AEAT - 5438 Issue 2

A method for predicting roadside CO concentrations in the UK

A report produced for The Department of the Environment, Transport and the Regions, The Welsh Office, The Scottish Office and The Department of the Environment for Northern Ireland

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Executive Summary

The Commission of the European Communities has recently published a proposal for a Directive relating to limit values for benzene and carbon monoxide (CO). This is the second Daughter Directive to be brought forward by the European Commission under the Framework Directive on Ambient Air Quality Assessment and Management. The proposed limit value for CO is 10 mgm^{-3} (8.59 ppm) as an 8-hour running mean, to be achieved by 1 January 2005.

Road traffic is the dominant source of CO in urban areas in the UK, typically contributing more than 90% of total emissions and concentrations are therefore likely to be highest at the roadside. A method for mapping maximum running 8-hour CO concentrations at the roadside has been developed. This method makes use of emissions estimates from the National Atmospheric Emissions Inventory and monitoring data from roadside monitoring sites within the UK national air quality monitoring networks. Maps of concentrations at the roadside of major urban roads in the UK are presented for both 1998 and 2004 for comparison with the proposed limit value.

Maximum running 8-hour CO concentrations in all background locations in 2004 are predicted to be well within the proposed limit value of 8.59 ppm. Estimated roadside CO concentrations in 2004 are expected to be higher. For typical meteorological conditions, the predictions show that no road links are expected to have concentrations higher than 8.59 ppm by 2004 and only 2 are expected to have concentrations greater than the proposed limit value by 2002. For extreme meteorological conditions, such as the poor dispersion conditions experienced in some UK cities in 1991, the predictions show that one road link is expected to have a concentration higher than 8.59 ppm by 2004 and only 14 are expected to have concentrations greater than the proposed limit value by 2002.

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1 Introduction

The Commission of the European Communities has recently published a proposal for a Directive relating to limit values for benzene and carbon monoxide (CO). This is the second Daughter Directive to be brought forward by the European Commission under the Framework Directive on Ambient Air Quality Assessment and Management. A common position was reached on the first Daughter Directive, which will set limit values for sulphur dioxide, nitrogen dioxide, lead and particles.

The proposed limit value for CO is 10 mgm^{-3} as an 8-hour running mean to be achieved by 1 January 2005. This is equivalent to 8.59 ppm at the standardisation of 293 K and 101.3 kPa specified in the proposal. This can be compared with the both the UK National Air Quality Strategy (NAQS) objective of 10 ppm as an 8-hour running mean to be achieved by 2005 (DoE, 1997) and the proposal to amend this objective of 10 ppm to be achieved by 2003 (DETR *et al*, 1999).

The analyses of roadside CO concentrations carried out as part of the review of the NAQS were limited to a 'worst case' analysis of roadside concentrations in Central London based on a simple addition of monitoring data from roadside and background monitoring sites and emissions projections. This analysis showed that policy measures already in place should lead to 8-hour CO concentrations at all roadside locations falling below 10 ppm by 2003 (DETR *et al*, 1999).

The proposal of a Daughter Directive limit value for CO of 8.59 ppm means that it is now appropriate to carry out a more detailed analysis of likely roadside CO concentrations in the UK. This report describes the development of such a method for calculating maps of predicted roadside CO concentrations in the UK. The method makes use of emissions estimates from the National Atmospheric Emissions Inventory and monitoring data from roadside monitoring sites within the UK national air quality monitoring networks. The empirical model of roadside CO presented here is the first attempt to estimate maximum CO concentrations at the roadside of urban major roads throughout the UK. The model is clearly subject to a number of uncertainties, including those due to the limited number of roadside monitoring sites in the UK national networks for which data are available. Maps are presented for both 1998 and 2004 for comparison with the proposed limit value (to come into force 1 January 2005).

A related report on 'Estimated benzene concentrations in the UK and proposed EU limit value' (Stedman, 1999) has already been prepared.

2 Emissions projections

Road traffic is the dominant source of CO in urban areas in the UK, typically contributing more than 90% of total emissions (Buckingham *et al*, 1997 and 1998). Table 1 shows estimates and projections of urban road traffic CO emissions from the National Atmospheric Emission Inventory (NAEI). This 'business as usual' scenario has been used throughout the work presented here and represents our best estimate of the results of current national policies.

Table 1. Urban UK Road Transport Emission Projections of CO (Ktonnes per year)

year	1990	1991	1992	1993	1994	1995	1996	1997	1998
CO	2888	2838	2671	2507	2359	2170	2002	1842	1678
year	1999	2000	2001	2002	2003	2004	2005	2006	2007
CO	1531	1346	1222	1114	1020	943	884	781	727

Road traffic has been assumed to dominate ambient CO concentrations in urban areas in GB and the projections presented here have been calculated by assuming that there are no other sources.

3 Individual site analyses

Projections of CO concentrations at monitoring sites have been calculated as a first step in the mapping process. These projections do not have the additional uncertainties associated with the mapping methods. Maximum running 8-hour CO concentrations show considerable year to year variability due to meteorology. Data from 1990 to 1998 were therefore examined and the maximum running 8-hour concentration from each site recorded for years with more than 50% data capture. The emissions projections listed in Table 1 were then applied to the maximum concentration at each site to calculate an equivalent concentration for 1998 and the years up to and including 2004 (the projection for Stevenage in 1998, for example, was calculated by dividing the maximum measured concentration, which was recorded in 1991, by the emissions total for 1991 and multiplying by the emissions total for 1998: 2.9 = (4.9 / 2838) x 1678 . The results of this analysis are presented in Table 2. Projections will be more reliable for the sites with the most years of data. Only 1 or 2 years data are available for about half of the sites so the projections from these sites will be subject to greater uncertainty and are more likely to be underestimates than overestimates.

The recently published emission inventory for Greater Belfast (Buckingham *et al*, 1999) concluded that road traffic contributes 75% of CO emissions in this urban area, with emissions from domestic combustion making up the bulk of the remainder. The projections of CO concentrations for the Belfast Centre and Derry background monitoring sites listed in Table 2 have therefore been calculated on this basis, with the assumption that domestic emissions will remain unchanged.

The first year that all sites are predicted to achieve the proposed limit value of 8.59 ppm is 2001. The highest projected concentrations are generally at roadside and kerbside monitoring sites. The development of a model of roadside concentrations is described in the next section.

Table 2. Individual monitoring site projections of maximum running 8-hour CO concentrations (ppm)

# of years	year of max	site	type	max	1998 equiv.	1999 equiv.	2000 equiv.	2001 equiv.	2002 equiv.	2003 equiv.	2004 equiv.
				maximum running 8-hour CO concentrations (ppm)							
4	1991	Stevenage	SUBURBAN	4.9	2.9	2.6	2.3	2.1	1.9	1.8	1.6
7	1990	London Cromwell Road	KERBSIDE	15.5	9.0	8.2	7.2	6.6	6.0	5.5	5.1
9	1991	West London	URBAN BACKGROUND	15.8	9.3	8.5	7.5	6.8	6.2	5.7	5.3
9	1991	Glasgow City Chambers	URBAN BACKGROUND	12.5	7.4	6.7	5.9	5.4	4.9	4.5	4.2
6	1992	Manchester Town Hall	URBAN BACKGROUND	12.5	7.9	7.2	6.3	5.7	5.2	4.8	4.4
7	1992	Sheffield Tinsley	URBAN INDUSTRIAL	7.4	4.6	4.2	3.7	3.4	3.1	2.8	2.6
8	1991	London Bridge Place	URBAN BACKGROUND	11.2	6.6	6.0	5.3	4.8	4.4	4.0	3.7
7	1997	London Bloomsbury	URBAN CENTRE	6.7	6.1	5.6	4.9	4.4	4.1	3.7	3.4
6	1993	Edinburgh Centre	URBAN CENTRE	4.8	3.2	2.9	2.6	2.3	2.1	2.0	1.8
7	1993	Cardiff Centre	URBAN CENTRE	5.9	3.9	3.6	3.2	2.9	2.6	2.4	2.2
7	1994	Belfast Centre	URBAN CENTRE	13.4	10.3	9.7	8.8	8.3	7.8	7.4	7.0
7	1992	Birmingham Centre	URBAN CENTRE	10.8	6.8	6.2	5.4	4.9	4.5	4.1	3.8
7	1993	Newcastle Centre	URBAN CENTRE	6.1	4.1	3.7	3.3	3.0	2.7	2.5	2.3
6	1994	Leeds Centre	URBAN CENTRE	9.5	6.8	6.2	5.4	4.9	4.5	4.1	3.8
6	1994	Bristol Centre	URBAN CENTRE	5.6	4.0	3.6	3.2	2.9	2.6	2.4	2.2
6	1993	Liverpool Centre	URBAN CENTRE	3.4	2.3	2.1	1.8	1.7	1.5	1.4	1.3
5	1994	Birmingham East	URBAN BACKGROUND	11.9	8.5	7.7	6.8	6.2	5.6	5.1	4.8
5	1994	Hull Centre	URBAN CENTRE	5.2	3.7	3.4	3.0	2.7	2.5	2.2	2.1
5	1995	Leicester Centre	URBAN CENTRE	7.9	6.1	5.6	4.9	4.4	4.1	3.7	3.4
5	1997	Southampton Centre	URBAN CENTRE	9.2	8.4	7.6	6.7	6.1	5.6	5.1	4.7
5	1996	London Bexley	SUBURBAN	8.5	7.1	6.5	5.7	5.2	4.7	4.3	4.0
4	1998	Swansea	URBAN CENTRE	4.2	4.2	3.8	3.4	3.1	2.8	2.6	2.4
4	1996	Middlesbrough	URBAN INDUSTRIAL	3	2.5	2.3	2.0	1.8	1.7	1.5	1.4
3	1996	Manchester Piccadilly	URBAN CENTRE	4.7	3.9	3.6	3.2	2.9	2.6	2.4	2.2
3	1996	Sheffield Centre	URBAN CENTRE	4.2	3.5	3.2	2.8	2.6	2.3	2.1	2.0
3	1996	Wolverhampton Centre	URBAN CENTRE	4.8	4.0	3.7	3.2	2.9	2.7	2.4	2.3
3	1997	London Brent	URBAN	9.9	9.0	8.2	7.2	6.6	6.0	5.5	5.1

# of years	year of max	site	type	max	1998 equiv.	1999 equiv.	2000 equiv.	2001 equiv.	2002 equiv.	2003 equiv.	2004 equiv.
			BACKGROUND								
3	1997	Sutton Roadside	ROADSIDE	10.4	9.5	8.6	7.6	6.9	6.3	5.8	5.3
3	1996	London N. Kensington	URBAN BACKGROUND	8	6.7	6.1	5.4	4.9	4.5	4.1	3.8
3	1997	Tower Hamlets Roadside	ROADSIDE	9.9	9.0	8.2	7.2	6.6	6.0	5.5	5.1
1	1998	Oxford Centre	ROADSIDE	3.7	3.7	3.4	3.0	2.7	2.5	2.2	2.1
2	1997	Exeter Roadside	ROADSIDE	12	10.9	10.0	8.8	8.0	7.3	6.6	6.1
2	1997	London Hillingdon	SUBURBAN	7	6.4	5.8	5.1	4.6	4.2	3.9	3.6
2	1997	Glasgow Centre	URBAN CENTRE	5.8	5.3	4.8	4.2	3.8	3.5	3.2	3.0
2	1997	Bristol Old Market	ROADSIDE	7.9	7.2	6.6	5.8	5.2	4.8	4.4	4.0
1	1998	Leamington Spa	URBAN BACKGROUND	2.7	2.7	2.5	2.2	2.0	1.8	1.6	1.5
2	1998	Nottingham Centre	URBAN CENTRE	6.8	6.8	6.2	5.5	5.0	4.5	4.1	3.8
2	1997	Thurrock	URBAN BACKGROUND	6.6	6.0	5.5	4.8	4.4	4.0	3.7	3.4
2	1997	Bath Roadside	ROADSIDE	4.1	3.7	3.4	3.0	2.7	2.5	2.3	2.1
1	1998	Stockport	URBAN BACKGROUND	4.7	4.7	4.3	3.8	3.4	3.1	2.9	2.6
2	1998	London Hackney	URBAN CENTRE	6.6	6.6	6.0	5.3	4.8	4.4	4.0	3.7
2	1997	Bury Roadside	ROADSIDE	4.7	4.3	3.9	3.4	3.1	2.8	2.6	2.4
2	1998	Bolton	URBAN BACKGROUND	4.5	4.5	4.1	3.6	3.3	3.0	2.7	2.5
2	1997	Coventry Centre	URBAN CENTRE	4.1	3.7	3.4	3.0	2.7	2.5	2.3	2.1
2	1997	London Southwark	URBAN CENTRE	8	7.3	6.7	5.8	5.3	4.8	4.4	4.1
2	1997	Glasgow Kerbside	KERBSIDE	8.3	7.6	6.9	6.1	5.5	5.0	4.6	4.3
1	1998	Salford Eccles	URBAN INDUSTRIAL	4.5	4.5	4.1	3.6	3.3	3.0	2.7	2.5
2	1998	Stoke-on-Trent Centre	URBAN CENTRE	7.8	7.8	7.1	6.3	5.7	5.2	4.7	4.4
2	1998	London A3 Roadside	ROADSIDE	7.6	7.6	6.9	6.1	5.5	5.0	4.6	4.3
2	1997	Southwark Roadside	ROADSIDE	12.1	11.0	10.1	8.8	8.0	7.3	6.7	6.2
2	1998	Derry	URBAN BACKGROUND	4.2	4.2	3.9	3.6	3.4	3.2	3.0	2.9
2	1998	Bromley Roadside	ROADSIDE	11	11.0	10.0	8.8	8.0	7.3	6.7	6.2
1	1998	Redcar	SUBURBAN	3.9	3.9	3.6	3.1	2.8	2.6	2.4	2.2
1	1998	Sandwell Oldbury	URBAN BACKGROUND	3.2	3.2	2.9	2.6	2.3	2.1	1.9	1.8
1	1998	London Marylebone Road	KERBSIDE	6.5	6.5	5.9	5.2	4.7	4.3	4.0	3.7
1	1998	Norwich Centre	URBAN CENTRE	5.2	5.2	4.7	4.2	3.8	3.5	3.2	2.9
1	1998	Reading	URBAN BACKGROUND	4.7	4.7	4.3	3.8	3.4	3.1	2.9	2.6
1	1998	Hove Roadside	ROADSIDE	4.4	4.4	4.0	3.5	3.2	2.9	2.7	2.5
1	1998	Hounslow Roadside	ROADSIDE	6.6	6.6	6.0	5.3	4.8	4.4	4.0	3.7

# of years	year of max	site	type	max	1998 equiv.	1999 equiv.	2000 equiv.	2001 equiv.	2002 equiv.	2003 equiv.	2004 equiv.
1	1998	Bradford Centre	URBAN CENTRE	5.2	5.2	4.7	4.2	3.8	3.5	3.2	2.9
1	1998	Plymouth Centre	URBAN CENTRE	2.9	2.9	2.6	2.3	2.1	1.9	1.8	1.6
1	1998	Brighton Roadside	ROADSIDE	4.8	4.8	4.4	3.9	3.5	3.2	2.9	2.7
1	1998	London Cromwell Road 2	ROADSIDE	4.1	4.1	3.7	3.3	3.0	2.7	2.5	2.3

4 Estimating roadside concentrations

4.1 INTRODUCTION

Maps of estimated roadside annual mean concentrations of nitrogen dioxide, benzene and 1,3-butadiene have been calculated for the review of the NAQS (DETR *et al*, 1999, Stedman *et al*, 1998, Stedman and Dore, 1998). These maps were calculated from estimates of background concentrations and a ‘roadside enhancement’ of concentrations, which was derived from estimates of traffic emissions for individual road links:

roadside concentration = background concentration + roadside enhancement

This calculation is reasonably straight forward for annual means since it is simply the sum of the two components. The calculation of maps for CO is more complex because the maximum 8-hour concentration at the roadside is unlikely to be the sum of maximum background and roadside enhancements. This was assumed to be the case in the ‘worst case’ calculations carried out for the review of the NAQS (DETR *et al*, 1999) but the results of the individual site analyses presented in Table 2 indicate lower concentrations than the worst case analysis.

Table 3 shows the maximum 8-hour CO concentrations measured at roadside sites during 1998. The maximum 8-hour concentration at nearby background sites is also listed along with the maximum 8-hour roadside enhancement (maximum running 8-hour concentration at the roadside - maximum running 8-hour concentration at a nearby background sites on the same day). The maximum roadside concentration is consistently higher than the maximum background concentration and the maximum roadside enhancement is generally greater than or equal to the maximum background concentration. The roadside concentration is, however, lower than the sum of the other two. The background site most likely to be appropriate to the location of each roadside monitoring site has been selected. In some cases this site is not in the same urban area as the roadside site. Additional information is provided by Figure 1, which shows that the roadside enhancement of the daily maximum of running 8-hour CO concentrations at Marylebone Road is not correlated with the background concentration. We have therefore assumed that the maximum roadside concentration can be estimated by adding a high percentile of the background concentration to the maximum roadside enhancement. The 99 th percentile of the running 8-hour background CO concentration has been chosen, since only 1 % of background concentrations will be higher than this value and the sum of these two statistics gives a reasonable estimate of the maximum roadside concentration for 1998 measurement data (mean of measurements = 5.4 ppm, mean of estimates = 5.4 ppm, r^2 = 0.61, n = 12).

Table 3. Analysis of maximum running 8-hour CO concentrations at roadside sites in 1998 (ppm)

Roadside site	Background site	maximum Roadside	maximum Background	maximum Enhancement
Bristol Old Market	Bristol Centre	5.7	3.2	4.0
Marylebone Road	London Bloomsbury	6.5	3.2	5.6
Sutton Roadside	London Bexley	4.8	3.4	2.6
Tower Hamlets Roadside	London Bexley	7.5	3.4	4.4
Exeter Roadside	Plymouth Centre	6.4	2.1	5.3
Cromwell Road 2	West London	4.1	2.5	2.3
Hounslow Roadside	London Brent	4.5	4.2	3.2
Southwark Roadside	London Bexley	5.9	2.9	4.1
Glasgow Kerbside	Glasgow Centre	3.2	2.0	2.0
Bath Roadside	Bristol Centre	3.9	3.2	3.1
Hove Roadside	London Bexley	4.4	2.4	2.4
London A3 Roadside	London Bexley	7.6	3.4	4.3

4.2 ESTIMATING THE ROADSIDE ENHANCEMENT

Figure 2 shows the relationship between the measured maximum of 8-hour running mean roadside enhancement of CO concentration and emissions of CO from the individual road links closest to these sites. Emissions estimates for 1996 from the NAEI road traffic emissions model were used. This model incorporates measured traffic counts for six different vehicle types for each road link along with information on traffic speeds and the relationships between speed and emissions. The unforced regression equation is:

maximum enhancement = 0.0367 x road link emissions (1996,kg/m/year) + 1.182 (r^2 = 0.86, n = 9)

A road link with zero emissions can reasonably be expected to have a maximum roadside enhancement of zero, so the regression was forced through the origin:

maximum enhancement = 0.0525 x road link emissions (1996,kg/m/year)

This relationship is reasonably robust for these nine sites but the data for three sites have been excluded. The roadside enhancements at Cromwell Road 2 and London A3 Roadside are much lower than indicated by this relationship. This was expected for the London A3 site, which is close to a busy highway and has a more open aspect than the majority of the other sites. This is less obviously the case for Cromwell Road 2, but the buildings are a considerable distance from the roadside at this site. The roadside enhancement of concentrations at Exeter Roadside is much higher than indicated by the relationship. The reason for this is not known but may reflect particularly poor dispersion conditions at this site, which is in a narrow street canyon.

4.3 THE BACKGROUND COMPONENT

Annual mean background concentrations of a range of pollutants have been successfully mapped by deriving estimates of concentrations from emission inventory estimates of low level area emissions using an empirical box model method (Stedman, 1998). A map of annual mean background CO concentrations has been published by Stedman (1998) but the relationship between ambient concentrations and emissions estimates is considerably less reliable than for pollutants such as oxides of nitrogen. This was assumed to be due to additional uncertainties in the spatial distribution of CO emissions due to local variations in traffic speeds and congestion. Figure 3 shows that there is no clear relationship between the 99 th percentile of measured running 8-hour mean CO concentrations during 1998 and area emission estimates from the NAEI for the 25 1 km squares surrounding each background monitoring site. For emissions between 1,000 and about 12,000 Tonnes per 25 km^2 per year the concentration ranges between 1 and 2.8 ppm. At the sites with the highest estimated emissions, which are in inner London, the 99 th percentile concentration is consistently less than 2 ppm. In the absence of a clear relationship between concentrations and emissions, a constant value of 2.9 ppm has been chosen as the maximum likely background contribution to the maximum running 8-hour roadside concentrations in 1998.

4.4 COMPARISON WITH CURRENT ROADSIDE MEASUREMENTS

The equation for estimating roadside CO concentration is 1998 is:

roadside concentration(1998, ppm) = 2.9 ppm + 0.0525 x road link emissions (1996, kg/m/year)

Estimates derived from this equation are compared with measured maximum running 8-hour CO concentrations in Figure 4. There is reasonably good agreement (mean of measurements = 5.2 ppm, mean of estimates = 5.8 ppm, r^2 = 0.56, n = 9). This equation was then used to calculate the maps of roadside CO concentrations in 1998 presented in section 5.

4.5 PROJECTIONS

Maps of CO in years other than 1998 can be calculated by applying appropriate emission change factors to the background and roadside components:

roadside concentration(year y, ppm) = 99 th percentile background (year y,ppm)
+ fe_y x [0.0525 x road link emissions (1996, kg/m/year)]

We have assumed that the roadside enhancement will be directly related to road link emissions; fe_y is therefore derived from the ratio of annual emissions estimates listed in Table 1. The measurements of 99th percentile concentrations at background sites do not show any relationship with the spatial variation of area emissions estimates (Figure 3). Figure 5, however, shows that there is a clear relationship between the year to year changes in measured 99 th percentile of 8-hour CO concentrations at background sites and estimates of annual emissions from low level sources (mostly traffic sources) from the NAEI. Urban road traffic emissions estimates for each year between 1990 and 1998 were taken from Table 1 and the CO concentration is the maximum value measured in that year at any of the three background monitoring sites for which data are available throughout (London Bridge Place, West London and Glasgow City Chambers). The regression equation for the 99 th percentile of running 8-hour mean CO at background sites, for data for years with typical meteorology (all years except 1991) is:

99 th percentile background (year y, ppm) = k_t *x urban traffic emissions in year y (Ktonnes per year)*
($r^2 = 0.69$, $n = 8$)

where k_t is 0.0017.

There was an extreme air pollution episode in December 1991 with very high levels of vehicle related pollutants measured in both London and Glasgow (Bower *et al*, 1994). The unusual meteorological conditions experienced during this episode lead to higher CO concentrations than would be predicted by the regression relationship with annual emissions totals. An alternative estimate of background CO concentrations for years with extreme meteorology can be defined, with $k_t = 0.0027$.

The equation for calculating projections for year *y* is therefore:

roadside concentration(year y, ppm) = [k_t *x urban traffic emissions in year y (Ktonnes per year)]*
+ [0.0525 x road link emissions (1996, kg/m/year)] x [urban traffic emissions in year y (Ktonnes per year) / urban traffic emissions in year 1998 (Ktonnes per year)]

where $k_t = 0.0017$ for typical meteorology and $k_t = 0.0027$ for extreme meteorology.

5 Results and discussion

5.1 THE MAPS

Maps of estimated roadside CO concentrations for 1998 and 2004 are shown in Figure 6 to 14 . Maps for both typical and extreme meteorology are included for 1998 and maps for extreme meteorology only are included for 2004. The maps show maximum 8-hour concentrations for urban major roads for the UK and for London, Birmingham and Manchester in more detail. Built up road links in Great Britain have been defined as urban. Road links in Northern Ireland have been defined as urban if the land cover is more than 50% urban/suburban in any 1 km x 1 km square intersected by the road link.

Table 4 summarises the numbers of urban major road links expected to exceed the proposed limit value in 1998 and 2004 and the NAQS objective in 1998 and 2003. The road links have been classified into six groups: Inner London, Outer London, rest of England, Scotland, Wales and Northern Ireland.

Roadside CO concentrations in Northern Ireland have been estimated on the same basis as those in the rest of the UK. In contrast to the projections for background sites in Northern Ireland included in Table 2, it has been assumed that maximum CO concentrations at roadside locations are likely to be dominated by road traffic emissions.

Table 4. Summary of mapping results (maximum running 8-hour CO concentrations, ppm)

Year	Met.	Inner London		Outer London		Rest of England		Scotland		Wales		Northern Ireland		UK
Proposed Daughter Dir limit value		links ≥ 8.59 ppm	max. conc. (ppm)	links ≥ 8.59 ppm	max. conc. (ppm)	links ≥ 8.59 ppm	max. conc. (ppm)	links ≥ 8.59 ppm	max. conc. (ppm)	links ≥ 8.59 ppm	max. conc. (ppm)	links ≥ 8.59 ppm	max. conc. (ppm)	links ≥ 8.59 ppm
1998	Typical	53	14.3	23	13.3	49	12.5	1	9.3	1	8.09	0	8.3	127
1998	Extreme	166	16.0	98	15.0	254	14.2	9	10.9	7	10.6	19	10.0	553
2004	Typical	0	8.0	0	7.5	0	7.0	0	5.2	0	5.0	0	4.7	0
2004	Extreme	1	9.0	0	8.4	0	8.0	0	6.2	0	6.0	0	5.6	1
Proposed NAQS objective		links ≥ 10.0 ppm	max. conc.	links ≥ 10.0 ppm	max. conc.	links ≥ 10.0 ppm	max.. conc.	links ≥ 10.0 ppm	max. conc.	links ≥ 10.0 ppm	max. conc.	links ≥ 10.0 ppm	max. conc.	links ≥ 10.0 ppm
1998	Typical	18	14.3	7	13.3	12	12.5	0	9.3	0	8.9	0	8.3	37
1998	Extreme	70	16.0	29	15.0	63	14.2	2	10.9	1	10.6	0	10.0	165
2003	Typical	0	8.7	0	8.0	0	7.6	0	5.6	0	5.4	0	5.0	0
2003	Extreme	0	9.7	0	9.1	0	8.6	0	6.7	0	6.5	0	6.1	0
Total urban links		792		819		4997		560		340		188		7696

No roads are expected to exceed the proposed limit value of 8.59 ppm in 2004 for typical meteorology and one road link is estimated to be at risk of exceeding this concentration for extreme meteorology, with a concentration of 9 ppm. This link is Park Lane (A4202) in Inner London and since this road has an open aspect on one side, it is likely that the concentration has been overestimated.

The road links with the highest concentrations are listed in Table 5. The model of roadside CO concentration that we have adopted has the same background CO contribution throughout the country. The distribution of the road links with the highest concentrations is therefore more uniform than for pollutants such as annual mean NO_2 or PM_{10} for which the contribution of background concentrations varies considerably, with the highest contribution in Inner London.

Table 5. The road links with the highest estimated roadside maximum 8-hour CO concentrations (typical meteorology, ppm)

	Link ID	Road number	Road name	Location	Length (m)	CO 1998	CO 2004	CC 200
Inner London	17639	A4202	Park Lane	Mayfair	1200	14.3	8.0	8.7
Outer London	27087	A406	North Circular Road	Hendon	900	13.3	7.5	8.1
Rest of England	48535	A58	West Street	Leeds	300	12.5	7.0	7.6
Scotland	50974	A739	Clyde Tunnel	Glasgow	2009	9.3	5.2	5.6
Wales	50660	A470	Kingsway	Cardiff	300	8.9	5.0	5.4
Northern Ireland	9000165	A12	West Link	Belfast	479	8.3	4.7	5.0

Table 6 shows the total number of urban major road links with concentrations greater than 8.59 and 10 ppm for each year between 1998 and 2004. No road links are expected to have concentrations higher than 8.59 ppm by 2004 and only 2 are expected to have concentrations greater than the proposed limit value by 2002 for typical meteorology (these two road links are A4020 Park Lane and A406 North circular Road, as listed in Table 5). One road link is expected to have a concentration higher than 8.59 ppm by 2004 and only 14 are expected to have concentrations greater than the proposed limit value by 2002 for extreme meteorology. These 14 links are listed in Table 7.

Table 6. The number of major urban road links projected to exceed 8.59 ppm and 10 ppm 1998 to 2004

	Typical Meteorology		Extreme Meteorology	
Year	links≥8.59 ppm	links≥10 ppm	links≥8.59 ppm	links≥10 p
1998	127	37	553	
1999	62	22	274	
2000	26	5	85	
2001	9	1	34	
2002	2	0	14	
2003	1	0	5	
2004	0	0	1	

Table 7. The road links with the highest estimated roadside maximum 8-hour CO concentrations in 2002 (extreme meteorology, ppm)

rank	Link ID	Road number	Road name	Location	Length (m)	CO 1998
1	17639	A4202	Park Lane	Mayfair	1200	16.0
2	18468	A3211	Embankment	Blackfriars	400	13.8
3	18496	A4	Great West Road	Hammersmith	1100	14.3
4	26116	A4	Ellesmere Road	Chiswick	1849	13.4
5	27087	A406	North Circular Road	Hendon	900	15.0
6	28003	A58	Wellington Road	Leeds	600	13.4
7	28505	A4	West Cromwell Road	West Kensington	400	13.7
8	36119	A4	Talgarth Road	Hammersmith	1300	13.9
9	38466	A4	Cromwell Road	South Kensington	300	13.1
10	46121	A4	Great West Road	Hammersmith	600	14.3
11	48251	A501	Marylebone Road	Paddington	400	13.4
12	48489	A46	Burleys Way	Leicester	400	14.1
13	48535	A58	West Street	Leeds	300	14.2
14	57537	A501	Marylebone Road	Baker Street	200	13.3

5.2 PROJECTIONS FOR MARYLEBONE ROAD BASED ON THE MAPPING METHOD

Figure 15 shows projections of the mapped maximum 8-hour roadside CO concentrations at Marylebone Road for both typical and extreme meteorology for all years from 1990 to 2010. The values for 1998 are 8.9 and 10.5 ppm respectively, which are higher than the individual site analysis result for this site of 6.5 ppm (Table 2). This is because the mapping method is designed to provide an estimate of the maximum possible concentration in each year. The individual site analysis for this site was derived from 1998 data and 1998 was a year of relatively low concentrations. The highest concentrations listed in Table 4 are higher than those estimated for Marylebone Road because there are several road links with higher traffic flows than Marylebone Road.

Measured maximum 8-hour CO concentrations at both background and roadside sites shown on Figure 15 are the maximum values from the whole of the UK networks for each year. The only roadside site in the years 1990 to 1995 was Cromwell Road and in many years higher concentrations were recorded at one or more of the background sites. Background concentrations were generally lower than our predicted maximum concentration for typical meteorology at roadside sites and always lower than our predictions for extreme meteorology. Data for more roadside sites are available from 1996 onwards and the measured maximum roadside concentration was higher than the maximum background in the years 1996, 1997 and 1998. Our predictions for extreme meteorology appear at Marylebone Road to give a safety margin of between 10 to 50% over the measured maximum 8-hour CO concentrations at roadside and background monitoring sites.

The ‘worst case’ projections that were calculated for the review of the NAQS are also shown on Figure 15. These projections were calculated by adding the maximum 8-hour roadside enhancement of concentrations at Marylebone Road to the maximum running 8-hour mean in Central London. It is clear that this method of adding the maxima gives much higher concentrations than the mapping methods used here and that the mapping method provides more realistic representation of concentrations.

6 Conclusions

Maximum running 8-hour CO concentrations in all background locations in 2004 are predicted to be well within the proposed limit value of 8.59 ppm.

Estimated roadside CO concentrations in 2004 are expected to be higher. For typical meteorology, the predictions show that no road links are expected to have concentrations higher than 8.59 ppm by 2004 and only 2 are expected to have concentrations greater than the proposed limit value by 2002. For extreme meteorology, such as that experienced in some UK cities in 1991, the predictions show that one road link is expected to have a concentration higher than 8.59 ppm by 2004 and only 14 are expected to have concentrations greater than the proposed limit value by 2002.

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