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Revised High Resolution Maps of Background Air Pollutant Concentrations in the UK: 1996

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Executive Summary

This is the third in a series of reports describing the high resolution air quality mapping work carried out at AEA Technology's National Environmental Technology Centre on behalf of the Department of the Environment, Transport and the Regions. Maps of estimated annual mean background concentrations of nitrogen dioxide, oxides of nitrogen, sulphur dioxide, benzene, 1,3-butadiene, carbon monoxide, particles (PM_{10}) and lead for 1996 are presented. These maps are a valuable resource for use within the assessment of local air quality as part of the United Kingdom National Air Quality Strategy. Results from dispersion or other models can be used to estimate the impact of individual sources on local air quality. Ambient air quality near to sources, such as at the edge of a busy road or near to an industrial chimney, can be estimated by calculating the sum of this local impact and the background concentration.

The general approach to mapping pollutant concentrations from a combination of monitoring site measurements and emissions inventory information is described. There have been several significant changes to the mapping methods since the previous compilation of maps was published. These include:

- High resolution emissions inventory maps for the UK have recently become available from the National Atmospheric Emissions Inventory. These maps of the spatial distribution of emissions on a 1 km x 1 km grid have been used to calculate the contribution of sources within a 25 km^2 area to local background air quality. Earlier work made use of surrogate emission statistics such as land-cover information.
- There has been a considerable increase in the availability of automatic monitoring data over the last few years. Data from many more sites are available for 1996 than were available for earlier mapping work.
- Maps of the concentrations of benzene and 1,3-butadiene have been calculated using estimates of emissions of volatile organic compounds. Carbon monoxide and PM_{10} maps have been calculated using carbon monoxide and PM_{10} emissions estimates respectively. The maps of these pollutants that were presented in earlier reports were derived indirectly from maps of the concentration of oxides of nitrogen.

Many of the maps presented in this report are available on-line from the following web sites
http://www.aeat.co.uk/netcen/airqual/
http://www.environment.detr.gov.uk/airq/aqinfo.htm

Contents

1 Introduction

1.1 BACKGROUND

This is the third in a series of reports describing the high resolution air quality mapping work carried out at AEA Technology's National Environmental Technology Centre (NETCEN) on behalf of the Department of the Environment, Transport and the Regions (DETR). In previous reports we have presented maps of estimated background air pollutant concentrations for the UK for 1991 (Stedman, 1995) and for 1994 (Stedman *et al*, 1997b). This report contains a new set of maps for 1996 and describes the significant enhancements to the mapping procedure that have been made since the last report.

Maps of ambient background air quality are required for the following:

- **Assessment of local air quality as part of the United Kingdom National Air Quality Strategy** (DoE, 1997). Local urban background concentrations can be considered as a combination of regional background concentrations onto which contributions from sources in the more immediate area are added. Results from dispersion or other models can be used to estimate the impact of individual sources on local air quality. Ambient air quality near to sources, such as at the edge of a busy road or near to an industrial chimney, can be estimated by calculating the sum of this local impact and the background concentration.
- **Air Quality assessments for the EU Framework and forthcoming Daughter Directives.** Maps of background concentrations are valuable in assessing the exposure of the population in different areas to particular levels of air pollutants. This type of analysis may assist with compliance with the EU Framework and forthcoming Daughter Directives on Air Quality.
- **Quantification of health impacts**. Estimates of population exposure can be combined with dose-response relationships for the health impact of air pollutants to provide estimates of the magnitude of health impacts across the country (Stedman *et al*, 1997a, Department of Health, 1997).
- **Comparison with critical levels**. Maps showing estimated pollutant concentrations in rural and urban areas are also useful for comparison with critical levels for the effects of pollutants on materials and vegetation.

Many of the maps presented in this report are available on-line from the following web sites
http://www.aeat.co.uk/netcen/airqual/
http://www.environment.detr.gov.uk/airq/aqinfo.htm

1.2 GENERAL APPROACH TO MAPPING

Our approach to mapping air pollutant concentrations has been described in detail in our previous report (Stedman *et al*, 1997b). A brief outline is presented here. Measured annual mean air pollutant concentrations can be considered to be made up of two parts:

- A contribution from relatively distant major source areas such as power stations or large conurbations. Measurements from monitoring sites well away from local sources, from sites within the DETR rural networks, for example, provide good indications of the spatial variation of concentrations due to distant sources.
- A contribution from more local emissions. In earlier work on the estimation of air pollutant concentrations from emission related parameters (Stedman *et al*, 1997c) 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. (Air quality at the roadside or very near to a major industrial source will be strongly influenced by this local emission and measured concentrations will reflect a combination of background and nearby influences).

The difference, *diff*, between measured ambient pollutant concentrations at urban automatic monitoring sites (not roadside or industrial sites) and an underlying rural concentration field is calculated where monitoring data are available. A regression analysis is then performed to find a coefficient, *k*, for the relationship between *diff* and estimated *emissions* in the vicinity of the monitoring sites:

$$diff = k.emissions$$

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 a rural map and emissions inventory estimates. Thus automatic monitoring data is used to calibrate the relationship between ambient air quality and emissions inventories.

Section 2 describes the important changes to the mapping methods since our last report. Maps of estimated annual mean concentrations of a range of air pollutants are presented in section 3. The input data and coefficients used to calculate the maps are tabulated along with an analysis of the reliability of the maps in section 3, and a discussion of the maps is presented in section 4. This discussion also highlights the changes in mapping methods for each pollutant, from those used in previous work.

The maps presented here are of annual mean concentration for all pollutants except ozone. The national air quality standards each pollutant are listed in Table 1 and, for some pollutants, are defined in terms of shorter averaging periods than annual mean. The corresponding national air quality objectives are that these standards should be achieved at a particular percentile by 2005 (DoE, 1997). In some cases reasonably robust empirical relationships between annual mean concentrations and these high percentiles have been derived. A comprehensive review of these relationships has been compiled by Willis *et al* (1998) and some relationships have also been discussed by Stedman *et al* (1997b).

Table 1. UK air quality standards and objectives.

Pollutant	Standard		Objective - to be achieved by 2005
	concentration	measured as	
Benzene	5 ppb	running annual mean	5 ppb
1,3-Butadiene	1 ppb	running annual mean	1 ppb
Carbon monoxide	10 ppm	running 8-hour mean	10 ppm
Lead	0.5µg/m^3	annual mean	0.5 µg/m^3
Nitrogen dioxide	150 ppb 21 ppb	1 hour mean annual mean	150 ppb, hourly mean* 21 ppb, annual mean*
Ozone	50 ppb	running 8-hour mean	50 ppb, measured as the 97th percentile*
Fine particles (PM_{10})	50 µg/m^3	running 24-hour mean	50 µg/m^3 measured as the 99th percentile*
Sulphur dioxide	100 ppb	15 minute mean	100 ppb measured as the 99.9th percentile*

ppm = parts per million; ppb = parts per billion; µg/m^3 = micrograms per cubic metre
* = these objectives are to be regarded as provisional.

2 Innovations

2.1 NAEI 1 KM X 1 KM EMISSIONS INVENTORIES

Considerable work has been undertaken at NETCEN over recent years to improve the spatial resolution of the UK National Atmospheric Emissions Inventory (NAEI). A report (Goodwin *et al*, 1997) has recently been published which details the Geographical Information System (GIS) methods that have been used to derive 1 km x 1 km grid resolution inventories for the UK. In our earlier mapping work, we used a combination of land cover information and estimates of emissions from the major road network at 5 km x 5 km grid resolution to estimate the local emissions of air pollutants (Stedman *et al*, 1997b). Land cover and emissions from major roads at a 1 km resolution have been used to derive higher resolution maps for NO_x and NO_2 for 1994 (Stedman *et al*, 1997c). The availability of high resolution maps of emissions estimates for the UK means that they can now be used directly to calculate estimates of ambient concentrations, without having to use land cover as a surrogate statistic.

Emissions estimates for 1995 were used in the work presented here. We have derived coefficients for the relationship between ambient air quality and the sum of all low level area and major road sources. We have then used these coefficients to calculate estimated maps. Background air quality is influenced by emissions from an area larger than an individual 1 km x 1 km square. The estimated concentration of a pollutant in each 1 km grid square is, therefore, derived from an estimate of the total of low level emissions from the twenty five 1 km x 1 km grid squares surrounding each location, as illustrated below.

The sum of all low level sources excludes the influence of emissions from Part A processes on local air quality. We have not set out to map the impact of these emissions on local air quality since this would best be addressed using a using dispersion model. The influence of these emissions on regional air quality has been implicitly included in the rural concentration fields which underpin the maps.

2.2 LARGER NUMBER OF AUTOMATIC MONITORING SITES

There has been a considerable increase in the availability of automatic monitoring data over the last few years. Data from many more sites are available for 1996 than were available for 1994. Details of the automatic monitoring sites used in the current mapping work can be found in Appendix 1. Data from the DETR Automatic Urban Network (AUN), Rural Monitoring Network (RMN) and Hydrocarbon Network (HC) were used supplemented with data from the Joint Environment Programme of National Power, Eastern Generation and PowerGen (JEP) and the London Air Quality Network (LAQN). Annual means for 1996 were used whenever possible. Annual means for 1995 were used if data for 1996 were not available.

Maps of rural concentrations of NO_2, SO_2 and ozone were also required for the mapping and maps of annual mean concentrations for 1995 were the most up to date maps that were available at the time of writing. Details of the measurement networks used to derive these rural maps are given in Appendix 2.

Further information on the DETR air quality monitoring networks can be found in Bower *et al* (1997); information on the LAQN can be found in Barratt *et al* (1996) and some information on the JEP monitoring sites can be found in Laxen (1996).

2.3 BENZENE AND 1,3-BUTADIENE MAPS FROM VOC EMISSIONS INVENTORY

In our previous report we used relationships between measured NO_x (oxides of nitrogen, NO + NO_2) concentrations and those of benzene and 1,3-butadiene to derive maps of these hydrocarbon species from a map of estimated NO_x concentrations. This was equivalent to assuming that the 5 km x 5 km square hydrocarbon emissions were proportional to the NO_x emissions. The relationships of the rate of emissions with vehicle speed are, however, very different and the hydrocarbon : NO_x ratio would therefore be expected to vary with mean vehicle speed. NO_x emissions are greatest (in grams per km) at high speeds but emissions of hydrocarbons are greatest at low speeds. The maps presented in our previous report were, therefore, likely to have overestimated concentrations of benzene and 1,3-butadiene in the vicinity of major roads with fast moving traffic, such as motorways. We have improved the mapping method by deriving relationships between measured benzene and 1,3-butadiene concentrations and volatile organic compounds (VOC) emissions. These relationships have then be used to derive maps of estimated concentrations from the VOC inventory.

2.4 CO MAP FROM CO EMISSIONS INVENTORY

In our previous report we used relationships between measured NO_x concentrations and those of CO to derive a map of CO from a map of estimated NO_x concentrations. This was equivalent to assuming that local CO emissions were proportional to NO_x emissions. The map presented in this report was derived from a CO emission inventory. As for hydrocarbons, the variation of emissions with vehicle speed for CO and NO_x are very different: NO_x emissions are greatest (in grams per km) at high speeds but emissions of CO are greatest at low speeds.The new map therefore, better represents the likely background CO concentrations in urban environments influenced by low-speed traffic.

2.5 LEAD MAP

A map of estimated background lead concentrations for the UK is presented for the first time. This map represents lead concentrations in areas where the predominant source is motor vehicle emissions. Ambient concentrations of lead in areas where concentrations are influenced by local industrial sources could be estimated by addition of the modelled concentration arising from the industrial source to the background level.

3 The Maps

3.1 INTRODUCTION

Maps of estimated background annual mean concentrations of a range of air pollutants for 1996 are shown in Figures 1 to 8. Each figure includes two graphs in addition to the map. The upper graph shows the relationship between measured air quality and low level emissions and the lower graph shows a comparison between measured and estimated concentrations. Each monitoring site is identified in these graphs by a unique *id* number (see Table A1 in Appendix 1). Figure 9 is a map of estimated summer mean ozone concentration for 1995 and Figure 10 shows the estimated number of days for which the running 8-hour mean national standard of 50 ppb was exceeded. There were more photochemical ozone episodes during the summer of 1995 than during the summer of 1996, so 1995 was chosen in preference to 1996 for the ozone maps. The ozone maps are therefore representative of levels during a summer with relatively high concentrations, rather than more typical concentrations. Details of the methods used to map ozone concentrations are given in section 4.

3.2 SUMMARY OF INPUT DATA AND COEFFICIENTS

All of the maps except for the maps of ozone concentration were calculated using the following type of expression:

estimated concentration = rural map + k x emissions (kTonnes per 25 km^2 per year)

Table 2 summarises the rural map, emissions estimates and coefficients used for each map. The coefficients also given in units of sm^{-1} (seconds/metres). For NO_x, for example, the coefficient k_1 was derived from the measured concentrations in ppb and emissions data in kTonnes per 25 km^2 area per year. The coefficient k_2 can be derived by expressing the measured concentration in gm^{-3} and the emissions data in gs^{-1}m^{-2}. Chamberlain *et al* (1979) estimated the approximate box model coefficient for a 5 km x 5 km box using appropriate meteorology for the UK. They arrived at a figure of 20 sm^{-1}, and as can be seen, our coefficients are of similar order. The coefficient for SO_2 is smaller, suggesting that the low-level emissions estimates are too large in the vicinity of the monitoring sites used to calibrate the mapping coefficient. The coefficients for benzene and 1,3-butadiene are higher than the rest but are dependent on the percentage of total the VOC emissions represented by benzene and 1,3-butadiene.

Table 2. Summary of input data and coefficients used to calculate the estimated maps for 1996.

pollutant	Fig No	units	interpolated rural map	emissions (kTonnes per 25 km^2 per year)	coefficient, k_1

NO_2	1	ppb	NO_2	area + major road NO_x	5.920
NO_x	2	ppb	NO_2 x 1.2	area + major road NO_x	17.349
SO_2	3	ppb	SO_2	area + major road SO_2	6.577
benzene	4	ppb	NO_2 x 0.031	area + major road VOC	0.281
1,3-butadiene	5	ppb	NO_2 x 0.00538	area + major road VOC	0.0566
CO	6	ppm	constant = 0.150	area + major road CO	0.03
PM_{10} (GB)	7	μgm^{-3}	particulate SO_4 + 6 + 0.00001 x grid easting[3]	minor + major road PM_{10}	28.67
PM_{10} (Northern Ireland)	7	μgm^{-3}	particulate SO_4 + 6 + 0.00001 x grid easting[3]	area + major road SO_2	5.91
Lead	8	ngm^{-3}	NO_2 x 1.344	area + major road NO_x	19.431

[1] Benzene assumed to be 1.55% to total VOC emissions (Salway *et al*, 1997)
[2] 1,3-butadiene assumed to be 0.23% of total VOC emissions (Hutchinson and Clewley, 1996)
[3] See section 4.5

3.3 SUMMARY OF MAP RELIABILITY

Table 3 gives an indication of the reliability of each map in terms of the correlation coefficient between the measured and estimated values and the means of the measured and estimated concentrations at background monitoring sites (not roadside or kerbside).

Table 3. Summary of map reliability

Pollutant	units	correlation coefficient (r)	mean of measurements	mean of estimates	number of sites
NO_2	ppb	0.881	20.08	19.75	5[illegible]
NO_x	ppb	0.822	40.09	38.05	5[illegible]
SO_2	ppb	0.726	6.01	5.84	5[illegible]
benzene	ppb	0.614	1.104	1.146	1[illegible]
1,3-butadiene	ppb	0.587	0.214	0.224	1[illegible]
CO	ppm	0.454	0.578	0.539	3[illegible]
PM_{10}	μgm^{-3}	0.0	24.10	24.40	2[illegible]
Lead	ngm^{-3}	0.970	36.46	31.02	1[illegible]
O_3 summer	ppb	0.960	26.51	26.98	2[illegible]
O_3 days	days	0.891	25.18	26.40	2[illegible]

4 Discussion

4.1 NITROGEN DIOXIDE AND OXIDES OF NITROGEN

Maps of annual mean concentration of NO_2 and NO_x for 1994 have been published by Stedman *et al* (1997b). Land cover information and NO_x emissions from major roads were used as surrogates for local emissions in this earlier work. In the maps presented here we have used estimates of low-level emissions to calculate ambient concentrations. Urban background concentrations of these pollutants are determined to a large extent by NO_x emissions from road transport. The good correlation between annual mean urban background NO_2 and NO_x concentrations and local emissions estimates indicates that the spatial variation in emissions at the scale used for the mapping is well represented by the NAEI methods.

The reliability and applicability of the NO_2 map to background locations is further examined in Figure 11 by comparison of the 1 km x 1 km grid square estimated annual mean concentrations from the map with the annual mean NO_2 concentrations for 1996 from 'urban background' (defined as being more than 50 m from any busy road and typically in a residential area) sites within the UK Nitrogen Dioxide Survey (Stevenson and Bush , 1997). The mean of the measured concentrations was 14.4 ppb; the mean of the estimated concentrations was 13.7 ppb; r = 0.63, n = 555. While this graph shows some scatter, there is no evidence of as large systematic error in the estimates of annual mean background NO_2 concentration. The estimated NO_2 concentrations in inner London are rather higher than indicated by the diffusion tube measurements. A comparison of the estimated values with automatic monitoring sites in inner London (Figure 1c) also indicates that the map overestimates concentrations at some of these sites, but not to the extent suggested by the diffusion tube measurements. It is likely therefore that concentrations in this area might be overestimated by the map, perhaps due to high emissions estimates, and/or that the diffusion tube measurements may under represent concentrations relative to automatic measurements.

Figure 12 shows a comparison of estimated annual mean NO_x concentrations and measured values for urban background and roadside and kerbside monitoring sites in London and the South East. Agreement between estimated and measured values is very good for background sites but is extremely poor for roadside and kerbside sites. This shows the influence of nearby traffic emission on NO_x concentrations in these locations. Roadside or kerbside NO_x concentrations can, in principle be calculated by adding a background value to a kerbside contribution derived from traffic activity information. This estimate of kerbside contribution could be calculated using a method such as that presented in the Design Manual for Roads and Bridges, or a simplified model based on the analysis of kerbside monitoring data and traffic activity.

4.2 SULPHUR DIOXIDE

In our previous report we presented a 10 x 10 km resolution map of estimated SO_2 concentrations for 1994 and noted that it underestimated concentration in coal use areas, particularly in Belfast. Estimates of domestic emissions of SO_2 in Northern Ireland within the NAEI have since been revised and the estimated concentrations for automatic monitoring sites in Belfast are now much nearer to the measured values. The majority of the automatic monitoring sites used to 'calibrate' the SO_2 map are in either city centre or rural locations. The map therefore provides a reasonably good estimate of concentrations in these areas. The accuracy of the estimates of concentration in smaller urban or suburban areas is dependent on fuel use and the map may still underestimate concentrations in some areas. Figure 13 shows a comparison of estimated concentrations with measurements from Basic Urban Network sites within the UK Smoke and Sulphur Dioxide Survey. It is clear that the map underestimates concentrations at many monitoring sites. The value of the ratio of measured concentration divided by estimated concentration has been calculated for each of these sites and the average value of this ratio has been calculated for different site environments. The agreement is slightly better, on average, at sites in smoke control areas (ratio = 1.8 (all sites); 1.7 (sites in smoke control areas); 1.9 (sites not in smoke control areas)). Agreement was best at sites in city and town centre locations (ratio = 1.6) and worst at sites with high (ratio = 1.9) or medium (ratio = 2.1) density housing and industrial areas (ratio = 2.3).

There may be a number of reasons for the poor performance of the map in comparison with Basic Urban Network measurements:

- inaccuracies in the measurements;
- the influence of very local sources (within a few hundred metres, domestic or industrial) on concentrations at the monitoring sites;
- inaccuracies in the way that domestic and industrial SO_2 emissions are spatially distributed within the emissions inventory.

4.3 BENZENE AND 1,3-BUTADIENE

The variation of emissions amount with vehicle speed is very different for VOC and NO_x. Maximum VOC emissions (in terms of g km^{-1}) are produced by slow moving vehicles, such as those on congested urban roads. Maximum NO_x emissions are produced by fast moving vehicles, such as free flowing traffic travelling on motorways.

Previous maps of estimated benzene and 1,3-butadiene concentrations were derived from maps of NO_x and made use of the relationship between measured ambient NO_x and benzene and 1,3-butadiene concentrations at a site where measurements are co-located. These maps therefore probably overestimated benzene and 1,3-butadiene concentrations in the vicinity of fast roads. The current benzene and 1,3-

butadiene maps (Figures 4 and 5) were derived directly from VOC emission inventories and show lower concentrations at these locations. The agreement between estimated and measured concentrations (Table 3) is similar to that for our previous maps because most of the monitoring sites are in city locations where our estimates have not changed much. Estimates of concentrations in the vicinity of motorways are probably more realistic in our current maps but it is not possible to validate these estimates without additional monitoring in these areas.

The only site for which concentrations are noticeably underestimated by the map is Southampton Centre, where a nearby busy road seems to lead to higher concentrations than are predicted by the map. This is particularly noticeable for benzene and 1,3-butadiene but Southampton Centre is one of the sites for which the concentration of several of the pollutants are underestimated by the maps.

4.4 CARBON MONOXIDE

Figure 6b shows that the correlation between measured CO concentrations and estimated local emissions is poorer than for NO_x. It is likely that there is a larger small-scale spatial variability in traffic CO emissions than for NO_x. CO emissions per unit distance increase markedly at low speeds relative to emissions of NO_x (Figure 14). The concentrations of CO recorded at monitoring sites are to some extent dependent on emissions in the immediate locality (<< 1 km) and concentrations would therefore be expected to increase where there is significant local traffic congestion. The poorer correlation between point measurements and map values for CO than for NO_x does not necessarily mean that the map values are worse estimates of the grid square average values.

The map presented as Figure 6 should provide more realistic estimates of CO concentrations in than our previous map of estimated concentrations. Our previous map was based on an average relationship of measured ambient CO and NO_x concentrations but we noted in the report (Stedman, *et al*, 1997b) that this relationship between CO and NO_x was rather uncertain due to the wide range in CO/NO_x ratio observed at monitoring sites.

4.5 PARTICLES (PM_{10})

PM_{10} is one of the most difficult pollutants to map due to the range of sources of both primary and secondary particles that contribute to ambient concentrations. The sources include:

- primary particles from vehicles;
- primary particles from stationary combustion sources;
- primary particles from non-combustion sources such as quarrying, demolition and wind blown dust;
- secondary particles.

Two alternative methods of estimating the secondary particle contribution were discussed in out previous report (Stedman *et al*, 1997b). Secondary particle concentrations were estimated from either photochemical ozone or rural particulate sulphate measurements. The secondary particle contribution to annual mean background PM_{10} concentration in the map presented in Figure 7 was derived from particulate sulphate measurements.

Primary particle concentrations (measured PM_{10} - estimated secondary particle concentration) is plotted against local vehicle emissions estimates from the NAEI in Figure 7b. There is a reasonably consistent relationship between these two parameters for all sites except London Brent and Kensington and Chelsea. The intercept concentration of primary particles at zero vehicle emissions represents primary particles from stationary and other sources. A spatially dissagregated emissions inventory is not currently available within the NAEI for these sources. Measurements of PM_{10} concentrations in rural areas provide a possible method for estimating the spatial variation in concentrations derived from these stationary combustion and non-combustion sources. Measurements of PM_{10} concentrations are now available from a limited number of rural sites. Available data is listed in Table 4 along with estimated secondary particle and vehicle derived particle contributions.

Table 4. Rural PM_{10} concentration measurements and the estimated contributions from different source types ($\mu g m^{-3}$).

id	Site	Network	Period for which mean was calculated	Measured PM_{10}	Secondary PM_{10}	Vehicle PM_{10}	Othe PM_{10}
15	Lough Navar	RMN	October 1996 - September 1997	9.8	5.9	0.0	
25	Rochester	RMN	Annual 1996	22.0	11.3	0.1	
88	Hall Farm	JEP	Annual 1995	22.9	11.2	0.9	
94	Cliffe	JEP	Annual 1995	21.0	9.6	0.1	
139	Bottesford	JEP	Annual 1996	21.9	10.3	0.1	
162	Ratcliffe	JEP	Annual 1996	22.8	9.8	0.1	
187	Narberth	RMN	March - September	15.0	8.3	0.0	

			1997				

Note: Some 1997 data are provisional

This table indicates that there is a higher concentration of PM_{10} from 'other' sources in England than in the west of Wales or Northern Ireland. In our previous map we assumed a constant value for this contribution across the entire country. In the map presented here we have assumed a spatially varying concentration for these sources; with a maximum value of 12 μgm^{-3} in eastern England and a minimum value in the west of Northern Ireland of 6 μgm^{-3}. The value of this contribution was therefore calculated by multiplying the Ordinance Survey grid reference easting (in metres) by 0.00001, as indicated in Table 2.

PM_{10} concentrations are likely to be more strongly influenced by domestic heating emissions in urban areas in Northern Ireland than in other UK cities. Concentrations of PM_{10} in Northern Ireland have been calculated using estimates of SO_2 emissions as a surrogate for PM_{10} emissions (see Table 2).

4.6 LEAD

In most areas airborne lead concentrations are dominated by the contribution from vehicle emissions due to the use of leaded petrol. Annual mean concentrations are available for a total of ten background monitoring sites for 1996. Lead concentrations were also measured in several locations where specific industrial sources of lead emissions give rise to higher concentrations. It is not possible to map the contribution industrial lead sources to ambient mean lead concentrations using the simple empirical box modelling approach used here. The map presented here therefore represents the road transport derived background lead concentration, onto which the impact of individual industrial sources could be added in more detailed modelling studies.

Spatially dissagregated lead emissions estimates are not available from the NAEI so the map presented here was based on the relationship between lead concentrations and local NO_x emissions. NO_x emissions are taken here to be reasonably representative of emissions of lead from vehicles. An alternative approach would be to use estimated lead emissions or a different surrogate such as leaded petrol fuel use.

4.7 OZONE

The estimated ozone maps presented here in Figure 9 and 10 have been derived using mapping methods which extend the work carried out jointly by NETCEN and the Institute of Terrestrial Ecology for publication in the 4th report of the Photochemical Oxidants Review Group (PORG, 1997). In contrast to the other pollutants in this report, the concentrations of ozone in urban areas are often lower than those in the surrounding rural areas. Land cover information at a 5 km x 5 km grid resolution was used by PORG as a surrogate for local NO_x emissions to estimate urban ozone concentrations from maps of rural ozone concentrations. Both 1 km x 1 km estimates of local NO_x emissions from the NAEI and 1 km x 1 km land cover information (Fuller *et* al, 1994) were investigated as alternative surrogate statistics from which to derive urban ozone concentrations for 1995 for inclusion in this report. Estimates of NO_x emissions were found to give the most reliable results for summer mean ozone concentration and land cover on a 1 km grid gave the best fit to the measurements for the number of days with concentrations greater than or equal to 50 ppb.

Maps of rural ozone concentration for 1995 were interpolated from measurements at RMN sites. Summer mean ozone concentrations vary with altitude (PORG, 1997), so a map cannot be interpolated directly from a network of rural monitoring sites at a range of elevations. A map of concentrations during the 'well mixed' part of the day (12-18 GMT) can, however, be interpolated with reasonable confidence because concentrations during this part of the day are not influenced by altitude. The difference between concentrations during this well mixed period and the mean over the whole day (DO_3) has been found to be dependent on altitude:

$$DO_3 = 3.4 + 7.7.\exp(-4.2x10^{-3}.altitude)$$

where the average *altitude* is in m for the 1 km x 1 km grid square including the site location (PORG, 1997). A map of rural summer mean ozone concentrations can therefore be calculated from the 'well mixed map' and an altitude map of the UK using the above equation.

The number of days with 8-hour mean ozone concentrations greater than or equal to 50 ppb does not vary with altitude so a map of this statistic can be interpolated directly from measurements at rural sites.

For all of the pollutant mapped in this report except ozone, local urban emissions tend to increase the concentration of pollutants in urban background locations. Conversely, local emissions of NO_x tend to decrease the ambient ozone concentration and the strength of this effect has been described by PORG in terms of an 'urban influence', UI, of these emissions:

UI = ((rural ozone concentration) - (measured urban ozone concentration)) / (rural ozone concentration).

The following relationships between UI and surrogate statistics, illustrated in Figure 9b and 10b, have been used to derive the ozone maps for the summer of 1995.

Summer mean ozone concentration (ppb):

UI = 0.1554 x [area + major road NO_x emissions, kTonnes per 25 km^2 per year].

Number of days with 8-hour mean ozone concentrations greater than or equal to 50 ppb:

UI = 0.00629 x [the proportion of land cover that is determined as urban or suburban].

5 Acknowledgements

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CONTENTS

Appendix 1
Monitoring Network Sites

The mapping work described in this report makes use of data from many of the Department of the Environment, Transport and the Regions Air Quality Monitoring Networks (see Bower *et al*, 1997 and references therein). Data from monitoring sites in the following DETR networks were used:

- Automatic Urban Monitoring Network (AUN)
- Automatic Rural Monitoring Network (RMN)
- Automatic Hydrocarbon Monitoring Network (HC)
- Acid Deposition Secondary Network (ADSN)
- Rural Sulphur Dioxide Monitoring Network (RSO_2)
- Multi Element (ME)
- Lead in Petrol (PB)
- Long-term rural (RUR)

Data from monitoring sites within the Joint Environment Programme of National Power, Eastern Generation and PowerGen (JEP) and the London Air Quality Network (LAQN) have also been made available and were used in this work.

Table A1 lists the sites in these networks. Only sites with sufficient data capture for annual concentrations to be calculated (generally >= 75%) were used in the mapping work. Each monitoring site is represented in the scatter plots shown in Figure 1 - 12 by a unique identification number, *id*, which is given in Table A1.

Table A1. Monitoring network sites.

id	name	type	network	east	north
1	Stevenage	SUBURBAN	AUN	5237	2225
2	Cromwell Road	KERBSIDE	AUN	5264	1789
3	Sibton	RURAL	RMN	6364	2719
4	West London	URBAN BACKGROUND	AUN	5251	1788
5	Glasgow City Chambers	URBAN BACKGROUND	AUN	2595	6653
6	Manchester Town Hall	URBAN BACKGROUND	AUN	3838	3980

id	name	type	network	east	north
7	Walsall Alunwell	URBAN BACKGROUND	AUN	3994	2982
8	Billingham	URBAN INDSUTRIAL	AUN	4470	5237
9	Sheffield Tinsley	URBAN INDSUTRIAL	AUN	4402	3906
10	Bridge Place	URBAN BACKGROUND	AUN	5291	1790
11	Aston Hill	RURAL	RMN	3298	2901
12	Lullington Heath	RURAL	RMN	5538	1016
13	Strath Vaich	RURAL	RMN	2347	8750
14	High Muffles	RURAL	RMN	4776	4939
15	Lough Navar	RURAL	RMN	192	5212
16	Yarner Wood	RURAL	RMN	2786	789
17	Ladybower	RURAL	RMN	4164	3892
18	Harwell	RURAL	RMN	4474	1863
19	Bottesford	RURAL	RMN	4797	3376
20	Bush	RURAL	RMN	3245	6635
21	Eskdalemuir	RURAL	RMN	3235	6028
22	Great Dun Fell	RURAL	RMN	3711	5322
23	Wharleycroft	RURAL	RMN	3698	5247
24	Glazebury	RURAL	RMN	3690	3959
25	Rochester	RURAL	RMN	5831	1762
26	Somerton	RURAL	RMN	3486	1268
27	London Teddington	SUBURBAN	RMN	5156	1706
28	Belfast East	URBAN BACKGROUND	AUN	1474	5309
29	Sunderland	URBAN BACKGROUND	AUN	4398	5570
30	Barnsley 12	URBAN BACKGROUND	AUN	4342	4067
31	London Bloomsbury	URBAN CENTRE	AUN	5302	1820
32	Edinburgh Centre	URBAN CENTRE	AUN	3254	6738
33	Cardiff Centre	URBAN CENTRE	AUN	3184	1765
34	Belfast Centre	URBAN CENTRE	AUN	1475	5300
35	Birmingham Centre	URBAN CENTRE	AUN	4064	2868
36	Newcastle Centre	URBAN CENTRE	AUN	4251	5649
37	Leeds Centre	URBAN CENTRE	AUN	4299	4343
38	Bristol Centre	URBAN CENTRE	AUN	3594	1732
39	Liverpool Centre	URBAN CENTRE	AUN	3349	3908
40	Birmingham East	URBAN BACKGROUND	AUN	4116	2889
41	Hull Centre	URBAN CENTRE	AUN	5097	4288
42	Leicester Centre	URBAN CENTRE	AUN	4590	3050
43	Southampton Centre	URBAN CENTRE	AUN	4440	1130
44	London Bexley	SUBURBAN	AUN	5518	1763
45	Swansea	URBAN CENTRE	AUN	2655	1931

id	name	type	network	east	north
46	Middlesbrough	URBAN INDSUTRIAL	AUN	4505	5194
47	Manchester Piccadilly	URBAN CENTRE	AUN	3843	3983
48	Sheffield Centre	URBAN CENTRE	AUN	4352	3869
49	Wolverhampton Centre	URBAN CENTRE	AUN	3914	2989
50	London Brent	URBAN BACKGROUND	AUN	5200	1840
52	Sutton 1	ROADSIDE	AUN	5256	1646
53	Sutton 3	SUBURBAN	AUN	5278	1648
54	Kensington and Chelsea 1	URBAN BACKGROUND	AUN	5240	1817
55	Tower Hamlets 2	ROADSIDE	AUN	5521	1816
56	Oxford Centre	URBAN CENTRE	AUN	4514	2092
57	Haringey 1	ROADSIDE	AUN	5339	1906
58	Haringey 2	SUBURBAN	AUN	5339	1907
59	Camden Roadside	KERBSIDE	AUN	5267	1843
60	London Eltham	URBAN BACKGROUND	AUN	5440	1747
61	Exeter ROAD	ROADSIDE	AUN	2929	918
62	London Hillingdon	SUBURBAN	AUN	5078	1806
63	Glasgow Centre	URBAN CENTRE	AUN	2558	6665
64	Bristol Old Market	ROADSIDE	AUN	3595	1731
65	Leamington Spa	URBAN BACKGROUND	AUN	4319	2657
66	Nottingham Centre	URBAN CENTRE	AUN	4574	3400
67	Thurrock	URBAN BACKGROUND	AUN	5611	1779
68	Bath ROAD	ROADSIDE	AUN	3375	1165
69	Stockport	URBAN BACKGROUND	AUN	3895	3908
70	Manchester South	SUBURBAN	AUN	3820	3850
71	Hackney 4	URBAN CENTRE	AUN	5348	1862
72	Port Talbot	URBAN BACKGROUND	AUN	2780	1882
73	Bury	ROADSIDE	AUN	3809	4048
74	London UCL	ROADSIDE	HC	5299	1822
75	Edinburgh Med.	URBAN BACKGROUND	HC	3257	6730
76	Belfast South	URBAN BACKGROUND	HC	1470	5297
77	Cardiff East	URBAN BACKGROUND	HC	3193	1773
78	Bristol East	URBAN BACKGROUND	HC	3599	1729
79	Leeds Potternewton	URBAN	HC	4307	4367

id	name	type	network	east	north
		BACKGROUND			
80	Liverpool Speke	URBAN BACKGROUND	HC	3438	3835
81	Bromley 4	KERBSIDE	AUN	5406	1695
82	Hounslow 1	ROADSIDE	AUN	5177	1782
83	Southwark 1	URBAN BACKGROUND	AUN	5324	1785
84	Southwark 2	ROADSIDE	AUN	5344	1778
85	Wandsworth 2	URBAN BACKGROUND	AUN	5258	1747
86	Bexley Heath	SUBURBAN	JEP	5483	1745
87	Fleet Hall	RURAL	JEP	5895	1893
88	Hall Farm	RURAL	JEP	5589	1848
89	Lower Shorne	RURAL	JEP	5703	1728
90	Wingham	RURAL	JEP	6243	1553
91	Wormdale	RURAL	JEP	5858	1634
92	Carr Lane	RURAL	JEP	4672	4274
93	Hemingbrough	RURAL	JEP	4669	4298
94	Cliffe	RURAL	JEP	4659	4336
95	North Duffield	RURAL	JEP	4672	4373
96	Wheldrake	RURAL	JEP	4690	4448
97	Dunnington	RURAL	JEP	4674	4523
98	Brentwood 1	SUBURBAN	LAQN	5599	1934
99	Bromley 5	SUBURBAN	LAQN	5424	1593
100	Castlepoint 1	URBAN BACKGROUND	LAQN	5802	1835
101	Croydon 2	ROADSIDE	LAQN	5312	1643
102	City 2	KERBSIDE	LAQN	5324	1818
104	Ealing 1	URBAN BACKGROUND	LAQN	5174	1807
105	Enfield 1	SUBURBAN	LAQN	5332	1961
106	Havering 1	ROADSIDE	LAQN	5531	1826
107	Islington 1	URBAN BACKGROUND	LAQN	5319	1843
108	Kingston 1	SUBURBAN	LAQN	5178	1634
109	Kingston 2	ROADSIDE	LAQN	5182	1697
110	Mole Valley 1	RURAL	LAQN	5156	1576
111	Scudders	RURAL	LAQN	5589	1674
112	Sutton 2	SUBURBAN	LAQN	5278	1648
113	Tower Hamlets 1	URBAN BACKGROUND	LAQN	5375	1809
114	Wandsworth 3	SUBURBAN	LAQN	5215	1741
115	Watford 1	ROADSIDE	LAQN	5105	1968
116	Westminster 1	URBAN BACKGROUND	LAQN	5279	1820

id	name	type	network	east	north
118	Eskdalemuir	RURAL	ADSN	3235	6030
119	Goonhilly	RURAL	ADSN	1723	214
120	Stoke Ferry	RURAL	ADSN	5700	2988
121	Lough Navar	RURAL	ADSN	192	5212
122	Barcombe Mills	RURAL	ADSN	5437	1149
123	Yarner Wood	RURAL	ADSN	2786	789
124	High Muffles	RURAL	ADSN	4776	4939
125	Strathvaich Dam	RURAL	ADSN	2347	8750
126	Glen Dye	RURAL	ADSN	3642	7864
127	Preston Montford	RURAL	ADSN	3432	3143
128	Flatford Mill	RURAL	ADSN	6077	2333
129	River Mharcaidh	RURAL	ADSN	2876	8052
130	Whiteadder	RURAL	ADSN	3664	6633
131	Loch Dee	RURAL	ADSN	2468	5779
132	Redesdale	RURAL	ADSN	3833	5954
133	Bannisdale	RURAL	ADSN	3515	5043
134	Cow Green Res.	RURAL	ADSN	3817	5298
135	Thorganby	RURAL	ADSN	4676	4428
136	Jenny Hurn	RURAL	ADSN	4816	3986
137	Beddgelert	RURAL	ADSN	2556	3518
138	Wardlow Hay Cop	RURAL	ADSN	4177	3739
139	Bottesford	RURAL	ADSN	4797	3376
140	Tycanol Wood	RURAL	ADSN	2093	2364
141	Llyn Brianne	RURAL	ADSN	2807	2492
142	Woburn	RURAL	ADSN	4964	2361
143	Compton	RURAL	ADSN	4512	1804
144	Driby	RURAL	ADSN	5386	3744
145	Achanarras	RURAL	ADSN	3151	9550
146	Hillsborough Forest	RURAL	ADSN	1369	5156
147	Pumlumon	RURAL	ADSN	2823	2854
148	Polloch	RURAL	ADSN	1792	7689
149	Balquhidder	RURAL	ADSN	2521	7206
150	Llyn Llydaw	RURAL	ADSN	2638	3549
151	Brockhill	RURAL	RSO2	4002	2702
152	Caenby	RURAL	RSO2	4993	3900
153	Camborne	RURAL	RSO2	1628	407
154	Camphill	RURAL	RSO2	2274	6546
155	Cardington	RURAL	RSO2	5082	2464
156	Corpach	RURAL	RSO2	2054	7782
157	Cresselly	RURAL	RSO2	2064	2062
158	Etton	RURAL	RSO2	4980	4445
159	Husborne Crawley	RURAL	RSO2	4964	2361
160	Little Horkesley	RURAL	RSO2	5971	2312
161	Marshfield	RURAL	RSO2	3255	1830
162	Ratcliffe	RURAL	RSO2	4408	3278

id	name	type	network	east	north
163	Rockbourne	RURAL	RSO2	4116	1181
164	Wakefield	RURAL	RSO2	4352	4132
165	Waunfawr	RURAL	RSO2	2533	3607
166	Fort Augustus	RURAL	RSO2	2366	8091
167	Loch Leven	RURAL	RSO2	3159	6990
168	Redesdale	RURAL	RSO2	3833	5961
169	Hebden Bridge	RURAL	RSO2	4011	4327
170	Preston Montford	RURAL	RSO2	3432	3143
171	Bentra	RURAL	RSO2	1587	5459
172	Pitlochry	RURAL	RSO2	2918	7599
173	Bush	RURAL	RSO2	3246	6638
174	Great Dun Fell	RURAL	RSO2	3711	5322
175	Wharleycroft	RURAL	RSO2	3697	5246
176	Cam Forest	RURAL	RSO2	1070	5785
177	Cwmystwyth	RURAL	RSO2	2774	2745
178	Rosemaund	RURAL	RSO2	3564	2476
179	Forsinard	RURAL	RSO2	2890	9425
180	Fairseat	RURAL	RSO2	5622	1615
181	Bylchau	RURAL	RSO2	2959	3596
182	Crai	RURAL	RSO2	2861	2183
183	Forsinain	RURAL	RSO2	2906	9486
184	Appleacre	RURAL	RSO2	3665	5208
185	Sutton Bonnington	RURAL	RSO2	4505	3267
186	Auchencorth Moss	RURAL	RSO2	3221	6562
187	Narberth	RURAL	RMN	2146	2127
188	Leeds Market	URBAN BACKGROUND	ME	4304	4335
189	Motherwell	URBAN BACKGROUND	ME	2757	6563
190	Glasgow	URBAN BACKGROUND	ME	2613	6645
191	Cottered	RURAL	PB	5322	2283
192	Newcastle	URBAN BACKGROUND	PB	4241	5688
193	Chilton	RURAL	RUR	4468	1861
194	Styrrup	RURAL	RUR	4606	3898
195	Windermere	RURAL	RUR	3362	4974

Appendix 2
The Rural Maps

MapsMaps

Maps of rural concentrations of air pollutants underpin the maps presented in this report. The derivation of these maps is given in Table A2.

Table A2. The derivation of the maps of rural concentrations

Pollutant	
NO_2	Interpolated from monthly measurements of NO_2 by diffusion tubes at Acid Deposition Secondary Network sites.
NO_x	Derived from the rural NO_2 map by multiplying by 1.2 (the measured ratio at Lullington Heath, which is very similar to that found at other rural automatic monitoring sites).
SO_2	Interpolated from measurements at Rural SO_2 Monitoring Network sites (daily and weekly bubbler measurements) and automatic measurements at Rural Monitoring Network sites and sites within the Joint Environment Programme.
benzene	Derived from the rural NO_2 map by multiplying by 0.031 (the measured ratio at Harwell).
1,3-butadiene	Derived from the rural NO_2 map by multiplying by 0.00538 (the measured ratio at Harwell).
CO	A constant value of 0.150 ppm was chosen in the absence of rural monitoring data.
PM_{10}	Secondary particle concentration estimated from measurements of particulate sulphate concentrations at eight Acid Deposition Monitoring sites (118, 120-126). The concentration of particles derived from stationary combustion and non-combustion sources was taken to be 6 μgm^{-3} in the west of Northern Ireland and 12 μgm^{-3} in Eastern England. These values were inferred from an examination of the concentrations of PM_{10} measured at rural monitoring sites.
Lead	Derived from the rural NO_2 map by multiplying by 1.344 (the ratio between estimated NO_2 and measured Pb concentrations at rural and urban background PB monitoring sites).
O_3 summer	Summer mean ozone concentration. Interpolated from measurements at Rural Monitoring Network sites and adjusted for the effects of altitude.
O_3 days	The number of days with maximum running 8-hour ozone

	concentration >= 50 ppb, Interpolated from measurements at Rural Monitoring Network sites.