

Mapping of nitrogen dioxide and PM10 in the UK for Article 5 Assessment

A report produced for The Department of the Environment, Transport and the Regions, The National Assembly for Wales, The Scottish Executive and the Department of the Environment in Northern Ireland

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Executive Summary

Article 5 of Directive 96/62/EC on Ambient Air Quality Assessment and Management (the Framework Directive), places a requirement upon Member States to undertake a preliminary investigation of ambient air quality, prior to the implementation of the Directive 1999/30/EC (the first Daughter Directive).

The objectives of the Article 5 assessment are to establish estimates for the overall distribution and levels of pollutants, and to identify additional monitoring requirements, which may be necessary in order to fulfil obligations under the Framework Directive. A report describing this Article 5 assessment for the UK has been prepared (Bush 2000). Maps of estimated annual mean concentrations of nitrogen dioxide (NO₂) and particles (PM₁₀) in 1999 have been used in the Article 5 assessment.

This report presents the NO₂ and PM₁₀ maps that have been prepared for the Article 5 assessment and describes the models that have been used. These maps have been derived from combination of emission estimates from the UK National Atmospheric Emissions Inventory (NAEI) and measurements from the national air monitoring networks. The models underlying the maps have been developed by AEA Technology Environment over a number of years.

Refinements to the PM₁₀ model now include contributions from the following components:

- Secondary PM₁₀
- European primary PM₁₀
- Regional primary PM₁₀ from UK sources
- Local primary PM₁₀
- Local urban coarse PM₁₀
- Regional coarse PM₁₀

The agreement between measured and modelled annual mean NO_x, NO₂ and PM₁₀ is shown to be good and is illustrated below, by the comparison of measured and modelled annual mean concentrations at monitoring stations within the national network.

	Annual Mean (µg/m ³)		Correlation coefficient (R ²)
	Mean measured	Mean modelled	
Urban background NO _x	69	64	0.56
Urban background NO ₂	36	37	0.65
Roadside NO _x	212	188	0.75
Roadside NO ₂	58	55	0.78
Urban background PM ₁₀	23	24	0.33

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1 Introduction

Directive 96/62/EC on Ambient Air Quality Assessment and Management (the Framework Directive) establishes a framework under which the EU will set limit values or target values for concentrations of specified air pollutants. Directive 1999/30/EC (the first Daughter Directive) sets limit values to be achieved for sulphur dioxide, nitrogen dioxide and oxides of nitrogen particles and lead.

Under Article 5 of the Framework Directive, a requirement has been placed on Member States to undertake a preliminary investigation of ambient air quality, prior to the implementation of the first Daughter Directive. The objectives of this assessment are to establish estimates for the overall distribution and levels of pollutants, and to identify additional monitoring requirements, which may be necessary in order to fulfil obligations under the Framework Directive.

A report describing this Article 5 assessment for the UK has been prepared (Bush 2000). Maps of estimated annual mean concentrations of nitrogen dioxide (NO₂) and particles (PM₁₀) in 1999 have been used in the Article 5 assessment. These maps have been derived from combination of emission estimates from the UK National Atmospheric Emissions Inventory (NAEI) and measurements from the extensive national air monitoring networks. The methods used to calculate these maps have been developed by AEA Technology Environment over a number of years and are described in detail in a number of reports and papers (Stedman et al 1997, Stedman, 1998, DETR *et al* 2000, Stedman et al 2000a, Stedman et al 1998b, Abbott and Stedman 1999).

This report presents the new NO₂ and PM₁₀ maps that have been prepared for the Article 5 assessment and describes the models that have been used.

2 Maps of NO₂ concentrations

2.1 MAP OF 1999 BACKGROUND NO₂ CONCENTRATIONS

A map of estimated annual mean background concentration NO₂ for 1999 at a 1 km resolution is presented in Figure 1. Our approach to mapping background NO₂ concentrations has been described in detail by Stedman et al (1997), Stedman (1998) and Stedman et al (2000a).

Measured annual mean background NO_x (the sum of NO and NO₂) concentrations have been considered to be made up of two parts:

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

- A contribution from more local emissions. In earlier work on the estimation of air pollutant concentrations from emission related parameters (Stedman *et al*, 1997) we have studied the spatial scale at which local emissions seem to influence ambient air quality. We found that estimates of emissions in an area of 25 km² centred on a background monitoring site provide the most robust relationships.

The difference, *diff*, between measured ambient NO_x concentrations at urban automatic monitoring sites (not roadside, industrial sites or urban or suburban sites that are significantly influenced by emissions from a nearby road) and an underlying rural concentration field is calculated where monitoring data are available.

$$\text{diff} = \text{measured annual mean urban NO}_x \text{ concentration} - \text{mapped rural NO}_x \text{ concentration}$$

A regression analysis was then performed to find the coefficient, k_b , for the relationship between *diff* and estimated NO_x emissions in the vicinity of the monitoring sites taken from the NAEI (Goodwin et al 1999):

$$\text{diff} = k_b \text{ emissions}$$

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

$$\text{estimated background NO}_x \text{ concentration } (\mu\text{gm}^{-3} \text{ as NO}_2) = \text{rural NO}_x \text{ map } (\mu\text{gm}^{-3} \text{ as NO}_2) + k_b \text{ emissions (Tonnes NO}_x \text{ as NO}_2 \text{ per 25 km}^2 \text{ per year)}$$

Local emissions within an area of 25 km² have been used to estimate the contribution that urban emissions make to ambient NO_x concentration in urban background locations. Figure 2 shows the comparison between *diff* and NO_x emissions. Monitoring sites in London are highlighted.

The coefficient k_b is systematically lower for sites in the London area than for the rest of the UK and there is an intercept at about 20 μgm⁻³. This combination of a lower coefficient and an intercept is due to the size of the urban area. The population of the London conurbation was over 7.5 million at the time of the 1991 census. Other conurbations in the UK are much smaller (populations in 1991- West Midlands: 2.3 million, Greater Manchester: 2.3 million, West Yorkshire: 1.5 million and Glasgow: 1.3 million). We consider that the exceptional size of London explains the need to use of a different dispersion coefficient and the incorporation of an intercept to take account of the contribution from emissions in the surrounding urban area of this city. The empirically derived coefficients used to calculate the map of background NO_x concentration for 1999 are listed in Table 1. The London specific coefficient, with an intercept of 20.4 μgm⁻³, was applied to all parts of the London area with at least 80% urban land cover. The use of this relationship with an intercept is not appropriate for the urban fringes of London, where the UK coefficient was applied.

Table 1 Coefficients used to calculate 1999 background annual mean NO_x map

	k_b
London	0.0225
Elsewhere in the UK	0.0394

It should be noted that these coefficients represent the relationship between measured NO_x concentration in 1999 and emissions estimates for 1997, which is the most recent year for which maps of emissions are available. The coefficients derived between 1999 measurements and 1999 emissions estimates would be expected to be higher due to the expected decline in emissions between 1997 and 1999.

The map of estimated annual mean background NO₂ concentration shown in Figure 1 was then calculated from the estimates of NO_x concentration using the following relationships (1 ppb NO₂ = 1.91 µgm⁻³ NO₂).

$$\begin{aligned} \text{Rural Background NO}_2 \text{ [ppb]} &= 0.833 \cdot \text{NO}_x \text{ [ppb]} \\ \text{(Elsewhere) Background NO}_2 \text{ [ppb]} &= 2.375 \cdot (\text{NO}_x \text{ [ppb]})^{0.6} \\ \text{Central London Background NO}_2 \text{ [ppb]} &= 1.750 \cdot (\text{NO}_x \text{ [ppb]})^{0.7} \end{aligned}$$

These have been derived from monitoring data from 1990 to 1999 inclusive (Stedman et al 2000b) and reflect the contrast between the behaviour of NO_x, which can be treated as a conserved pollutant and NO₂, for which the ambient concentration is dependent on the availability of oxidant and distance from source. The majority of NO_x is present as NO₂ at rural locations because these areas are generally distant from sources and oxidant (ozone) is available in excess. Annual mean NO₂ concentrations in urban areas are more limited by the availability of oxidant. Measured NO₂ concentrations in Central London are found to be higher than in other urban areas. It is thought that this is due to the large size of the urban area, which enables relatively aged NO_x from other parts of London to contribute to NO₂ in Central London. Pending further analysis, this relationship has been applied to grid squares forming a circle of approximate radius 3 km centred in the centre of London.

The highest estimated background concentrations are in the centres of the large cities. Areas strongly influenced by emissions from busy motorways are also evident. The good agreement between measured and mapped annual mean NO_x and NO₂ concentrations is illustrated in Figures 3 and 4 (mean of NO_x measurements = 69 µgm⁻³, mean of NO_x estimates = 64 µgm⁻³, r² = 0.56, mean of NO₂ measurements = 36 µgm⁻³, mean of NO₂ estimates = 37 µgm⁻³, r² = 0.65, number of measurements = 47).

2.2 MAP OF 1999 ROADSIDE NO₂ CONCENTRATIONS

A map of estimated annual mean roadside NO₂ concentrations in 1999 is shown in Figure 5. We have considered that the annual mean concentration of NO_x at a roadside location is made up of two parts: the background concentration (as described above) and a roadside increment (Stedman et al 1998a).

$$\text{roadside concentration} = \text{background concentration} + \text{roadside increment}$$

The NAEI provides estimates of NO_x emissions for a total of 14075 major road links in the UK for 1997 (Goodwin et al, 1999). Figure 6 shows a comparison of the roadside increment of annual mean NO_x concentrations at roadside or kerbside national automatic monitoring with NO_x emission estimates for the individual road links alongside which these monitoring sites are located. The background NO_x component at these roadside monitoring sites was derived from the map described above. The sites chosen for this analysis are those for which emission estimates are available that are in built up areas. There is clearly a strong dependence of the roadside increment on NO_x emission at these sites.

$$\text{roadside increment of annual mean NO}_x \text{ (}\mu\text{gm}^{-3} \text{ as NO}_2\text{)} = k_r \text{NO}_x \text{ emission from road link (kg NO}_2 \text{ km}^{-1} \text{ y}^{-1}\text{)}$$

The value of k_r is 0.0069. Note that, as with the coefficient k_b , this is the relationship between 1999 measurements and emissions estimates for 1997.

Roadside NO_x monitoring sites at locations with a more open aspect, such as roads in rural areas, do not conform to this relationship. The NO_x emissions from vehicles travelling on these roads are generally more effectively dispersed than the emissions on built up urban roads. We have therefore restricted our mapping to urban major roads (7736 A-road and motorway road links), where the relationship is reliable.

Roadside annual mean NO₂ concentration was calculated from the estimate of the roadside annual mean NO_x concentration using following relationship (Stedman et al 2000b):

$$\text{Roadside NO}_2 \text{ (ppb)} = 1.8767 \cdot (\text{NO}_x \text{ [ppb]})^{0.6}$$

NO₂ concentrations at roadside monitoring sites are lower than at background locations with the same total NO_x concentration because these sites are very close to sources and limited by the availability of oxidant. Figures 7 and 8 shows the good agreement between measured and estimated roadside NO_x and NO₂ concentrations (mean of NO_x measurements = 212 μgm⁻³, mean of NO_x estimates = 188 μgm⁻³, r² = 0.75, mean of NO₂ measurements = 58 μgm⁻³, mean of NO₂ estimates = 55 μgm⁻³, r² = 0.78, number of measurements = 11).

3 Map of PM₁₀ concentrations

The map of estimated annual mean background PM₁₀ concentrations for 1999, shown in Figure 9, has been produced using similar methods to those described above for NO₂. Mapping of PM₁₀ concentrations is, however, more complex and subject to greater uncertainties, due to the wide range of different sources and processes contributing to ambient particle concentrations. The source apportionment of PM₁₀ in the UK has been reviewed by the Airborne Particles Expert Group (APEG, 1999) and a receptor model of ambient concentrations has been developed (Stedman et al 1998b). The knowledge derived from the results of these receptor model studies has been applied to the calculation of maps of estimated annual mean concentrations by Abbott and Stedman (1999). The majority of PM₁₀ measurements within the national monitoring networks are made using a TEOM instrument, which has been found to read lower concentrations than measurements carried out using a gravimetric instrument (which is the reference method for the Daughter Directive). A scaling factor of 1.3 has therefore been applied to the TEOM measurement data and used to calculate the map presented here, as recommended by APEG (1999). These mapping methods have now been developed further and the map of PM₁₀ concentrations presented here was calculated by adding together a number of different components:

- Secondary PM₁₀ derived from maps of measured rural sulphate concentrations using a typical coefficient of 2.45 derived from the site specific receptor modelling analysis. The value of this component ranges from about 4 to 13 µgm⁻³ (gravimetric or equivalent), with the highest concentrations in the south east of England.
- European primary PM₁₀ has been modelled at Imperial College from a primary PM₁₀ emission inventory published by TNO (TNO, 1997). The value of this component ranges from about 0.5 to 2.0 µgm⁻³ (gravimetric or equivalent), with the highest concentrations in the south east of England.
- Regional primary PM₁₀ from UK sources has also been modelled at Imperial College using emissions estimates on a 1 km grid from the NAEI. The value of this component ranges from 0 to about 2.5 µgm⁻³ (gravimetric or equivalent), with the highest concentrations in the London area and urban parts of northern England.
- The contribution from local primary PM₁₀ emissions has been estimated using 1 km primary PM₁₀ emission maps from the NAEI for 1997 and an empirical dispersion coefficient calibrated using measurement data. The value of this component ranges from 0 to about 10.5 µgm⁻³ (gravimetric or equivalent), with the highest concentrations in the central London.
- A local urban coarse component has been estimated using 1 km maps of PM₁₀ emissions from construction activities from the NAEI for 1997 and an empirical dispersion coefficient calibrated using measurement data. The value of this component ranges from 0 to about 2.5 µgm⁻³ (gravimetric or equivalent), with the highest concentrations in the London area.
- A constant regional coarse component of 9 µgm⁻³ (gravimetric or equivalent) has also been added. This value was derived as the intercept of the calibration of the empirical dispersion coefficient.

Figure 10 shows the good agreement between measured and estimated background PM₁₀ concentrations (mean of measurements = 23.3 µgm⁻³ (gravimetric or equivalent), mean of estimates = 24.2 µgm⁻³(gravimetric or equivalent), $r^2 = 0.33$, number of measurements = 41).

A map of roadside PM₁₀ concentrations have not been included in the Article 5 assessment due to the greater uncertainty associated with such a map, relative to maps of roadside NO₂. This greater uncertainty of roadside PM₁₀ concentrations is due to the smaller relative magnitude of the roadside increment, compared with background concentrations, and the greater uncertainty associated with the background estimates.

4 Acknowledgement

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Figure 1.
Estimated annual mean background nitrogen dioxide concentration, 1999 ($\mu\text{g}\text{m}^{-3}$)
Ref NETCEN 05/05/2000 TB uk1no219991

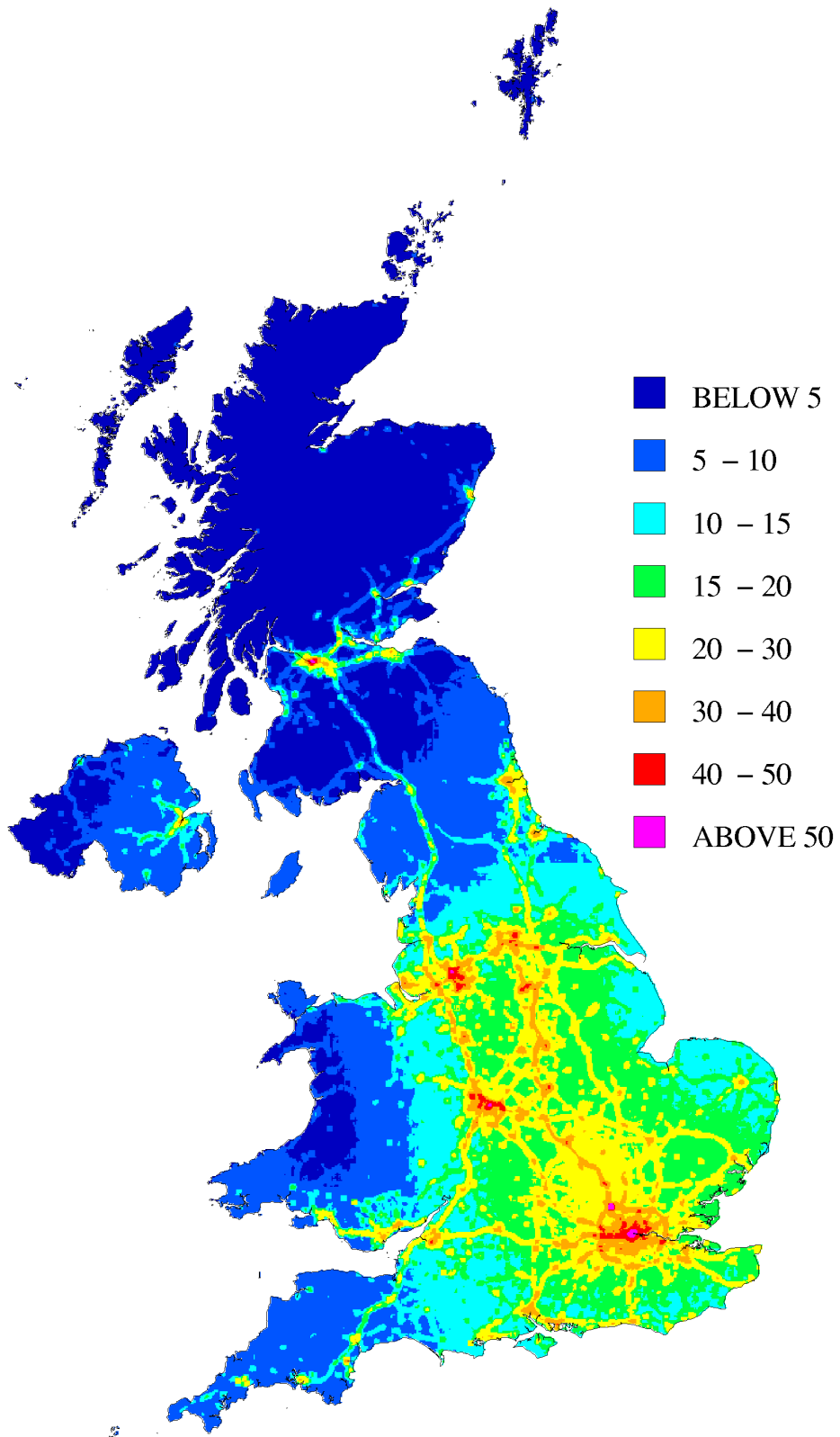


Figure 2 Relationship between measured annual mean urban background NOx minus rural background annual mean NOx (*diff*) and NOx emission

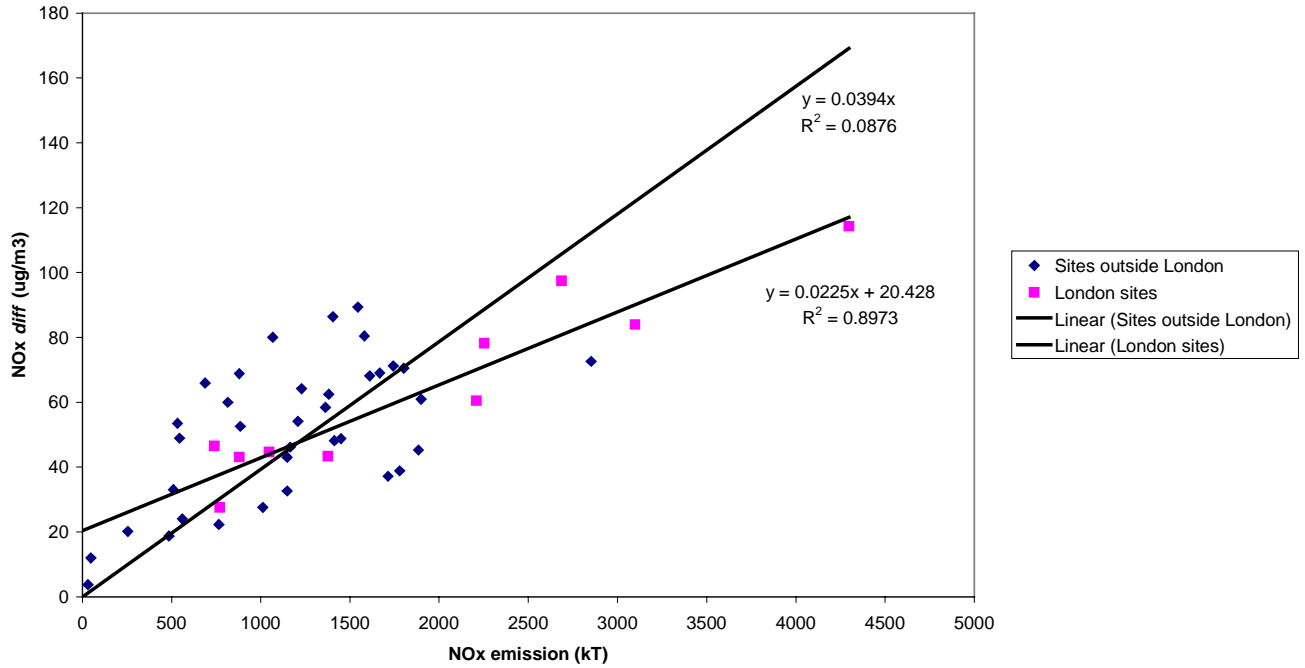


Figure 3 Estimated and measured annual mean urban background NOx 1999

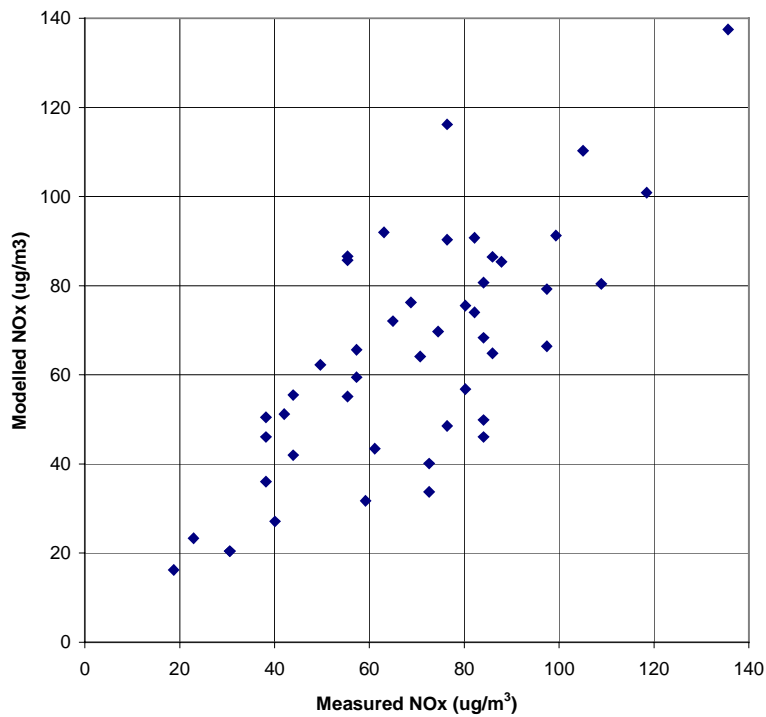


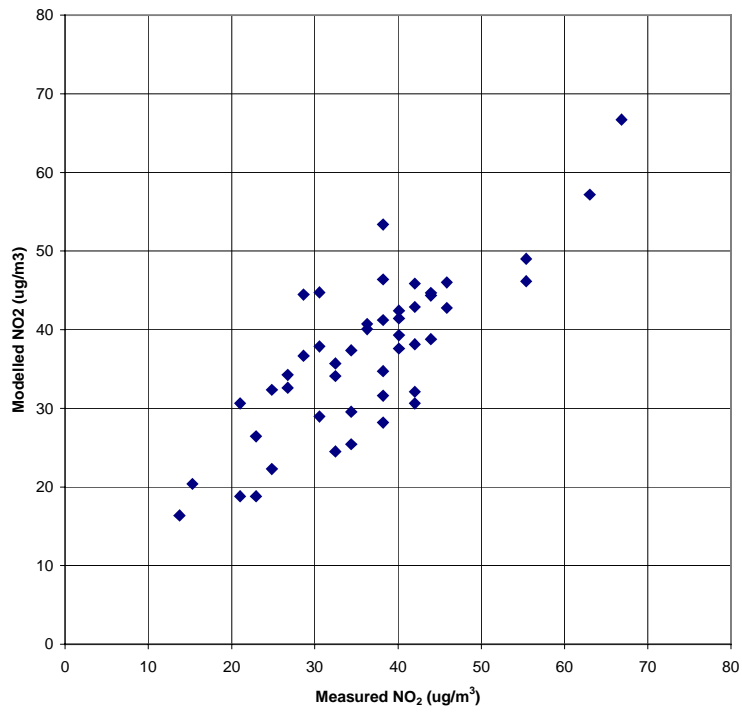
Figure 4 Estimated and measured annual mean urban background NO₂ 1999

Figure 5

Major urban roads, estimated annual mean roadside nitrogen dioxide concentration, 1999 ($\mu\text{g}\text{m}^{-3}$), Ref NETCEN 09/05/2000

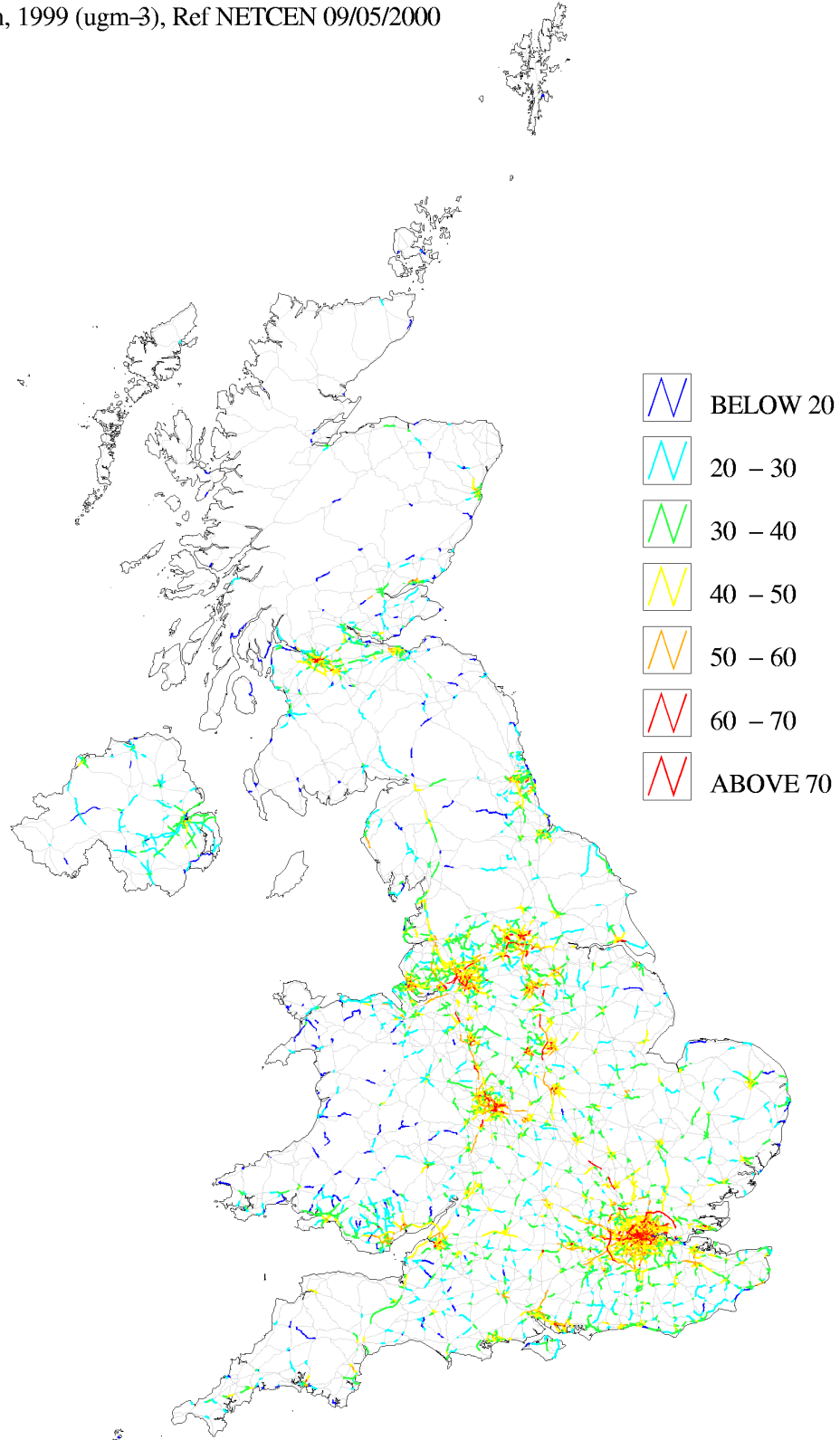


Figure 6 Relationship between roadside enhancement of NOx and road link NOx emission

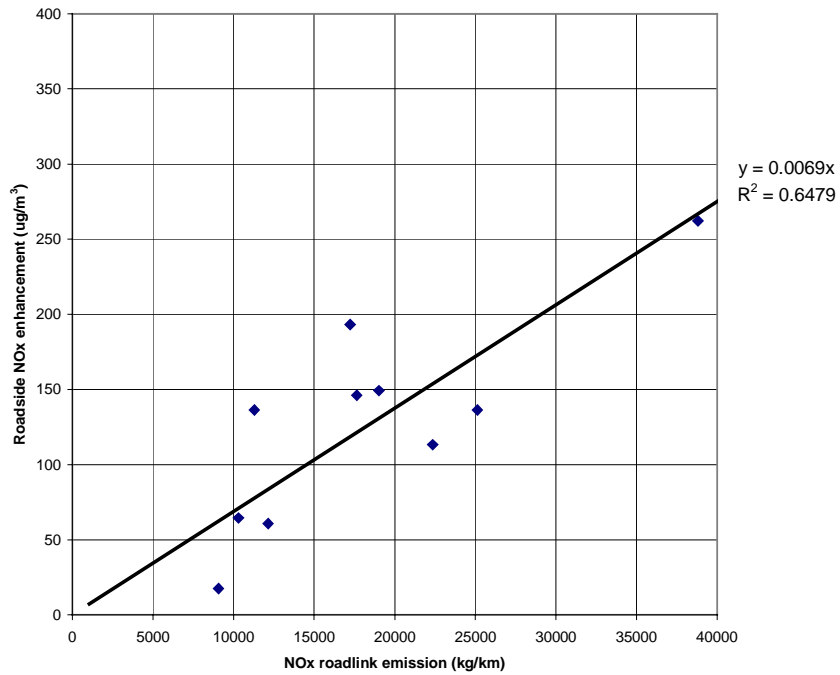


Figure 7 Estimated and measured annual mean roadside NOx concentrations 1999

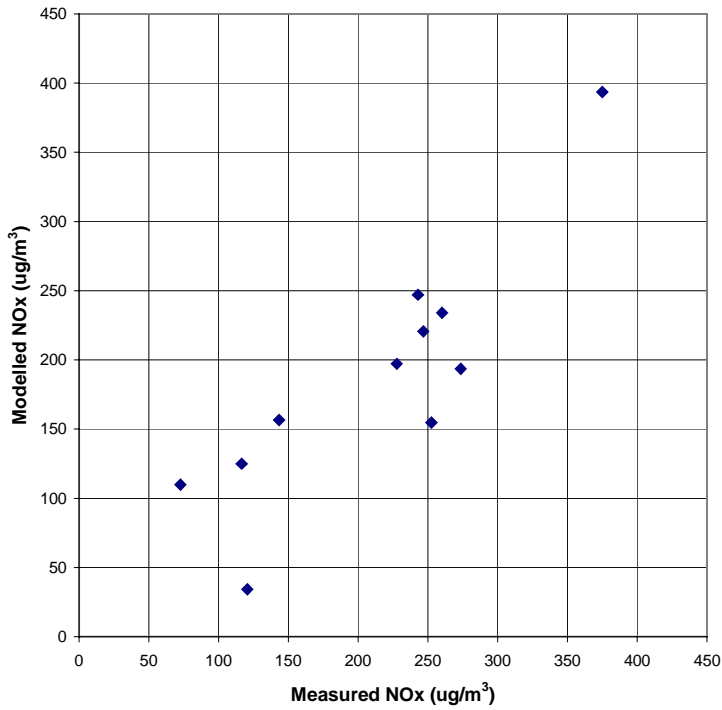


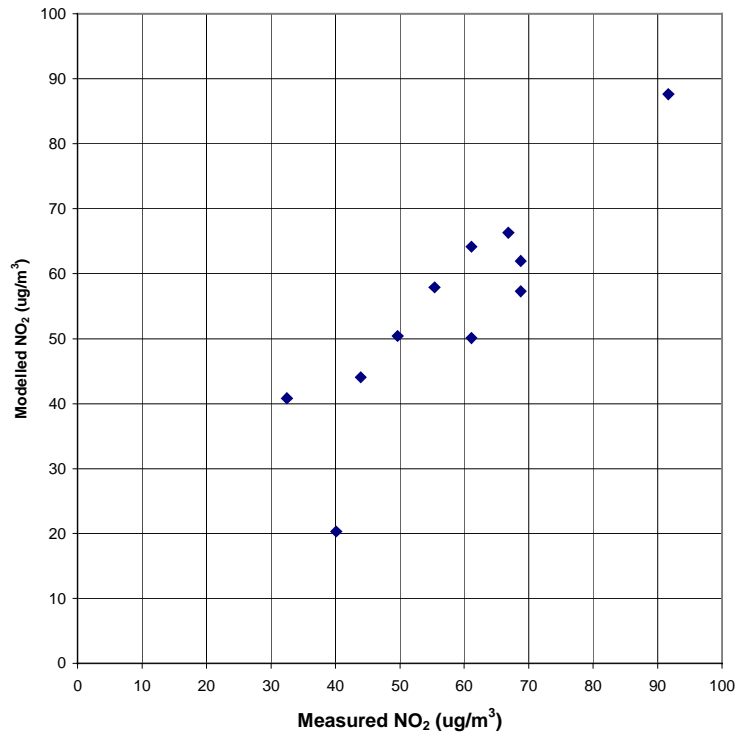
Figure 8 Estimated and measured annual mean roadside NO₂ concentrations 1999

Figure 9.
Estimated annual mean background PM10 concentration, 1999 (ugm-3, gravimetric)
Ref NETCEN 16/03/2000 JRS UK1_1999G10Y1

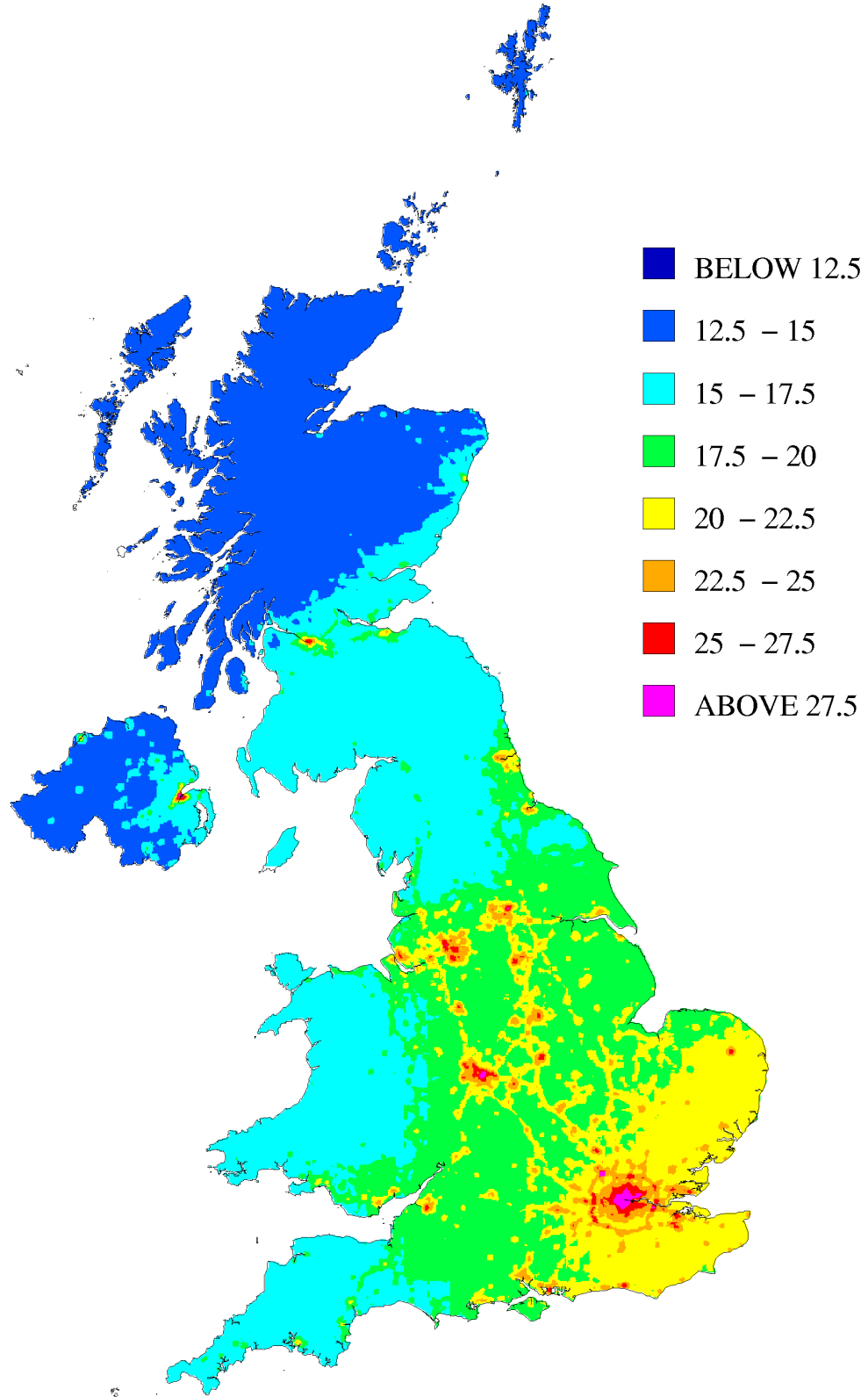


Figure 10. Estimated and measured background annual mean PM10 concentrations in 1999

