

Report

London Wide Benzene Diffusion Tube Survey Annual Report 2001

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Prepared for

London Borough of Barking and Dagenham
London Borough of Bexley
London Borough of Brent
London Borough of Camden
London Borough of Greenwich
London Borough of Hammersmith and Fulham
London Borough of Harrow
London Borough of Hounslow
Royal Borough of Kensington and Chelsea
Corporation of London
London Borough of Newham
London Borough of Richmond
London Borough of Sutton
London Borough of Wandsworth
City of Westminster

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Executive Summary

This report presents the results of the 2001 London Wide Benzene Monitoring Programme. The main objective of the programme is to determine the ambient concentration of benzene to which people are exposed in urban areas. Concern currently exists over levels of benzene in urban areas as benzene is a genotoxic carcinogen and as such is strongly linked to the formation of cancer.

During the 2001 programme participating boroughs maintained a total of eighty sites across London. These sites included urban background locations, thus allowing the levels of benzene to which the general public are exposed for significant periods of time to be quantified. Monitoring sites also included roadside and petrol station locations, as motor vehicles are the major source of atmospheric benzene, with significant evaporative emissions resulting from the handling, distribution and storage of petrol. Toluene, ethyl benzene, m, p-xylene and o-xylene were also monitored at thirty-one sites in five boroughs across London. Such measurements can be of use in determining possible emission sources. Benzene, toluene, ethyl benzene, m, p-xylene and o-xylene levels were determined using passive diffusion tubes. These provide long term measurements, which give a good indication of personal exposure.

In the majority of boroughs, maximum benzene concentrations were recorded at roadside locations. Annual mean benzene concentrations ranged from $2.4\mu\text{g m}^{-3}$ to $8.2\mu\text{g m}^{-3}$ at roadside locations, $1.8\mu\text{g m}^{-3}$ to $4.6\mu\text{g m}^{-3}$ at background locations and $2.5\mu\text{g m}^{-3}$ to $12.1\mu\text{g m}^{-3}$ at petrol stations. The annual mean benzene concentrations for the three different location types were $4.0\mu\text{g m}^{-3}$, $2.5\mu\text{g m}^{-3}$ and $6.0\mu\text{g m}^{-3}$ at roadside, background and petrol station locations respectively.

These results are consistent with road traffic and petrol being significant sources of atmospheric benzene. This is shown in the results where a reduction in benzene occurs with increasing distance from the road. Ambient benzene levels are influenced by several factors; for example traffic flow, meteorological conditions and height of sampler. This partially explains why there appeared to be little influence of road traffic on benzene levels in some boroughs.

During 2001 benzene levels exhibited some seasonal variation similar to that of previous years with mean concentrations at many sites showing little variation. In most boroughs concentrations followed the pattern

documented for other primary pollutants, with much greater variation in ground level concentrations occurring in winter months.

Benzene levels recorded in this study were compared against the Air Quality Objective and the Air Quality Standard (AQS) for benzene set by the Expert Panel on Air Quality Standards, consequently both are the same. Making such comparisons gives a good indication of likely exceedences of such criteria, as direct comparisons cannot be made, due to different averaging periods. However, as a guide, the annual mean can be converted in to a running mean by using a multiplication factor of 1.1⁽¹⁸⁾. The Objective and AQS is set at 16.25µg m⁻³ as a running annual mean and is the level 'at which the risks are exceedingly small and unlikely to be detectable'.

In 2001 annual mean concentrations at all sites were below the Standard and Objective of 16.25µg m⁻³. The results of this study thus support the assertion made by the Expert Panel on Air Quality Standards that annual average benzene concentrations rarely exceed the AQS.

Policy measures introduced to reduce benzene emissions include the introduction of catalytic converters, emission testing as part of the annual MOT and measures to reduce evaporative emissions along the petrol distribution and use chain. Given present policies, it is estimated that at present traffic levels exceedences of the AQS of 16.25µg m⁻³ are unlikely at any UK roadside locations by the year 2003. However, further measures would be necessary for the EPAQS target concentration of 1ppb to be met at many roadside locations within the London area.

1 Introduction

This report presents the results of the 2001 London Wide Benzene Monitoring Programme. The report describes results collected from January 2001 to December 2001, which covers the tenth year during which the programme was in operation. The Benzene Monitoring Programme forms part of the London Wide Environmental Programme (*LWEP*), an integrated programme dealing with environmental issues for London Boroughs.

The following London Boroughs sponsored the 2001 Benzene Monitoring Programme:

London Borough of Barking and Dagenham
London Borough of Bexley
London Borough of Brent
London Borough of Camden
London Borough of Greenwich
London Borough of Hammersmith and Fulham
London Borough of Harrow
London Borough of Hounslow
Royal Borough of Kensington and Chelsea
Corporation of London
London Borough of Newham
London Borough of Richmond
London Borough of Sutton
London Borough of Wandsworth
City of Westminster

The main objective of the Benzene Monitoring Programme is to determine the ambient concentrations of benzene to which people are exposed in urban areas. The programme was initiated in response to continuing concern that people living within urban areas are often exposed to elevated concentrations of benzene, which may be harmful to human health. Monitoring conducted as part of the Programme also allows compliance with relevant guidelines to be assessed.

During the 2001 programme, participating boroughs maintained a total of ninety-seven sites across London of which seventeen are not included in statistics due to data capture. Benzene levels were surveyed using the passive diffusion sampler technique incorporating procedures developed by Casella Stanger (formally Stanger Science & Environment), specifically for monitoring ambient benzene levels. Diffusion samplers were despatched to participating boroughs at regular intervals, exposed

by local staff and returned to Casella Stanger following a standard exposure period.

Toluene, ethyl benzene, m, p-xylene and o-xylene were also monitored at a total of thirty-one sites within five boroughs across London. This additional analysis was carried out on the same diffusion samplers used for benzene monitoring. There are currently no ambient air quality guidelines or standards regarding these volatile organic compounds, however monitoring can be useful in determining possible emission sources in order to aid the understanding of the pollutant occurrence. The ratio between benzene and toluene varies depending on the emission source and so can be used to determine whether road traffic or industrial sources are the main contributors to VOC levels at certain locations. A benzene/toluene ratio of approximately 1:2-1:4 is indicative of road traffic as a main contributor to VOC concentration at a particular location. Benzene/toluene ratios for this study can be found in Appendix H, table 4. Given the lack of published data regarding these VOC's this report concentrates primarily on sources and effects of benzene.

As road traffic and petrol stations are major sources of atmospheric benzene, at least one site in each borough was located near one of these emission sources. However, as the overall objective of the study was to determine long term concentrations to which the general public are exposed for significant periods of time, within each borough samplers were also located at background sites away from direct sources, such as residential areas. Sites were located at varying distances from busy roads, which enabled the importance of road traffic as a source of benzene to be assessed.

2 Sources of Benzene

Benzene is an aromatic hydrocarbon occurring as a colourless, clear liquid. Benzene is one of a group of substances known as volatile organic compounds (*VOC's*); this group of compounds also includes toluene, ethyl benzene and xylenes.

There are no well-defined natural sources of benzene although it is known to occur naturally as a constituent of natural gas and of light oil recovered from coal carbonisation gases. Other industrial processes including the pyrolysis of petrol also synthetically produce benzene. In Western Europe in the early 1980s production of benzene was estimated to be 6.9 million tonnes, with the UK, Federal Republic of Germany and Netherlands being the major producers.

Benzene is added to petrol as an anti-knock agent. Since 1 July 1989 the content of benzene in petrol in the UK had been limited to 5% by volume in leaded or unleaded petrol by the EC Directive *COM (84) 226*. In practice this amount varied since refineries often used a variety of other compounds to obtain the same effect depending upon the availability and cost. Since January 2000, EU legislation implemented through the Auto-Oil Programme requires that the amount of benzene in petrol be below 1% in volume and is presently about 0.6 by volume on average for fuel sold in the UK⁽¹⁹⁾.

Benzene in ambient air arises mainly from human activities, in particular through the combustion of petrol and oil, although natural benzene emissions occur from plant and animal matter and seepage from petroleum reservoirs. Table 1 shows the benzene emission inventory for the UK, which illustrates motor vehicles being the major source of benzene emissions. On a national basis, this accounted for about 60% of total emissions in 1997, with petrol engine exhausts contributing 56% of the total. These sources are also significant contributors to ambient concentrations of other *VOC's* such as toluene, ethyl benzene and xylenes.

An additional significant source of ambient benzene is petrol evaporation from vehicles and evaporative emissions from the handling, distribution and storage of petrol. A study undertaken in Leeds identified motor vehicles, as the single largest source of *VOC's*, responsible for almost half of all releases. A high proportion of *VOC* emissions were also attributed to solvent use, particularly in the city centre where there was a large number of industrial point sources (*Clarke et al 1996*).

Tobacco smoke contains high concentrations of benzene (*up to 200-mg m⁻³*) and is a further source of environmental benzene especially in the

indoor environment, as is diet; benzene is found in drinking water and some foods and therefore enters the body via normal ingestion processes.

Table 1: UK Annual Benzene Emissions, 1990 – 1997 (ktonnes)

Source	1990	1991	1992	1993	1994	1995	1996	1997	% of 1997 emissions
Petroleum refining plants	0.00	0.00	0.00	0.01	0.00	0.01	0.01	0.01	0.0%
Other comb. & trans.	0.31	0.31	0.30	0.30	0.34	0.13	0.14	0.14	0.4%
Comm, public & agri. combustion	0.11	0.12	0.12	0.12	0.12	0.13	0.15	0.14	0.4%
Residential plant	3.43	3.55	3.40	3.40	3.06	2.77	2.92	2.81	7.4%
Iron & steel combustion	0.31	0.32	0.30	0.30	0.31	0.32	0.34	0.35	0.9%
Other comb. In industry	0.56	0.53	0.51	0.49	0.54	0.58	0.61	0.61	1.6%
Processes in industry	9.71	9.36	9.23	8.88	8.50	8.26	7.73	7.26	19.1%
Gasoline distribution	0.57	0.58	0.59	0.57	0.56	0.54	0.56	0.56	1.5%
Road transport –									
petrol combustion	35.61	35.67	34.24	31.85	29.52	26.96	24.33	21.29	56.0%
diesel combustion	2.64	2.59	2.41	2.28	2.21	1.98	1.82	1.69	4.4%
petrol evaporation	2.23	2.21	2.16	2.01	1.87	1.71	1.6	1.46	3.8%
Civil aircraft	0.04	0.04	0.04	0.04	0.05	0.05	0.05	0.05	0.1%
Military	0.04	0.03	0.03	0.03	0.03	0.03	0.02	0.02	0.1%
Off-road sources	1.30	1.35	1.38	1.34	1.30	1.23	1.26	1.20	3.2%
Railways	0.03	0.03	0.05	0.04	0.04	0.04	0.04	0.04	0.1%
Shipping	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.2%
Landfill	0.10	0.10	0.09	0.09	0.09	0.08	0.08	0.08	0.2%
Total	57	57	55	52	49	45	42	38	

(From The Air Quality Strategy, Jan 2000)

3 Human Exposure to Benzene

Since benzene is a primary pollutant, concentrations are generally higher close to the emission source. However, the sources of personal exposure to benzene may be very different from those contributing to outside air due to time activity and behavioural patterns. Smoking, in particular, is linked to benzene exposure, as tobacco smoke contains significant benzene concentrations. Smoking will undoubtedly be the major source of exposure to benzene for smokers, but passive smoking may also be a significant factor.

Personal exposure to benzene in the home may also result from evaporative emissions from consumer products, such as paints, adhesives and marker pens, while in homes with attached garages, evaporative emissions from petrol tanks of cars could be significant. However, the importance of these sources for personal exposure in the UK is unknown and yet to be established.

Benzene in motor vehicles is likely to be a significant source of exposure. These exposures can result from exhaust and evaporative emissions arising from the vehicle itself or from the higher concentrations of this primary pollutant in the road. The actual concentrations may be influenced by the age and model of the vehicle, by traffic and weather conditions, and by whether the vehicle is being driven with window open or with fans or heaters on. Again, there is very little data on actual UK exposures in vehicles, but data from elsewhere suggest these exposures could be 2-10 times those at urban monitoring sites. Finally, exposure while refilling vehicles with petrol may be high, although the time spent by most individuals at such locations is generally small.

These complex sources of benzene mean that contributions from different sources to total outdoor emissions give a poor indication of the importance of different sources to personal exposure. For example, in the US it has been estimated that direct outdoor exposure only contributes 15% of the total population exposure, whereas 60% is due to direct and indirect exposure to tobacco smoke.

Since the health consequences of ambient benzene exposure are not respiratory effects, and the pollutant tends to accumulate in fatty tissue within the body, exposure in food and drink may be important, as well as that in air. However, most calculations suggest that exposure through food and drink is likely to be small relative to that through the lungs, on a population basis. Deposition to local gardens and allotments could additionally contribute to the total benzene dose of some individuals in

urban areas, although little is known about actual rates of benzene deposition to, and accumulation in, vegetation.

Benzene exposure is especially high in certain groups of industrial workers, in the chemical and petrochemical sectors, and also among certain groups with a high exposure to adhesive. These exposures are much greater than those due to ambient benzene and it is studies of these occupational groups, which have provided the clearest evidence of adverse health effects of this pollutant.

4 Health Effects of Benzene

At extremely high concentrations, relatively short-term exposure to benzene can cause anaesthesia or fatal damage to the bone marrow. However, such concentrations can only build up as a result of accidental release into poorly ventilated indoor environments, and are several orders of magnitude higher than ambient concentrations (*10 to 100mg m⁻³*). Consequently these toxicological effects are of little relevance when considering the health effects of ambient concentrations of benzene, which are orders of magnitude lower.

The concerns relating to normal ambient exposure is related to the fact that it is a proven genotoxic carcinogen and as such no absolutely safe level can be specified for ambient levels of benzene. Benzene has the effect of modifying the genetic makeup of living cells, which has been deduced from laboratory studies with animals. There is also evidence from several studies of occupational groups that long-term exposure to high concentrations of benzene is associated with a small increase in the probability of developing certain types of leukaemia.

Since leukaemia is a relatively rare disease, and since lifetime exposures as a result of ambient exposure are relatively low, it is effectively impossible to carry out epidemiological studies of the association between benzene exposure and the risk of contracting leukaemia in the general population. Thus any assessment of the health risks associated with ambient benzene exposure is usually based on extrapolation from the occupational studies.

These occupational investigations are primarily cohort studies, in which defined groups of workers are followed forward over many years, and the number of deaths due to leukaemia recorded. In most of these studies, the number of subjects was no more than 3000, and since the chances of contracting leukaemia overall are only 1 in 6000, the results are generally based on a very small number of deaths. This fact, together with the relatively crude estimates of benzene exposure, which were made in some cases, makes it very difficult to establish exposure-response relationships for benzene.

The data from these studies provide good evidence of an effect after exposure at 32,440 $\mu\text{g m}^{-3}$ over 20 years, and some evidence of an effect at exposures between 3,244 $\mu\text{g m}^{-3}$ and 32,440 $\mu\text{g m}^{-3}$. However, any assessment of the risk of adverse health effects from long-term exposures to ambient benzene, which are likely to range from 3.24 $\mu\text{g m}^{-3}$ to 32.44 $\mu\text{g m}^{-3}$ in non-smokers, must rely on extrapolation downward over several orders of magnitude assuming a particular shape to the exposure-

response relationship. Assuming a linear exposure-response relationship, it would be possible to calculate the benzene exposure corresponding to any particular level of risk, but there is no means of verifying the actual shape of the exposure-response relationship.

Some research (*Yu, R et al, 1996*) has suggested that the health risk from exposure to low levels of benzene, such as ambient levels, may be greater than that predicted by extrapolation of occupational research. Muconic acid, a harmful metabolite of benzene, is produced in much higher quantities at lower concentrations than high concentrations. A 2% increase in muconic acid levels was typical at high ppm exposures whereas at exposures 2 to 3 orders of magnitude 25% was produced. This is consistent with enzymes involved in the metabolic pathway processing much more efficiently at low concentrations. This effect was measured in humans exposed to tobacco smoke but is likely to be relevant to other petrochemical exposures.

Clearly, the understanding of the health effects of benzene is increasing all the time through studies of the type quoted here. However, until further evidence is gathered, it shall be assumed that there is no acceptable level of benzene that should be set against which health risks become acceptable.

5 The Air Quality Strategy

In March 1997 the Government published *The United Kingdom Air Quality Strategy*. This fulfilled the requirement for a National Air Quality Strategy under the Environment Act 1995, by setting out policies for the management of ambient air quality. The aim of this strategy was to map out, as far as possible, the future of ambient air quality policy in the United Kingdom for at least the next ten years. A particular purpose was to ensure that all those who contribute to air pollution, or are affected by it, or have a part to play in its abatement, can identify both what is statutorily required from them and what further contribution they could voluntarily make in as efficient manner as possible.⁽¹⁷⁾

The revised *Air Quality Strategy* was published in January 2000 and addresses remaining problems on air quality issues. Standards are set in the Strategy, which are concentrations below which effects are unlikely, even in sensitive population groups, or below which risks to public health would be exceedingly small. They are based purely on the effects of a particular pollutant.

The Government has established air quality objectives for pollutants, which are based on recommendations of the Expert Panel on Air Quality Standards (*EPAQS*). These set out the extent to which the standards are to be achieved by 2003. They take account of the costs, benefits, feasibility and practicality of achieving the standards.

The European Parliament and Council of Ministers concluded a conciliation agreement on three Auto-Oil vehicle emissions and fuel quality directives in 1998, which were introduced from January 2000.

This agreement includes stringent emission standards for new vans and cars sold from January 2001 (*Euro III standards*) and January 2006 (*Euro IV standards*). These are complemented by tighter fuel quality specifications applying to all petrol and diesel sold from 2000 and 2005. These alone should result in a reduction in benzene emissions from road transport by 2005.

The Strategy is currently under review following the published consultation document of September 2001.

6 Air Quality Standards and Objectives for Benzene

The UK Expert Panel on Air Quality Standards (*EPAQS*) set an Air Quality Standard (*AQS*) for benzene in 1994. A running annual mean

concentration of 5ppb was recommended which was based on a study of occupational data and the consideration of medical evidence for carcinogenic effects. In the report EPAQS also recommended a long-term policy target of 1ppb as a running annual mean in order to keep exposure to benzene as low as practicable. As recommended by EPAQS, the objective for benzene has been set at 5 ppb ($16.25\mu\text{g m}^{-3}$) as a running annual mean, to be achieved in all areas by the end of 2003.

The provisions of the Air Quality Regulations 1997 in relation to England have been replaced by the Air Quality (*England*) Regulations 2000, which were authorised by the Secretary of State for the Environment, Transport and the Regions. Such regulations incorporate an objective of $16.25\mu\text{g m}^{-3}$ for benzene. The Government's intention is that this objective will be used for the purposes of Local Air Quality Management (LAQM).

6.1 Future Air Quality for Benzene

In November 2000 the Second Air Quality Daughter Directive was adopted, which sets limit values for benzene and carbon monoxide (*Council Directive 2000/69/EC*). This European Directive sets a limit value for benzene in ambient air of $5\mu\text{g m}^{-3}$ as an annual mean to be achieved by Member States by 1 January 2010⁽¹⁹⁾.

The Government is confident that measures currently in place will be sufficient to allow current objectives to be met by 2003. Annual mean concentrations recorded at background locations are well below $16\mu\text{g m}^{-3}$ and forecasts from mapping work suggest the objective of $16\mu\text{g m}^{-3}$ being achieved at all urban background and roadside locations by the end of 2003⁽²⁰⁾. The longer-term aim of policy for the Government and devolved administrations is to strengthen and supplement the existing benzene objective of $16\mu\text{g m}^{-3}$. It is proposed to set a target value of $3.25\mu\text{g m}^{-3}$ as a running annual mean, which would be the new UK wide objective to be achieved by the end 2010. By reducing benzene levels as far as practical and achieving the target value, the EU limit value of $5\mu\text{g m}^{-3}$ will also be reached. Additionally it is proposed to incorporate the new objective in to regulations for the purposes of LAQM⁽¹⁹⁾.

7 Methodology

7.1 Monitoring Sites

Descriptions of all 97 monitoring sites are given in Appendix A on an individual borough basis in the following pages. As motor vehicle emissions are a major source of benzene, sites have been categorised

according to distance from the nearest busy road. Over time site classifications tend to change within air quality surveys due to assessment of new data and opinion. Theoretically this could mean the relocation of a site to meet new criteria, which could result in the loss of a valuable data source. Individual borough data thus includes sites that have been moved, ceased to exist, or new sites established.

For the purpose of this survey sites are defined using roadside, petrol station and background locations only. The term kerbside location is no longer used but instead classified as roadside if within 20m from the kerb edge. A background site is one, which is beyond 20 m of any road, usually situated in a residential area. A petrol station site can be located within roadside or background locations. Monitoring was conducted at 47 roadside sites, 29 background sites and 4 petrol station sites as shown in Figure A below.

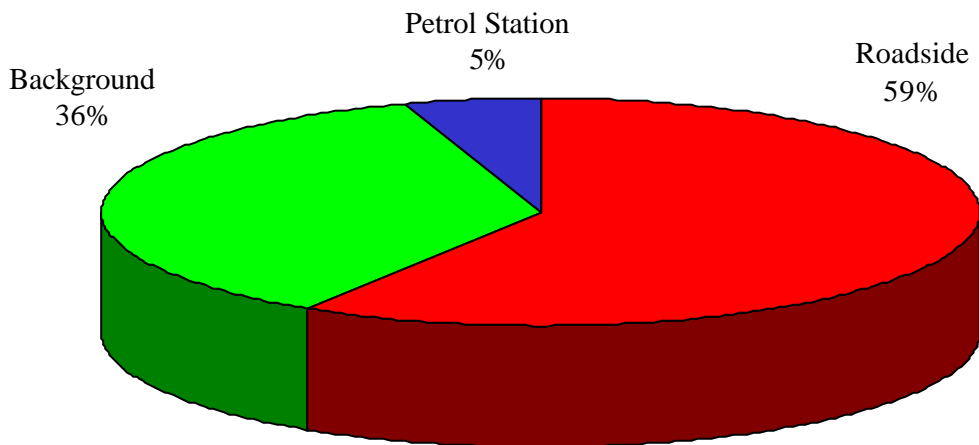


Figure A. Percentage of classified sites which participated in the survey

7.2 Measurement Technique

Benzene, toluene, ethyl benzene, m, p and o-xylene (*BTEX*) measurements were made using Perkin-Elmer type diffusive samplers⁽²⁰⁾. These are 9 cm long stainless steel tubes packed with Chromosorb 106 polymer, an adsorbent material with an excellent affinity for benzene, and sealed at both ends with protective caps. One end is sealed with a brass

fitting containing a teflon ferrule, the other end a white teflon cap. On exposure, the white teflon cap is removed and replaced with a diffusion cap, which allows air to diffuse at a constant rate into the tube.

The samplers operate on the principle of molecular diffusion, whereby during exposure benzene in air will migrate to the adsorbent at a rate dependent on several quantifiable variables defined by Fick's First Law of Diffusion:

- (a) The pathlength between the top surface of the monitor and the adsorbent bed
- (b) The cross sectional area of the sampler
- (c) The exposure time
- (d) The diffusion coefficient of benzene through air
- (e) The ambient concentration of benzene

Casella Stanger prepared all tubes in accordance with in-house technical procedure note: TP44 AIR(C). The tubes were despatched by special post to each borough and exposed for periods of approximately 2-weeks, following which the diffuser head was replaced with the original protective cap. Upon receipt the tubes were stored in a refrigerator prior to analysis.

Although tubes are exposed for 2-week periods previous work has shown that the uptake rate for benzene on to Chromosorb 106 differs by less than 1% for exposure periods of one, two and four weeks⁽²⁰⁾. For most adsorbents uptake rates decline rapidly over the first 16-24 hours of sampling, after which rates tend to stabilise.

7.3 Sample Analysis

All tubes were analysed using desorption scanning gas chromatography/mass spectrometry (*GC/MS*). This method of analysis gives unequivocal identification of the BTEX peaks.

The mass of BTEX collected in the tube is then expressed as an average airborne concentration (μgm^{-3}) measured over the monitoring period.

This calculation is shown in Appendix B. The diffusion coefficient for benzene has been empirically calculated at Casella Stanger as described in Section 7.4.

Quality control procedures integral to the analytical procedure involve verification of the benzene peak and calibration against internal spiking solutions. All cleaned tubes are analysed prior to exposure to ensure the Chromosorb retains no benzene. Duplicate tubes are also exposed at a selection of boroughs each month thus allowing the coefficient of variation between tubes to be assessed.

7.4 Empirical Determination of the Benzene Diffusion Coefficient

Benzene tubes were exposed to a known benzene concentration in air generated using a permeation vial held at 50°C in a glass oven, in turn held in a thermostatic water bath. A purge flow of pure air from an Aadco Model 737 Pure Air Generator was passed through a glass ball filled heat exchanger at a rate of 1 litre/minute to flush the benzene from the oven.

The generated benzene/air mix was further diluted with pure air at a rate of 5 l/m and fed to a 30-cm diameter spherical glass reaction vessel. Diffusion tubes were mounted on a carousel turning at approximately 1.2 revs per minute.

Tubes were exposed over a period of two weeks and benzene uptake was determined by thermal desorption and detection with flame ionisation detection (*FID*) using internal standards. The diffusion coefficient was calculated according to the equation shown in Appendix B. A Photovac, photo ionisation detector with gas chromatography (*PID GC*) was used to determine any losses of benzene in the diffusion coefficient test rig.

8 Results of the 2001 Benzene Monitoring Programme

Benzene, toluene, ethyl benzene, m, p and o-xylene data collected between January 2001 and December 2001 are given on an individual borough basis in Appendices C, D, E, F and G respectively.

Annual mean benzene concentrations have been calculated for each monitoring site in order to allow comparison with the published Air Quality Standard (*AQS*) and Objective. Making such comparisons gives a good indication of likely exceedences of such criteria. Due to different averaging periods, direct comparisons cannot be made, however, as a guide, the annual mean can be converted to a running mean by using a multiplication factor of 1.1 (*LAQM.TE4 (00)*). For the purposes of Local Air Quality Management (*LAQM*) results have been expressed in micrograms per cubic metre.

The following section provides results for individual boroughs, given in alphabetical order. In order to maintain validity of results, annual means have not been reported for site locations with data capture of less than 75% or where blocks of seasonal data are missing. London Borough of Richmond joined the survey in July so are not included in statistics.

8.1 London Borough of Barking and Dagenham

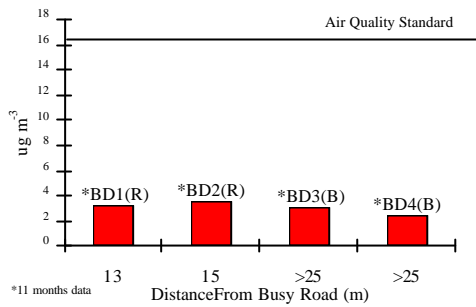


Figure 1A. Annual Mean Benzene Concentrations – 2001

Annual Mean Concentration

Annual mean benzene concentrations of 3.2 and 3.5 $\mu\text{g m}^{-3}$ were recorded at the two roadside locations, BD1 and BD2. Annual mean values of 3.0 and 2.4 $\mu\text{g m}^{-3}$ were recorded at BD3 and BD4, which are background locations. The highest mean level of 3.5 $\mu\text{g m}^{-3}$ was recorded for roadside location BD2 situated at Maplestead Road, Barking. The AQS was not approached or exceeded at any site.

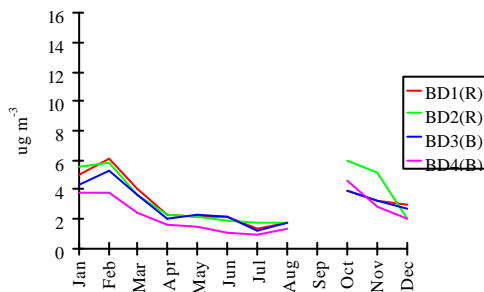


Figure 1B. Temporal Variation 2001

Temporal Variation

As illustrated in figure 1B, benzene concentration at all four sites followed a similar pattern with some seasonal variation. Benzene levels peaked in January, February and October at sites with a maximum concentration of 6.1 $\mu\text{g m}^{-3}$ recorded for site BD1 located at Marsh Green Infants School, White Bart Lane, Barking.

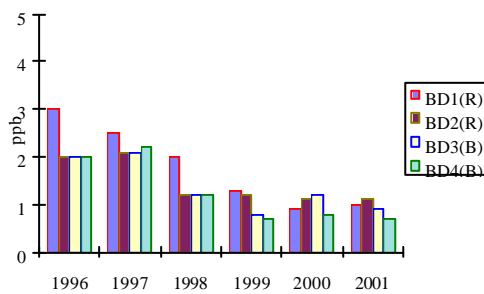


Figure 1C. Trends in Annual Average Benzene Concentrations

Annual Trends

Figure 1C illustrates annual average benzene concentrations for 1996-2001. A similar pattern has been evident each year; concentrations at site BD1 have been higher than those at the remaining sites up until 1999. A new trunk road in the area of site BD1 has diverted some of the traffic flow, which has evidently had an impact on benzene levels at this location. Although levels are shown to decline since 1996, they are now showing little variation.

8.2 London Borough of Bexley

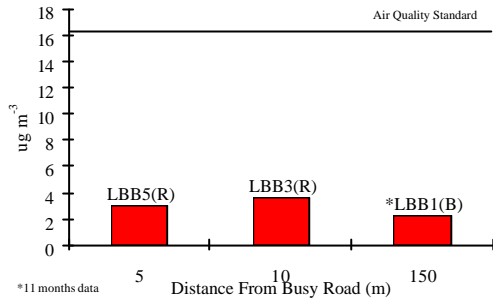


Figure 2A. Annual Mean Benzene Concentrations – 2001

Annual Mean Concentration

Mean concentrations of 3.0 and 3.6 $\mu\text{g m}^{-3}$ were recorded at sites LBB5 and LBB3, which are roadside locations. The highest mean value of 3.6 $\mu\text{g m}^{-3}$ was recorded for site LBB3 located at Crayford Library, Crayford Road. A lower mean value of 2.2 $\mu\text{g m}^{-3}$ was recorded at the background site LBB1 located at White Hall lane. The AQS was not exceeded or approached at any of the three sites.

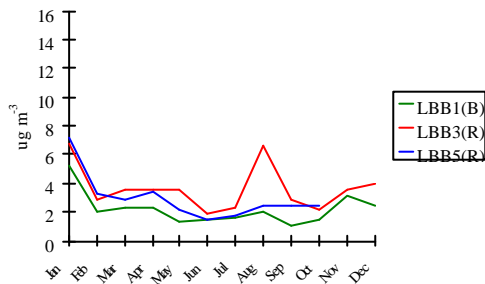


Figure 2B. Temporal Variation 2001

Temporal Variation

Figure 2B illustrates temporal trends for the three site locations. Throughout the year benzene levels followed a similar pattern with some seasonal variation. A maximum peak level of 6.6 $\mu\text{g m}^{-3}$ was recorded for August at site LBB3 a roadside site located at Crayford Library, Crayford Road.

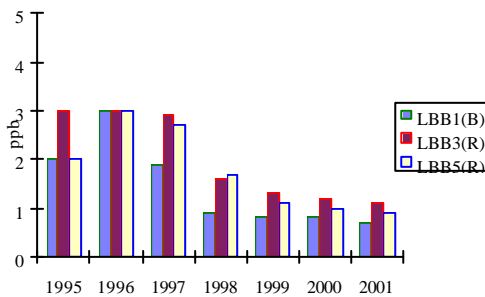


Figure 2C. Trends in Annual Average Benzene Concentrations

Annual Trends

Annual mean benzene concentrations have remained consistently below the AQS since 1995 with levels showing a continued decrease since 1996. Concentrations recorded since 1999 are showing little variation.

8.3 London Borough of Brent

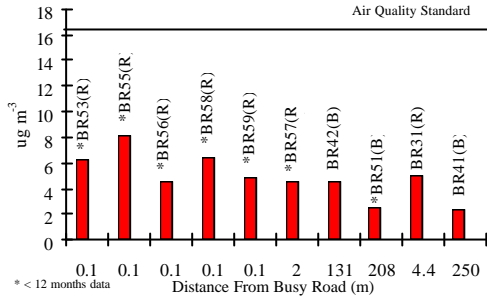


Figure 3A. Annual Mean Benzene Concentrations – 2001

Annual Mean Concentration

Annual mean benzene concentrations ranged from $2.4\mu\text{g m}^{-3}$ at site BR41, background to $8.2\mu\text{g m}^{-3}$ recorded at site BR55, roadside. The highest mean level of $8.2\mu\text{g m}^{-3}$ was recorded at 79 High Street, Harlesden. The AQS was not exceeded or approached at any site.

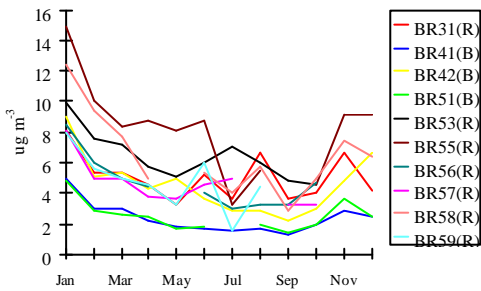


Figure 3B. Temporal Variation 2001

Temporal Variation

Temporal trends for 2001 are illustrated in figure 3B. Concentrations followed a similar pattern throughout the year with a prominent increase in levels during January, February and December. A maximum peak level of $14.9\mu\text{g m}^{-3}$ was recorded for January at site BR55 a roadside site, located at 79 High Street, Harlesden

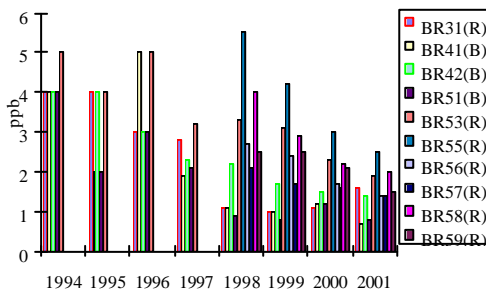


Figure 3C. Trends in Annual Average Benzene Concentrations

Annual Trends

Since 1998 levels recorded have continued to show a general decline in benzene concentration, with the highest mean level being calculated for site BR55.

8.4 London Borough of Camden

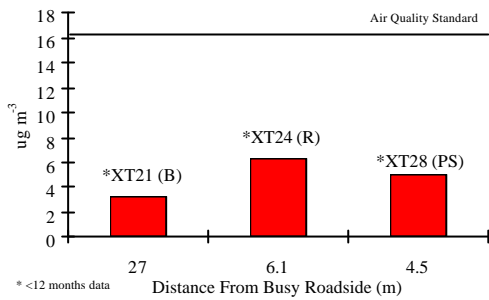


Figure 4A. Annual Mean Benzene Concentrations - 2001

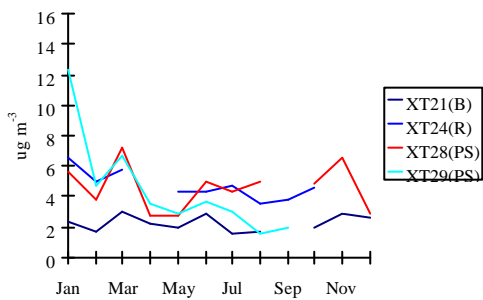


Figure 4B. Temporal Variation 2001

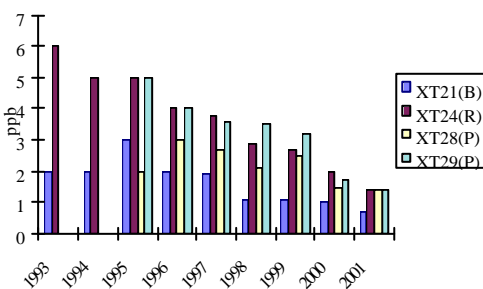


Figure 4C. Trends in Annual Average Benzene Concentrations

Annual Mean Concentration

Mean concentrations ranged from $2.2\mu\text{g m}^{-3}$ at background site XT21 to $4.7\mu\text{g m}^{-3}$ recorded for site XT24, a roadside location. The lowest mean level of $2.2\mu\text{g m}^{-3}$ was recorded at St Andrews Church on Finchley Road. The maximum mean of $4.7\mu\text{g m}^{-3}$ was recorded at the Town Hall, Euston Road. The annual mean was not included for site XT29 due to insufficient data. The AQS was not exceeded at any of the site locations.

Temporal Variation

Figure 4B illustrates temporal variation throughout the year. Concentrations followed similar patterns with peak levels during January, March and November. Within these periods, maximum concentrations of $6.5\mu\text{g m}^{-3}$ were recorded for sites XT24 and XT29, a roadside and petrol station location.

Annual Trends

Figure 4C illustrates the continued decline in annual average benzene concentrations since 1996.

8.5 London Borough of Greenwich

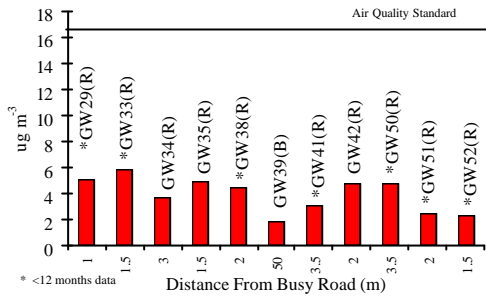


Figure 5A. Annual Mean Benzene Concentrations – 2001

Annual Mean Concentration

Mean concentrations ranged from 1.9 $\mu\text{g m}^{-3}$ recorded at site GW39, a background location to 5.8 $\mu\text{g m}^{-3}$ recorded at site GW33, a roadside location at 9 Blackheath Hill, Blackheath SE3. There was some relationship between mean concentration and distance from roadsides. The AQS was not exceeded or approached at any time.

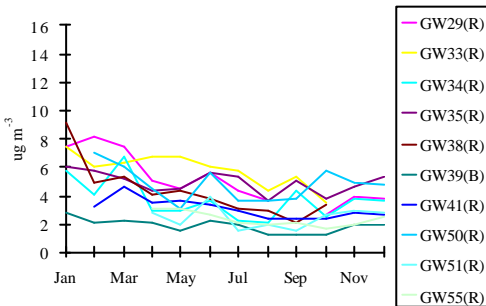


Figure 5B. Temporal Variation 2001

Temporal Variation

Figure 5B illustrates temporal trends for the eleven sites. All sites followed a similar pattern with benzene concentration consistently lower at the background site GW39. A maximum peak level of 9.2 $\mu\text{g m}^{-3}$ was recorded for January at roadside location GW38.

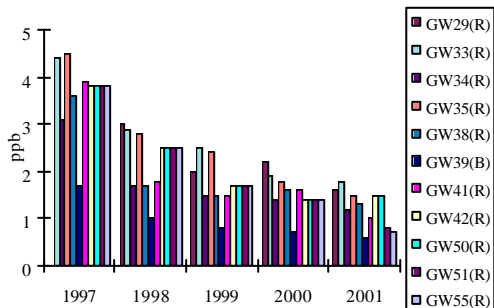


Figure 5C. Trends in Annual Average Benzene Concentrations

Annual Trends

Figure 5C illustrates the level of benzene declining since 1997. Levels recorded for 2001 were similar to those recorded during 2000.

8.6 London Borough of Hammersmith and Fulham

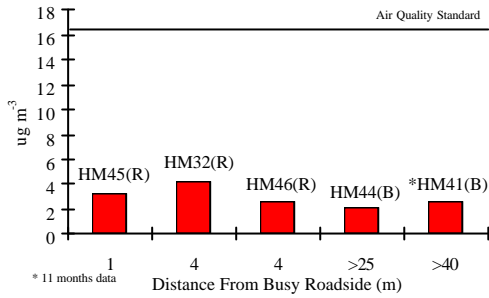


Figure 6A. Annual Mean Benzene Concentrations – 2001

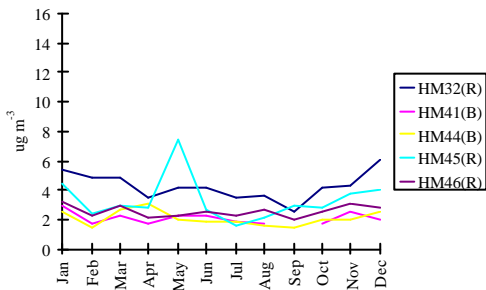


Figure 6B. Temporal Variation 2001

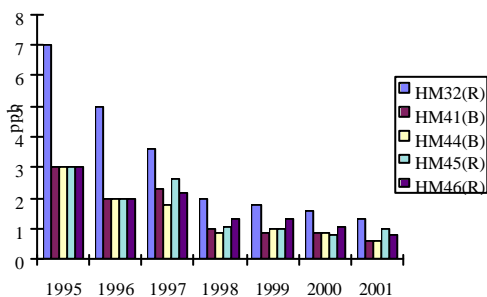


Figure 6C. Trends in Annual Average Benzene Concentrations

Annual Mean Concentration

Annual mean concentrations ranged from $2.1\mu\text{g m}^{-3}$ to $4.3\mu\text{g m}^{-3}$. The highest annual mean concentration of $4.3\mu\text{g m}^{-3}$ was recorded at site HM32, a roadside location in the vicinity of Hammersmith Broadway. The lowest mean level was recorded at site HM41 and HM44, both background locations situated at Bishops Park and Eel Brook Common. The AQS was not approached or exceeded at any site.

Temporal Variation

Figure 6B shows that benzene concentration followed similar trends with maximum levels during the winter months. Roadside location HM32 recorded consistently higher levels throughout the year with a maximum peak level of $6.1\mu\text{g m}^{-3}$ in December. The peak level of $7.4\mu\text{g m}^{-3}$ in May at site HM45 should be treated with caution due to inconsistency with other data.

Annual Trends

Levels of benzene have been declining since 1995. Figure 6C illustrates this and shows similar levels for the past four years with little fluctuation.

8.7 London Borough of Harrow

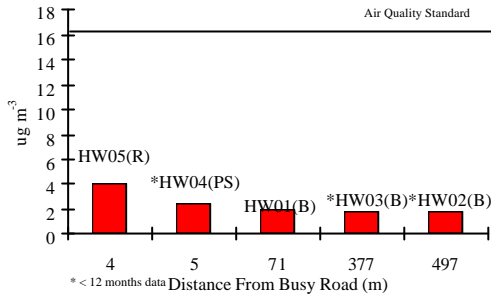


Figure 7A. Annual Mean Benzene Concentrations - 2001

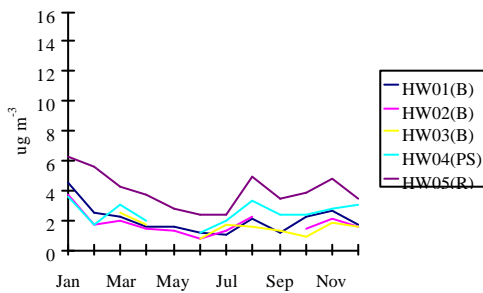


Figure 7B. Temporal Variation 2001

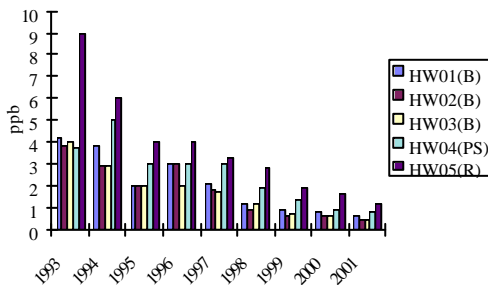


Figure 7C. Trends in Annual Average Benzene Concentrations

Annual Mean Concentration

Figure 7A clearly demonstrates the relationship between benzene concentration and distance from the roadside. Mean concentrations decreased with increasing distance from the roadside.

Annual mean levels ranged from $1.8\mu\text{g m}^{-3}$ at sites HW02 and HW03 to $4.0\mu\text{g m}^{-3}$ at site HW05. The highest mean of $4.0\mu\text{g m}^{-3}$ was recorded at a roadside location on Station Road, Harrow. The lowest mean of $1.8\mu\text{g m}^{-3}$ was recorded at Aylward School in Stanmore and Grimsdyke School at Hatch End, both background locations. The AQS was not exceeded or approached at any site.

Temporal Variation

Temporal trends shown in Figure 7B were similar at all sites with some seasonal variation. Concentrations peaked at sites HW04 and HW05, the petrol station and roadside location in January, August and November. Roadside location HW05 remained consistently higher than other sites throughout the year with a maximum concentration of $6.3\mu\text{g m}^{-3}$ in January.

Annual Trends

Figure 7C clearly shows that annual mean concentrations at all sites have continued to decline since 1993.

8.8 London Borough of Hounslow

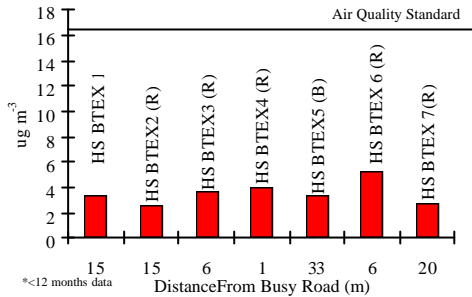


Figure 8A. Annual Mean Benzene Concentrations - 2001

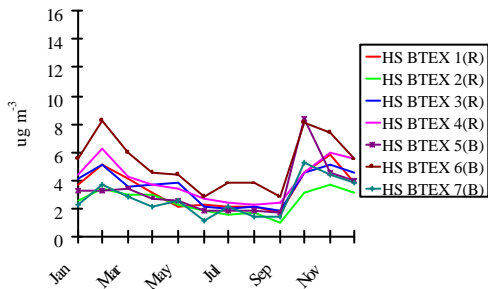


Figure 8B. Temporal Variation 2001

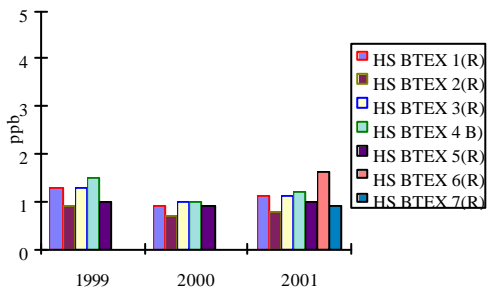


Figure 8C. Trends in Annual Average Benzene Concentrations

Mean Concentration

Annual mean concentrations ranged from $2.6\mu\text{g m}^{-3}$ to $5.3\mu\text{g m}^{-3}$ both at roadside locations. The highest mean value of $5.3\mu\text{g m}^{-3}$ was recorded for site HS BTEX6 located at 24 Adelaide Terrace, Brentford. The lowest mean value of $2.6\mu\text{g m}^{-3}$ was recorded for site HS BTEX2 located at Marjory Kinnon School, Hatton Road. The AQS was not exceeded or approached at any time.

Temporal Variation

Figure 8B shows temporal trends for 2001. Benzene levels followed similar trends throughout the year with peak concentrations for February and October. During October a maximum peak value of $8.4\mu\text{g m}^{-3}$ was recorded for HS BTEX5 a background site located at the Church of the Good Shepherd at Great South West Road. In February a peak concentration of $8.2\mu\text{g m}^{-3}$ was recorded for roadside site HS BTEX6.

Annual Trends

Figure 8C shows levels of benzene at all sites to be similar to those observed in previous years with little fluctuation.

8.9 Royal Borough of Kensington & Chelsea

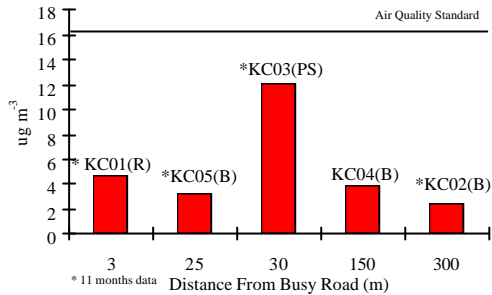


Figure 9A. Annual Mean Benzene Concentrations - 2001

Annual Mean Concentration

Mean concentrations ranged from 2.4 $\mu\text{g m}^{-3}$ to 12.1 $\mu\text{g m}^{-3}$. The lowest mean value was recorded for background site KC02, located at Holland Park Offices. The highest mean value was recorded for site KC03, located at Warwick Road, a petrol service station. The AQS was not exceeded but was approached at the service station site KC03 as illustrated in figure 9a.

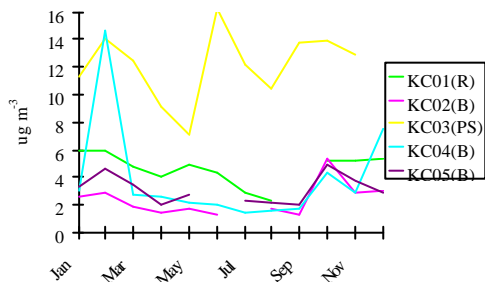


Figure 9B. Temporal Variation 2001

Temporal Variation

Figure 9B illustrates temporal trends for 2001. Levels of benzene were consistently higher at site KC03 than other sites throughout the year, with a maximum peak level of 16.2 $\mu\text{g m}^{-3}$ recorded for June. There was a peak level of 14.6 $\mu\text{g m}^{-3}$ in February recorded for background site KCO4, which is inconsistent with other data for that location. The value obtained should therefore be treated with caution.

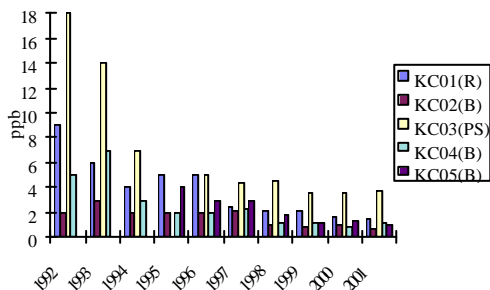


Figure 9C. Trends in Annual Average Benzene Concentrations

Annual Trends

Figure 9C shows a general decline in benzene concentration over previous years. Site KC03, the petrol service station has continued to produce the highest benzene levels since 1992.

8.10 Corporation of London

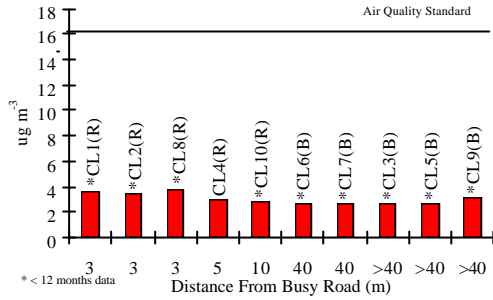


Figure 10A. Annual Mean Benzene Concentrations - 2001

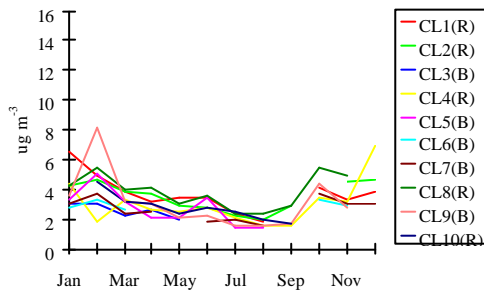


Figure 10B. Temporal Variation 2001

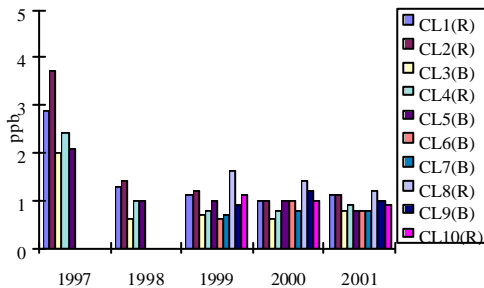


Figure 10C. Trends in Annual Average Benzene Concentrations

Annual Mean Concentration

Annual mean benzene concentrations ranged from $2.7\mu\text{g m}^{-3}$ at sites CL3, CL6 and CL7 background locations, to $3.8\mu\text{g m}^{-3}$ at site CL8, a roadside location. The lowest mean level of $2.7\mu\text{g m}^{-3}$ was recorded at Pleach Walk, Barbican, St Pauls Cathedral and St Bartholomews Hospital. The highest mean level of $3.8\mu\text{g m}^{-3}$ was recorded at London Bridge, Lower Thames Street. Mean levels were low with no exceedences of the AQS at any site.

Temporal Variation

Figure 10B shows concentrations at all sites following similar trends with higher levels generally recorded at roadside locations. A maximum peak concentration of $8.1\mu\text{g m}^{-3}$ was recorded in February for site CL9, a background location. From October to December levels increased at all sites with a peak concentration of $7.0\mu\text{g m}^{-3}$ at site CL4, a roadside location at Crescent House, Goswell Road.

Annual Trends

Figure 10C illustrates annual average benzene concentrations. Following 1997, levels showed a decrease at the five locations monitored at that time. For the past three years data show levels at all sites to be similar with little fluctuation.

8.11 London Borough of Newham

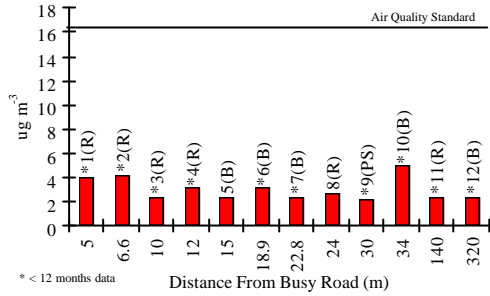


Figure 11A. Annual Mean Benzene Concentrations - 2001

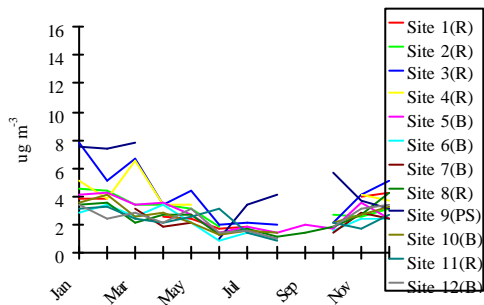


Figure 11B. Temporal Variation 2001

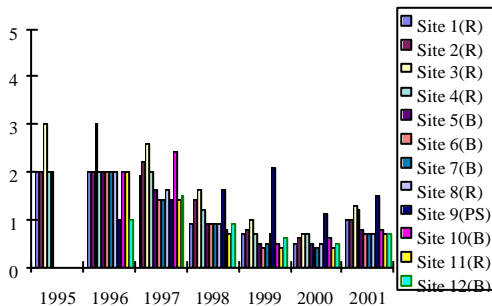


Figure 11C. Trends in Annual Average Benzene Concentrations

Annual Mean Concentration

Mean benzene concentrations ranged from $2.2\mu\text{g m}^{-3}$ to $4.9\mu\text{g m}^{-3}$. The maximum mean concentration of $4.9\mu\text{g m}^{-3}$ was recorded for site 9, located at a service station on Barking road. The lowest mean value of $2.2\mu\text{g m}^{-3}$ was recorded for site 6, a background site located at East London Cemetery at Grange Road. A concentration of $2.4\mu\text{g m}^{-3}$ was recorded for sites 8, 11 and 12, which were roadside locations. There was no apparent relationship between mean concentrations and distance from busy roadsides. The AQS was not exceeded or approached at any site

Temporal Variation

Figure 11B illustrates temporal trends for 2001. Levels of benzene followed similar trends with peak concentrations during the winter months. A maximum peak concentration of $7.8\mu\text{g m}^{-3}$ was recorded for sites 3 & 9 for January and March respectively.

Annual Trends

Since 1995 levels of benzene have shown a downward trend as shown in Figure 11C. However, mean benzene concentrations for 2001 were slightly higher than levels obtained for 2000 at all sites. Site 9 located at a service station on Barking Road has continued to produce elevated levels since 1998.

8.12 London Borough of Richmond

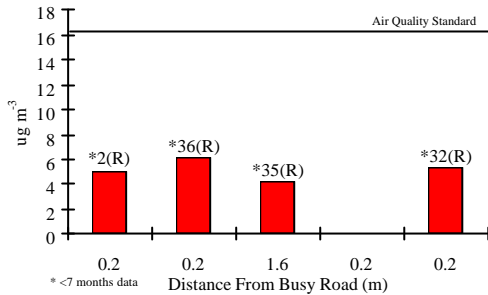


Figure 12A. Annual Mean Benzene Concentrations - 2001

Annual Mean Concentration

A maximum of 6-months data is available therefore no annual means can be calculated. However, Figure 12A provides an indication of likely mean values based on available data.

The maximum mean concentration of $6.1\mu\text{g m}^{-3}$ was recorded for site 36 located at Upper Richmond Road West, East Sheen SW14. The lowest mean value of $4.2\mu\text{g m}^{-3}$ was recorded for site 35 a roadside site located at High Street, Hampton Wick.

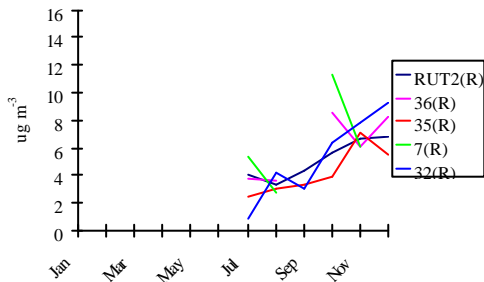


Figure 12B. Temporal Variation 2001

Temporal Variation

Due to insufficient data few comments can be made. However, there was an increase in levels at all sites from October to December.

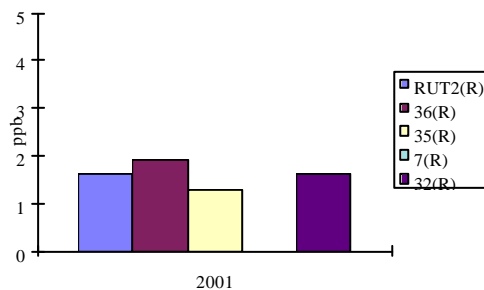


Figure 12C. Trends in Annual Average Benzene Concentrations

Annual Trends

Due to insufficient data no comment can be made.

8.13 London Borough of Sutton

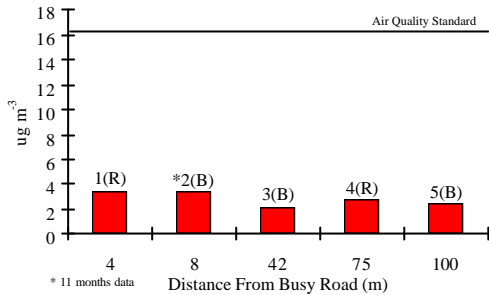


Figure 13A. Annual Mean Benzene Concentrations - 2001

Annual Mean Concentration

Mean benzene concentrations ranged from $2.2\mu\text{g m}^{-3}$ to $3.5\mu\text{g m}^{-3}$. The minimum mean value of $2.2\mu\text{g m}^{-3}$ was recorded for site 2, a background location at Devonshire Primary School, Devonshire Avenue. The highest mean value of $3.5\mu\text{g m}^{-3}$ was recorded for site 4, a roadside location at Robin Hood Junior School, Thorncroft Road. The AQS was not approached or exceeded at any site.

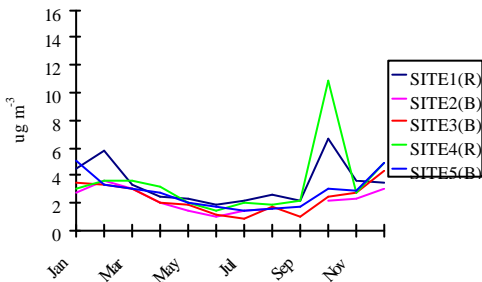


Figure 13B. Temporal Variation 2001

Temporal Variation

Temporal trends, illustrated in figure 13B, were similar at all five sites with peak concentrations in February and October. The highest peak value of $10.8\mu\text{g m}^{-3}$ was recorded in October for site 4.

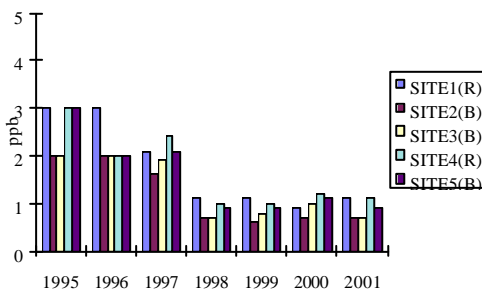


Figure 13C. Trends in Annual Average Benzene Concentrations

Annual Trends

Annual trends are illustrated in figure 13C. Concentrations decreased from 1997 to 1998 and have since remained fairly constant showing little change.

8.14 London Borough of Wandsworth

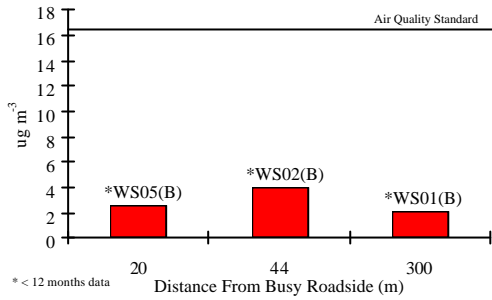


Figure 14A. Annual Mean Benzene Concentrations - 2001

Annual Mean Concentration

Annual mean concentrations ranged from $2.1\mu\text{g m}^{-3}$ to $4.0\mu\text{g m}^{-3}$. A mean value of $2.1\mu\text{g m}^{-3}$ was recorded at WS01, a background site located on Holybourne Avenue in Roehampton. A maximum mean value of $4.0\mu\text{g m}^{-3}$ was recorded at WS02, also a background site, located at the Environmental Offices on Garrett Lane. The AQS was not approached or exceeded at any site.

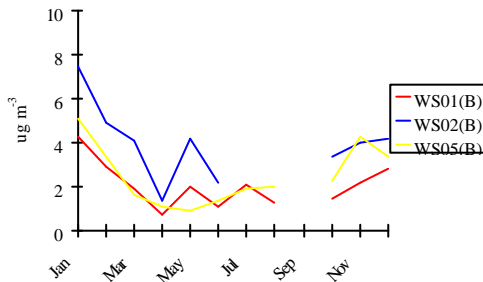


Figure 14B. Temporal Variation 2001

Temporal Variation

Levels followed a similar pattern throughout the year with an increase in concentration during the winter months. A maximum peak level of $7.4\mu\text{g m}^{-3}$ was recorded in January at background site WS02.

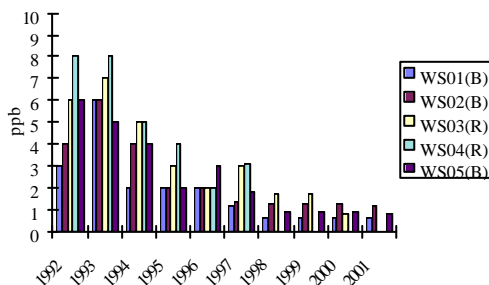


Figure 14C. Trends in Annual Average Benzene Concentrations

Annual Trends

Figure 14C shows that annual benzene levels have been on the decline since 1993 with some inter-site variation. Annual means decreased at all sites in 1998 with levels now showing little change over recent years.

8.15 London Borough of Westminster

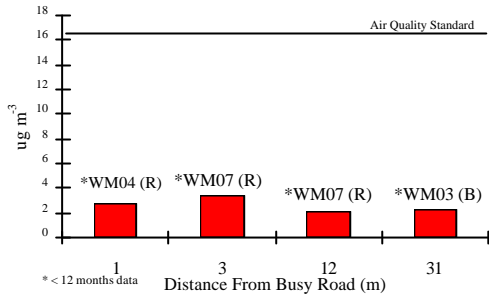


Figure 15A. Annual Mean Benzene Concentrations - 2001

Annual Mean Concentration

Mean benzene concentrations ranged from $2.1\mu\text{g m}^{-3}$ to $3.4\mu\text{g m}^{-3}$. The lowest mean value of $2.1\mu\text{g m}^{-3}$ was recorded for WM05, a roadside site, located at Victoria Street. The highest value of $3.4\mu\text{g m}^{-3}$ was recorded for WM07, a roadside site located at Westminster Council House. The AQS was not exceeded at any of the sites.

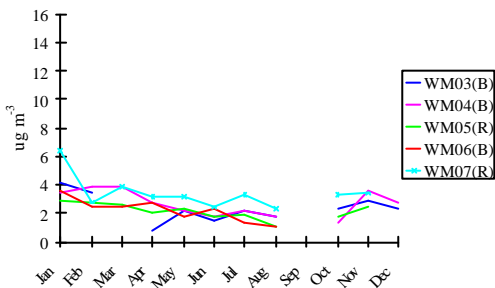


Figure 15B. Temporal Variation 2001

Temporal Variation

Figure 15B illustrates benzene levels following a similar pattern. A maximum peak level of $6.4\mu\text{g m}^{-3}$ was recorded in January at background site WM04 located at Lancaster Gate Hotel.

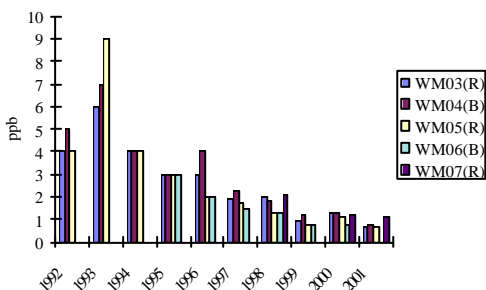


Figure 15C. Trends in Annual Average Benzene Concentrations

Annual Trends

Figure 15C shows annual mean concentrations declining steadily from 1993 to 1999, with a slight increase in 2000. Mean levels for 2001 are now showing a decrease.

8.16 Summary of 2001 Annual Mean Benzene Concentrations

Across all boroughs, mean concentrations recorded at roadside sites ranged from $2.4\mu\text{g m}^{-3}$ recorded in Newham, to $8.2\mu\text{g m}^{-3}$ in Brent. At background sites, mean benzene concentrations varied from $1.8\mu\text{g m}^{-3}$ at Harrow and Newham to $4.6\mu\text{g m}^{-3}$ at Brent. Mean concentrations recorded at petrol stations varied from $2.5\mu\text{g m}^{-3}$ at Harrow to $12.1\mu\text{g m}^{-3}$ at Kensington & Chelsea.

The annual mean benzene concentrations for the three different location types are summarised in Table 2 below:

Table 2: Summary of 2001 Annual Mean Concentrations ($\mu\text{g m}^{-3}$)

Site Type	Minimum	Mean	Maximum
Background	1.8	2.5	4.6
Roadside	2.4	4.0	8.2
Petrol Station	2.5	6.0	12.1

9 Quality Assurance and Quality Control

9.1 Duplicate Exposures at Monitoring Sites

As part of the quality assurance/control procedures integral to the London-wide Benzene Survey, a selection of boroughs are sent one extra diffusion tube for duplicate exposure at a monitoring site within the borough. In 2001 duplicate exposures were made on twenty-three occasions. The results of these tubes indicate satisfactory agreement between duplicate tubes. The maximum difference between duplicates is $\pm 0.8 \mu\text{g m}^{-3}$. The results of these duplicate exposures are summarised below in figure 16a-16c and are also given in appendix I.

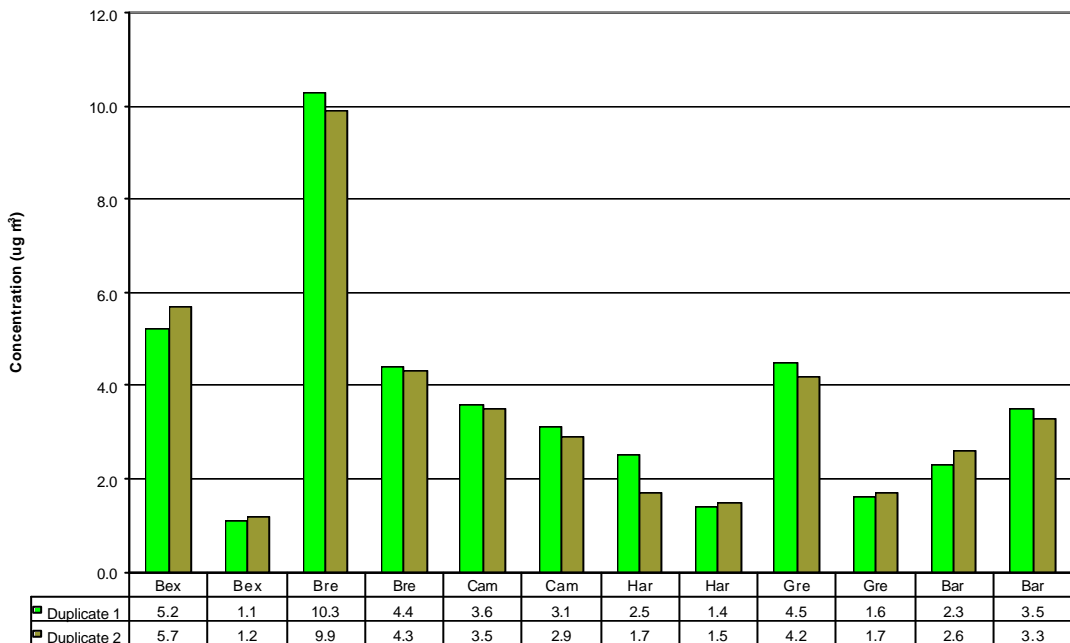


Figure 16a: Summary of 2001 Duplicate Exposures within London Boroughs

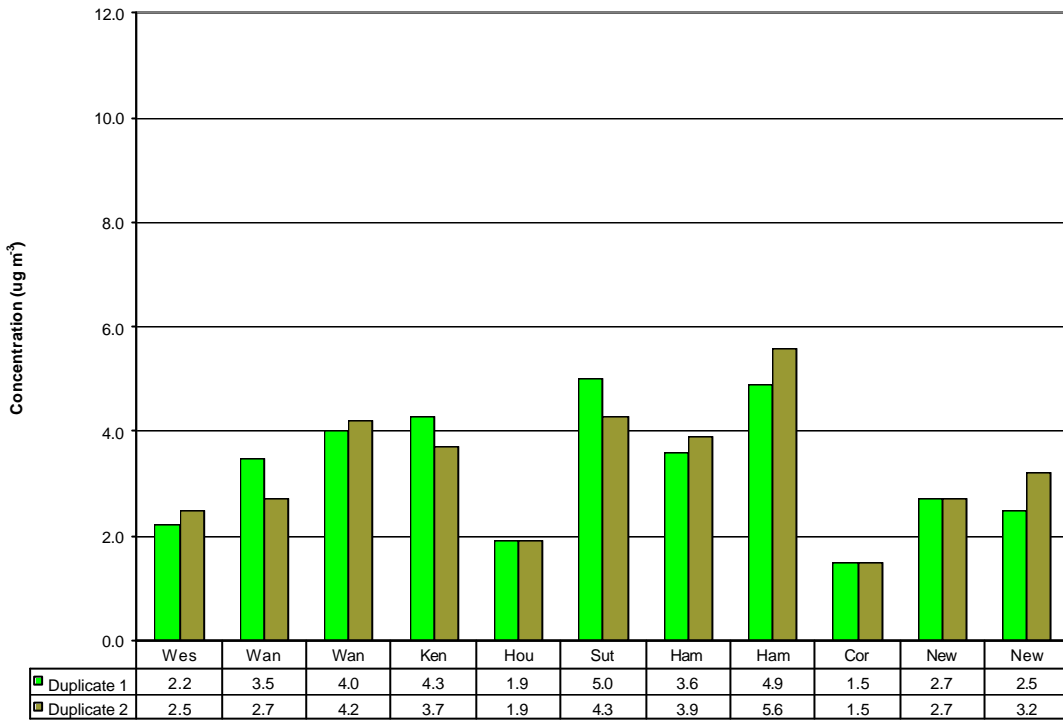


Figure 16b: Summary of 2001 Duplicate Exposures within London Boroughs

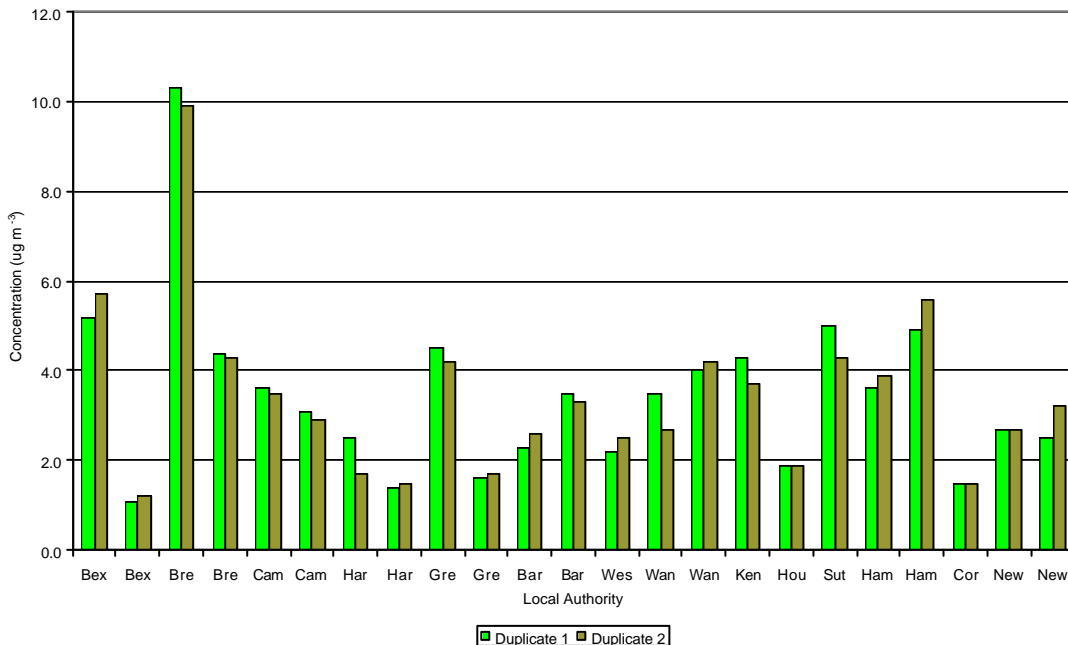


Figure 16c: Summary of 2001 Duplicate Exposures within London Boroughs showing all twenty-three exposures.

9.2 Duplicate Exposures at the Hydrocarbon Network

As an additional part of the quality assurance/control procedures, diffusion tubes were also exposed at the Hydrocarbon Network site on Marylebone Road (*Super-Site*). Tubes exposed at this site were analysed for benzene, toluene, ethyl benzene, m, p-xylene and o-xylene (*btex*).

Results for the year included eight-months of validated data excluding March, July, September and December. Benzene levels ranged from $3.3\mu\text{g m}^{-3}$ recorded in August to $15.8\mu\text{g m}^{-3}$ recorded in January. Using the available data, an annual mean value of $6.8\mu\text{g m}^{-3}$ was calculated for the duplicate exposures, which can be compared with the calculated annual mean value of $4.9\mu\text{g m}^{-3}$ recorded for the Hydrocarbon Network. Mean values for Toluene ranged from $20.2\mu\text{g m}^{-3}$ recorded in June to $50.2\mu\text{g m}^{-3}$ recorded in April. Calculated mean values for ethyl benzene ranged between $3.4\mu\text{g m}^{-3}$ in June to $6.3\mu\text{g m}^{-3}$ in August. Results for m, p-xylene ranged from $10.8\mu\text{g m}^{-3}$ in February to $25.7\mu\text{g m}^{-3}$ in August. Mean values for o-xylene ranged between $4.2\mu\text{g m}^{-3}$ in February and June to $10.4\mu\text{g m}^{-3}$ in August. Figures 17a–17e illustrate the comparison between duplicate tubes for BTEX. Data is also provided in Appendix I.

Table 3 below shows a comparison between the Hydrocarbon Network and the diffusive sampling at that location. Data has been calculated and compared for the same exposure periods. Results for the network are higher, but are considered to show satisfactory correlation between the data sources considering the different averaging periods. The Hydrocarbon Network data was based on hourly data and the diffusive sampling was based on one exposure period within a calendar month.

Table 3: Comparison of Annual mean Concentrations at Marylebone Road Hydrocarbon Station

Species (mg m^{-3})	Casella Stanger tubes	Network analyser
Benzene	6.8	4.5
Toluene	38.9	17.5
Ethyl Benzene	6.1	3.0
m, p Xylene	18.2	10.5
o Xylene	6.9	3.9

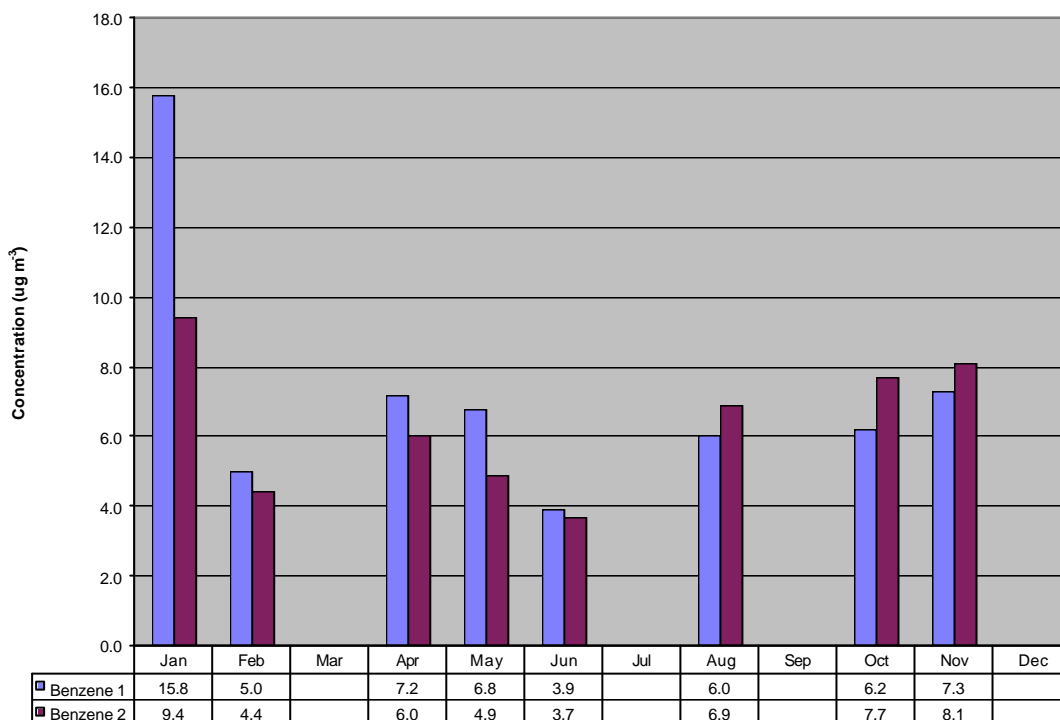


Figure 17a: Summary of 2001 Duplicate Benzene Exposures at London Marylebone Road

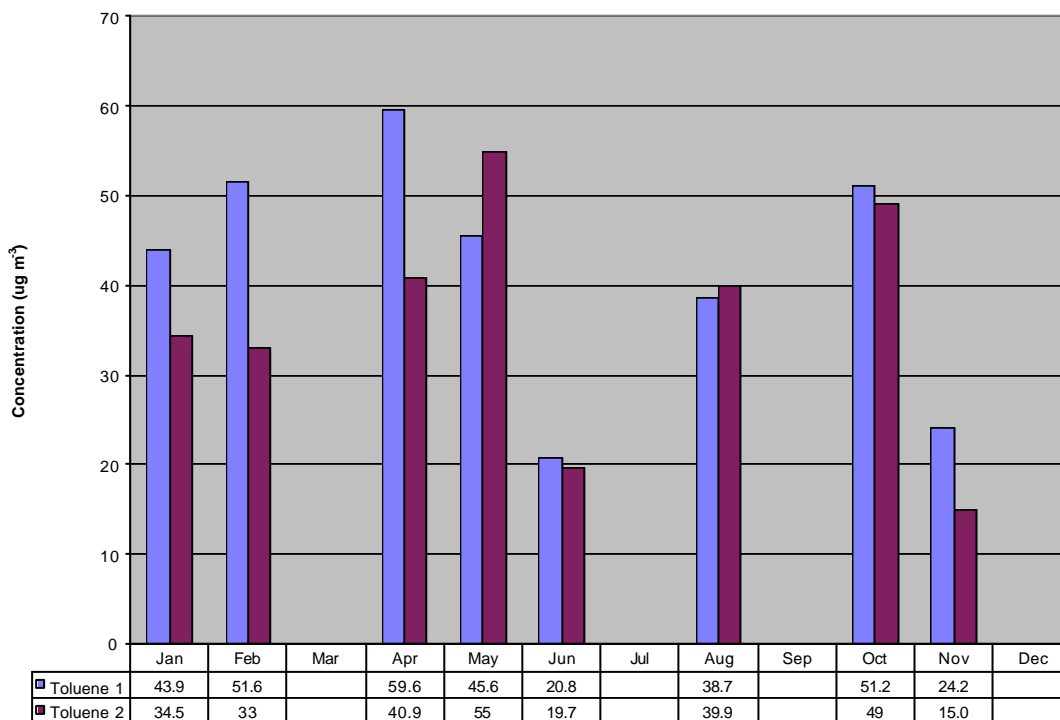


Figure 17b: Summary of 2001 Duplicate Toluene Exposures at London Marylebone Road

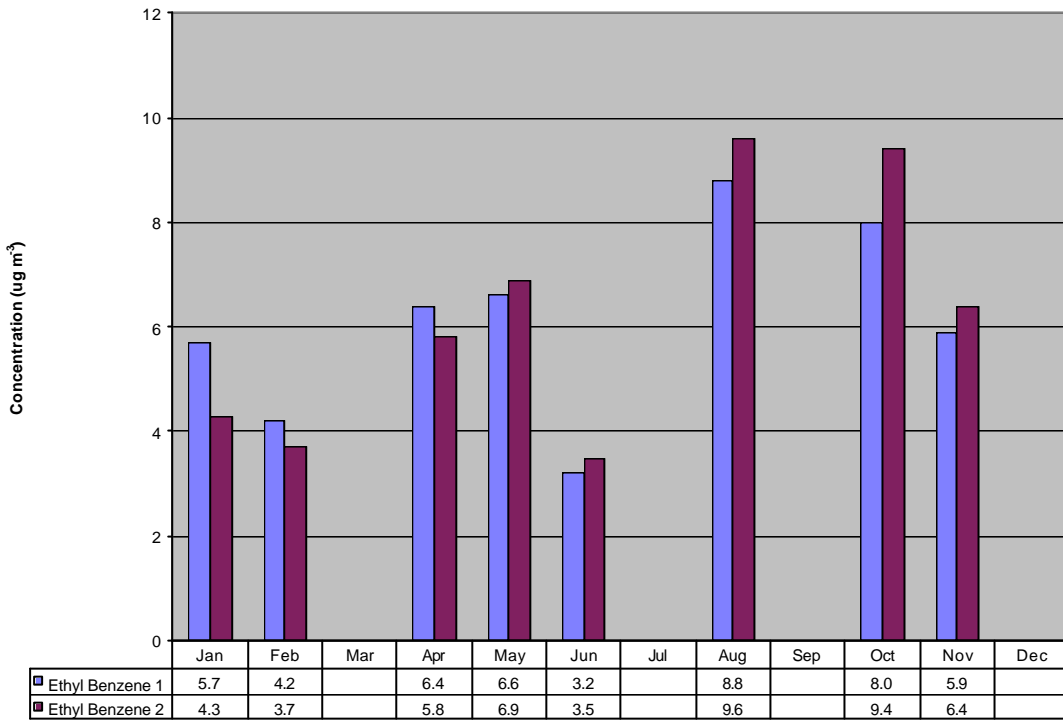


Figure 17c: Summary of 2001 Duplicate Ethyl Benzene Exposures at London Marylebone Road

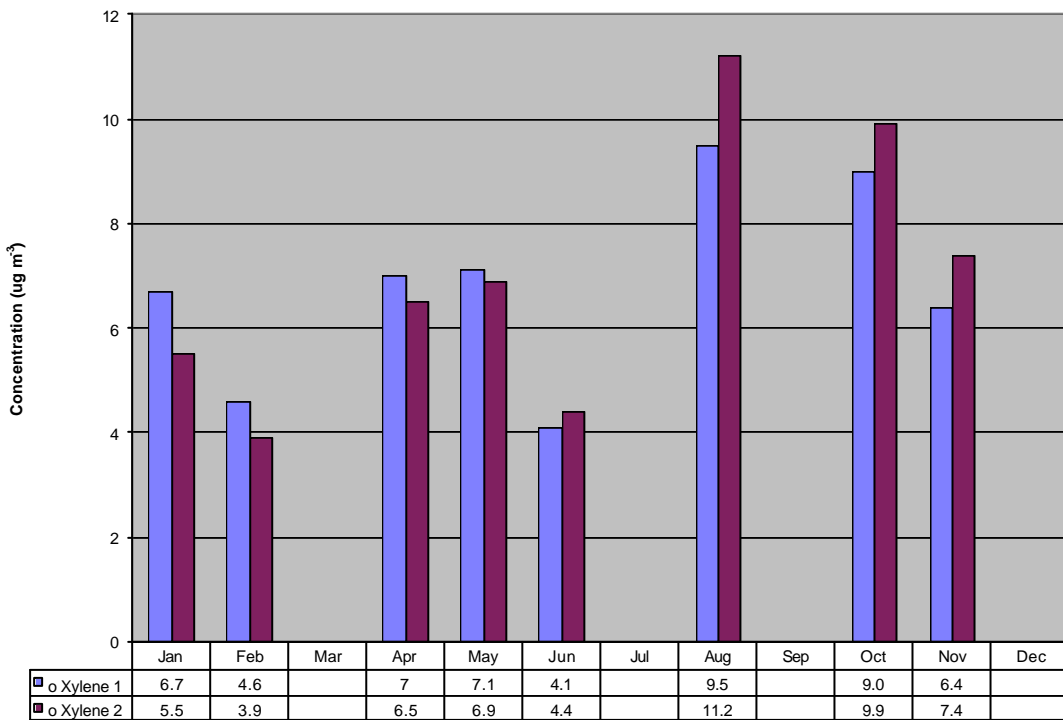


Figure 17d: Summary of 2001 Duplicate m, p Xylene Exposures at London Marylebone Road

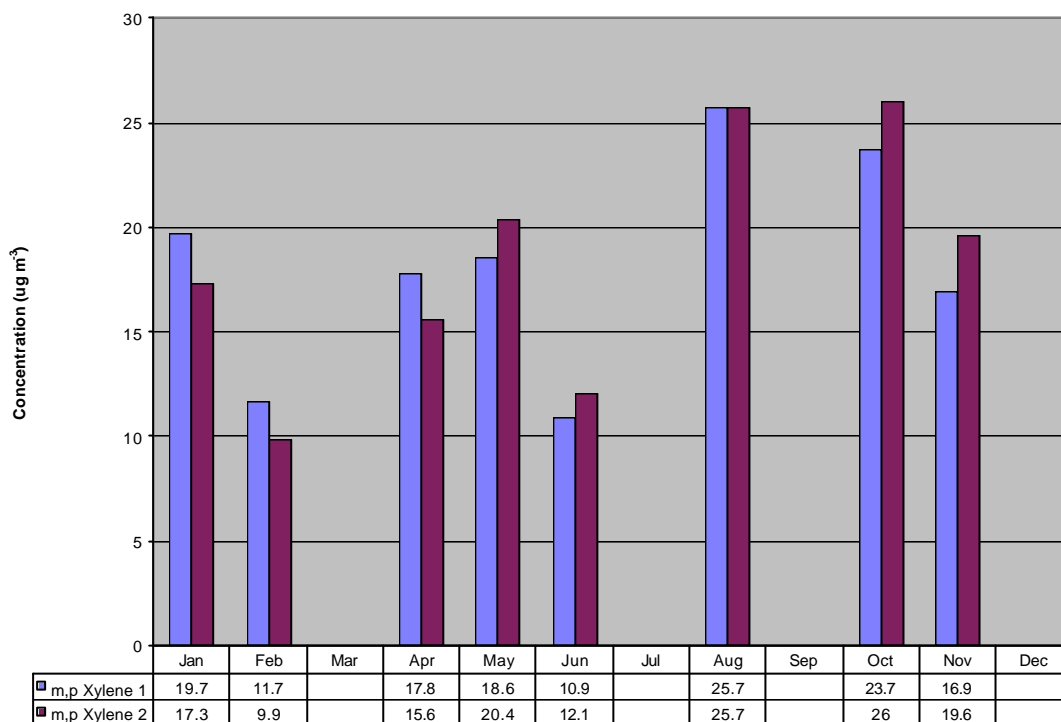


Figure 17e: Summary of 2001 Duplicate o Xylene Exposures at London Marylebone Road

10 Discussion

10.1 Mean Benzene Concentrations

Maximum concentrations were recorded at roadside locations, which contributed to 59% of the total sites in the survey. These recordings are consistent with motor vehicle emissions and evaporative emissions from petrol being significant sources of atmospheric benzene. Within some boroughs there was some relationship between distance from a busy road and mean concentration. Benzene levels decreased with increasing distance from the roadside, further emphasising the significance of traffic as a source of benzene and the strong influence of this emission source on urban benzene levels.

Concentrations at background sites across London were generally lower than at roadside, although results do show some category overlap when assessing mean values across boroughs. For example, mean levels recorded at background sites ranged from $1.8\mu\text{g m}^{-3}$ to $4.6\mu\text{g m}^{-3}$ and at roadside mean values ranged from $2.4\mu\text{g m}^{-3}$ to $8.2\mu\text{g m}^{-3}$. Although this overlap exists maximum mean values are consistent across the three categories. Such variability mainly reflects spatial variation in intensity of traffic flow, which in turn is attributable to heterogeneity in London's road network. Benzene concentrations are also influenced by factors such as meteorological conditions and height of sampler. Factors, which influence ambient benzene concentrations, will obviously vary from site to site and from borough to borough. This may explain why in some boroughs there was no clear relationship between distance from roadside and benzene concentrations.

In Camden, Harrow, Newham and Kensington & Chelsea, mean benzene levels recorded at the petrol station sites were similar to levels recorded at the busy roadside sites, although the site located in Kensington & Chelsea produced the highest mean of the survey $12.1\mu\text{g m}^{-3}$. This suggests that the influence of evaporative emissions on benzene levels at these sites is similar to the influence of exhaust emissions at roadside sites. Benzene levels at the petrol station site, located in Kensington & Chelsea, were consistently higher than typical roadside levels within the borough and were also higher than petrol station levels recorded in other boroughs. Thus, at this site, it would appear that evaporative emissions of benzene from petrol have a very significant effect on benzene levels. It is likely that this petrol station site is located near a fairly busy road and thus vehicle emissions would have contributed to levels recorded at this site and also may reflect the number of transactions taking place and/or size of the station.

10.2 Comparison with other Data

Comparison of the LWEP data with calculated mean data for the Automatic Hydrocarbon Monitoring Network (*AHMN*) indicates that levels of benzene recorded in this survey are broadly comparable with such data considering the different averaging periods used for each method. Indications are that the diffusion tube method may tend to over-estimate concentrations and thus present a worst-case scenario when assessing annual means. This can be seen when assessing the toluene levels in Figure 18, although such levels can be attributed to possible contamination.

The calculated annual mean level for the roadside location type was $4.0\mu\text{g m}^{-3}$ which compares with $4.5\mu\text{g m}^{-3}$ calculated for London Marylebone Road. Within the survey, the maximum annual mean recorded at roadside was $8.2\mu\text{g m}^{-3}$, which was recorded for Brent. The maximum annual mean recorded at background was $4.6\mu\text{g m}^{-3}$, which was also recorded at Brent.

Hydrocarbon species (*BTEX*) measured at London Marylebone Road were comparable with diffusion tube data recorded at that location. Figure 18 illustrates the comparison in mean levels between species measured.

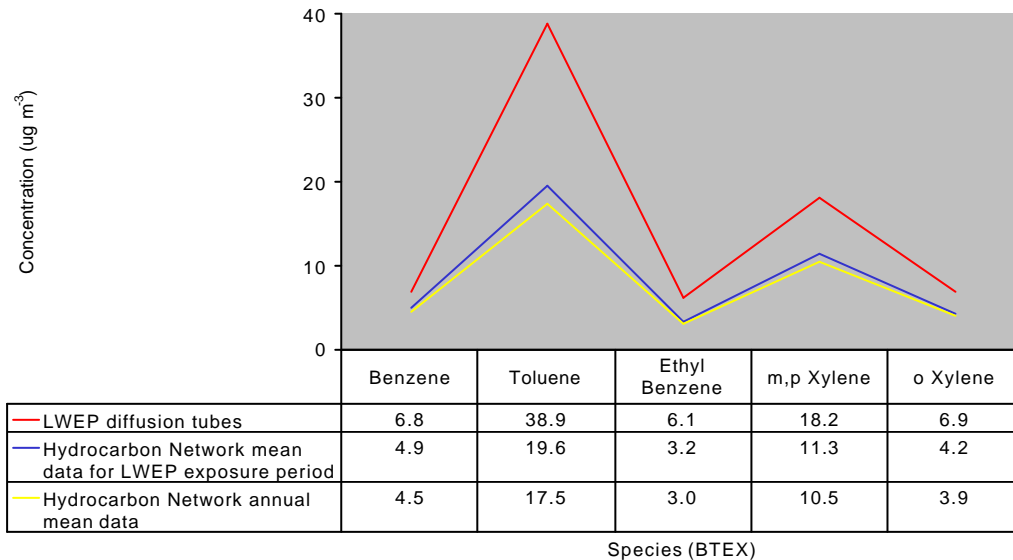


Figure 18: Comparison of Species Measured at London Marylebone Road

10.3 Seasonal Trends

All site locations showed some degree of inter-site variation with elevated benzene levels recorded for March and October. At these times levels were elevated across site categories. Such peaks are consistent with previous reports that suggest benzene concentrations may increase sharply during pollution episodes typical of winter months. Measurements of benzene made by Imperial College during the London 1991 pollution episode showed a substantial episodic increase in benzene levels, with a concentration of $58.3\mu\text{g m}^{-3}$ (2 day mean) prior to the episode, increasing to a mean of $382.7\mu\text{g m}^{-3}$ (4 day mean) during the episode (QUARG, 1993).

It therefore seems that benzene concentrations follow the pattern described for other primary pollutants, with high ground levels occurring in winter as a result of cold temperatures and low wind speeds trapping the pollution in a stable air mass near to the ground.

To some extent the degree of temporal variation observed in the data for individual boroughs reflects the differences in benzene levels between the site categories, such that greater variation was recorded at the roadside sites as opposed to the background sites. In turn this possibly again reflects the variation in traffic flow, which will only have a marked influence on roadside sites.

11.0 Predictions for Future Urban Benzene Concentrations

Several measures have been introduced over the past few years to reduce the emissions of pollutants from the transport sector. The current trend of decreasing annual benzene emissions 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*). Policy developments such as the *Auto-oil Programme (Euro Standards)* implemented in January 2000 are expected to further reduce benzene levels in future years.

Forecasts from mapping work suggests policy measures now in place should achieve the objective of $16.25\mu\text{g m}^{-3}$ at all urban background and roadside locations by the end of 2003. The EPAQS longer-term target level of $3.25\mu\text{g m}^{-3}$ should be achieved at urban background locations by the end of 2005 and most roadside locations by 2010.

12.0 Report Statement

We confirm that in preparing this report we have exercised all reasonable skill and care.

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13.0 References

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