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An Empirical Model for Quantifying Current and Future Benzene and 1,3-Butadiene Concentrations at the Roadside

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Executive Summary

The UK National Air Quality Strategy gives the following objectives for benzene and 1,3-butadiene, to be reached by 2005:

- Benzene: The maximum annual running mean must not exceed 5 ppb
- 1,3-Butadiene: The maximum annual running mean must not exceed 1 ppb

National measures are likely to deliver significant reductions in the emissions of these two pollutants from road traffic sources between now and 2005. It is therefore important to examine current concentrations of these pollutants at roadside locations and to determine whether current policies are likely to reduce concentrations at these locations sufficiently to meet the objectives by 2005.

An empirical model for predicting roadside concentrations of benzene and 1,3-butadiene in the UK has been developed. This model uses previously published maps of estimated background concentrations as it's starting point, to which a "roadside enhancement" of concentrations is added. The empirical relationships between this "roadside enhancement" and individual road link emissions estimates have been derived from an analysis of both automatic monitoring data from the Marylebone Road monitoring site and diffusion tube monitoring data from a more extensive group of sites.

Our estimates of roadside concentrations for 2005 indicate that current policies are likely to lead to roadside concentrations well within the objectives. Concentration estimates for intermediate years have also been calculated in order to provide an indication of the earliest date at which the objective concentrations are likely to be achieved. The benzene objective is likely to be achieved by 2002 and the 1,3-butadiene objective by 2004. Our calculations also show that, at most, only one or two roads will be at risk of exceeding the benzene and 1,3-butadiene objectives in 2001 and 2003 respectively.

Urban background concentrations of benzene and 1,3-butadiene have also been calculated for 2005 at the locations of sites on the UK Hydrocarbon Monitoring Network. Several emission reduction scenarios have been used. The highest concentrations of benzene and 1,3-butadiene, 0.78 and 0.14 ppb respectively, are arrived at using a "business as usual" scenario.

Concentration predictions have also been made with respect to the 1 ppb target value for benzene, set by EPAQS. Estimates indicate that over 500 road links will exceed this target value in 2010, although the highest concentration is estimated to be 1.3 ppb with concentrations rapidly falling away to 1.0 ppb. Some 80% of the 500 road links are located in the London area. Results from hypothetical emission reduction scenarios have been investigated, and it is postulated that a national reduction in traffic emissions of 30% is not adequate to attain the target value for benzene in 2010- the majority of exceedances occurring in the London area.

Contents

Appendices

1 Introduction

Over the last 10 years the issue of urban air pollution has become a major factor driving environmental legislation within the European Union and the United Kingdom. An extensive programme of urban air monitoring has been established in the UK, and health based air quality standards, and targets for improvement, have been set.

Part IV of the Environment Act, 1995, establishes a national framework for air quality management, and requires all local authorities in Wales and Scotland and London borough, district and unitary councils in England to conduct local air quality reviews. Where the reviews indicate that objectives set out in the Air Quality Regulations, 1997, will not be met by 2005, the relevant authority is required to designate an Air Quality Management Area. Further work is then required to investigate ways to ensure compliance of the area by 2005. Accurately predicting the extent to which current concentration levels will have decreased by 2005 is thus fundamental in achieving the aims of the National Air Quality Strategy (NAQS).

The NAQS gives the following objectives for benzene and 1,3-butadiene, to be reached by 2005:

Benzene: The maximum annual running mean must not exceed 5 ppb
1,3-Butadiene: The maximum annual running mean must not exceed 1 ppb

In addition, a target value of 1 ppb for benzene (expressed as an annual running mean) has been set by EPAQS (Benzene- EPAQS 1994).

There are two primary sources of Volatile Organic Compounds (VOCs)- emissions from road transport and industrial activities. As part of the local authority reviews several “pilot studies” have already been conducted to investigate benzene concentrations in the vicinity of major industrial installations. However, in the urban environment emissions from road transport are usually the primary source of both benzene and 1,3-butadiene.

Several measures have already been introduced to reduce the emissions of pollutants from the road transport sector. The current trend, of decreasing annual emissions of benzene and 1,3-butadiene has primarily been caused by the introduction of catalytic converters for cars (Directive 91/441/EEC) and a further directive implemented in 1996 (94/12/EEC). Other measures include the introduction of carbon canisters to reduce evaporative emissions and the introduction low benzene fuel.

This report investigates the current and predicted concentrations of benzene and 1,3-butadiene at locations likely to be dominated by the emissions from road transport- roadside and urban background locations.

The methodology for estimating current and future benzene and 1,3-butadiene roadside concentrations is described in Section 4 and outlined below:-

- Maps of current background concentrations have been calculated from a combination of emission inventories and ambient measurements. This is discussed in Section 2
- Current roadside benzene and 1,3-butadiene measurement data have been examined to determine the relationship between the "roadside enhancement" of concentrations and vehicle emission estimates. This is discussed in Section 3.
- Current roadside concentrations throughout the UK have been estimated from the sum of background concentrations and this enhancement.
- Future roadside concentrations have been predicted by applying emissions reductions to the modelled roadside concentrations.

Predictions of benzene and 1,3-butadiene concentration have also been made, for 2005, at the urban background locations on the UK Hydrocarbon Monitoring Network. Several emission reduction scenarios have been used to investigate the potential reductions of concentration.

Conclusions and results from this study are used to indicate whether compliance with the Air Quality Regulations is likely to be met on a national level (Section 5). In addition, the potential for compliance with the target value for benzene, by 2010, has been investigated. Results are reported in Section 4.

Concentrations of benzene, 1,3-butadiene and NO_x are expressed as either ppb or µg m^{-3} in this report as appropriate. Final results are generally expressed in ppb for comparison with the NAQS objectives; while some intermediate calculations are best expressed in terms of µg m^{-3} since this enables ratios of concentrations and emissions of different pollutants to be compared directly.

The following conversion factors have been applied:-

Benzene:	1 ppb = 3.29 µg m^{-3}
1,3-Butadiene	1 ppb = 2.25 µg m^{-3}
NO_x	1 ppb = 1.91 µg m^{-3}

2 Mapping Background Benzene & 1,3-Butadiene

2.1 CURRENT BACKGROUND BENZENE AND 1,3-BUTADIENE MAPS

Maps of estimated annual mean background benzene and 1,3-butadiene concentrations for 1996 are presented in Figures 2.1 and 2.2. These maps have been taken from an earlier report on background concentration maps (Stedman 1998), where details of the mapping methods can be found. The general approach to mapping background concentrations has been described in Stedman (1998) and Stedman *et al* (1997).

Measured annual mean background concentrations have been considered to be made of two parts :

- A contribution from relatively distant major sources, such as large conurbations. Measurements from rural monitoring sites well away from local sources are generally found to provide an indication of the spatial variation of concentrations due to these distant sources. A rural map can be interpolated from measurements at these rural sites.

- A contribution from more local emissions. We have found that estimates of emissions in an area of 25 km^2 centred on a background monitoring site location can be used to derive this local contribution.

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

diff = measured urban concentration - mapped rural background

diff = k_m*.emissions (urban)*

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 derive the relationship between ambient air quality and emissions inventories.

The three inputs required to construct a map of total background concentration are therefore a rural map of concentration, an emissions inventory and automatic measurements in urban areas.

Maps of background benzene and 1,3-butadiene could ideally be derived from a combination of rural and urban ambient measurements and emission inventories for benzene and 1,3-butadiene. While sufficient urban measurement data are available for these species, rural automatic measurements of benzene and 1,3-butadiene are only available for one monitoring site (Harwell) and emission inventory maps of these two hydrocarbon species are not yet available.

Maps of rural concentrations of benzene and 1,3-butadiene have therefore been derived from a map of rural NO_2 concentrations by multiplying by the benzene to NO_2 and 1,3-butadiene to NO_2 ratios measured at the Harwell site (0.031 and 0.00538 respectively, with all concentrations expressed as ppb).

The implicit assumption in using rural NO_2 measurements to estimate rural benzene and 1,3-butadiene concentrations is that traffic emissions are a dominant source of these pollutants on a regional scale.

The contribution to background concentrations from local emissions has been derived from a map of low level (area plus road sources) VOC emissions (Goodwin *et al* 1997). Future work will be able to incorporate benzene and 1,3-butadiene emission maps directly, once they are available from the National Atmospheric Emissions Inventory (NAEI). The following empirically derived regression coefficients were used to calculate the map of background concentrations.

$$\underset{\text{(ppb)}}{\textit{estimated concentration}} = \underset{\text{(ppb)}}{\textit{rural map}} + \underset{\text{(kTonnes of VOC/25 km}^2\text{/year)}}{k_m.\textit{emissions}}$$

Benzene: $k_m = 0.281$
1,3-Butadiene: $k_m = 0.0566$

The highest background concentrations are in city centre locations as expected. The maximum values on these 1996 maps are 2.6 ppb for benzene and 0.5 ppb for 1,3-butadiene.

2.2 2005 BACKGROUND BENZENE AND 1,3-BUTADIENE MAPS

Maps of the projected annual mean background concentrations of benzene and 1,3-butadiene for 2005 have been calculated from the 1996 maps (Figures 2.1 and 2.2). The 2005 maps shown in Figures 2.3 and 2.4 have been calculated by scaling the 1996 maps by the changes in emissions that current policies are likely to deliver- calculated by the NAEI road transport model (*pers. comm.* Murrells 1998). The recently published local emissions inventories for a number of UK cities (Hutchinson and Clewley 1996, Buckingham *et al* 1997a, 1997b, Buckingham *et al* 1998) have indicated that road traffic emissions generally dominate the emissions of these pollutants in urban areas. Taking these inventories together, it is reasonable to assume that road traffic emissions currently contribute 90% of the benzene and 1,3-butadiene observed at urban background locations and background concentrations for 2005 have been projected on this basis. Estimates of urban road traffic emissions for both current and future years are available from the NAEI road transport model (*pers. comm.* Murrells 1998) and it is reasonable to assume that the roadside enhancement of concentrations is directly attributable to traffic emissions. Table 2.1 lists the emission reduction factors for emissions in 2005, relative to 1996. These emissions reduction factors are appropriate for calculation of concentrations for both urban background and for the roadside.

Table 2.1 Emission reductions that current policies are likely to deliver, expressed as the ratio 2005:1996.

	Emission Reduction Factors	
	Background	Roadside
Benzene	0.31	0.23
1,3-Butadiene	0.33	0.25

The non traffic emissions contributing the remaining 10% of background concentration are assumed to remain unchanged.

The background maps for benzene and 1,3-butadiene indicate that exceedances of the NAQS objectives at background locations are unlikely in 2005. The maximum estimated background concentrations are 0.8 and 0.2 ppb for benzene and 1,3-butadiene respectively.

3 Current Roadside Benzene & 1,3-Butadiene Concentrations

3.1 ROADSIDE CONCENTRATIONS

For the purposes of the methodology used here, the concentrations observed at the roadside have been broken down into "background" and "roadside enhancement" contributions. Hence "roadside enhancement" is defined as follows:-

roadside concentration = background concentration + roadside enhancement

For roadside, we have included all monitoring sites located within about 10m of the edge of the road.

This enables a simple relationship between the emissions from road traffic and the "roadside enhancement" contribution to be determined. Similar work has already been conducted for NO_x, and the relationship has been well characterised (see Stedman and Bush 1998).

In the case of NO_x the road traffic emissions data was taken from the NAEI (Salway *et al* 1997), which holds spatially disaggregated emissions data. The empirical relationship between the annual NO_x emissions from a major road link and the annual mean of roadside enhancement NO_x concentration was found to be:-

Roadside enhancement of NO_x = k_{NOx} . NO_x *emission from road link*
($\mu g\ m^{-3}$ as NO_2) ($kg\ NO_2\ m^{-1}\ y^{-1}$)

k_{NOx} is found to be 5.73 (Stedman and Bush). This coefficient was derived from a comparison of measurements of NO_x concentrations at roadside automatic monitoring sites and NAEI road link emissions estimates.

Similarly k_{Bz} and k_{13} can be defined as follows:
Roadside enhancement of benzene = k_{Bz} . *benzene emission from road link*
($\mu g\ m^{-3}$) ($kg\ m^{-1}\ y^{-1}$)

Roadside enhancement of 1,3-butadiene = k_{13} . *1,3-butadiene emission from road link*
($\mu g\ m^{-3}$) ($kg\ m^{-1}\ y^{-1}$)

However, automatic measurements of roadside benzene and 1,3-butadiene concentrations have recently commenced, and monitoring is currently restricted to a small number of sites. Hence two alternative methods for determining an appropriate value for the coefficients k_{Bz} and k_{13} have been adopted. Both methods have been applied for benzene and the results can be compared, providing a robust estimate of k_{Bz}. Method 2 is the only method that can be used for 1,3-butadiene due to the lack of extensive monitoring data.

Method 1: Annual mean concentrations measured by both automatic and diffusion tube methods have been compared with road link emission estimates. This provides a value for k_{Bz} directly.

Method 2: A detailed comparison of the daily mean enhancement of roadside benzene and NO_x concentrations measured at Marylebone Road can provide an alternative estimate of k_{Bz} and an estimate of k_{13}. Marylebone Road is the only kerbside monitoring site in the National Hydrocarbon Network, and hence is the only site for which this analysis can be carried out. London UCL is used as the background site.

3.2 DATA COLLECTION

Benzene data is primarily available from two sources- BTEX diffusion tube surveys and automatic point monitors. The automatic point monitors may be broken down into two categories depending on whether they also measure 1,3-butadiene. Detailed site information is also required, such as grid reference and distance to the nearest major road- this enables mapping and determines whether the location is truly roadside or background.

Although diffusion tubes are often used to monitor concentrations in the vicinity of industrial installations, the extensive number of surveys conducted by local authorities has meant that a large number of roadside and associated background sites are available. It has taken considerable time to compile this information as there is currently no national co-ordination of BTEX diffusion tube surveys. The available data is dominated by sites located in the London area, and details of all site locations are given in Appendix 1. Acknowledgements for the provision of data are given in Section 7 and Appendix 1.

3.3 ANALYSIS OF ANNUAL MEAN BENZENE CONCENTRATION

Annual means of roadside and background concentration were calculated for each site. Where sites had less than an annual period of data, the average across the period was re-scaled (by using seasonal data trends from automatic sites) to give a value representative of an annual value. Background measurement sites were then paired with roadside sites. The roadside enhancement was then calculated for each site by subtracting the annual mean background concentration from the annual mean roadside concentration. The background concentration was taken from the map of estimated background concentrations and checked against nearby background measurements, where available. This enables the relationship between the road link emissions data and the "roadside enhancement" to be examined in Figure 3.1. The numbers on the scatter plot correspond to the Site ID numbers (given in Appendix 1).

Fig 3.1 Benzene, All Sites, Roadside Enhancement vs Road Link Emissions

Measurements from a total of 39 sites were included in this scatter plot. These are the sites for which NAEI road link emissions estimates are available, and for which it was possible to make unambiguous identification of this road link location.

Roadside enhancement of Benzene ($\mu g\ m^{-3}$) $= k_{Bz}$. *Benzene emission from road link* ($\mu g\ m^{-1} y^{-1}$)

k_{Bz} is found to be 11.5, i.e. approximately twice that of k_{NOx} (see Section 3.1).

There is considerable scatter in the data ($R^2 = 0.37$). In addition to any real differences, there are uncertainties within the measurement method, background concentration values and emissions estimates.

The value of k_{Bz} is initially surprising, as the factor relating emissions and concentrations (k_m) should be indicative of dispersion processes, and hence is expected to be similar to that for NO_x (assuming that the emissions estimates are reasonably accurate).

3.4 ANALYSIS OF DAILY ROADSIDE ENHANCEMENT OF CONCENTRATION FOR BENZENE AND 1,3-BUTADIENE

As NO_x has been well characterised in the past, and is measured in numerous locations, the "roadside enhancement" of benzene and 1,3-butadiene were compared with similar NO_x measurements.

The daily mean roadside enhancement of the NO_x, benzene and 1,3-butadiene concentrations have been calculated for the Marylebone Road monitoring site for the period January to July 1998. Daily mean background NO_x concentrations from the London Bloomsbury monitoring site and daily mean background benzene and 1,3-butadiene concentrations from the London UCL monitoring site were subtracted to calculate this roadside enhancement. The scatter plots (Figures 3.2 and 3.3) show the excellent correlation between the enhanced roadside concentration of these three pollutants.

Benzene to NO_x and 1,3-butadiene to NO_x ratios from both measurements and road link emissions estimates for Marylebone Road were then calculated as follows (with concentrations expressed in µg m^{-3}):-

$$\frac{\text{Roadside enhancement of Benzene}}{\text{Roadside enhancement of } NO_x} = c_{Bz/NOx} = 0.041$$

$$\frac{\text{Benzene emissions from road link}}{NO_x \text{ emissions from road link}} = q_{Bz/NOx} = 0.020$$

Fig 3.2 Marylebone Daily mean NO_x enhan vs Benz enhan

Fig 3.3 Marylebone Daily mean NO_x enhan vs 1,3-Butadi enhan

Comparison of the benzene:NO_x emissions ($q_{Bz/NOx}$) and benzene:NO_x roadside enhancement ($c_{Bz/NOx}$) indicates that for the same estimated emission, the benzene roadside enhancement is approximately twice that of NO_x (i.e. $c_{Bz/NOx} \approx 2.q_{Bz/NOx}$). So, the coefficient for benzene roadside enhancement k_{Bz} will be approximately twice that for NO_x (i.e. $k_{Bz} \approx 2.k_{NOx}$), which is as observed: k_{NOx} = 5.73 and k_{Bz} = 11.5 (from Sections 3.1 and 3.3).

For 1,3-butadiene the situation is somewhat different. Due to the limited number of roadside 1,3-butadiene measurement sites it has not been possible to determine k_{13} directly. The alternative method (Method 2) using only the Marylebone Road site has been used. k_{13} is determined by using the relationship between the roadside enhancement of 1,3-butadiene and NO_x derived from the Marylebone Road data. From previous definitions it can be shown that:

$$k_{13} = \frac{c_{13/NOx}}{q_{13/NOx}} . k_{NOx} = 7.5$$

Evidently there is better agreement between the concentration and emissions ratios for 1,3-butadiene and NO_x than for benzene and NO_x.

3.4.1 Factors Affecting the Benzene:NO_x Road Link Emissions Ratio and Benzene:NO_x Roadside Enhancement

There are several possible explanations for the observed differences between $c_{Bz/NOx}$ and $q_{Bz/NOx}$ - i.e. the observed difference between the benzene to NO_x ratio of roadside enhancement, and the ratio of benzene to NO_x road link emissions. These originate from several assumptions made in the methodology for estimating the road link emissions which may not be entirely appropriate for the Marylebone Road site.

First, and thought to be the most important, the benzene to NO_x ratio of emissions from road vehicles ($q_{Bz/NOx}$) is strongly speed dependent. Currently, the NAEI methodology assumes an average speed of 55 km h^{-1} (34 miles h^{-1}), which is the default value for a dual carriageway with a speed limit of 40 miles h^{-1}. It is thought that this is an overestimate of the average vehicle speed. Figure 3.4 illustrates the speed dependence of the benzene to NO_x emissions ($q_{Bz/NOx}$), and the values of $q_{Bz/NOx}$ and $c_{Bz/NOx}$ are indicated on this plot.

The value of $c_{Bz/NOx}$ suggests an average vehicle speed of 15 to 20 km h^{-1}, which is more consistent with the value of 11 miles h^{-1} (17.7 km h^{-1}) for average traffic speed in the central London area, given in Road Transport Statistics for London (1996).

Similar comparisons for 1,3-butadiene between $c_{13/NOx}$ and $q_{13/NOx}$ suggest a higher average vehicle speed. The estimated vehicle speed from the value of $c_{13/NOx}$ is approximately 45 kmh^{-1}, as shown in Figure 3.5. While there is twice as much roadside enhancement of benzene concentrations than is predicted by the emissions estimates, 1,3-butadiene concentrations are closer to, thought not exactly equal to, the expected values for this road link.

It is recommended that the estimates for road vehicle speeds in the London area be addressed by the NAEI in the near future. Examination of likely vehicle speeds at the monitoring sites shown in Figures 3.4 and 3.5 may help in this analysis.

Fig 3.4 Speed dependence of NOx/Benz
Fig 3.5 Speed dependence of NOx/1,3-but

In addition to the above, it should be noted that evaporative losses of benzene are not included in the road link emissions data. The evaporative losses of benzene contribute 7% to the total vehicle emissions, when expressed as a national average. Also, it has recently been suggested that prolonged engine idling can reduce the efficiency of some types of catalytic converters. This would increase the emissions of benzene relative to NO_x, but at present it is not possible to determine whether this impact on the benzene to NO_x emission ratio would be significant.

4 Maps of Estimated Roadside Benzene & 1,3-Butadiene Concentrations

4.1 CURRENT BACKGROUND AND ROADSIDE CONCENTRATIONS

Figure 4.1 shows a scatter plot of the estimated current roadside concentration (mapped background + estimated roadside enhancement) and diffusion tube and automatic benzene measurements. The numbers on the scatter plot correspond to the individual Site ID numbers (given in Appendix 1). The overall correlation is reasonably good (R^2=0.40). Since these are the monitoring sites that were used to derive this plot, it does not provide an independent validation of the estimates. It does, however, provide a useful indication of the uncertainties of the overall estimates of roadside benzene concentrations.

An equivalent plot for 1,3-butadiene is not possible because of the small number of available sites. It is therefore assumed that the estimates of roadside1,3-butadiene have similar levels of uncertainty as the benzene estimates

The road link emissions data and the mapped estimates of background concentrations are then used to derive a concentration map of roadside concentration levels for both benzene and 1,3-butadiene (for all of the 15226 road links in the current GIS database) across the UK in 1996 and 2005.

Figure 4.1 Estimated Current Benz Roadside concentrations vs measurements- all sites

Figures 4.2 and 4.3 show examples of the estimates of current roadside benzene and 1,3-butadiene annual concentrations. The majority of roads already have current concentrations lower than the objectives for 2005. In 1996 a total of 75 roads have estimated benzene concentrations greater than 5 ppb and 324 road links have estimated 1,3-butadiene concentrations greater than 1 ppb.

The majority of the road links with the highest concentrations are either motorways or major trunk roads close to, or within, large cities. Several roads in central London, Birmingham, Manchester, Bristol and Glasgow have estimated roadside concentrations of benzene in excess of 5 ppb.

The methodology used to arrive at these results has used measurements from built up urban areas only, and it does not necessarily follow that the relationships found here will hold for other road types. It is likely that concentrations adjacent to major roads in more open rural areas will have lower concentrations. As a result it is more appropriate to consider the number of urban roads that exceed the air quality objectives.

Most of the 43 urban road links with current benzene concentrations above 5 ppb are in London.

4.2 PREDICTED ROADSIDE CONCENTRATIONS

4.2.1 Introduction

There is a considerable uncertainty in determining the relationship between the observed roadside enhancement and the emissions from the associated road links (k_{Bz}). This was clearly illustrated in Figure 3.1 and discussed in Section 3.3. The scatter on this plot indicates that the mean benzene concentration can be up to approximately 1 ppb higher than the estimated value.

In addition to this, it should be noted that the concentration maps indicate the mean concentration value taken across a particular calendar year. As explained in Appendix 2, this may give a different value to the maximum annual running mean taken across a period of one year (as specified in the NAQS). The maximum annual running mean taken across a period of one year cannot be determined from diffusion tube measurements alone. A statistical analysis between the annual “calendar” mean and the maximum running annual mean (taken from a period of one year) has been conducted (see Appendix 2). The results indicate that, for benzene, the maximum running mean across a period of one year is approximately 10% higher than the annual “calendar” mean.

These two factors can be combined to give the estimated annual “calendar” mean of 3.5 ppb as a concentration limit, within our analysis, equivalent to the NAQS objective. It has been assumed that the uncertainties in estimating likely exceedances of the NAQS objective for 1,3-butadiene are similar to those for benzene. The equivalent concentration limit for 1,3-butadiene is therefore 0.7 ppb.

The concentration estimates for urban road links are likely to have the lowest uncertainties because the model has been calibrated for this type of site. Road links in Northern Ireland are not broken down into different road classes, as this information is not available from our road link database. Where exceedances occur, these roads are listed in a separate class.

The following section estimates the predicted roadside concentrations, and relates the results to the NAQS. The values of 3.5 ppb and 0.7 ppb for benzene and 1,3-butadiene have been used to determine exceedance of the NAQS for the reasons given above. This ensures that a safety margin is incorporated to allow for uncertainties associated with the calculation methodology.

4.2.2 Comparison with NAQS Objectives

Estimates of roadside concentration for 2005 have been calculated by scaling the current background and roadside enhancement concentrations by the emissions reduction factors given in Table 2.1. Figures 4.2 and 4.3 show that no roadside locations are expected to have benzene or 1,3-butadiene concentrations exceeding the NAQS objectives by 2005. The highest predicted roadside concentrations for 2005 are 1.9 ppb and 0.5 ppb for benzene and 1,3-butadiene respectively.

Since these concentrations are significantly below the NAQS objectives it is instructive to calculate an estimate of the earliest year by which these objectives are likely to be met. It is clearly important that an adequate safety factor is incorporated into these estimates. Therefore the earliest years for which benzene and 1,3-butadiene are below 3.5 and 0.7 ppb respectively have been identified.

Tables 4.1 and 4.2 shows the number of road links with annual mean concentrations greater than or equal to 3.5 ppb of benzene or 0.7 ppb of 1,3-butadiene along with the maximum concentration for each year from 1996 to 2005. In addition to listing the total number of road links, this table also shows a breakdown into urban/built up roads and rural/non-built up roads. Motorways have been included with the rural roads.

Table 4.1 Number of Road Links Exceeding Benzene NAQS

Benzene	**All Road Types**		**Urban Roads**		**Rural and Motorways**	
Year	**# of Road Links**	**Max. Conc. (ppb)**	**# of Road Links**	**Max.Conc. (ppb)**	**# of Road Links**	**Max Conc. (ppb)**
1996	771	7.7	571	7.7	200	6.2
1997	423	6.9	292	6.9	131	5.6
1998	201	6.1	129	6.1	72	4.9
1999	62	5.3	38	5.3	24	4.3
2000	17	4.6	15	4.6	2	3.6
2001	2	3.9	2	3.9	0	3.1
2002	0	3.3	0	3.3	0	2.6
2003	0	2.7	0	2.7	0	2.2
2004	0	2.3	0	2.3	0	1.8
2005	0	1.9	0	1.9	0	1.5
	Total # of road links		**Urban road links**		**Rural/M.way road links**	
	15226		7508		7718	

Table 4.2 Number of Road Links Exceeding 1,3-Butadiene NAQS

1,3-Butadiene	All Road Types		Urban Roads		Rural and Motorways	
Year	**# of Road Links**	**Max. Conc. (ppb)**	**# of Road Links**	**Max. Conc. (ppb)**	**# of Road Links**	**Max. Conc. (ppb)**
1996	1616	2.1	1288	2.1	328	1.5
1997	1113	1.9	876	1.9	237	1.3
1998	645	1.6	493	1.6	147	1.2
1999	327	1.4	249	1.4	78	1.0
2000	140	1.2	104	1.2	36	0.9
2001	35	1.1	30	1.1	5	0.7
2002	12	0.9	12	0.9	0	0.6
2003	1	0.8	1	0.8	0	0.5
2004	0	0.6	0	0.6	0	0.4
2005	0	0.5	0	0.5	0	0.4
	Total # of road links		**Urban road links**		**Rural/M.way road links**	
	15226		7508		7718	

If benzene is considered, the mapped results indicate that all roadside locations will be below 3.5 ppb of benzene (expressed as an annual fixed mean) by the year 2002. 1,3-Butadiene roadside locations will be below 0.7 by the year 2004.

The two road links with the highest concentrations are A4202 Park Lane and A4 Talgarth Road in London. Apart from these two links the benzene objective should be achieved by 2001 and the 1,3-butadiene objective by 2003.

The latest years with significant exceedances of the objectives are 2000 for benzene and 2002 for 1,3-butadiene, with 13 and 12 urban links exceeding respectively. These links include several sections of the A4, including Talgarth Road, Cromwell Road and Knightsbridge, several sections of the A501 Marylebone Road, along with A4202 Park Lane, A3 Kensington Park Road and A3200 Stamford Street in central London. The only urban links outside central London are the A406 North Circular Road at Brent Cross and the A46 in Leicester city centre.

The five motorway road links with estimated roadside annual mean 1,3-butadiene concentrations greater than 0.7 ppb in 2001 include three sections of the M25 near Heathrow, and short sections of the M8 in Glasgow and the M62 near Manchester. Note that these concentrations are probably overestimates as indicated above.

Fig 4.2 1996 2005 Benzene map

Fig 4.3 1996 2005 1,3-but map

5 Projections for Individual Monitoring Site Locations

Projections of the maximum running annual mean for benzene and 1,3-butadiene have been made for 12 of the sites on the UK Hydrocarbon Monitoring Network. For the purposes of this report, all 12 sites have been considered to be urban background, with the exception of Harwell (a rural site).

Several hypothetical scenarios have been considered (see below), and the estimated concentrations for 2005 are given in Figures 4.4 and 4.5. The two hypothetical scenarios given in Figures 4.4 and 4.5 are in addition to the business as usual scenario.

Scenario a	Business as usual (as used with all other projections in this report)		
Scenario h	Reduction in emissions from **traffic**:	30%	In Inner/Central London
		30%	In Outer London
		30%	In all other Locations
Scenario i	Reduction in emissions from **cars**:	30%	In Inner/Central London
		30%	In Outer London
		30%	In all other Locations

The ratios of concentration between the sites remain relatively constant, even though the absolute concentrations decrease substantially. In each of the scenarios, all of the sites comply with the target value for benzene of 1ppb (see Section 6).

The method used to generate these projections does not incur the uncertainties associated with the mapping methods. Consequently, the projections for each site may be compared with the 1.0 ppb value, rather than the 0.7 ppb threshold (chosen to account for the uncertainties in the mapping methodology and the difference between maximum annual running means and fixed annual means).

Figures 5.1 and 5.2 Projections for UK NHN sites (3-D columns).

6 Comparison with Benzene Target Value

6.1 INTRODUCTION

A target value for benzene of 1 ppb (expressed as an annual running mean) has been set by EPAQS as a long term target level. The following section shows a comparison between this target value and estimated roadside concentrations. The locations of the road links exceeding this value are also highlighted. In addition, hypothetical emission reduction scenarios have been used to estimate the potential impact on the number of road links exceeding the target value.

The method of estimating future benzene roadside and background concentrations is similar to that used for calculating exceedances of the 5 ppb standard. In this case, the threshold used to indicate exceedance of the 1 ppb target value is 0.7 ppb (the rationale for this is explained in Section 4.2.1).

6.2 ESTIMATED EXCEEDANCES IN 2010

6.2.1 Business as Usual- "Scenario a"

Figure 4.6 indicates the estimated number of road links exceeding the target value, from 1996 to 2010 using the business as usual scenario (scenario a- see Section 5). The road links are broken down into urban, rural/motorway and Northern Ireland classes. It is clear from the plot that there are expected to be exceedances of the target value in 2010.

Figure 4.7 illustrates the estimated maximum concentration from 1996 to 2010. It is evident that although there are exceedances in 2010, the maximum concentration (1.3 ppb) approaches the target value. It is also clear from Figure 4.7 that if a "business as usual scenario" is assumed, further reductions in the maximum benzene concentration after 2010 are estimated to be small.

It is possible to specify the location of the urban road links exceeding the target values more precisely. Table 4.3 gives an indication of the number of road links exceeding the target value on a town by town basis, and also classifies the exceeding road links on a concentration basis. It is clear that relatively few roads account for the higher concentrations. Consequently reduction measures at a relatively few locations would have a significant impact on the maximum concentration estimated for 2010. However, further reductions would involve an increasing number of road links, and hence considerably more stringent measures to reduce emissions. The total number of road links in the database is 15,226 (the breakdown into different classes is given in Table 4.1).

It is important to note that the errors associated with the methodology used for these projections are significant, and are large when compared to the narrow concentration ranges under consideration here. As a result, small changes in the threshold used to indicate compliance with the target value (in this case 0.7 ppb) will have a large impact on the number of road links estimated to be compliant in 2010 (see Table 6.1).

Figure 6.1 The number of Exceedances (0.7 Benzene) up to 2010
Figure 6.2 Max. Benzene road link concentrations up to 2010

Table 6.1 Location and Concentration frequency distribution of the Road Links Exceeding the 0.7 ppb Target Value for Benzene in 2010

Location*	# of Urban Road Links Exceeding 0.7 ppb Benzene (2010)	Concentration Range (ppb)	# of Road Links (Urban and Rural/Motorway)
Inn./Cen. London	303		
Outer London	48		
Leicester	13	**1.3 - 1.4**	1
Liverpool	13	**1.2 - 1.3**	2
Birmingham	9	**1.1 - 1.2**	9
Leeds	8	**1.0 - 1.1**	13
Manchester	8	**0.9 - 1.0**	43
Bristol	6	**0.8 - 0.9**	145
Sheffield	5	**0.7 - 0.8**	314
Coventry	2		
Glasgow	2		
Nottingham	2	**Total**	527
Bolton	1	**of Which:**	
Newcastle	1	**Rural/M.way**	106
Total	**421**	**Urban**	**421**

* The location of the road links specified here is only to intended to be indicative. For example, road links in Warsall have been included under Birmingham for convenience- however the division of the London areas has been done accurately.

The location of the 50 road links with the highest estimated concentrations of benzene in 2010 are given in more detail in Appendix 3 (Table A3.1). Sites in the London area clearly dominate the table, with 35 of the 50 sites located in "Inner/Central London", 5 in "Outer London" and 3 on the M25. This is as expected; London has already been identified as the region most likely to have exceedances of the annual mean NO_2 objective in 2005 (Stedman J R and Bush A J, 1998).

6.2.2 Emission Reduction Scenarios

It is possible to apply different emission reduction scenarios to the projected concentrations. In this way it is possible to investigate the impact that changes in policy may have on the number of road links exceeding the target value in 2010.

Three scenarios have been used in the previous sections, as given in Section 5. The "business as usual" scenario has been considered above, in Section 6.2.1. Two further hypothetical scenarios hL and iL are considered here and compared to scenario h (which has been applied to roadside benzene concentrations). Scenarios hL and iL are defined as follows:-

Scenario hL	Reduction in emissions from **traffic**: 30%	In Inner/Central London
	10%	In Outer London
	Business as usual	In all other Locations
Scenario iL	Reduction in emissions from **cars**: 30%	In Inner/Central London

	10%	In Outer London
	Business as usual	In all other Locations

The following table (Table 6.2) summarises the findings from applying Scenarios hL, iL and h to the benzene emissions.

Table 6.2 Estimated Benzene Concentrations and Exceedances of the Target Value for Scenarios hL, iL and h.

	Estimated Number of Road Links Exceeding 0.7 ppb			
	Built Up Road Links Only		All Road Links	
	2005	2010	2005	2010
Scenario a	1811	421	2236	527
Scenario hL	1414	117	1839	205
Scenario iL	1499	142	1924	232
Scenario h	609	36	735	39
	Estimated Maximum Benzene Concentration (ppb)			
	Built Up Road Links Only		**All Road Links**	
	2005	**2010**	**2005**	**2010**
Scenario a	1.9	1.3	1.9	1.3
Scenario hL	1.7	1.1	1.7	1.1
Scenario iL	1.7	1.1	1.7	1.1
Scenario h	1.4	0.9	1.4	0.9

All scenarios result in a number of road links exceeding the target value in 2010. If only the built up road links are considered for Scenarios h, hL and iL, then of exceeding road links, the majority are located in “Inner/Central London”, followed by “Outer London”. The following table (Table 6.3) indicates the location of the exceeding road links for Scenarios h, hL and iL.

Table 6.3 Location of the Road Links Estimated to Exceed 0.7 ppb of Benzene in 2010 for Scenarios hL and iL.

Location*	# of Urban Road Links Exceeding 0.7 ppb Benzene (2010)		
	Scenario h	Scenario hL	Scenario iL
Inner/Central London	30	30	54
Outer London	4	17	18
Liverpool	0	13	13
Leicester	2	13	13
Birmingham	0	9	9
Leeds	0	8	8
Manchester	0	8	8
Bristol	0	6	6
Sheffield	0	5	5
Other	0	8	8
Total	36	117	142

* The location of the road links specified here is only to intended to be indicative.

From Table 6.3 it is evident that for scenarios hL and iL there are many road links exceeding the threshold value of 0.7 ppb in the major cities and towns. By combining estimates from the different scenarios it may be concluded that reducing emissions by 30% (whether from cars or from all road traffic) appears likely to meet the 0.7 ppb threshold in 2010 for all major towns and cities with the exception of London..

One of the results of significant reduction in benzene emissions from road traffic is an increase in the relative importance of non-traffic sources. The identification of Leicester and Liverpool as the cities with a large number of exceedances reflects the relatively high estimates of non-traffic emissions in these cities, relative to other cities. The spatial distribution of benzene emissions from industrial sources within the NAEI has, at best in part, been constructed from surrogate activity statistics. The spatial distribution of these sources is therefore considerably less certain than for sources such as road traffic.

7 Conclusions

Roadside concentrations of benzene and 1,3-butadiene have been estimated for future years. A comparison between these estimates and equivalent concentrations chosen to represent the National Air Quality Strategy Objectives has shown that national policies are likely to deliver compliance with these objectives at all major road links well before 2005. All but two road links are expected to comply for benzene by 2001, with all roads complying by 2002. For 1,3-butadiene our analysis suggests that only one link will exceed the objective in 2003, with all links complying by 2004.

Estimates of roadside benzene concentrations have been made in the context of complying with the target value of 1.0 ppb. The number, and location, of exceeding road links has been estimated, and scenarios assuming the implementation of hypothetical emissions reductions have been considered.

It is likely that considerable emission reduction measures, on top of those considered as business as usual, would be required to meet this target concentration by 2010.

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9 Acknowledgements

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Appendices

CONTENTS

Appendix 1 Monitoring Site Information

CONTENTS

Table A1a Roadside Monitoring Sites: Part 1

Site ID	Site Name	Town, City, District	Data Provider	Measurement Method	Grid Reference E	N	Road Name	Concentration (ppb)
2	Marylebone Road	London	National Network Site	Automatic	528100	182000	Marylebone Road	5.5
4	Regent Street	Cambridge	Cambridge City Council	Automatic BTX	545400	258000	Regent Street	1.6
15	S13 Drinks Cabin	Neath Port Talbot	Neath Port Talbot CC	Diffusion Tubes	266980	198163	Woodfield Street	3.3*
16	S14 General Store	Neath Port Talbot	Neath Port Talbot CC	Diffusion Tubes	266906	197833	Woodfield Street	2.7*
17	AUN	Southampton	National Network Site	Automatic	444000	113000		1.8
19	A3024	Southampton	Portsmouth City Council	Diffusion Tubes	443600	113300	A3024	1.4
20	A35	Southampton	Portsmouth City Council	Diffusion Tubes	438500	113400	A35	2.8
24	Colston Ave.	Bristol	Bristol City Council	Diffusion Tubes	358600	573100	Colston Ave.	3.7
25	Newfoundland Way	Bristol	Bristol City Council	Diffusion Tubes	359800	573800	Newfoundland Way	5.2
26	Whiteladies Road	Bristol	Bristol City Council	Diffusion Tubes	357500	574600	Whiteladies Road	5.0
27	Bath Road	Bristol	Bristol City Council	Diffusion Tubes	359700	572300	Bath Road	7.1
28	Old Market Street	Bristol	Bristol City Council	Diffusion Tubes	359800	573200	Old Market Street	5.1
29	J4 M56	Manchester	Manchester City Council	Diffusion Tubes	381670	387500	M56	1.3
30	Newton Street	Manchester	Manchester City Council	Diffusion Tubes	384560	398270	Newton Street	2.0
32	Town Hall	Oxford	Oxford City Council	Diffusion Tubes	451000	208000	St Aldates	3.0
33		Henley	OXCIS	Diffusion Tubes				1.3*
35	Watling Street	Bexley	LB of Bexley	Diffusion Tubes	550000	175000	A207	2.7
37	Harlesdon Police Station	Brent	LB of Brent	Diffusion Tubes	521200	184000	A407	2.4
38	High Road	Brent	LB of Brent	Diffusion Tubes	522800	184700	A407	3.2
39	Theobalds Road	Camden	LB of Camden	Diffusion Tubes	530700	181800	A5201	2.4
40	Russell Square	Camden	LB of Camden	Diffusion Tubes	530200	182000	A4200	2.1
41	Euston Road	Camden	LB of Camden	Diffusion Tubes	529800	182600	A501	3.9
44	Blackheath Hill	Greenwich	LB of Greenwich	Diffusion Tubes	538000	176700	A2	4.5
45	Banockburn Sch. Plumstead Rd	Greenwich	LB of Greenwich	Diffusion Tubes	544100	178900	A206	3.2
46	459 Westhorne Avenue	Greenwich	LB of Greenwich	Diffusion Tubes	541300	174500	A205	3.8
47	Greenwich Church Street	Greenwich	LB of Greenwich	Diffusion Tubes	538000	177700	A206	3.6
48	Hammersmith Broadway	Hammersmith	LB of Hammersmith	Diffusion Tubes	523400	178600	A315	3.6
51	Station Road	Harrow	LB of Harrow	Diffusion Tubes	515600	189000	A409	3.4

Table A1a Roadside Monitoring Sites: Part 2

53	Pembridge Square	Kensington	LB of Kensington	Diffusion Tube	525200	180800	A4206	3.0
54	Eden Street	Kingston	LB of Kingston	Diffusion Tube	518300	169500	A307	2.4
55	Clarence Street	Kingston	LB of Kingston	Diffusion Tube	518300	169500	A307	3.3
56	Clarence Street	Kingston	LB of Kingston	Diffusion Tube	518300	169500	A307	2.6
59	Salisbury Sch, Romford Road	Newham	LB of Newham	Diffusion Tube	541900	185400	A118	2.7
63	York St, Twickenham	Richmond	LB of Richmond	Diffusion Tube	516200	173200	A305	3.3
65	Croydon Rd, Wallington	Sutton	LB of Sutton	Diffusion Tube	530100	164900	A232	2.2
71	St Dunstans Church Fleet Street	Corporation	Corporation of London	Diffusion Tube	531230	181150	A4	3.4
72	Crescent House Goswell Road	Corporation	Corporation of London	Diffusion Tube	532130	182040	A1?	2.2

* Supplied data were considered to be suffering from overestimation. The values presented here represent the modified data.

Appendix 2
Statistical Comparison of Annual Means

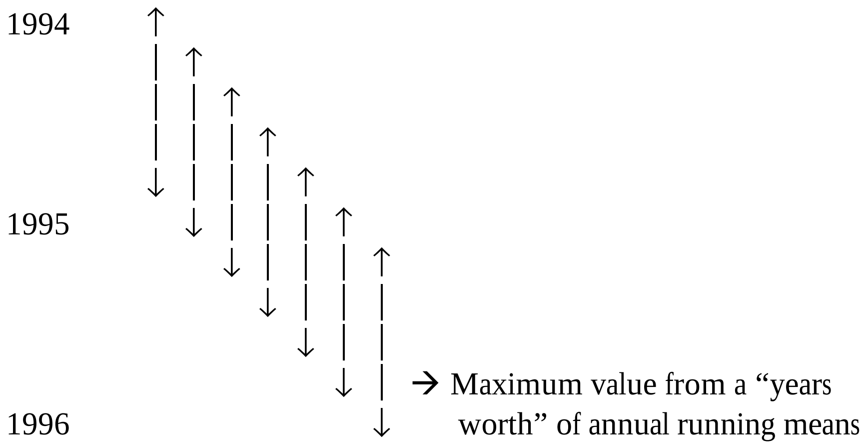
CONTENTS

A2.1 Introduction

First it is important to clarify several definitions. An annual mean is the mean taken across any annual period. For convenience this is usually done across a calendar year, and is commonly referred to as a fixed annual mean. The use of the term “maximum annual running mean” is misleading, as the period across which the running mean is being considered is not specified. The term is intended to refer to the maximum annual running mean from a dataset consisting of one year of running means (which requires two years worth of data). In addition, periods are quoted as time ending- i.e. running means from 01/01/94 - 01/01/95 through until
31/12/94 - 31/12/95 would give the maximum running annual mean for 1995. The “fixed” average across the period 01/01/1995 to 31/12/1995 (inclusive) is labelled as 1995.

So, the comparison between a “fixed” annual mean, and the maximum value from a dataset of one years worth of annual running means may be visualised as follows:-

1995 ↑
Average taken across all
instantaneous values → “Fixed Annual” Mean
1996 ↓



(annual running means generated from instantaneous values)

Due to the large amounts of data involved, the "fixed" annual mean, and the maximum value from a dataset of one years worth of annual running means were calculated from daily average data, rather than instantaneous values. This is considered to have little impact on the results. Only days with data capture in excess of 75% were used, and only annual periods with data capture in excess of 75% were used.

A2.2 Long Term Trends

There is a complicating factor which arises during this comparison. If the measured concentrations are generally falling with time, then the annual running means are expected to decrease with time. As a result the relationship between the two parameters skewed. The maximum running annual mean would be expected to occur towards the start of the annual period (in the above example: the mean from January '94 to January '95). The "fixed" annual average will give a lower value.

A2.3 Previous Work

Work conducted in the report "Investigation into the use of Surrogate Pollutant Statistics for Local Authority Air Quality Review and Assessment" (Draft- March 1998 A Loader, P Willis and G Broughton) considered Benzene and 1,3-Butadiene data from several sources across the period 1994 to 1996. The following conclusions were reached:-

"The benzene maximum running annual mean can be accurately estimated from fixed annual mean measurements".

"The 1,3-butadiene maximum running annual mean can accurately be predicted from fixed annual mean measurements."

The following relationships were arrived at:-

Benzene
Max. Annual Running Mean = 1.1015 Annual Calendar Mean + 0.0198

(R^2 = 0.9328)

1,3-Butadiene
Max. Annual Running Mean = 1.0075 Annual Calendar Mean + 0.0291
(R^2 = 0.7907)

A2.4 Results

Results from the current statistical analysis are shown in Figures A2.1 and A2.2. In summary the following relationships were found:-

Benzene
Max. Annual Running Mean = 1.102 Annual Calendar Mean - 0.004
(R^2 = 0.960)

1,3-Butadiene
Max. Annual Running Mean = 1.022 Annual Calendar Mean + 0.016
(R^2 = 0.933)

The following summarises the date corresponding to the maximum value of the running means across the sites and years used for the statistical analysis above. It appears that an unusually high proportion of the dates for benzene occur at the start of the calendar year, indicating that concentrations are falling (see Section A2.2 above). This trend for 1,3-butadiene is less evident. However, without further, more in depth, statistical analysis it is not possible to confirm whether this trend is significant.

Table A2a Date for Max. Running Annual Mean- Benzene

Site Name	1994	1995	1996	1997	1998 (to21/08)
Belfast	01-Jan	02-Jan	07-Apr	04-Dec	01-Jan
Birmingham	06-Jan	12-Dec	07-Oct	07-Nov	01-Jan
Bristol	24-Dec	31-Dec	07-Apr	12-Nov	01-Jan
Cardiff	08-Jan	03-Jan	16-Apr	04-Dec	06-Jan
Edinburgh	01-Jan	29-Dec	11-Apr	31-Jan	01-Jan
Harwell		03-Jan	17-Apr	05-Dec	28-Apr
Leeds		05-Jan	26-Sep	04-Dec	01-Jan
London UCL	08-Jan	03-Jan	08-Oct	13-Nov	01-Jan
London Eltham	08-Jan	04-Feb	08-Oct	13-Nov	01-Jan
Liverpool		12-Dec	02-Jan	23-Dec	01-Jan
Middlesbrough	12-Nov	01-Jan	23-Apr	09-Nov	03-Jan
Marylebone Rd					15-Feb
Southampton		14-Sep	05-Jan	13-Nov	01-Jan

Table A2b Date for Max. Running Annual Mean- 1,3-Butadiene

Site Name	1994	1995	1996	1997	1998 (to21/08)
Belfast	27-Dec	12-Dec	07-Apr	04-Dec	24-May
Birmingham	24-Dec	12-Dec	07-Oct	07-Jun	08-Mar
Bristol		31-Dec	04-Apr	20-Aug	03-Jul
Cardiff	24-Dec	02-Jan	22-Apr	20-Feb	27-Jul
Edinburgh	14-Dec	29-Dec	02-Apr	31-Jan	
Harwell			18-Oct	24-Jan	
Leeds		29-Dec	03-Sep	31-Jul	
London UCL	11-Nov	01-Jan	17-Apr	29-Jan	01-Mar
London Eltham		12-Dec	29-Feb	13-Nov	07-Jan
Liverpool			06-Dec	13-May	
Middlesbrough		29-Aug	09-Apr	19-Feb	
Marylebone Rd					
Southampton			04-Jul	28-Jan	

XXXFigure A2.1 Benzene running mean vs fixed meanXXX

XXXFigure A2.2 1,3-Butadiene running mean vs fixed meanXXX

Appendix 3
Exceedance of Benzene Target Value (2010)

CONTENTS

Table A3.1 The 50 Road Links with the Highest Benzene Concentrations in 2010

	Road Number	Road Class*	Location**	2010 Benzene Conc. (ppb)	Grid Reference North	East
1	A4202	PB	Inn/Cen London	1.33	179909	527927
2	A4	TB	Inn/Cen London	1.22	178414	525037
3	A4	PB	Inn/Cen London	1.20	178627	525361
4	A501	TB	Inn/Cen London	1.17	181700	527404
5	A3	PB	Inn/Cen London	1.17	177642	531360
6	A501	TB	Inn/Cen London	1.16	181917	527933
7	A4	PB	Inn/Cen London	1.15	178831	527007
8	A46	PB	Leicester	1.14	304394	458310
9	A4	TB	Inn/Cen London	1.13	178414	523528
10	A4	TB	Inn/Cen London	1.12	178384	521893
11	A3211	PB	Inn/Cen London	1.11	180833	531146
12	A406	TB	Outer London	1.10	187912	522849
13	A4	PB	Inn/Cen London	1.08	179809	527762
14	A501	TB	Inn/Cen London	1.06	182331	528926
15	A4	TB	Outer London	1.06	177881	521893
16	A404	PB	Inn/Cen London	1.06	181700	526517
17	A4	PB	Inn/Cen London	1.04	179925	528392
18	A501	TB	Inn/Cen London	1.04	181917	527404
19	A4	TB	Inn/Cen London	1.04	178384	523773
20	A40M	MT	Inn/Cen London	1.02	181118	527068
21	A40M	MT	Inn/Cen London	1.02	181118	527068
22	A46	PB	Leicester	1.02	304711	458550
23	A4	PB	Inn/Cen London	1.02	179909	528337
24	A3211	PB	Inn/Cen London	1.02	180301	531146
25	M8	MT	Glasgow	1.01	666390	260240
26	A406	TB	Outer London	1.00	186025	522627
27	A4	TB	Outer London	0.99	177881	519624
28	M25	MT	M25	0.99	172734	503724
29	A40	PB	Inn/Cen London	0.98	180952	527927
30	A40	TB	Inn/Cen London	0.98	181113	521605
31	A40	PB	Inn/Cen London	0.97	181004	527772
32	A4	PB	Inn/Cen London	0.96	179809	528337
33	A202	PB	Inn/Cen London	0.96	178040	529962
34	M62	MT	Manchester	0.95	399024	374687
35	M8	MT	Glasgow	0.95	664630	258020
36	A3	PB	Inn/Cen London	0.94	178891	531796
37	A5201	PB	Inn/Cen London	0.94	182567	533256
38	A3205	PB	Inn/Cen London	0.93	177871	528693
39	A40	PB	Inn/Cen London	0.93	180501	525215
40	M25	MT	M25	0.93	185687	504590
41	A4209	PB	Inn/Cen London	0.93	180816	526702
42	A406	TN	Outer London	0.93	190457	539351
43	M6	MT	Birmingham	0.93	296469	401777
44	A3211	PB	Inn/Cen London	0.93	180818	533503
45	A306	PB	Inn/Cen London	0.93	178555	523226
46	A58	PB	Leeds	0.93	433276	428961
47	A40	PB	Inn/Cen London	0.92	180501	526665
48	A3205	PB	Inn/Cen London	0.92	175273	527083
49	M25	MT	M25	0.92	178396	503724
50	A3220	PB	Inn/Cen London	0.92	177495	526469

*Road Classses are defined as follow:-

MT- Motorway **P/T**- Primary/Tertiary **B/N**- Built up/Non-Built up

** Motorway and non-built up road link estimates have greater uncertainty than the estimates for built up road links.