as well as emissions from road traffic and domestic heating systems. To represent the full range of emissions configurations, the explicit source types available within ADMS-Urban are:

- **Industrial points**, for which plume rise and stack downwash are included in the modelling.
- **Roads**, for which emissions are specified in terms of vehicle flows and the additional initial dispersion caused by moving vehicles is also taken into account.
- **Areas**, where a source or sources is best represented as uniformly spread over an area.
- **Volumes**, where a source or sources is best represented as uniformly spread throughout a volume.

In addition, sources can also be modelled as a regular grid of emissions. This allows the contributions of large numbers of minor sources to be efficiently included in a study while the majority of the modelling effort is used for the relatively few significant sources.

ADMS-Urban can be used in conjunction with CERC's Emissions Inventory Toolkit, EMIT, which facilitates the management and manipulation of large and complex data sets into usable emissions inventories.

Presentation of Results

The results from the model can be based on a wide range of averaging times, and include rolling averages. Maximum concentration values and percentiles can be calculated where appropriate meteorological input data have been input to the model. This allows ADMS-Urban to be used to calculate concentrations for direct comparison with existing air quality limits, guidelines and objectives, in whatever form they are specified.

ADMS-Urban can be integrated with the ArcView or MapInfo GIS to facilitate both the compilation and manipulation of the emissions information required as input to the model and the interpretation and presentation of the air quality results provided.

Complex Effects - Street Canyons

The *Operational Street Pollution Model (OSPM)*[6], developed by the Danish National Environmental Research Institute (NERI), has been incorporated within ADMS-Urban. The OSPM uses a simplified flow and dispersion model to simulate the effects of the vortex that occurs within street canyons when the wind-flow above the buildings has a component perpendicular to the direction of the street. The model takes account of vehicle induced turbulence. The model has been validated against Danish and Norwegian data.

Complex Effects - Chemistry

ADMS-Urban includes the *Generic Reaction Set (GRS)*[7] atmospheric chemistry scheme. The original scheme has seven reactions, including those occurring between nitrogen oxides and ozone. The remaining reactions are parameterisations of the large number of reactions involving a wide range of Volatile Organic Compounds (VOCs). In addition, an eighth reaction has been included within ADMS-Urban for the situation when high concentrations of nitric oxide (NO) can convert to nitrogen dioxide (NO_2) using molecular oxygen.

In addition to the basic GRS scheme, ADMS-Urban also includes a trajectory model[8] for use when modelling large areas. This permits the chemical conversions of the emissions and background concentrations upwind of each location to be properly taken into account.

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[6] Hertel, O., Berkowicz, R. and Larssen, S., 1990, 'The Operational Street Pollution Model (OSPM).' *18th International meeting of NATO/CCMS on Air Pollution Modelling and its Applications.* Vancouver, Canada, pp741-749.

[7] Venkatram, A., Karamchandani, P., Pai, P. and Goldstein, R., 1994, 'The Development and Application of a Simplified Ozone Modelling System.' *Atmospheric Environment,* Vol 28, No 22, pp3665-3678.

[8] Singles, R.J., Sutton, M.A. and Weston, K.J., 1997, 'A multi-layer model to describe the atmospheric transport and deposition of ammonia in Great Britain.' In: *International Conference on Atmospheric Ammonia: Emission, Deposition and Environmental Impacts. Atmospheric Environment*, Vol 32, No 3.

Complex Effects - Terrain

As well as the effect that complex terrain has on wind direction and, consequently, pollution transport, it can also enhance turbulence and therefore increase dispersion. These effects are taken into account in ADMS-Urban using the FLOWSTAR[9] model developed by CERC.

Data Comparisons – Model Validation

ADMS-Urban is a development of the Atmospheric Dispersion Modelling System (ADMS), which is used throughout the UK by industry and the Environment Agency to model emissions from industrial sources. ADMS has been subject to extensive validation, both of individual components (e.g. point source, street canyon, building effects and meteorological pre-processor) and of its overall performance.

ADMS-Urban has been extensively tested and validated against monitoring data for large urban areas in the UK, including Central London and Birmingham, for which a large scale project was carried out on behalf of the DETR (now DEFRA).

Further details of ADMS-Urban and model validation, including a full list of references, are available from the CERC web site at www.cerc.co.uk.

[9] Carruthers D.J., Hunt J.C.R. and Weng W-S. 1988. 'A computational model of stratified turbulent airflow over hills – FLOWSTAR I.' Proceedings of Envirosoft. In: *Computer Techniques in Environmental Studies,* P. Zanetti (Ed) pp 481-492. Springer-Verlag.

APPENDIX B: Monitoring Data QA/QC Procedures

B1 Hillingdon Automatic Urban and Rural Network (AURN)

Data management is contracted to Stanger Science and Environment, and the Quality Assurance and Quality Control functions to NETCEN. Stanger has direct telephone access to the analysers and both parties receive the fortnightly manual calibrations by fax. NETCEN carries out technical audits of the site twice a year, which includes auditing of the local site operators.

The maintenance contract for the instrumentation including servicing and call-out is performed by SIGNAL.

B2 Hillingdon Local Air Quality Network (LAQN)

Data management and the Quality Assurance and Quality Control functions are contracted to the Environmental Research Group at King's College (ERG). ERG has direct telephone access to the analysers and receives the fortnightly manual calibrations by fax. An independent inter-calibration audit is carried out under subcontract every six months, with traceability to national standards provided through the audit organisations' calibration laboratory. EMC Engineering performs the maintenance contract for the instrumentation, including servicing and call-out.

B3 Hounslow Continuous Monitoring Sites

Fortnightly manual calibrations are undertaken by the borough to help ensure that the analysers are functioning correctly. Quality Assurance and Quality Control are contracted to ERG and NPL, both parties have direct telephone access to the analysers and receive details of the manual calibration by fax. ERG accesses the logged data on the hour. NPL carries out a technical audit of the site twice yearly.

A maintenance contract has been let to allow for servicing every six months and covering the instrumentation for breakdown.

B4 Slough Continuous Monitoring Sites

These sites are part of NETCEN's National Automatic Air Monitoring Calibration Club, which ensures that the monitoring data are managed with the same procedures applied to the AURN monitoring stations. This includes data collection and screening; checking the fortnughtly manual calibrations; full ratification of datasets; and independent six monthly equipment audits with calibration traceability to national metrology standards. EMC Engineering performs the maintenance contract for the instrumentation, including servicing and call-out.

B5 Diffusion tubes

Diffusion tubes are passive devices comprising inverted perspex cylinders that sample NO_2 by absorption onto chemically coated discs. The tubes are 71mm long by 12mm internal diameter and are sealed at one end with a polythene cap containing two stainless steel mesh discs coated with triethanolamine. The other end is sealed with a removable lid when not in use. On exposure, ambient NO_2 diffuses up the tube and is absorbed by the triethanolamine.

All Hillingdon and Slough diffusion tubes are supplied and analysed by Stanger Science and Environment. Quality Assurance, in the form of contamination, blank and precision checks, is performed on each manufactured batch of test tubes. Stanger Science and Environment also participate in an inter-comparison scheme for nitrogen dioxide tubes run by NETCEN.