# The impacts of the Gloucester Safer City Project on air quality—1997-1998

## Prepared for Charging and Local Transport Division, Department of the Environment, Transport and the Regions

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# Executive Summary

TRL Limited is monitoring the environmental effects of the Gloucester Safer City Project, particularly in terms of emissions, air quality, noise and vibration. As part of the work on emissions and air quality, a city-wide network of monitoring sites has been set up to determine concentrations of nitrogen dioxide, $PM_{10}$ and benzene at kerbside and background locations in Gloucester. The network comprises 10 kerbside sites and a background site. The aim of the network is to monitor the effect on air quality of the Safer City Project. This document reports on the first two years (1997 and 1998) of the air quality monitoring in Gloucester.

During the period of the report a number of traffic management/calming measures were installed in Gloucester. The ones most likely to affect vehicle emissions and hence air quality are carriageway narrowings combined with cycle lanes on Finlay Road, a range of traffic calming measures on Cheltenham Road and the closure of Northgate and Southgate in preparation for pedestrianisation. A separate study has shown that vehicle emissions on the major routes in Gloucester decreased steadily between 1996 and 1998, largely as a result of the introduction into the fleet of more catalyst equipped light-duty vehicles with significantly lower emission rates.

In both years benzene concentrations at all of the sites were below the Air Quality Standard of 5 ppb, with the highest values seen on Barton Street and on Northgate before it was pedestrianised. Over the monitoring period, the mean concentrations fell at the kerbside locations by 24% and at the background by 53%. This is consistent with the general decline in hydrocarbon emissions from traffic in Gloucester, and the general decrease with time in benzene concentrations across the whole of the UK.

For nitrogen dioxide, concentrations measured using diffusion tubes at the kerbside were close to or greater than the Air Quality Standard of 40 $\mu g/m^3$. Over the monitoring period, concentrations fell at the kerbside by on average 9% but at the background site there was a statistically insignificant increase of 7%. There is some evidence to suggest that as emissions of oxides of nitrogen from traffic in Gloucester decrease, measured concentrations of nitrogen dioxide at the kerbside also decrease.

By comparing the results from nitrogen dioxide diffusion tubes and $PM_{10}$ MiniVol samplers with a chemiluminescent oxides of nitrogen analyser and a Partisol sampler it was found that the cheaper sampling methods did provide good results. However, in the case of $PM_{10}$, the limited number of MiniVol surveys did not give a reliable estimate of the annual mean or the number of exceedences of the Air Quality Standard at the kerbside.

During 1998, Northgate Street was closed to traffic in preparation for pedestrianisation, and here the greatest reduction in average benzene and nitrogen dioxide concentrations (59% and 26% respectively) were seen: both decreases were statistically significant.

The continuous measurements at the background site highlighted a number of periods where pollutant concentrations were relatively high. These episodes were also experienced in Plymouth and Bristol. Two of the episodes in May and September appear to be as a result of secondary processes as concentrations of the primary pollutants were not elevated.

Air quality monitoring will continue to the end of 2001 largely as described, except for additional sampling of kerbside $PM_{10}$. This additional sampling is necessary because the data collected at the background site suggests that the current sampling frequency leads to an underestimate of the annual mean and the number of exceedences of the $PM_{10}$ standard.

# 1 Introduction

### 1.1 The Gloucester Safer City Project

In December 1995, the City of Gloucester was chosen by the Department of Environment, Transport and the Regions (DETR) as the preferred location for the 'Safe Town Initiative': the Gloucester Safer City Project. The objective of the Gloucester Safer City Project is to reduce the number of road casualties by implementing a coherent range of actions for road safety according to a well-defined strategy. The measures include:

- changes to the road hierarchy;
- traffic redistribution;
- measures for vulnerable road users;
- traffic management measures (e.g. parking controls, signals, junction design pedestrianisation, public transport, traffic restraint, park & ride);
- education and publicity.

The measures are being introduced in stages over five years starting in the financial year 1996/7.

As part of more general research into the environmental impact of urban traffic management and safety schemes, the Charging and Local Transport (CLT) Division of the DETR commissioned TRL Limited to monitor the environmental effects of the Gloucester Safer City Project (Project UG106).

The purpose of Project UG106 is to monitor, evaluate and report on the environmental effects, particularly in terms of traffic noise, emissions, and ground vibrations, of safety and traffic management measures installed in Gloucester during the tenure of the Safer City Project. It is intended that the results from such work will provide local authorities with a framework to determine the likely benefits and disbenefits of selected traffic management schemes in relation to their effects on the environment and in terms of accident reduction.

As part of a separate project TRL will also be monitoring accident and casualty occurrence, traffic distribution and speed and the level of public response.

### 1.2 Assessment of effects on air quality

The main part of the work in the air pollution area will be to achieve an understanding of the effect on emissions of the different safety and traffic management elements of the Safer City Project. In addition, measurements of pollutant concentrations will be made in order to relate changes in emissions to those in local air quality.

The first step in this assessment was the compilation of an inventory of emissions to the atmosphere in Gloucester. Emissions in Gloucester will change throughout the lifetime of the project in terms of source strength, composition and location. For example, as a result of the introduction of more stringent emission limits for new vehicles, the total emissions from road transport will decrease steadily as the fleet changes. The inventory will be updated at the end of the project in order to track emissions in Gloucester providing a background against which changes in air quality can be compared.

The inventory showed that road transport is the major source of carbon monoxide (87%), volatile organic compounds (71%) and oxides of nitrogen (89%). The domestic sector was estimated to make the largest single contribution to carbon dioxide whilst industry contributes the majority of airborne particulate material. However, the lack of reliable data on small-scale industrial combustion processes means that relative contributions of the other sectors (e.g. domestic, industrial, other transport) to emissions are likely to be overestimated.

### 1.3 Scope of the report

This report describes the design of an air quality monitoring network to determine changes in pollutant concentrations as a result of the measures implemented in Gloucester. In Chapter 3 the results for 1997 and 1998 are reported along with a description in Chapter 4 of the changes in traffic and emissions that occurred at the same time as the air quality measurements were made. Chapter 5 discusses the air quality in Gloucester during 1997 and 1998 and also changes in concentrations in relation to the changes in traffic emissions. Finally, recommendations for the continuation of the air quality surveys are made in Chapter 6.

The assessment of the impact of specific measures such as area wide traffic calming will be reported elsewhere.

# 2 Air Quality Surveys

### 2.1 Air Quality Standards and objectives

The Air Quality Strategy (AQS) (Department of the Environment et al., 2000) details the Government's policies with respect to the management of air quality in the UK. Within the Strategy, air quality objectives have been set which relate to concentrations of the pollutants nitrogen dioxide ($NO_2$), particulates of aerodynamic diameter less than 10 micrometres (μm) ($PM_{10}$), benzene, 1,3-butadiene, carbon monoxide (CO), lead, ozone ($O_3$) and sulphur dioxide ($SO_2$). The Air Quality Regulations 2000 prescribe the air quality standards and these relate to health-based limit values for each of the pollutants. Table 1 lists the objectives for these pollutants, which apply in non-occupational near-ground-level locations where people might be exposed over the relevant averaging period. Also included in Table 1 is information on the helath effects drawn from the reports of the Expert Panel on Air Quality Standards (EPAQS, 2000).

It should be noted that $O_3$ has been excluded from the process of local air quality management: because of the nature of the formation of this pollutant and the magnitude of the exceedence of the AQS objective, only concerted action on a national and international scale can be effective in achieving the objective.

### 2.2 Site considerations

To assess the impact of the Safer City Project on local air quality, a citywide network of sites was required. These sites would need to be close to the source (i.e. close to the kerb) so as to be able to detect with some confidence

**Table 1 UK air quality objectives**

| *Pollutant* | *Objective* | *Health effects* |
|---|---|---|
| Benzene | Running annual mean should not exceed 16.25 μg/m³ (5 ppb) by 31/12/2003[1].<br><br>Provisional objective of 3.25 μg/m³ (1 ppb) by 31/12/2005. | Benzene is a genotoxic compound linked to an increased risk of developing certain types of leukaemia. |
| 1,3-butadiene | Running annual mean should not exceed 2.25 μg/m³ (1 ppb) by 31/12/2003. | 1,3-butadiene is a potent carcinogen and, through its metabolite, is also genotoxic. |
| Carbon monoxide | 8-hour running average should not exceed 11.6 μg/m³ (10 ppm) by 31/12/2003. | Carbon monoxide interferes with the transport of oxygen by red cells in the blood and also by blocking essential biochemical reactions in cells. |
| Lead | Annual mean should not exceed 0.5 μg/m³ by 31/12/2004.<br><br>Annual mean should not exceed 0.25 μg/m³ by 31/12/2008. | At lower levels the health effects of lead are related to the effects on the central nervous system, particularly on the developing brain of children. |
| Nitrogen dioxide | Hourly values should not exceed 200 μg/m³ (104.6 ppb) by 31/12/2005 for more than 18 times each year.<br><br>Provisional annual mean objective of 40 μg/m³ (21 ppb) for 31/12/2005. | At high concentrations, some studies have shown changes in lung function for people with asthma. Exposure to nitrogen dioxide can enhance the response of someone with asthma to the inhalation of allergens. |
| $PM_{10}$ | Annual mean should not exceed 40 μg/m³.<br><br>24-hour mean should not exceed 50 μg/m³ for more than 35 times each year by 31/12/2004. | Studies in the US have found that a rise in the daily concentration of $PM_{10}$ by about 10 μg/m³ may be associated with an increase in daily mortality of about 1%. The acute worsening of pre-existing conditions such as coronary artery disease and chronic lung disease appears to be the main cause of the excess deaths observed in these studies. |
| Sulphur dioxide | 15 minute average should not exceed 266 μg/m³ (100 ppb) for 99.9% of the time by 31/12/2005.<br><br>24 hour mean should not exceed 125μg/m³ (47 ppb) more than three times a year by 31/12/2004.<br><br>Hourly mean should not exceed 350 μg/m³ (132 ppb) more then 24 times a year by 31 December 2004. | Sulphur dioxide is an irritant, affecting the lining of the nose, throat and the lung's airways, causing coughing, irritation, and a feeling of chest tightness, and can lead to narrowing of the airways. This latter effect is particularly likely to occur in people suffering from asthma and chronic lung disease. |

[1] *In between carrying out the surveys and reporting the results, the units for concentration have changed from ppb to μg/m³, thus benzene concentrations throughout the report are quoted in ppb.*

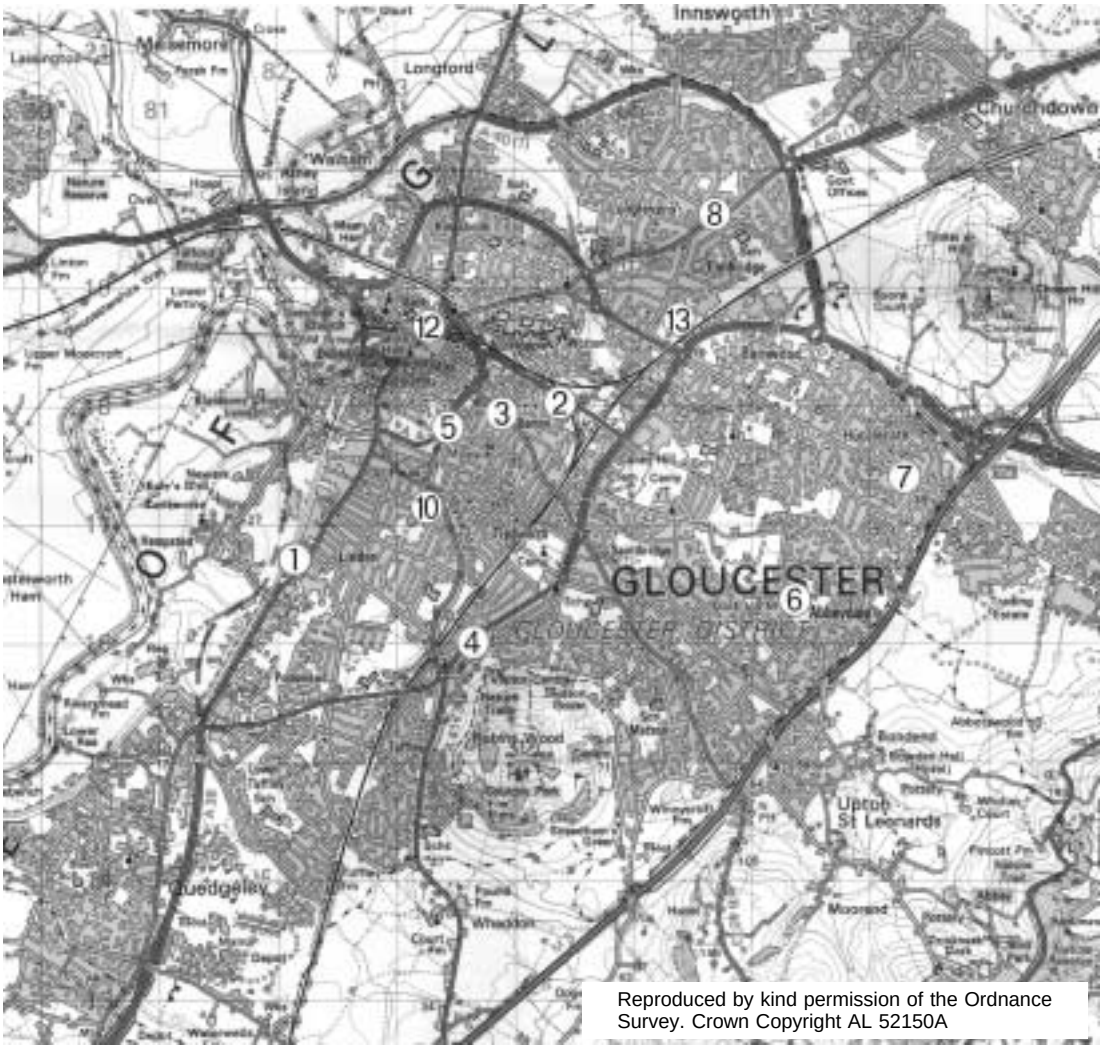
changes in air quality as a result of modified driving patterns or flows or speeds. As part of the evaluation of the Safer City Project in terms of safety, TRL was monitoring traffic speed and flow at a number of sites on main roads throughout Gloucester and it was advantageous to locate air quality monitoring sites close to these locations. Ten kerb-side air quality monitoring sites were therefore chosen with the intention of placing samplers either side of the road as close to the traffic speed and flow monitors as practicable.

There is a need to be able to distinguish between changes in air quality brought about by the Safer City measures and those as a result of other factors which may change on an hourly, daily, monthly and yearly basis. These other factors that will also influence air quality throughout the survey include: changes in emissions from non-traffic sources (e.g. increased combustion of fuels for domestic heating in the winter), changes in the emission characteristics of the traffic (e.g. an increase in the number of 'cleaner' vehicles in Gloucester) and different meteorological conditions (e.g. increased incidence of weather patterns that transport pollutants produced in mainland Europe to the UK). Therefore a site where pollutant concentrations are not directly related to traffic activity was required, and this was established at Elmbridge School. Figure 1 shows the monitoring locations. Appendix A contains photographs of the layout of the roads.

### 2.3 Measurement methods

In terms of the pollutants to be measured and the type of sampler, the decision was based on the contribution traffic makes to emissions and also the availability of a relatively cheap but effective method.

Probably of most interest in terms of the National Air Quality Strategy are the pollutants $NO_2$ and $PM_{10}$. There is evidence that in some areas, although not necessarily in Gloucester, concentrations of these pollutants regularly exceed the current and proposed air quality standards, and may continue to do so in future years. Road traffic makes a large contribution to emissions of these pollutants, and so they are included in the routine surveys. Benzene and CO were also included in the surveys because of their importance in terms of local air quality and also because they are largely derived from vehicle exhausts.




| | | | | | |
|---|---|---|---|---|---|
| Site 1 | Bristol Road | Site 5 | Trier Way | Site 10 | King Edward's Avenue |
| Site 2 | Metz Way | Site 6 | Abbeymead Avenue | Site 12 | Northgate |
| Site 3 | Barton Street | Site 7 | Hucclecote Road | Site 13 | Elmbridge School |
| Site 4 | Finlay Road | Site 8 | Cheltenham Road | | |

**Figure 1** Location of air quality monitoring sites

Sampling of $NO_2$ and benzene was achieved using diffusion tubes supplied and analysed by Bristol Scientific Services. MiniVol portable samplers manufactured by Airmetrics were used to collect $PM_{10}$. Daily samples of particulate material are collected on a pre-weighed filter and the difference in mass converted to a concentration from a knowledge of the flow rate through the sampler. It was intended to use Streetbox sensors developed by University College London and Learian to monitor CO concentrations in Gloucester. However the technology was not sufficiently proven and so measurements of CO at the roadside were not made in these first two years.

In January 1998, a site measuring concentrations of $NO_2$, total oxides of nitrogen ($NO_X$) and CO on a continuous basis and $PM_{10}$ on a daily basis was established at Elmbridge School. This site provides a means of comparing concentrations measured using diffusion tubes and portable analysers with concentrations measured using more conventional, but more expensive, methods. It will also provide more comprehensive data with which to identify relative changes in Gloucester's air quality. An Advanced Pollution Instrumentation (APi) Model 200 analyser was used to measure concentrations of NO (nitric oxide), $NO_x$ and $NO_2$ (as the difference between $NO_x$ and NO). CO was measured using a Horiba ambient CO monitor. Daily $PM_{10}$ measurements are made using a Partisol 2000 with $PM_{10}$ inlet.

In locating samplers care was taken to avoid, if possible, positions where traffic was likely to queue (i.e. close to traffic lights), other known pollution sources identified in the emission inventory, also where the sampler would be sheltered for instance by bushes or trees.

At the kerbside sites, a benzene diffusion tube and a $NO_2$ diffusion tube were mounted on lampposts on either side of the road and at about 2-3 m above ground to minimise losses due to vandals. At two locations, the sampling height was higher than this: at Elmbridge School the height was about 4 m and at site 1 on Northgate Street

it was 3-4 m. $PM_{10}$ samplers were located at ground level in a metal cage secured by a padlocked chain generally at the foot of a lamp post.

### 2.4 Monitoring periods

Diffusion tubes are generally deployed for periods of between one and four weeks depending on the ambient concentrations at the site. To gain as much detail in the data as possible in terms of temporal variation, but without the risk of values being below detection limits, a sampling period of two weeks was chosen.

Ideally, monitoring would continue throughout the year, but because of budgetary constraints it was only possible to monitor air quality at all kerbside sites for six months each year. It is generally accepted that a period of three months is probably the bare minimum in which to determine 'mean' concentrations and so monitoring for 6 months should give a good degree of confidence in the results. To increase the representativeness of the data gathered, monitoring was spread out over the year rather than in one block. Sampling was carried out in three blocks of eight weeks. Figure 2 shows the sampling schedule for 1997 and 1998. Monitoring at the continuous site at Elmbridge School was maintained throughout 1998, except for brief periods when instruments or the logging system malfunctioned

### 2.5 Statistical analysis of air quality data

The report compares concentrations at each of the monitoring locations and also between years. To determine the significance of the differences observed, t-tests were employed. The test assumed that concentrations at each of the locations and also within each year were independent of each other. In each test the null hypothesis, that there is no difference between two means, was rejected at a probability of less than 0.05, i.e. the difference can be said to be significant at the 5% level.

## 3 Results

### 3.1 Air quality in 1997

#### *3.1.1 Benzene concentrations*

Table 2 summarises the results for 1997 and Figure 3 illustrates the mean concentrations for each location (the raw data are contained in Table B1 in Appendix B). In 1997 the mean kerbside concentration in Gloucester was 3.12 ppb, with the highest values being found on Barton Street (4.70 ppb), Northgate Street (4.14 ppb) and Trier Way (3.64 ppb). The lowest concentrations were found at the background site, Elmbridge School (1.65 ppb). Mean benzene concentrations at all sites were below the Air Quality Standard of 5 ppb (16.25 $\mu g/m^3$).

Statistical analysis of the data showed that concentrations on Barton Street, Northgate and Elmbridge School were significantly different to those at the other locations. In addition it was found that concentrations either side of the road on Barton Street were significantly different from each other. These differences between the two sites were found to be consistent, with the concentrations on each side of the road being linearly correlated.

The benzene concentrations measured at the background site were generally less than at the kerbside sites. However in May, benzene concentrations were similar to or higher than at most of the kerbside sites. The reason for this anomaly is not known.

#### *3.1.2 Nitrogen dioxide concentrations*

Table 3 summarises the results for 1997 and mean concentrations are illustrated in Figure 4 (the raw data are included in Table B2 of Appendix B). In 1997 the mean kerbside concentration in Gloucester was 51.5 $\mu g/m^3$, with the highest values being found on Barton Street (58.1 $\mu g/m^3$), Northgate Street (58.0 $\mu g/m^3$), Bristol Road (63.2 $\mu g/m^3$) and Finlay Road (56.4 $\mu g/m^3$). .The lowest concentrations were found at the background site, Elmbridge School (29.9 $\mu g/m^3$). Mean $NO_2$ concentrations at all the kerbside sites were above the Air Quality Standard of 40 $\mu g/m^3$. The background $NO_2$ concentration measured at Elmbridge School was below the Air Quality Standard.

Statistical analysis of the data showed that concentrations on Barton Street, Northgate Street, Bristol Road and Elmbridge School were significantly different to those at the other locations. In addition it was found that there was a significant difference between concentrations on either side of the road for Northgate Street, but their relationship did not have a high correlation. Large differences between concentration on either side of the road were also seen for Bristol Road and Metz Way, although these were not found to be significant.

#### *3.1.3 $PM_{10}$ concentrations*

Daily $PM_{10}$ concentrations in Gloucester measured at seven of the locations during June 1997 showed a great deal of variability as shown in Figure 5 (the raw data are included in Table B3 of Appendix B). Mean kerbside concentrations were 24.7 $\mu g/m^3$, and at the background site (Elmbridge School) the mean was 21.5 $\mu g/m^3$. All $PM_{10}$ concentrations were below the Air Quality Standard of 50 $\mu g/m^3$ (24-hour mean).

In general concentrations were highest on Northgate Street and Finlay Road and lowest at Elmbridge School (e.g. Figure 6), but values at these locations were not significantly different to the others. Table 4 summarises the results for this monitoring period.

It should be noted that a MiniVol sampler located at Trier Way was stolen and so no data were collected at this site from 27 June. The gaps in the data for Elmbridge School were due to problems with entry into the school site and damage to the filter media during removal from the sampler.

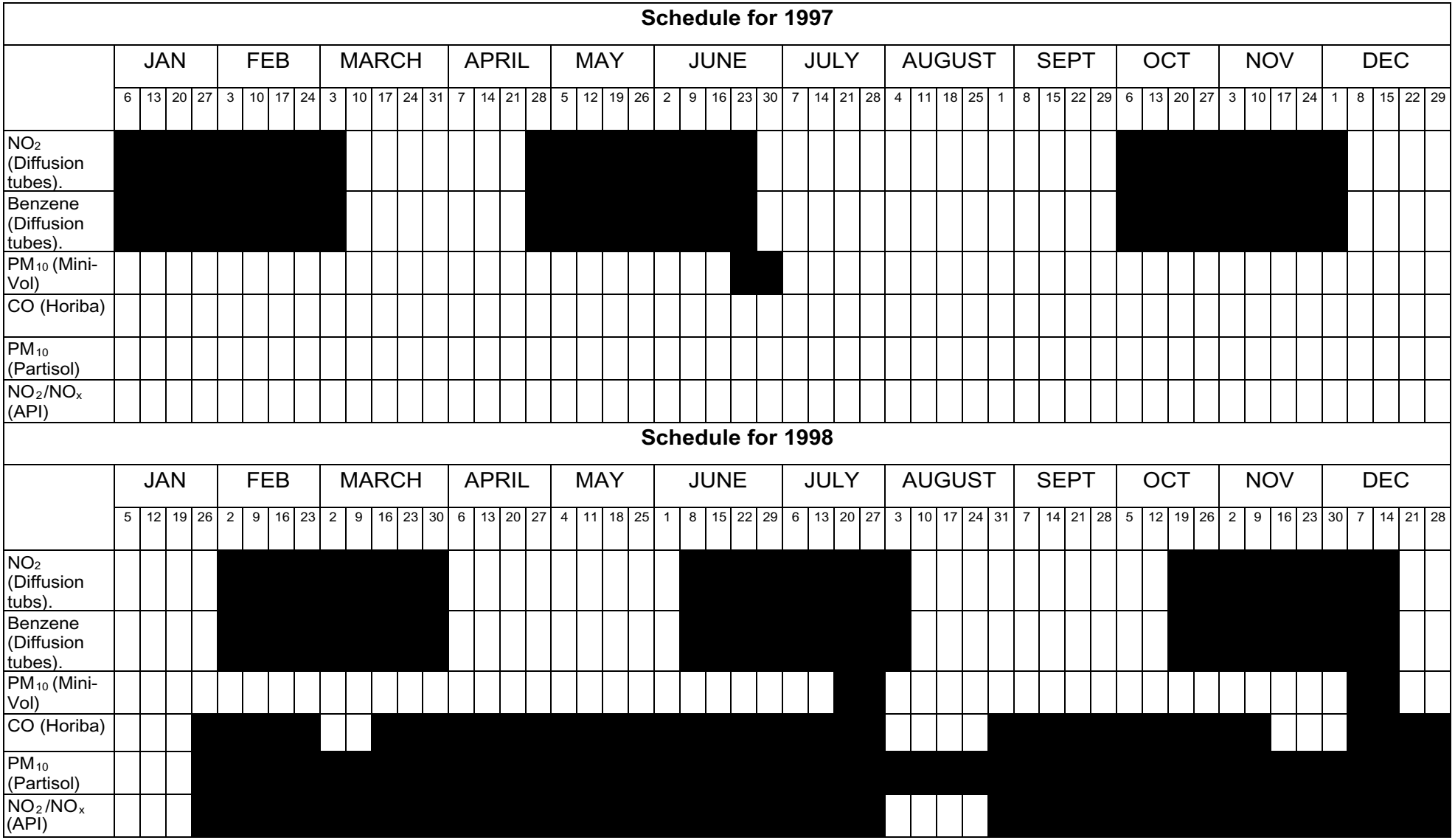



**Figure 2** Monitoring schedule

**Table 2 Mean benzene concentrations (ppb) in 1997**

| | *Elmbridge School* | *Northgate Street* | *King Edwards Avenue* | *Barton Street* | *Metz Way* | *Abbey -mead Avenue* | *Chel -tenham Road* | *Huccle -cote Road* | *Bristol Road* | *Finlay Road* | *Trier Way* |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Mean | 1.65 | 4.14 | 2.99 | 4.70 | 2.10 | 2.55 | 2.98 | 2.64 | 2.92 | 2.54 | 3.64 |
| Standard deviation | 0.84 | 1.27 | 1.37 | 1.76 | 1.17 | 1.33 | 1.31 | 1.33 | 0.88 | 1.04 | 1.34 |
| Minimum | 0.50 | 2.40 | 1.50 | 2.20 | 0.75 | 1.25 | 1.20 | 0.95 | 1.75 | 1.30 | 1.60 |
| Maximum | 2.80 | 6.15 | 5.60 | 7.65 | 4.60 | 4.85 | 5.60 | 5.10 | 4.70 | 4.45 | 5.50 |

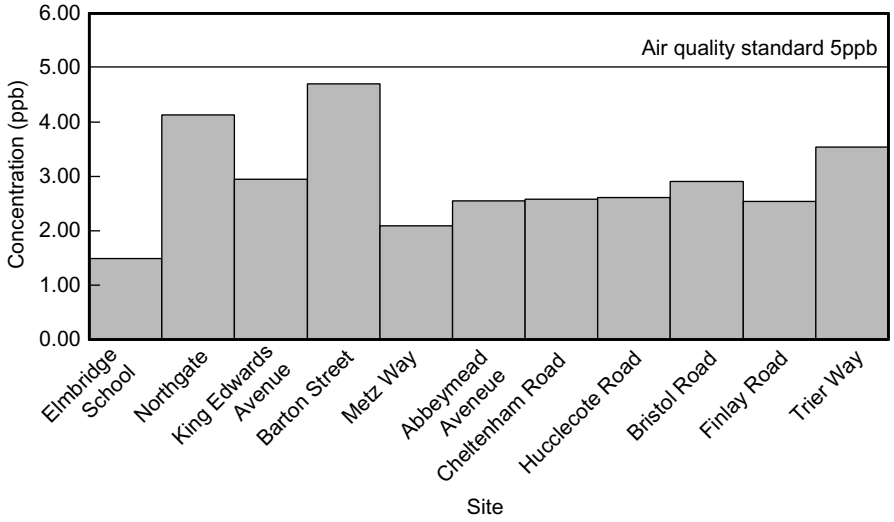



**Figure 3** Mean benzene concentrations in 1997

**Table 3 Mean nitrogen dioxide concentrations (µg/m$^3$) in 1997**

| | *Elmbridge School* | *Northgate Street* | *King Edwards Avenue* | *Barton Street* | *Metz Way* | *Abbey -mead Avenue* | *Chel -tenham Road* | *Huccle -cote Road* | *Bristol Road* | *Finlay Road* | *Trier Way* |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Mean | 29.90 | 58.00 | 44.43 | 58.10 | 46.52 | 44.09 | 50.29 | 45.18 | 63.25 | 56.43 | 51.23 |
| Standard deviation | 11.39 | 11.00 | 10.90 | 17.60 | 11.60 | 11.20 | 10.54 | 12.50 | 16.70 | 11.50 | 16.10 |
| Minimum | 10.30 | 30.60 | 27.20 | 39.00 | 28.20 | 28.50 | 28.60 | 19.20 | 33.70 | 37.40 | 11.80 |
| Maximum | 46.90 | 70.60 | 61.30 | 100.00 | 63.80 | 63.00 | 62.60 | 64.40 | 96.90 | 75.40 | 69.50 |

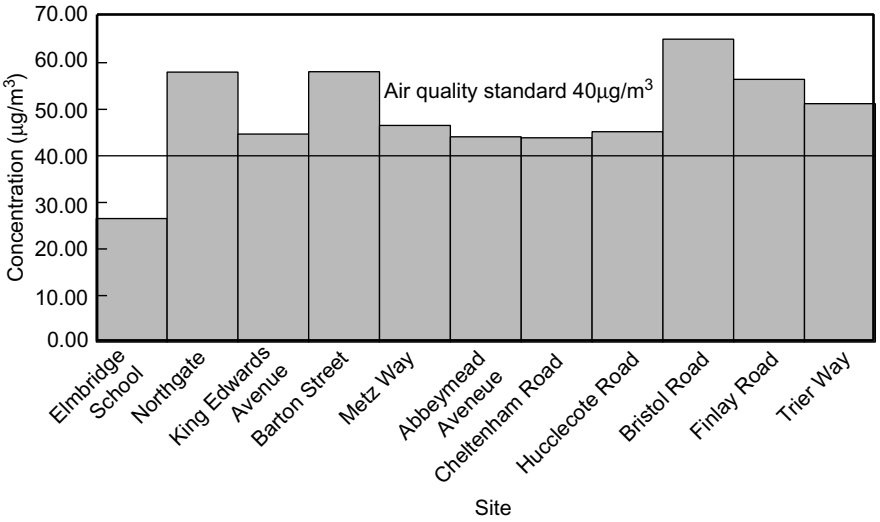



**Figure 4** Mean $NO_2$ concentrations in 1997

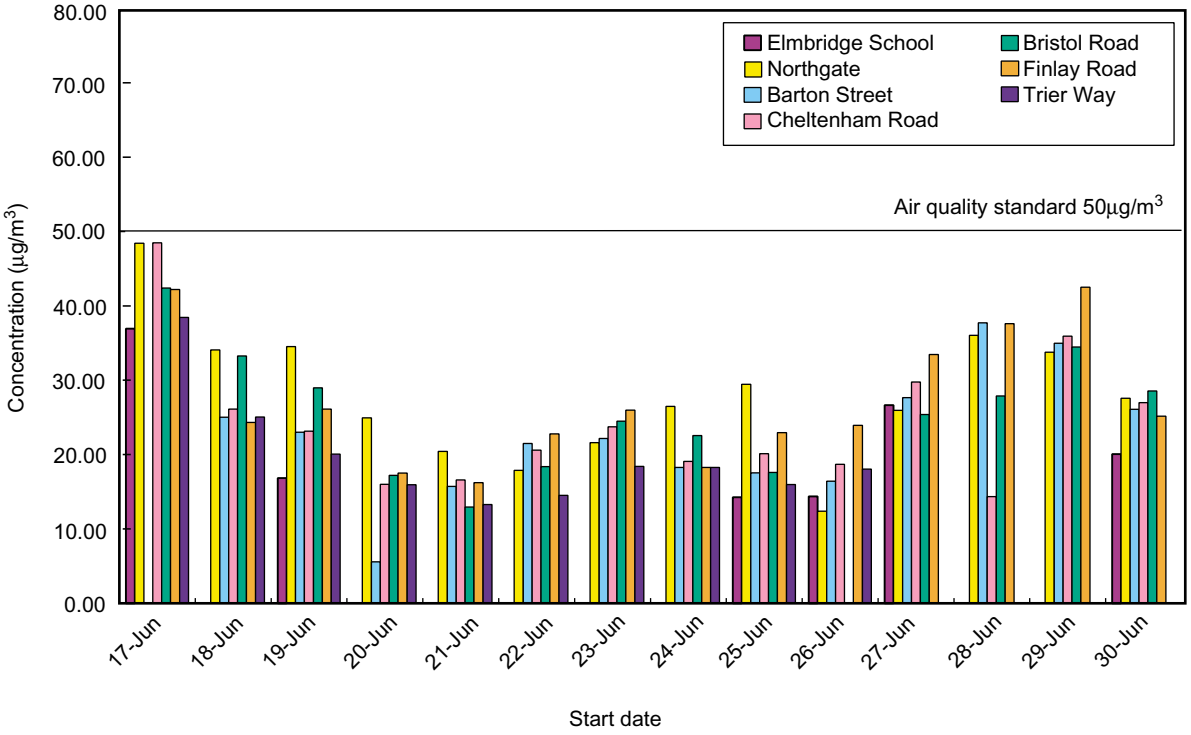



**Figure 5** Daily concentrations of $PM_{10}$, June 1997

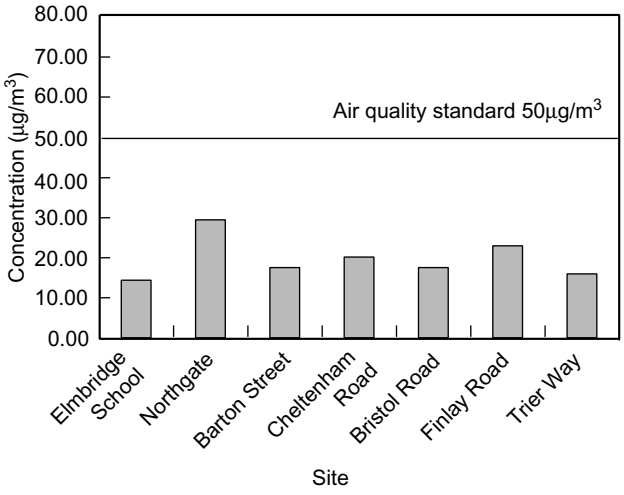



**Figure 6** Mean $PM_{10}$ concentrations on June 25, 1997

**Table 4 Mean $PM_{10}$ concentrations (µg/m3) in June 1997**

| | *Elmbridge School* | *North-gate Street* | *Barton Street* | *Chel-tenham Road* | *Bristol Road* | *Finlay Road* | *Trier Way* |
|---|---|---|---|---|---|---|---|
| Mean | 21.52 | 28.11 | 22.43 | 24.26 | 25.70 | 27.07 | 19.80 |
| Standard deviation | 8.84 | 9.02 | 8.40 | 9.11 | 8.17 | 8.61 | 7.32 |
| Minimum | 14.30 | 12.40 | 5.59 | 14.30 | 12.90 | 16.21 | 13.30 |
| Maximum | 36.90 | 48.40 | 37.70 | 48.50 | 42.40 | 42.50 | 38.40 |

## 3.2 Air quality in 1998

### *3.2.1 Benzene concentrations*

Table 5 summarises the results for 1998 and Figure 7 illustrates the mean concentration for each location (the raw data are given in Table B4 in Appendix B). The mean kerbside concentration in Gloucester was 2.22 ppb and at the background site 0.77 ppb. The highest values were found on Barton Street (4.19 ppb) and Cheltenham Road (2.53 ppb) and Trier Way (2.40 ppb). Mean benzene concentrations at all sites were below the Air Quality Standard of 5 ppb.

Statistical analysis of the data showed that concentrations on Barton Street and Elmbridge School were significantly different to those at the other locations. In addition it was found that the concentrations on either side of the road were significantly different from each other on Barton Street, Bristol Road and Trier Way. These differences were found to be consistent as the concentrations on each side of the road were found to be linearly correlated. Large differences were also seen at Abbeymead Avenue, although these were not found to be significant.

### *3.2.2 Oxides of nitrogen*

*3.2.2.1 Nitrogen dioxide diffusion tubes*

Table 6 summarises the results for 1998 and Figure 8 illustrates the mean concentrations for each location (the raw data are given in Table B5 in Appendix B). The mean kerbside concentration in Gloucester was 46.0 µg/m$^3$ and at the background site 32.1 µg/m$^3$. The highest values were found on Bristol Road (53.9 µg/m$^3$), Barton Street (51.1 µg/m$^3$) and Finlay Road (51.1 µg/m$^3$). Mean $NO_2$ concentrations at all the kerbside sites other than King Edwards Avenue and Abbeymead Avenue were above the Air Quality Standard of 40 µg/m$^3$. The background $NO_2$ concentration at Elmbridge School was below the Air Quality Standard.

Statistical analysis of the data showed that concentrations on Bristol Road and Elmbridge School were significantly different to those at the other locations. It was also found that there was a significant difference between concentrations on either side of the road for Metz Way, Bristol Road and Trier Way. These differences either side of the road were not found to be consistent as there was poor correlation between concentrations on each side of the road. Large differences were also seen for Barton Street and Hucclecote Road, although these were not found to be significant.

*3.2.2.2 Continuous monitoring of $NO_2$ at Elmbridge School*

Table 7 summarises the annual and monthly average $NO_2$ concentrations as measured at Elmbridge School using an APi series 200 $NO_X$ analyser. Figure 9 shows the hourly concentrations for the whole year. The annual mean concentration was 29.1 µg/m$^3$, with a maximum hourly concentration of 211 µg/m$^3$ occurring during March: hourly concentrations were thus above the Air Quality Standard of 200 µg/m$^3$. Gaps in the data are due to analyser or data logging malfunction.

*3.2.2.3 Comparison between the two $NO_2$ measurement methods*

An analysis of $NO_2$ concentrations as measured by diffusion tubes and the chemiluminescent analyser was carried out for the background site.

For measurements taken over the same 6 month period, the average $NO_2$ concentration as measured by diffusion tubes was 32.1 µg/m$^3$ and with the chemiluminescent analyser was 31.9 µg/m$^3$. The difference in the mean concentrations was not statistically significant. The small difference in concentrations may be partly due to the different sampling heights as the chemiluminescent analyser samples at 1.5 m, whereas the diffusion tubes are about 4 m above the ground.

The chemiluminescent analyser measured $NO_2$ concentrations almost continuously through 1998: the mean concentration over this period was 29.1 µg/m$^3$. The difference between this value and that for the diffusion tubes measuring over a 6 month period was not statistically significant.

This comparison demonstrates that the two very different methods give very similar results and that diffusion tubes placed throughout the city are giving valid results. It also demonstrates that a measurement period of 6 months can give a good approximation of the annual mean.

*3.2.2.4 Continuous monitoring of Nitric oxide (NO) at Elmbridge School.*

Concentrations of NO at the background site during 1998 are summarised in Table 8. The mean hourly annual concentration was 28.2 µg/m$^3$, with a maximum recorded concentration of 1531 µg/m$^3$ occurring during February.

### *3.2.3 $PM_{10}$ Concentrations*

*3.2.3.1 MiniVol samplers*

Daily $PM_{10}$ concentrations in Gloucester were measured at seven locations for a fortnight during both July and December (the raw data are given in Table B7 in Appendix B). The values show a great deal of variability as shown in Figure 10 and Figure 11. All average $PM_{10}$ concentrations over the monitored periods were below the Air Quality Standard of 40 µg/m$^3$ for an annual mean. Daily concentrations of $PM_{10}$ during 1998 were in general less than the Air Quality standard of 50 µg/m$^3$, but there were 3 exceedences of this value. Two occurred in the July survey and the other in December. As all three exceedences are 'outliers' within the data sets (mean plus 2 standard deviations) and occur on different dates and at different sites, it suggests that they could be due to very localised processes. For example, one of the exceedences occured in Northgate Street during July 1998 when construction work for pedestrianisation was taking place.

During July 1998 the mean concentration at the kerbside was 22.2 µg/m$^3$ and at the background was 12.6 µg/m$^3$. In general, concentrations were highest on Barton Street and Bristol Road and the lowest at Elmbridge School. Concentrations recorded at Trier Way and Elmbridge School were significantly lower than those at the other locations. Table 10 summarises the results for July 1998.

**Table 5 Mean benzene concentrations (ppb) in 1998**

| | *Elmbridge School* | *Northgate Street* | *King Edwards Avenue* | *Barton Street* | *Metz Way* | *Abbey -mead Avenue* | *Chel -tenham Road* | *Huccle -cote Road* | *Bristol Road* | *Finlay Road* | *Trier Way* |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Mean | 0.77 | 1.71 | 2.10 | 4.19 | 1.60 | 1.83 | 2.53 | 1.85 | 2.08 | 1.76 | 2.40 |
| Standard deviation | 0.47 | 1.13 | 0.92 | 1.48 | 0.77 | 1.02 | 1.05 | 0.99 | 0.82 | 0.73 | 1.05 |
| Minimum | 0.30 | 0.45 | 1.05 | 2.50 | 0.80 | 0.70 | 1.60 | 0.80 | 1.15 | 1.00 | 1.25 |
| Maximum | 1.80 | 3.45 | 3.75 | 6.80 | 3.35 | 4.15 | 4.60 | 4.20 | 3.75 | 3.40 | 4.60 |

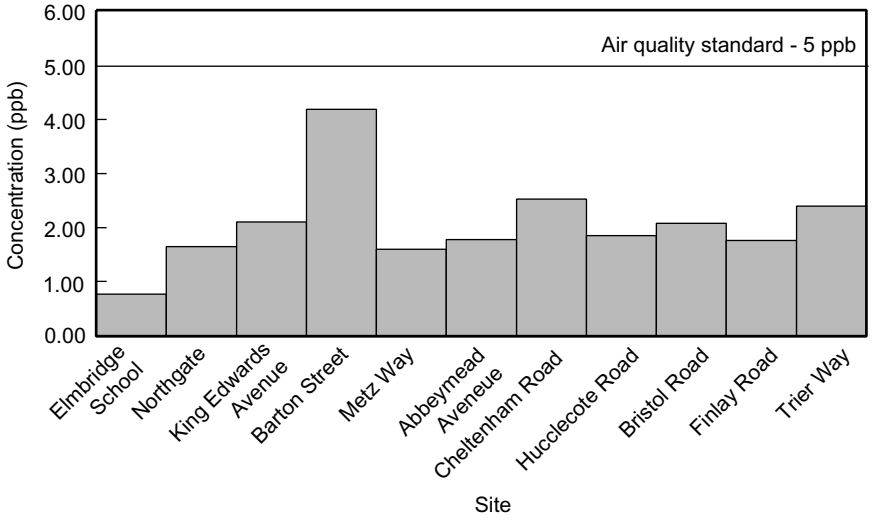



**Figure 7** Mean benzene conentration in 1998

**Table 6 Mean nitrogen dioxide concentrations (µg/m$^3$) in 1998**

| | *Elmbridge School* | *Northgate Street* | *King Edwards Avenue* | *Barton Street* | *Metz Way* | *Abbey -mead Avenue* | *Chel -tenham Road* | *Huccle -cote Road* | *Bristol Road* | *Finlay Road* | *Trier Way* |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Mean | 32.05 | 42.91 | 39.73 | 51.11 | 44.83 | 39.93 | 47.22 | 40.09 | 53.90 | 51.08 | 48.42 |
| Standard deviation | 11.09 | 17.36 | 12.67 | 9.70 | 9.76 | 9.86 | 9.64 | 9.73 | 10.11 | 8.99 | 10.95 |
| Minimum | 18.00 | 18.10 | 23.00 | 35.30 | 29.05 | 25.90 | 33.00 | 27.40 | 39.00 | 37.40 | 32.35 |
| Maximum | 50.80 | 74.15 | 57.95 | 64.20 | 60.45 | 57.00 | 66.50 | 53.95 | 72.05 | 69.75 | 64.15 |

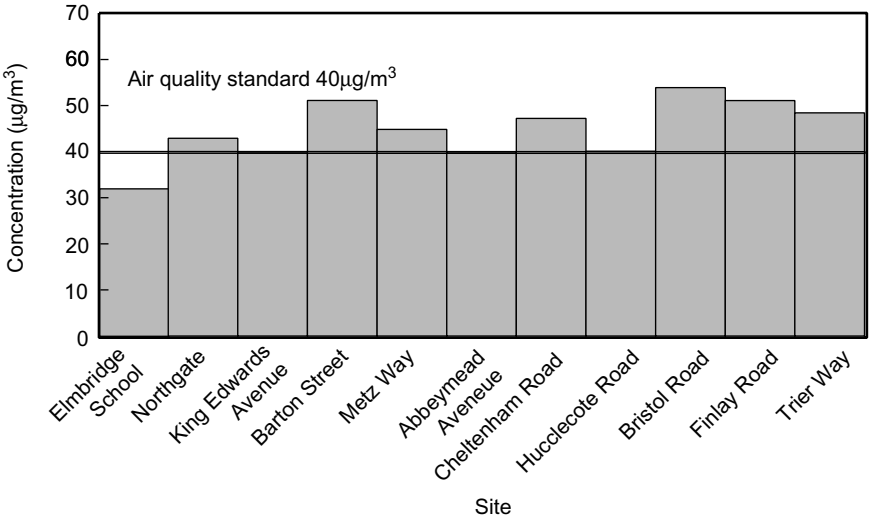



**Figure 8** Mean nitrogen dioxide concentrations in 1998

**Table 7 Annual and monthly nitrogen dioxide concentration (µg/m³) in 1998 as measured at Elmbridge School using an APi Series 200 $NO_x$ analyser**

| | *Annual* | *Feb* | *Mar* | *Apr* | *May* | *Jun* | *Jul* | *Aug* | *Sept* | *Oct* | *Nov* | *Dec* |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Mean | 29.12 | 47.44 | 38.73 | 24.69 | 24.21 | 22.60 | 20.37 | 22.85 | 26.88 | 23.92 | 30.90 | 37.37 |
| Standard deviation | 18.48 | 26.19 | 18.75 | 15.02 | 17.65 | 9.92 | 8.42 | 9.44 | 15.79 | 12.25 | 17.42 | 19.33 |
| Minimum | 0.00 | 7.69 | 7.23 | 0.00 | 0.00 | 0.00 | 0.00 | 0.15 | 0.04 | 0.02 | 0.19 | 3.94 |
| Maximum | 233.90 | 216.12 | 233.90 | 79.27 | 116.83 | 57.58 | 56.83 | 64.02 | 92.38 | 67.50 | 94.40 | 109.04 |

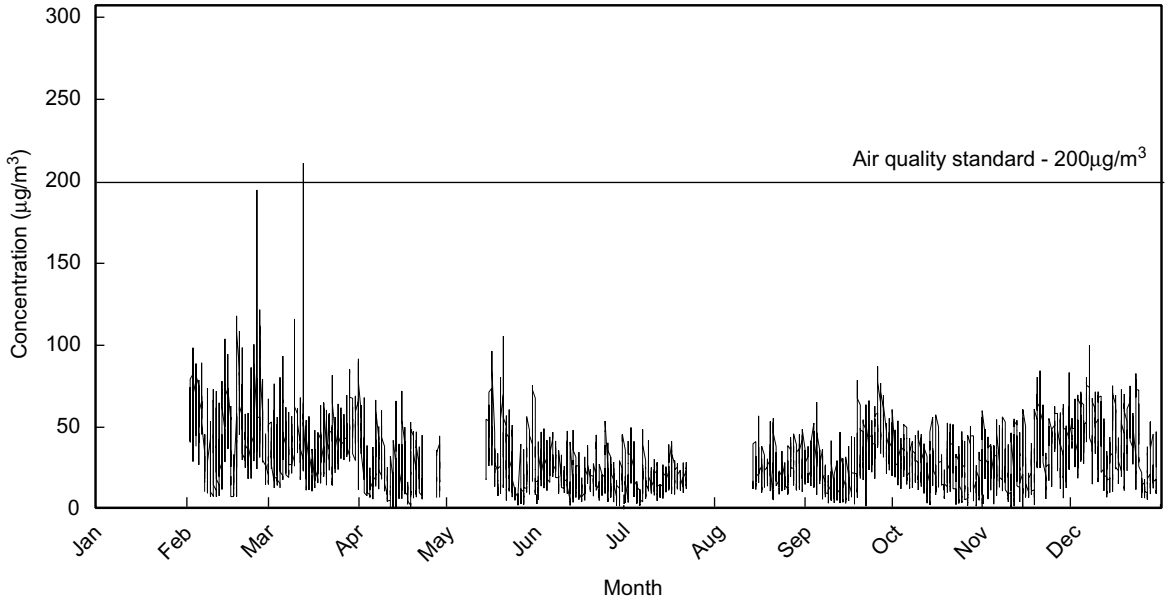



**Figure 9** Hourly nitrogen dioxide concentrations in 1998 as measured at Elmbridge School using an APi Series 200 analyser

**Table 8 Annual and monthly nitrogen oxide (NO) concentration (µg/m³) in 1998 as measured at Elmbridge School using an APi Series 200 $NO_x$ analyser**

| | *Annual* | *Feb* | *Mar* | *Apr* | *May* | *Jun* | *Jul* | *Aug* | *Sept* | *Oct* | *Nov* | *Dec* |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Mean | 28.21 | 42.75 | 33.40 | 15.58 | 17.73 | 13.02 | 11.96 | 20.75 | 18.48 | 24.75 | 63.71 | 47.98 |
| Standard deviation | 70.54 | 114.94 | 70.73 | 2 5.33 | 22.02 | 10.75 | 16.69 | 39.60 | 26.00 | 41.46 | 136.65 | 89.10 |
| Minimum | 0.00 | 0.92 | 0.00 | 0.00 | 6.44 | 3.56 | 2.29 | 0.00 | 2.04 | 0.33 | 0.00 | 2.56 |
| Maximum | 1530.85 | 1530.85 | 621.50 | 430.23 | 202.35 | 146.31 | 195.85 | 328.56 | 269.71 | 624.21 | 1137.52 | 1147.15 |

**Table 9 Annual and monthly mean oxides of nitrogen ($NO_x$) concentration (µg/m³) in 1998 measured at Elmbridge School using an APi Series 200 $NO_x$ analyser**

| | *Annual* | *Feb* | *Mar* | *Apr* | *May* | *Jun* | *Jul* | *Aug* | *Sept* | *Oct* | *Nov* | *Dec* |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Mean | 51.79 | 81.29 | 61.48 | 32.21 | 32.96 | 25.79 | 24.15 | 37.40 | 38.63 | 28.58 | 95.12 | 80.23 |
| Standard deviation | 80.21 | 124.63 | 75.57 | 33.88 | 31.69 | 16.10 | 19.90 | 41.35 | 31.63 | 44.79 | 142.48 | 100.15 |
| Minimum | 0.52 | 7.69 | 10.42 | 0.52 | 2.48 | 2.23 | 2.29 | 5.44 | 0.98 | 1.92 | 2.81 | 5.50 |
| Maximum | 1572.73 | 1572.73 | 846.73 | 474.27 | 261.77 | 157.79 | 19.85 | 333.15 | 276.40 | 645.21 | 1231.92 | 1241.77 |

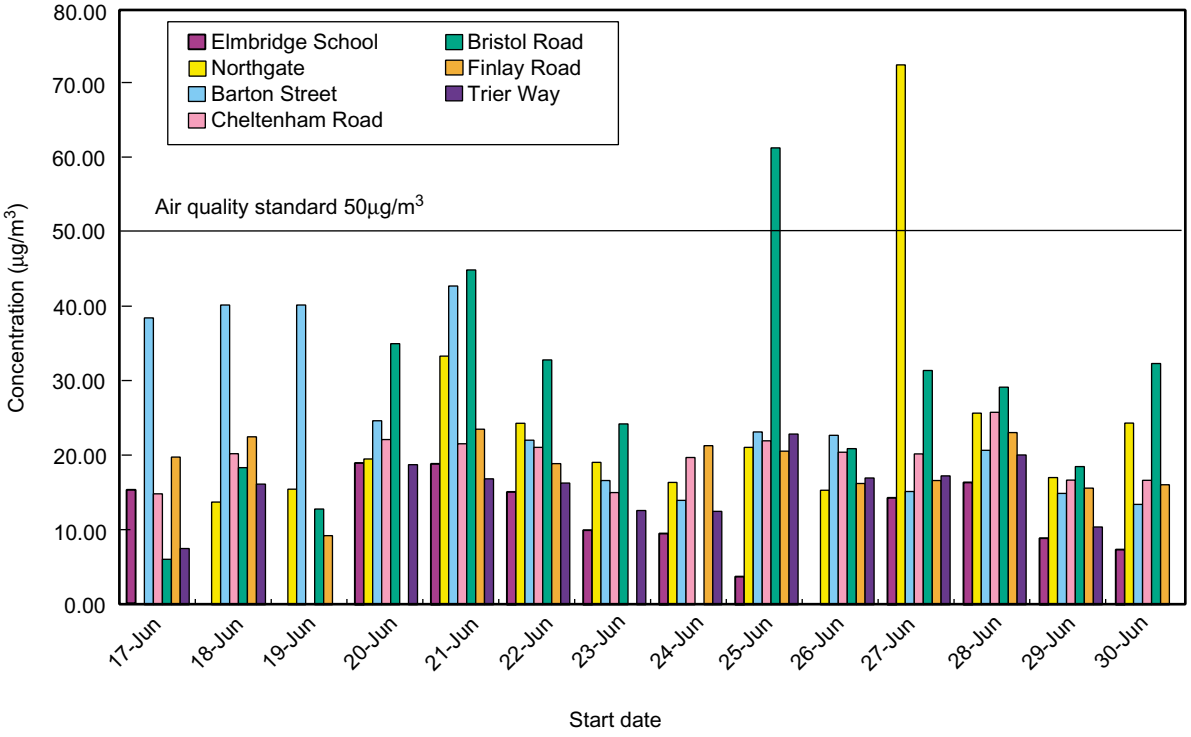



**Figure 10** Daily concentration of $PM_{10}$ in July 1998

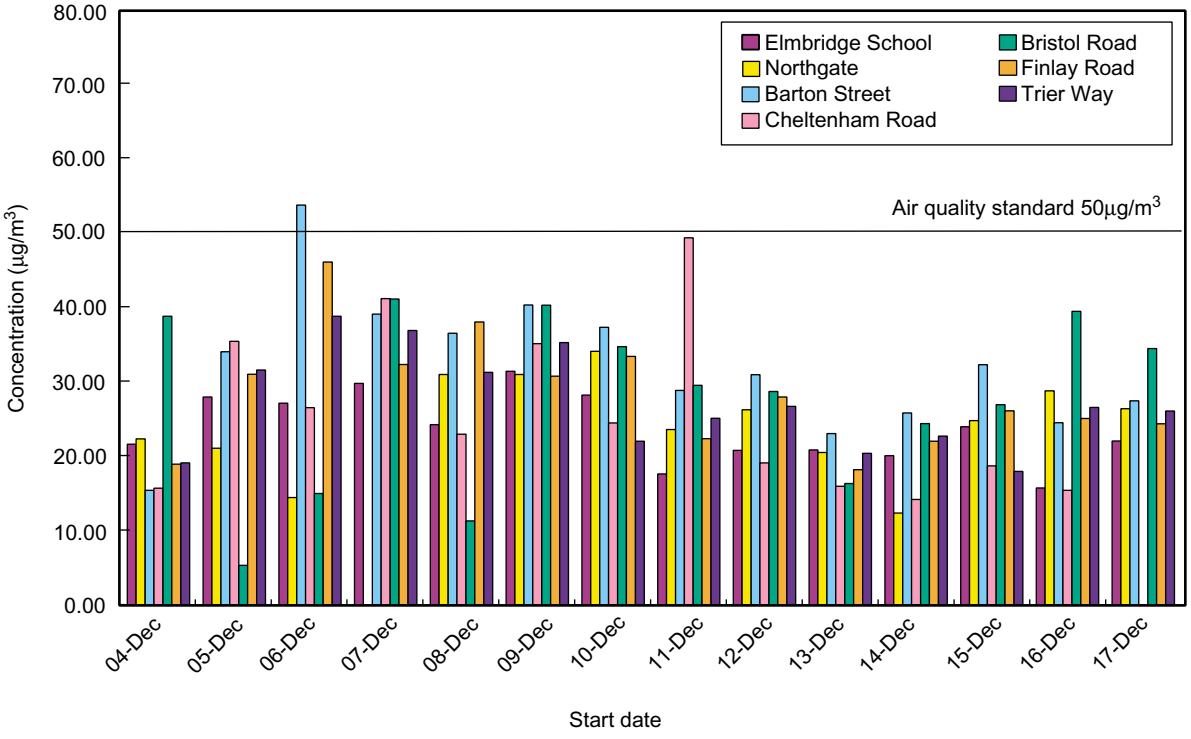



**Figure 11** Daily concentration of $PM_{10}$ in December 1998

**Table 10 Mean $PM_{10}$ concentrations (µg/m³) in July 1998**

| | *Elmbridge School* | *Northgate Street* | *Barton Street* | *Cheltenham Road* | *Bristol Road* | *Finlay Road* | *Trier Way* |
|---|---|---|---|---|---|---|---|
| Mean | 12.63 | 24.48 | 24.96 | 19.75 | 28.33 | 18.66 | 16.20 |
| Standard deviation | 4.98 | 15.40 | 9.95 | 4.76 | 13.21 | 5.69 | 3.53 |
| Minimum | 3.77 | 13.79 | 13.47 | 5.97 | 12.84 | 3.82 | 10.44 |
| Maximum | 19.03 | 72.47 | 42.79 | 25.83 | 61.33 | 23.57 | 22.90 |

During the December 1998 survey, the mean concentration at the kerbside was 27.1 µg/m³ and at the background was 23.6 µg/m³. In general concentrations were highest on Barton Street and the lowest at Elmbridge School and Northgate Street, but values at these locations were not significantly different to those at the others. Table 11 summarises the results for December 1998.

For both survey periods, the mean kerbside concentration in Gloucester was 24.9 µg/m³ and at the background site the mean was 18.8 µg/m³. Table 12 summarises the mean concentrations over the two survey periods. Taken as a whole, concentrations at the background were significantly lower than at the other locations. Concentrations on Barton Street and Bristol Road were the highest, but differences were not statistically significant.

*3.2.3.2 Background measurements using a Partisol 2000.*

Daily measurements were also made at the Elmbridge School background site using a Partisol 2000 sampler fitted with an automatic filter-change cartridge. The results for 1998 are summarised in Table 13 and Figure 12 illustrates the daily mean concentration for the whole year. Gaps in the data are due to instrument malfunction.

The annual mean of the daily concentrations using the Partisol sampler was 23.0 µg/m³, with a maximum daily concentration of 130.6 µg/m³ occurring during September. There were 23 days in 1998 where 50 µg/m³ was exceeded. The exceedences occurred mainly as one off events, however there were episodes where the concentration exceeded the proposed standard for 4 days running. $PM_{10}$ concentrations at the background site were therefore below the Air Quality Standard for the annual mean (40 µg/m³) and probably below the daily mean standard (50 µg/m³ not to be exceeded more than 35 times a year).

*3.2.3.3 Comparison between measurement methods*

An analysis of $PM_{10}$ concentrations as sampled by the MiniVol and the Partisol 2000 at the same location and over the same period showed good agreement in values. The average $PM_{10}$ concentration as measured by the MiniVol was 18.76 µg/m³ and 22.97 µg/m³ with the series 2000 Partisol. The difference in the concentrations was not statistically significant.

This demonstrates that the two different methods of sampling $PM_{10}$ are compatible. The Partisol sampler is a generally accepted method of sampling particulates but is not able to be battery operated like the MiniVol.

***3.2.4 Carbon monoxide concentrations.***

Carbon monoxide was monitored at the background site only. The results for 1998 are summarised in Table 14 and Figure 13 illustrates the hourly mean concentration for the whole year. The hourly mean concentration was 0.34 ppm, with a maximum of 9.82 ppm occurring during February. All concentrations were below the Air Quality Standard of 10 ppm (8-hour running average).

The lack of data during November was due to water ingress into the analyser. This has since been overcome by placing water traps in the inlet pipe and there has been no reoccurrence of the problem.

**Table 11 Mean $PM_{10}$ concentrations (µg/m³) in December 1998**

| | *Elmbridge School* | *Northgate Street* | *Barton Street* | *Cheltenham Road* | *Bristol Road* | *Finlay Road* | *Trier Way* |
|---|---|---|---|---|---|---|---|
| Mean | 23.63 | 24.31 | 32.04 | 25.66 | 27.55 | 28.29 | 27.13 |
| Standard deviation | 4.66 | 6.00 | 9.29 | 11.22 | 10.12 | 7.64 | 6.66 |
| Minimum | 15.71 | 12.36 | 15.41 | 14.17 | 11.31 | 18.16 | 17.95 |
| Maximum | 31.35 | 34.04 | 53.63 | 49.23 | 41.03 | 46.00 | 38.74 |

**Table 12 Mean $PM_{10}$ concentration (µg/m³) data combined for July and December 1998**

| | *Elmbridge School* | *Northgate Street* | *Barton Street* | *Cheltenham Road* | *Bristol Road* | *Finlay Road* | *Trier Way* |
|---|---|---|---|---|---|---|---|
| Mean | 18.79 | 24.40 | 28.50 | 22.71 | 27.93 | 23.84 | 22.08 |
| Standard deviation | 7.29 | 11.53 | 10.54 | 8.61 | 12.74 | 7.86 | 7.71 |
| Minimum | 3.77 | 12.36 | 13.47 | 5.97 | 11.31 | 3.82 | 10.44 |
| Maximum | 31.35 | 72.47 | 53.63 | 49.23 | 61.33 | 46.00 | 38.74 |

**Table 13 Annual and monthly $PM_{10}$ concentration (µg/m³) in 1998 measured at Elmbridge School with Partisol 2000 $PM_{10}$ sampler**

| | *Annual* | *Jan* | *Feb* | *Mar* | *Apr* | *May* | *Jun* | *Jul* | *Aug* | *Sept* | *Oct* | *Nov* | *Dec* |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Mean | 22.97 | 50.87 | 30.28 | 23.71 | 16.03 | 30.82 | 14.57 | 14.53 | 20.53 | 30.80 | 17.24 | 24.80 | 20.90 |
| Standard deviation | 17.20 | 37.31 | 15.34 | 13.05 | 9.33 | 20.12 | 6.59 | 5.71 | 13.39 | 30.17 | 7.22 | 14.03 | 9.53 |
| Minimum | 6.01 | 16.37 | 12.10 | 8.91 | 7.65 | 9.84 | 6.01 | 7.84 | 6.53 | 7.16 | 7.01 | 7.44 | 7.19 |
| Maximum | 130.62 | 119.97 | 68.39 | 53.43 | 46.73 | 91.55 | 39.69 | 34.82 | 71.26 | 130.62 | 30.74 | 57.87 | 51.00 |

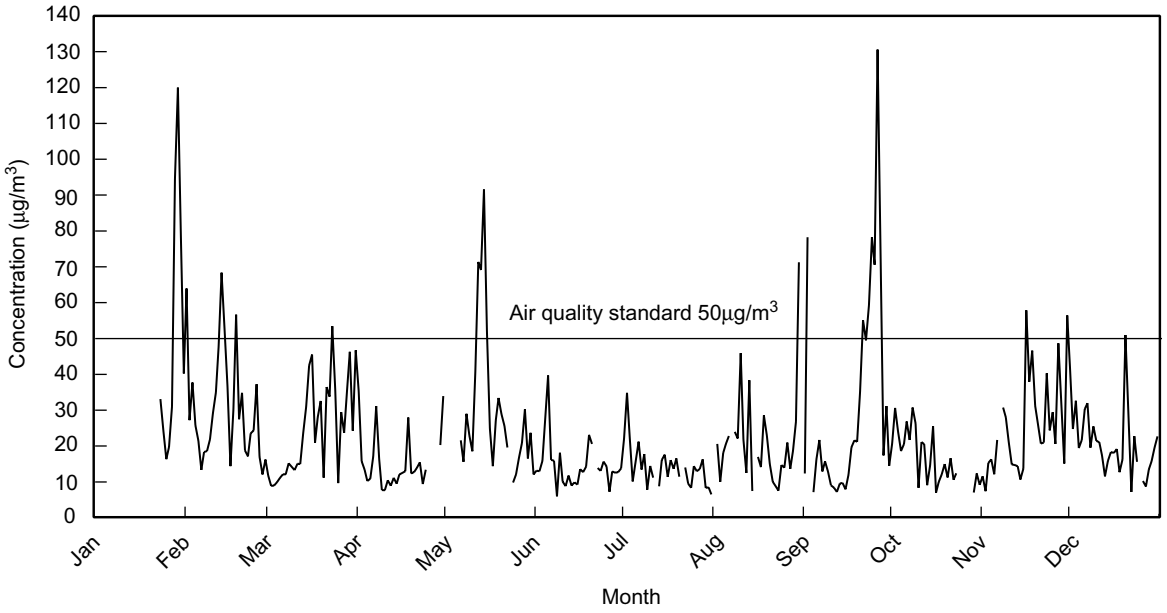



**Figure 12** Daily $PM_{10}$ concentration for 1998 measured at Elmbridge School with Partisol 2000 $PM_{10}$ sampler

**Table 14 Annual and monthly hourly average carbon monoxide concentrations (ppb) in 1998 measured at Elmbridge School using a Horiba CO analyser**

| | *Annual* | *Feb* | *Mar* | *Apr* | *May* | *Jun* | *Jul* | *Aug* | *Sept* | *Oct* | *Nov* | *Dec* |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Mean | 0.34 | 0.68 | 0.31 | 0.24 | 0.24 | 0.15 | 0.21 | 0.36 | 0.35 | 0.43 | N/A | 0.32 |
| Standard deviation | 0.37 | 0.78 | 0.31 | 0.15 | 0.12 | 0.06 | 0.09 | 0.15 | 0.17 | 0.27 | N/A | 0.41 |
| Minimum | 0.01 | 0.03 | 0.01 | 0.01 | 0.08 | 0.02 | 0.01 | 0.07 | 0.02 | 0.02 | N/A | 0.01 |
| Maximum | 9.82 | 9.82 | 2.16 | 1.90 | 1.03 | 0.54 | 0.67 | 0.88 | 1.16 | 2.83 | N/A | 3.23 |

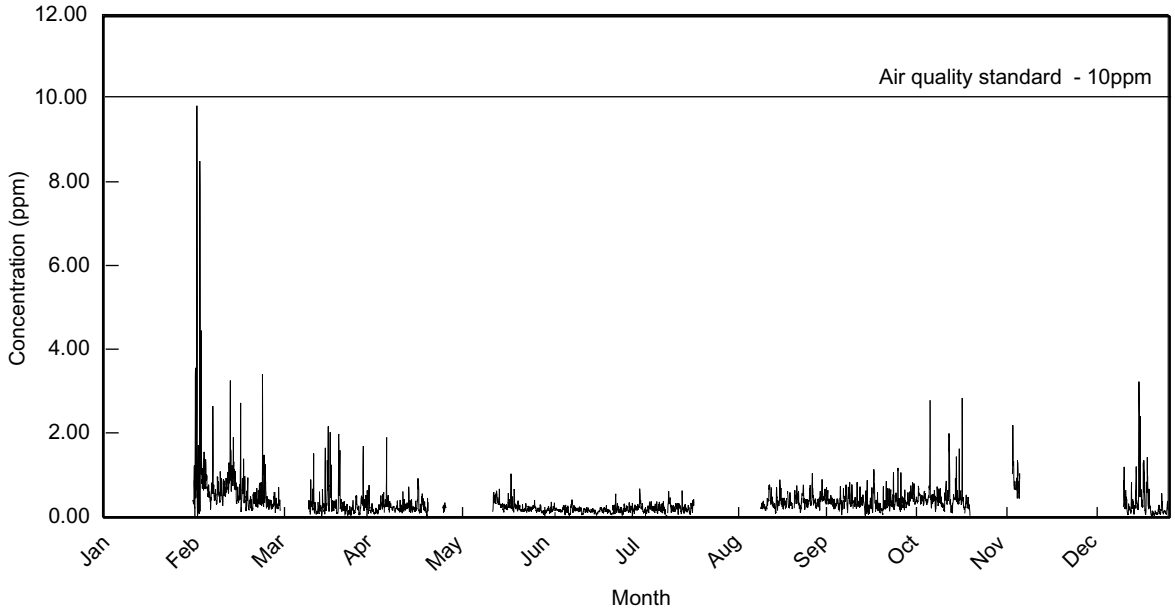



**Figure 13** Hourly average carbon monoxide concentrations in 1998 measured at Elmbridge School

# 4 Traffic and emissions

## 4.1 Traffic safety measures installed

During the period this report covers (i.e. 1997 and 1998) a number of safety and traffic management measures were implemented, and these are listed in Table 15.

## 4.2 Flows and speeds

### 4.2.1 Survey locations

Automatic traffic flows and speeds (unclassified) have been measured routinely (and since 1998 continuously) by TRL at all the locations where kerbside air quality is measured, except for Northgate Street.

Classified traffic counts have been obtained in November of each year to coincide with the drive cycle surveys carried out to provide an input to emissions modelling: the sites where classified counts were obtained are Northgate (1997 only), Barton Street, Cheltenham Road, Metz Way, Bristol Road, Finlay Road and Trier Way.

### *4.2.2 Traffic flows*

Daily traffic flows for 1997 and 1998 are shown in Table 16 and Table 17 respectively. It should be noted that only in 1998 were traffic data collected continuously at these sites. Traffic flows are highest, and normally in excess of 25,000 vehicles/day, on Trier Way and Finlay Road. The lowest traffic flows are seen on King Edwards Avenue with less than 6500 vehicles/day.

Comparing the 1997 and 1998 data for September and December, in general traffic flows were higher in 1998 on Finlay Road, Abbeymead Avenue and Hucclecote Road: flows were reduced on King Edwards Avenue, Barton Street, Bristol Road, Metz Way and Cheltenham Road.

### *4.2.3 Classified traffic counts*

Traffic flows for 1997 and 1998, classified according to the number of cars/taxis and medium and heavy goods vehicles (M&HGVs), are shown in Table 18 and Table 19 respectively. Bristol Road and Finlay Road have the highest proportion of M&HGVs (about 8% and 6% respectively). Cheltenham Road and Barton Street have the lowest proportions of HGVs (less than 3%). In general, 1998 saw an increase in the number and overall proportion of M&HGVs in the traffic.

### *4.2.4 Traffic speeds*

Average daily traffic speeds for 1997 and 1998 are shown in Table 20 and Table 21 respectively. In general the lowest speeds were observed on Barton Street and King

**Table 15 Traffic management and safety measures installed (November 1996 to November 1998)**

| *Description* | *Started* | *Finished* | *Location* |
|---|---|---|---|
| Anti-skid surfacing | 3/97 | 3/97 | Cheltenham Road |
| Anti-skid surfacing | 11/96 | 11/96 | Metz Way |
| Anti-skid surfacing | 11/96 | 12/96 | Eastern Avenue/Metz Way |
| Anti-skid surfacing | 11/96 | 11/96 | Eastern Avenue/Coney Hill |
| Anti-skid surfacing | 2/97 | 3/97 | Eastern Avenue/Painswick |
| Anti-skid surfacing | 3/97 | 3/97 | Parkend Road/Trier Way |
| Carriageway narrowing / cycle lane | 7/97 | 9/97 | Finlay Road |
| Gateway | 4/97 | 9/97 | Bristol Road |
| Gateway | 4/97 | 9/97 | Stroud Road |
| Gateway | 6/97 | 9/97 | Painswick Road |
| Gateway | 6/97 | 9/97 | Hucclecote Road |
| Gateway | 6/97 | 9/97 | Cheltenham Road |
| Gateway | 5/97 | 9/97 | Innsworth Lane |
| Gateway | 5/97 | 9/97 | Longford Lane |
| Gateway | 5/97 | 9/97 | Tewksbury Road |
| Speed camera | 2/97 | 4/97 | Bristol Road/Linden Road |
| Speed camera | 2/97 | 4/97 | Bristol Road/Philip Street |
| Speed camera | 2/97 | 4/97 | Stroud Road |
| Speed camera | 2/97 | 4/97 | Eastern Avenue/Metz Way |
| Speed camera | 2/97 | 4/97 | Eastern Avenue/Carne Place |
| Signal modifications | 2/97 | 5/97 | Painswick Road/Heron Way |
| Area-wide scheme | 3/97 | 9/97 | Elmbridge |
| Pedestrian refuges | 10/96 | 3/97 | London Road |
| Toucan | 2/97 | 4/97 | Severndale Drive |
| Roundabout | – | – | St. Oswald's |
| Area-wide traffic calming | 11/97 | 07/98 | Longlevens (Cheltenham Road[1]) |
| Various traffic calming | 2/98 | 6/98 | Tredworth Road |
| Pedestrianisation | 4/98 | 5/99 | Northgate/Southgate |

[1] *On Cheltenham the measures included a raised pedestrian crossing, a set of speed cushions, a bus lane, cycle lanes and modifications to traffic signals.*

## Table 16 Average daily two-way traffic flows in 1997

| | *Jan/Feb* | *May/June* | *September* | *December* |
|---|---|---|---|---|
| King Edwards Avenue | n/a | 6119 | 6308 | 6409 |
| Barton Street | 7846 | 11994 | 11919 | 11944 |
| Metz Way | 13842 | 18803 | 17377 | 19007 |
| Abbeymead Avenue | 14440 | 15975 | 15478 | 16398 |
| Cheltenham Road | 13663 | 13571 | 13691 | 14563 |
| Hucclecote Road | 13375 | 13993 | 14141 | 14342 |
| Bristol Road | 21305 | 22877 | 22483 | 25712 |
| Finlay Road | 21647 | 26877 | 24396 | 25712 |
| Trier Way | n/a | 27734 | 25560 | 28258 |

## Table 17 Average daily two-way traffic flows in 1998

| *Location* | *Jan* | *Feb* | *March* | *April* | *May* | *June* | *July* | *August* | *Sept* | *Oct* | *Nov* | *Dec* | *Average* |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| King Edwards Avenue | 5800 | 6028 | 6203 | 6400 | 6188 | 6313 | 6336 | 5860 | 6200 | 5980 | 6205 | 5698 | 6101 |
| Barton Street | 11003 | 11260 | 11185 | 11696 | 11332 | 11414 | 11577 | 11146 | 11090 | 11551 | 11546 | 11870 | 11389 |
| Metz Way | 16057 | 18134 | 17729 | 17982 | 17344 | 17676 | 17910 | 17219 | 17824 | 18025 | 18360 | 17989 | 17687 |
| Abbeymead Avenue | 14983 | 15586 | 16003 | 16377 | 15909 | 16070 | 15969 | 15118 | 16079 | 15963 | 16071 | 16573 | 15892 |
| Cheltenham Road | 14235 | 13964 | – | 12138 | 10603 | 12439 | 12481 | 12211 | 12245 | 12548 | 12798 | 11471 | 12467 |
| Hucclecote Road | 13606 | 14770 | 14877 | 14916 | 14453 | 14815 | 14387 | 13941 | 14491 | 14721 | 14734 | 14628 | 14528 |
| Bristol Road | 20909 | 22427 | 22507 | 22551 | 21620 | 21441 | 21660 | 21943 | 21685 | 21875 | 21922 | 22184 | 21894 |
| Finlay Road | 25183 | 26083 | 26425 | 26889 | 26226 | 26351 | 26490 | 25760 | 26127 | 26748 | 26410 | 26685 | 26281 |
| Trier Way | 25628 | 25791 | 26597 | 27717 | 24690 | 27608 | 27833 | 20301 | – | 27381 | – | – | 25950 |

## Table 18 Classified traffic counts November 1997

| | *Northgate Street* | *Barton Street* | *Metz Way* | *Cheltenham Road* | *Bristol Road* | *Finlay Road* | *Trier Way* |
|---|---|---|---|---|---|---|---|
| ***12 – hour*** | | | | | | | |
| Cars and taxis (%) | 5149 (75) | 7755 (82) | 15750 (91) | 11088 (87) | 12347 (76) | 15834 (77) | 16640 (88) |
| Medium and heavy goods (%) | 294 (4.3) | 233 (2.4) | 449 (2.6) | 271 (2.1) | 1377 (8.4) | 1256 (6.2) | 448 (2.4) |
| Total vehicles | 6905 | 9538 | 17282 | 12780 | 16329 | 20139 | 18965 |
| ***Peak hour*** | | | | | | | |
| Cars and taxis (%) | 519 (74) | 548 (76) | 1663 (91) | 1292 (89) | 1414 (76) | 1780 (80) | 1610 (86) |
| Medium and heavy goods (%) | 35 (5.0) | 19 (2.6) | 37 (2.0) | 19 (1.3) | 155 (8.4) | 109 (4.9) | 43 (2.3) |
| Total vehicles | 701 | 723 | 1834 | 1449 | 1850 | 2234 | 1863 |

## Table 19 Classified traffic counts in November 1998

| | *Barton Street* | *Metz Way* | *Cheltenham Road* | *Bristol Road* | *Finlay Road* | *Trier Way* |
|---|---|---|---|---|---|---|
| ***12 – hour*** | | | | | | |
| Cars and taxis (%) | 8637 (84) | 15791 (90) | 10566 (84) | 15402 (79) | 16103 (78) | 18146 (87) |
| Medium and heavy goods (%) | 286 (2.8) | 587 (3.4) | 318 (2.5) | 1478 (7.6) | 1276 (6.2) | 646 (3.1) |
| Total vehicles | 10288 | 17454 | 12505 | 19446 | 20511 | 20862 |
| ***Peak hour*** | | | | | | |
| Cars and taxis (%) | 933 (85) | 1843 (94) | 1482 (88) | 1892 (87) | 1763 (80) | 2017 (90) |
| Medium and heavy goods (%) | 36 (3.3) | 31 (1.6) | 36 (2.1) | 98 (4.5) | 108 (6.1) | 33 (1.5) |
| Total vehicles | 1097 | 1961 | 1689 | 2169 | 2214 | 2251 |

**Table 20 Average daily traffic speeds (mph) in 1997**

| | *King Edwards Avenue* | *Barton Street* | *Metz Way* | *Abbeymead Avenue* | *Cheltenham Road* | *Hucclecote Road* | *Bristol Road* | *Finlay Road* | *Trier Way* |
|---|---|---|---|---|---|---|---|---|---|
| Jan/Feb | 20.3 | 23.9 | 40.3 | 33.1 | 31.9 | 31.2 | 32.6 | 39.1 | 28.7 |
| May/June | 25.3 | 23.4 | 41.3 | 33.7 | 31.6 | 30.1 | 31.2 | 35.9 | 31.7 |
| Sept | 26.7 | 24.4 | 40.8 | 33.1 | 30.6 | 30.3 | 31.9 | 33.6 | 32.3 |
| Dec | 27.1 | 24.9 | 40.8 | 32.3 | 31.6 | 29.9 | 31.5 | 32.5 | 32.1 |
| Average | 24.9 | 24.2 | 40.8 | 33.1 | 31.4 | 30.4 | 31.8 | 35.3 | 31.2 |

**Table 21 Average daily traffic speeds (mph) in 1998**

| *Location* | *Jan* | *Feb* | *March* | *April* | *May* | *June* | *July* | *August* | *Sept* | *Oct* | *Nov* | *Dec* | *Average* |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| King Edwards Avenue | 26.4 | 26.3 | 26.4 | 27.0 | 27.0 | 26.6 | 26.8 | 26.6 | 26.4 | 26.8 | 26.6 | 26.5 | 26.6 |
| Barton Street | 25.2 | 25.2 | 24.9 | 25.2 | 25.1 | 24.8 | 24.8 | 24.7 | 24.5 | 24.9 | 24.9 | 24.7 | 24.9 |
| Metz Way | 40.8 | 40.7 | 40.7 | 40.8 | 41.2 | 41.0 | 41.1 | 42.1 | 41.1 | 40.9 | 40.1 | 39.9 | 40.9 |
| Abbeymead Avenue | 34.2 | 34.6 | 34.8 | 35.3 | 35.5 | 35.2 | 36.2 | 35.8 | 34.9 | 35.0 | 34.4 | 33.4 | 34.9 |
| Cheltenham Road | 31.4 | 31.3 | N/A | 28.1 | 23.9 | 23.5 | 23.4 | 23.5 | 23.4 | 23.5 | 23.5 | 23.8 | 25.4 |
| Hucclecote Road | 30.8 | 29.9 | 29.8 | 31.0 | 31.7 | 30.9 | 30.9 | 31.7 | 30.0 | 29.9 | 29.8 | 29.4 | 30.5 |
| Bristol Road | 31.4 | 31.5 | 31.7 | 32.0 | 31.6 | 31.1 | 30.9 | 31.4 | 31.6 | 31.6 | 31.2 | 31.2 | 31.4 |
| Finlay Road | 32.4 | 32.7 | 32.9 | 33.6 | 33.6 | 33.1 | 33.2 | 33.5 | 32.5 | 32.7 | 32.7 | 32.5 | 33.0 |
| Trier Way | 31.8 | 32.2 | 32.1 | 31.5 | 31.6 | 31.4 | 31.1 | 31.5 | N/A | 31.4 | N/A | N/A | 31.6 |

Edwards Avenue, and also on Cheltenham Road after April 1998: all three roads have a speed limit of 30 mph. The highest speeds were in general observed on Metz Way, which has a 40 mph speed limit. In 1998, speeds increased on Abbeymead Avenue and King Edwards Avenue (by about 2 mph) and reduced on Finlay Road (by 2 mph) and Cheltenham Road (by 6 mph)

### 4.3 Emissions

#### *4.3.1 Method of estimation*

In addition to the measurement of air quality in Gloucester, changes in emissions from traffic as a result of the Safer City Project are being estimated. The main experimental work involves driving an instrumented car along a number of routes in Gloucester to measure vehicle speed. This speed information is then input into the MODEM emission model to determine emissions of CO, $NO_x$, carbon dioxide ($CO_2$) and total hydrocarbons (HC, which include benzene) from light-duty vehicles. For heavy-duty vehicles, empirically derived functions are used, which relate emissions to average speed. The exercise is repeated annually in November, the first survey being in 1996. A full description of the method and results for the first three surveys can be found in Boulter (2000).

#### *4.3.2 Traffic emissions on individual links and city-wide*

A number of the drive cycle links coincide with the air quality monitoring locations and average daily emission rates for these have been calculated and are presented in Table 22. Emissions of CO and HC are highest on Trier Way, whilst those of $NO_x$ are generally highest on Finlay Road. This is consistent with the highest traffic flows being generally on Trier Way, with Finlay Road having a high traffic flows and a large proportion of HGVs. Figure 14 shows that in general emissions of CO and HC reduced between 1996 and 1998. Emissions of $NO_x$ either reduced or remained the same over the period, except for on Metz Way where there was a slight increase.

Over the whole city, emissions from traffic steadily decreased over the period November 1996 to November 1998. During 1996-7 CO, HC and $NO_x$ emissions reduced by 4%, 6% and 6% respectively; during 1997/8 they were reduced by a further 8%, 6% and 6%. This was due principally to the increase in the proportion of catalyst-equipped vehicles into the light-duty vehicle fleet. A comparison of the estimated changes in emissions and the measured changes in air quality is made in section 5.3.

## 5 Discussion

### 5.1 Air quality in Gloucester

#### *5.1.1 Benzene concentrations*

Mean benzene concentrations during the periods sampled in 1997 and 1998 are shown in Table 23 and illustrated in Figure 15. Also shown are the differences in concentrations between the years and their significance.

In both years benzene concentrations at all of the sites were below the Air Quality Standard of 5 ppb. At most of the sites concentrations were well below this Standard, except for on Barton Street (4.70 ppb in 1997; 4.19 ppb in 1998) and on Northgate Street before it was closed to traffic (4.14 ppb in 1997).

The mean concentrations fell at all kerbside locations between 1997 and 1998. The mean of all kerbside sites fell by 29% from 3.12 ppb to 2.22 ppb during this period and the decrease is statistically significant. During 1998, Northgate Street was closed to traffic in preparation for pedestrianisation, and here the greatest reduction (59%) in concentration was seen. This decrease in benzene concentrations is similar to those seen at the background site. If the values for Northgate are removed from the comparison, the reduction in mean kerbside concentration

**Table 22 Emissions from traffic in Gloucester (kg/km.day)**

| | *CO* | | | *HC* | | | *$NO_x$* | | | *$CO_2$* | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| *Site* | *1996* | *1997* | *1998* | *1996* | *1997* | *1998* | *1996* | *1997* | *1998* | *1996* | *1997* | *1998* |
| Metz Way | 109 | 125 | 124 | 14 | 16 | 16 | 22 | 23 | 23 | 1784 | 2095 | 2243 |
| | 98 | 109 | 105 | 13 | 14 | 13 | 21 | 21 | 21 | 1612 | 1829 | 1950 |
| Trier Way | 261 | 206 | 188 | 35 | 27 | 25 | 38 | 33 | 35 | 3784 | 3327 | 3530 |
| | 286 | 229 | 245 | 39 | 30 | 32 | 34 | 29 | 33 | 3829 | 3400 | 4151 |
| Abbeymead Avenue | 90 | 87 | 81 | 12 | 11 | 10 | 19 | 18 | 17 | 1481 | 1537 | 1549 |
| | 88 | 86 | 79 | 12 | 11 | 10 | 18 | 17 | 16 | 1449 | 1514 | 1525 |
| Barton Street | 98 | 99 | 97 | 13 | 13 | 13 | 19 | 21 | 20 | 1637 | 1886 | 1969 |
| | 125 | 111 | 102 | 17 | 15 | 13 | 22 | 21 | 20 | 2108 | 2068 | 2044 |
| Hucclecote Road | 86 | 83 | 80 | 12 | 11 | 11 | 16 | 16 | 15 | 1358 | 1433 | 1479 |
| | 95 | 90 | 82 | 13 | 12 | 11 | 17 | 16 | 16 | 1498 | 1546 | 1541 |
| Bristol Road | 146 | 144 | 127 | 20 | 19 | 17 | 33 | 34 | 29 | 2696 | 2898 | 2694 |
| | 137 | 131 | 116 | 19 | 18 | 15 | 31 | 31 | 28 | 2531 | 2635 | 2538 |
| Finlay Road | 159 | 157 | 155 | 20 | 20 | 20 | 38 | 32 | 30 | 2942 | 2849 | 2962 |
| | 169 | 167 | 141 | 22 | 22 | 18 | 41 | 37 | 32 | 3198 | 3165 | 2910 |
| Cheltenham Road | 96 | 93 | 85 | 13 | 13 | 11 | 18 | 17 | 16 | 1493 | 1547 | 1579 |
| | 92 | 85 | 77 | 12 | 11 | 10 | 17 | 15 | 13 | 1464 | 1453 | 1385 |
| Northgate | 92 | 99 | – | 12 | 13 | – | 16 | 16 | – | 1606 | 1762 | – |
| | 88 | 68 | – | 12 | 9 | – | 14 | 13 | – | 1439 | 1290 | – |
| King Edwards Avenue | 55 | 53 | 52 | 7 | 7 | 7 | 9 | 9 | 9 | 841 | 868 | 933 |
| | 59 | 57 | 54 | 8 | 8 | 7 | 10 | 9 | 9 | 892 | 943 | 963 |

*(Adapted from Boulter, 2000)*

of 24% (from 3.00 ppb to 2.27 ppb) remains significant. At the other kerbside sites, reductions in concentration were generally of the order of 25-35%, except on Cheltenham Road (15%) and Barton Street (11%). At these latter locations the reductions were not statistically significant.

At the background location (Elmbridge School), mean concentrations fell by 53% over the monitoring period, from 1.65 ppb to 0.77 ppb; the difference is statistically significant.

Examining data from the National Air Quality Archive shows that there is a general decrease with time in benzene concentrations across the whole of the UK. Data from several sites in southern England and Wales are presented in Table 24. This shows that at these sites average benzene concentrations reduced by between 6% and 33%, which is not inconsistent with the reductions seen in Gloucester.

### *5.1.2 Nitrogen dioxide concentrations*

#### *5.1.2.1 Diffusion tube surveys*

Mean $NO_2$ concentrations during the periods sampled in 1997 and 1998 are shown in Table 25 and illustrated in Figure 16. Also shown are the differences in concentrations between the years and their significance.

In both years, $NO_2$ concentrations were close to or greater than the Air Quality Standard of 40 µg/m$^3$ at all the kerbside sites. The mean kerbside $NO_2$ concentration fell at all locations between 1997 and 1998. Over all kerbside locations, the mean concentration fell by 11% from 51.5 µg/m$^3$ to 46.0 µg/m$^3$, the difference was significantly different. When considered individually however, it is only on Northgate Street where the decrease in concentration (of 26%) is significant. If the values for Northgate Street are removed from the comparison, the reduction in mean kerbside concentration by 9% (from 50.8 µg/m$^3$ to 46.3 µg/m$^3$) remains significant.

At the background location (Elmbridge School), the mean $NO_2$ concentration increased by 7% from 29.9 µg/m$^3$ to 32.1 µg/m$^3$, the difference in concentration between the two years is not statistically significant.

#### *5.1.2.2 Continuous monitoring at the Background site*

Most hourly $NO_2$ concentrations in 1998 were below the Air Quality Standard of 200 µg/m$^3$, with the mean of the hourly concentrations being 29.1 µg/m$^3$. Figure 17 and Figure 18 show the diurnal NO, $NO_2$ and $NO_x$ concentrations in the summer months (April to September) and the winter months (October to March).

The maximum concentrations of $NO_x$ and NO occur at about 8 am during both summer and winter, coinciding with the morning peak in traffic activity: this demonstrates that even at the background site, vehicles are important source of $NO_x$. In the winter, there is also a broader peak of lesser magnitude around 7-8 pm. As the temperature increases during the day, there is generally more thermal mixing which tends to reduce concentrations.

In the summer, $NO_x$ concentrations rise steadily throughout the night to a second peak at 11 pm. As traffic flows tend to decrease after about 6 pm, then other processes such as local meteorology must be involved. For example, Gloucester is situated on the flat floodplain of the River Severn, with the Cotswold Hills to the east. As a result inversions that limit dispersion can often occur.

Because of the influence of photochemical activity, the profile of $NO_2$ concentrations throughout the day is slightly different. Like $NO_x$ and NO, there is a peak in concentration at 8 am in both the summer and winter.

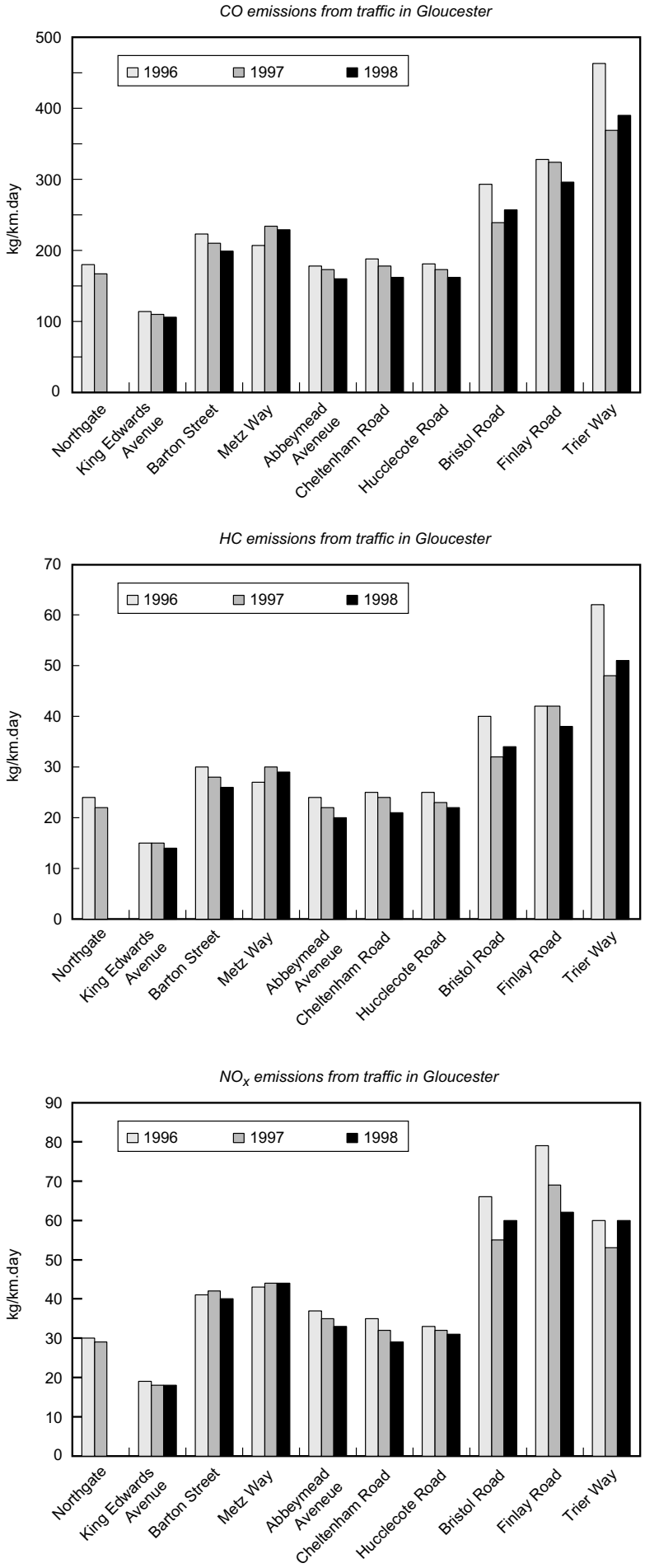



**Figure 14** The trend in emissions from traffic in Gloucester over the period 1996 to 1998

**Table 23 A comparison of mean benzene concentrations (ppb) in 1997 and 1998**

| | Mean kerbside | Elm -bridge School | North -gate | King Edwards Avenue | Barton Street | Metz Way | Abbey -mead Avenue | Chel -tenham Road | Huccle -cote Road | Bristol Road | Finlay Road | Trier Way |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1997 | 3.12 | 1.65 | 4.14 | 2.99 | 4.70 | 2.10 | 2.55 | 2.98 | 2.64 | 2.92 | 2.54 | 3.64 |
| 1998 | 2.22 | 0.77 | 1.71 | 2.10 | 4.19 | 1.60 | 1.88 | 2.53 | 1.85 | 2.08 | 1.76 | 2.40 |
| Difference | -0.90 | -0.88 | -2.43 | -0.89 | -0.51 | -0.50 | -0.67 | -0.45 | -0.79 | -0.84 | -0.78 | -1.24 |
| %Difference | -29 | -53 | -59 | -30 | -11 | -24 | -26 | -15 | -30 | -29 | -31 | -34 |
| Sample size | 237 | 12 | 24 | 24 | 24 | 22 | 23 | 24 | 24 | 24 | 24 | 24 |
| P value | $9.38x10^{-7}$ | 0.0045 | $1.02x10^{-3}$ | 0.073 | 0.488 | 0.252 | 0.187 | 0.363 | 0.128 | 0.029 | 0.045 | 0.025 |
| Significant? | Yes | Yes | Yes | No | No | No | No | No | No | Yes | Yes | Yes |

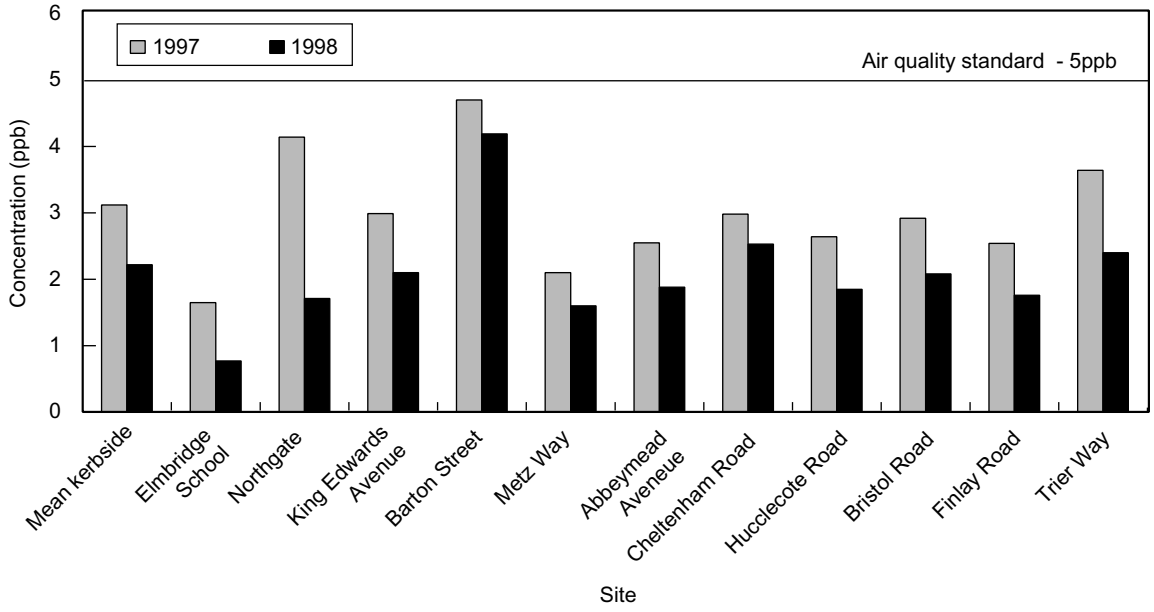



**Figure 15** Mean benzene concentrations in 1997 and 1998

**Table 24 Annual average benzene concentration (ppb) at selected sites in southern UK**

| *Site* | *1995* | *1996* | *1997* | *1998* |
|---|---|---|---|---|
| Harwell<br>Rural | 0.38 | 0.38<br>(0%) | 0.35<br>(-9%) | 0.33<br>(-6%) |
| Bristol East<br>Urban background | 1.22 | 1.22<br>(0%) | 1.4<br>(+15%) | 0.94<br>(-33%) |
| Birmingham East<br>Urban background | 1.04 | 1.02<br>(-2%) | 1.0<br>(-2%) | 0.85<br>(-15%) |
| London UCL<br>Roadside | 1.69 | 1.87<br>(-6%) | 1.75<br>(-6%) | 1.2<br>(-31%) |
| Cardiff East<br>Urban background | 1.22 | 1.21<br>(-1%) | 1.14<br>(-6%) | 0.98<br>(-14%) |

**Table 25 A comparison of mean nitrogen dioxide concentrations (µg/m³) in 1997 and 1998**

| | *Mean Kerbside* | *Elm -bridge School* | *North -gate* | *King Edwards Avenue* | *Barton Street* | *Metz Way* | *Abbey -mead Avenue* | *Chel -tenham Road* | *Huccle -cote Road* | *Bristol Road* | *Finlay Road* | *Trier Way* |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1997 | 51.53 | 29.90 | 58.00 | 44.43 | 58.10 | 46.52 | 44.09 | 50.29 | 45.18 | 63.25 | 56.43 | 51.23 |
| 1998 | 45.98 | 32.05 | 42.91 | 39.73 | 51.11 | 44.83 | 39.93 | 47.22 | 40.09 | 53.90 | 51.08 | 48.42 |
| Change in concentration | -4.76 | +2.15 | -15.09 | -4.70 | -6.99 | -1.69 | -4.16 | -3.06 | -5.09 | -9.35 | -5.35 | -2.81 |
| Difference % | -11 | +7 | -26 | -11 | -12 | -4 | -9 | -6 | -11 | -15 | -9 | - 5 |
| Sample size | 240 | 12 | 24 | 24 | 24 | 24 | 24 | 24 | 24 | 24 | 24 | 24 |
| P value | 0.0013 | 0.652 | 0.023 | 0.35 | .241 | 0.703 | 0.349 | 0.465 | 0.277 | 0.124 | 0.217 | 0.536 |
| Significant? | Yes | No | Yes | No | No | No | No | No | No | No | No | No |

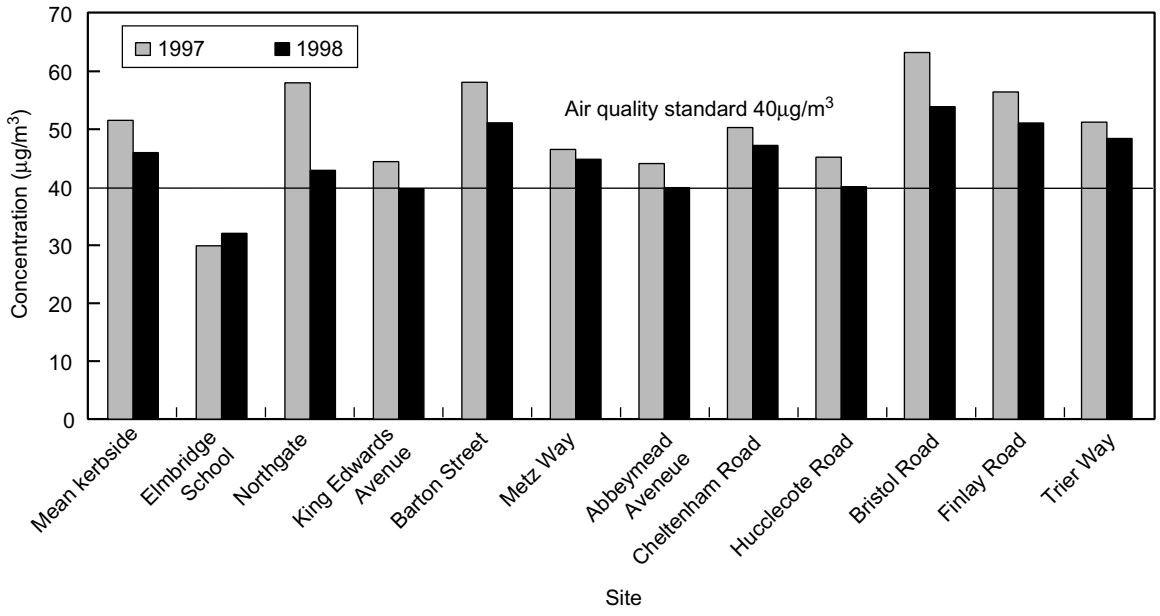



**Figure 16** Mean nitrogen dioxide concentrations in 1997 and 1998

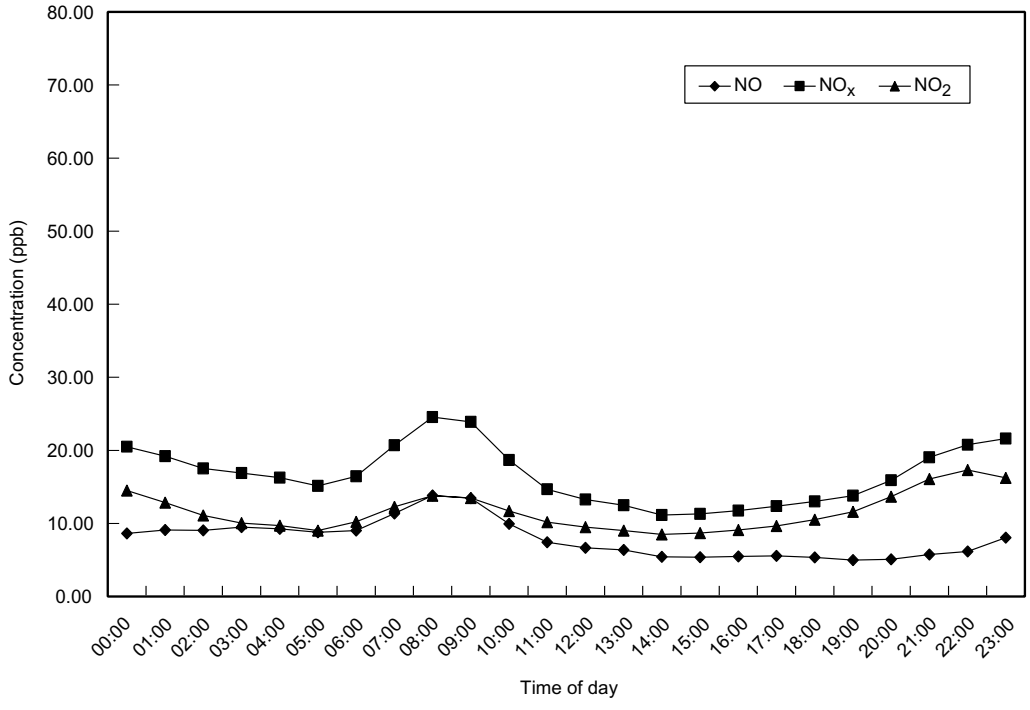



**Figure 17** Summer (April–September) diurnal NO, $NO_x$ and $NO_2$ concentrations

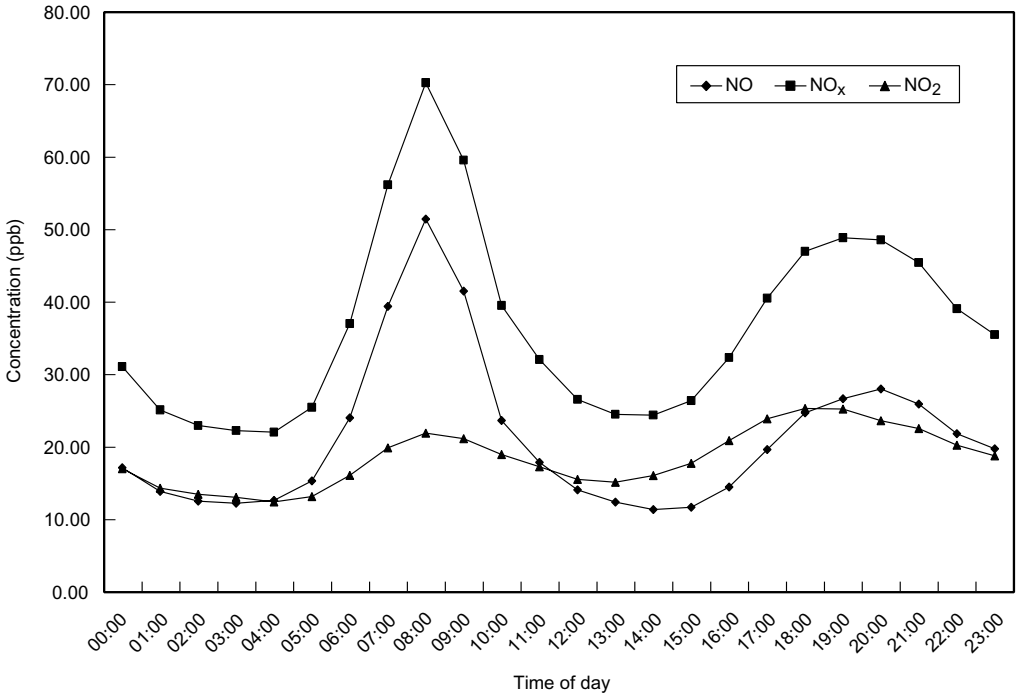



**Figure 18** Winter (October–March) diurnal NO, $NO_X$ and $NO_2$ concentrations

However, the maximum $NO_2$ concentration occurs in the evening: at about 6 pm in winter and 10 pm in summer. Because there is more daylight in summer, photochemical reactions can continue until later in the day than in winter.

In general concentrations of all of the pollutants were lower during the summer than in the winter. Assuming that the emissions from traffic are fairly constant throughout the year, then this implies that other processes such as meteorology are involved. For example, higher temperatures in the summer lead to greater thermal mixing and dispersion.

### *5.1.3 Carbon monoxide*

All hourly carbon monoxide (CO) concentrations monitored at the background site were below the Air Quality Standard of 10 ppm (8 hour running average). The maximum concentration of 9.82 ppm occurred as part of a pollution episode when all measured pollutants at the site were high. The mean hourly concentration was 0.34 ppm.

### *5.1.4 $PM_{10}$ concentrations*

#### *5.1.4.1 June 1997 and July 1998*

Mean $PM_{10}$ concentrations in June 1997 and July 1998 are shown in Table 26 and in Figure 19. Also shown are the differences in concentrations between the two sampling periods and their significance. The mean kerbside concentration decreased between June 1997 and July 1998 from 24.1 µg/m$^3$ to 22.1 µg/m$^3$, this decrease was statistically significant. The mean background concentration (Elmbridge School) fell between June 1997 and July 1998 from 21.5 µg/m$^3$ to 12.6 µg/m$^3$, the decrease was statistically significant.

The average $PM_{10}$ concentration increased at Bristol Road and Barton Street, but the increase was not significant. Average $PM_{10}$ concentrations fell at all the other sites monitored. The decrease in concentration at Finlay Road represented a significant decrease between the two monitoring periods. Concentrations at other kerbside sites were statistically indistinguishable between the two monitoring periods.

The results suggest that although there is a great deal of day-to-day variability in the data, concentrations of $PM_{10}$ in the summer of 1997 were higher than in summer 1998.

#### *5.1.4.2 July 1998 and December 1998*

Mean $PM_{10}$ concentrations in July 1998 and December 1998 are shown in Table 27 and Figure 19. Also shown are the differences in concentrations between the two sampling periods and their significance.

The mean kerbside concentration increased between July 1998 and December 1998 from 22.1 µg/m$^3$ to 28.2 µg/m$^3$, this increase was statistically significant. The mean background concentration (Elmbridge School) also increased between July 1998 and December 1998 from 12.6 µg/m$^3$ to 23.6 µg/m$^3$, this increase is statistically significant. This suggests that concentrations of $PM_{10}$ are higher in winter than in summer.

The average $PM_{10}$ concentration at Bristol Road and Northgate Street decreased between the two sampling periods, but the concentrations were statistically indistinguishable between the periods. Concentrations at the other kerbside sites all increased between the two monitoring periods, with concentrations at Finlay Road and Trier Way being significantly different. Concentrations at other kerbside sites were statistically indistinguishable between the two monitoring periods.

**Table 26 Mean $PM_{10}$ concentrations (µg/m³) June 1997 and July 1998**

| | *Mean kerbside* | *Elmbridge School* | *Northgate Street* | *Barton Street* | *Cheltenham Road* | *Bristol Road* | *Finlay Road* | *Trier Way* |
|---|---|---|---|---|---|---|---|---|
| June 1997 | 24.10 | 21.52 | 28.11 | 22.43 | 24.26 | 25.70 | 27.07 | 19.80 |
| July 1998 | 22.06 | 12.63 | 24.48 | 24.96 | 19.75 | 28.33 | 18.66 | 16.20 |
| Difference % | -8 | -41 | -13 | +10 | -18 | +9 | -31 | -18 |
| Sample size | 84 | 13 | 14 | 14 | 14 | 14 | 14 | 14 |
| P value | 0.034 | 0.017 | 0.458 | 0.506 | 0.104 | 0.870 | 0.005 | 0.147 |
| Significant ? | Yes | Yes | No | No | No | No | Yes | No |

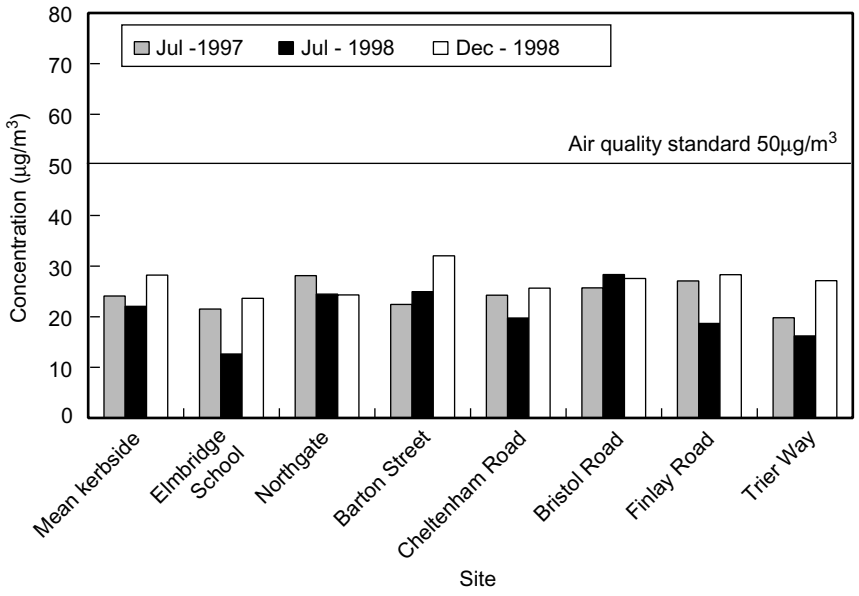



**Figure 19** Mean $PM_{10}$ concentration in June 1997, July 1998 and December 1998

**Table 27 Mean $PM_{10}$ concentration (µg/m³) July 1998 and December 1998**

| | Mean kerbside | Elmbridge School | Northgate Street | Barton Street | Cheltenham Road | Bristol Road | Finlay Road | Trier Way |
|---|---|---|---|---|---|---|---|---|
| July 1998 | 22.06 | 12.63 | 24.48 | 24.96 | 19.75 | 28.33 | 18.66 | 16.20 |
| December 1998 | 28.22 | 23.63 | 24.31 | 32.04 | 25.66 | 27.55 | 28.29 | 27.13 |
| Difference % | +22 | +47 | -2 | +23 | +23 | -3 | +34 | +41 |
| Sample size | 84 | 12 | 14 | 14 | 14 | 14 | 14 | 14 |
| P value | $1.59x10^{-6}$ | $8.6X10^{-6}$ | 0.972 | 0.074 | 0.08 | 0.8778 | $6.71X10^{-4}$ | $3.27 \times 10^{-5}$ |
| Significant ? | Yes | Yes | No | No | No | No | Yes | Yes |

*5.1.4.3 Continuous monitoring at the background site*

Using the Partisol sampler, the mean concentration at the background site in 1998 was 23.4 µg/m³ with 22 exceedences of the Air Quality Standard of 50 µg/m³. This was higher than was measured using the MiniVol sampler over the two surveys in 1998 (18.8 µg/m³ with 3 exceedences). However, over the same sampling periods, the Partisol gave a mean concentration of 16.9 µg/m³, which was statistically indistinguishable from the MiniVol results. The results obtained from the MiniVol samplers are therefore comparable to those obtained using the Partisol. However, because of the underestimate of the annual mean and the number of exceedences it would be prudent to increase the number or length of the MiniVol surveys to give a better overview of the $PM_{10}$ concentration in Gloucester.

## 5.2 More detailed observations on selected sites

### *5.2.1 Barton Street*

At first glance it is surprising that pollutant concentrations on Barton Street are relatively high given its traffic flow. However observations during site visits suggest that this road is probably the most congested in the city. Vehicles progress relatively slowly with sets of traffic lights and other obstacles to negotiate (see Photograph 2, Appendix A). It is also a busy bus route. Figure 20 and Figure 21 compare the diurnal variation in the flows and speeds on Hucclecote Road and Barton Street. Despite the similar flows on both roads, we can see that speeds on Barton Street are about 6 mph lower. At lower mean speeds, emission rates tend to be greater because of the inherent inefficiency of engines during stop-start operation. This is

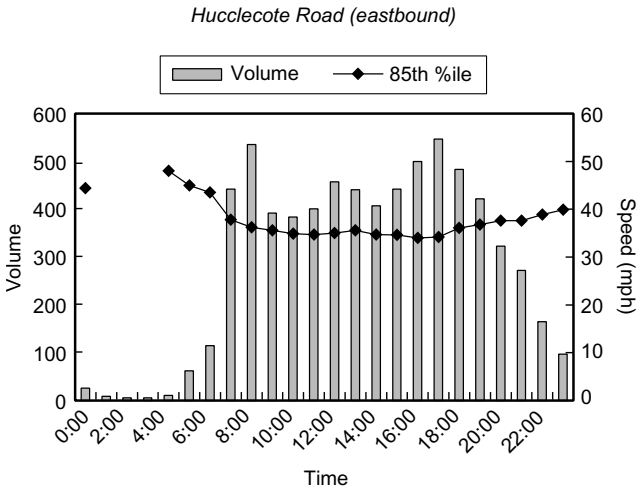



**Figure 20** Speeds and flows on Hucclecote Road (May 1997)

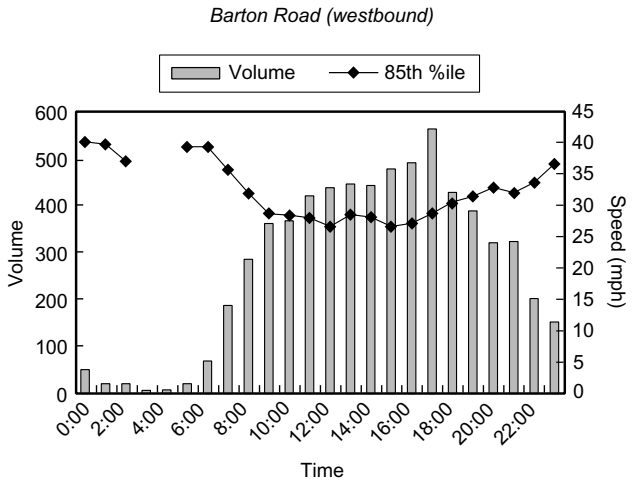



**Figure 21** Speeds and flows on Barton Street (May 1997)

also demonstrated in Table 22 where emissions of $NO_x$, HC and CO are higher on Barton Street than on Hucclecote Road. Greater emission rates would give rise under equivalent conditions to higher concentrations.

An additional factor to consider for Barton Street is that it is relatively narrow, with buildings fronting onto the pavement. This could adversely affect dispersion such that concentrations would tend to be higher. There is evidence to suggest that dispersion is indeed relatively poor on Barton Street. For example, HC emission rates on Barton Street are much lower than on Trier Way, and yet concentrations of benzene are significantly higher on Barton Street than on Trier Way.

### *5.2.2 Northgate Street*

In April 1998 Northgate Street was closed to general traffic so as to allow the area to be pedestrianised. The pedestrianisation of the area has had a marked effect on the air quality. Benzene concentrations measured at the site have decreased by 59% between 1997 and 1998, dropping from an average of 4.14 ppb to 1.71 ppb, this being a much larger decrease than the other kerbside sites. The concentrations of $NO_2$ and $PM_{10}$ have also decreased between 1997 and 1998. $NO_2$ concentrations decreased by 26%, dropping from an average of 58.0 µg/m$^3$ to 42.9 µg/m$^3$ (but still above the Air Quality Standard). $PM_{10}$ concentrations in the summer decreased by 13%, dropping from an average of 28.1 µg/m$^3$ to 24.5 µg/m$^3$. These decreases demonstrate that the closing of the street to general traffic and the subsequent pedestrianisation have produced a marked decrease in pollutant concentrations. Average concentrations on Northgate may decrease further once the pedestrianisation is complete as the construction work may be contributing to pollutant concentrations, particularly of $PM_{10}$ from dust.

### *5.2.3 Cheltenham Road*

During 1997 and 1998 Cheltenham Road was included in the area wide traffic calming of Longlevens. A range of traffic calming and traffic management measures were introduced on Cheltenham Road. These included a raised pedestrian crossing, a set of speed cushions, a bus lane, cycle lanes and modifications to traffic signals. Between 1997 and 1998, average vehicle speeds dropped by 6 mph and traffic flows reduced by about 1500 vehicles per day. Emissions from vehicles will have reduced due to the reduced traffic flow but increased per vehicle due to the reduced speed and the subsequent stop start nature of having to negotiate speed cushions and other traffic calming measures. These combined effects may account for the relatively small decrease in benzene concentrations at the monitoring site on Cheltenham Road, compared to the other kerbside sites.

### *5.2.4 Differences either side of the road*

Although differences were observed between pairs of samplers either side of the road, in most cases the variation was not statistically significant. The exceptions were benzene concentrations on Barton Street (1997 and 1998), Bristol Road (1998) and Trier Way (1998) and $NO_2$ concentrations on Northgate Street (1997), Bristol Road (1998), Metz Way (1998) and Trier Way (1998).

It is possible that that on Northgate Street the difference is as a result of differences in sampling height: one site is at about 2.5 m whilst the other is at 3–4 m. Concentrations of $NO_2$ in 1997 were significantly higher (by 14.4 µg/m$^3$) at the lower sampling height.

It is possible that on Bristol Road, Barton Street and Trier Way, these differences are caused by differences in vehicle operation. For example on Bristol Road, the samplers are located on a gradient caused by a railway bridge. It is likely that drivers would need to press harder on the accelerator, possibly increasing emissions rates, when driving up the gradient: the higher concentrations of benzene were found on the southbound carriageway on the approach to the railway bridge. On Trier Way both samplers are located near traffic lights. Along the northbound carriageway, vehicles are likely to be slowing down and possibly queuing, whereas southbound, the traffic is likely to be flowing more freely. The differences

became significant in 1998 probably because the site on the southbound carriageway was moved closer to the traffic lights. Similarly for Barton Street, the samplers are located close to a pedestrian crossing that causes traffic to queue close to the sampling site alongside the westbound carriageway: concentrations of both pollutants are highest at this site . All three of these sites are not easily relocated, as there are many junctions, bus stops and traffic signals along the length of the road that could also affect concentrations.

Another explanation for the differences observed on Barton Street is that in street canyon situations like this, one side of the road can effectively be sheltered from incoming clean air, leading to elevated concentrations. However, in this case the difference is consistent, and there is a linear relationship between concentrations at either side of the road. Since this effect would be dependent on wind direction, one would not expect the differences to be so consistent.

For the other kerbside locations, there were no statistical differences between average concentrations at each location or either side of the road. As such it is therefore not critical, scientifically, that monitoring is carried out on both sides of the road at these locations. Nor would it compromise the validity of the overall interpretation of air quality if some of these locations were discontinued in order to concentrate resources on other aspects of the project. However having diffusion tubes located either side of the road does give some protection from the loss of data due to theft of the samplers: in nearly all cases, tubes have been stolen from only one side of the road at a time.

### 5.3 Comparison of changes in emissions and concentrations

Over all the drive cycle links, it has been estimated that emissions of CO, HC and $NO_x$ decreased steadily, between November 1996 and November 1998 as shown in Table 28. During this period, emissions of HC, CO and $NO_x$ reduced by 12%. This reduction was largely as a result of the introduction of more catalyst equipped light-duty vehicles into the fleet. The emission characteristics of the light-duty vehicle fleet is changing rather dramatically at present as the newer vehicles entering the fleet are typically ten times less polluting than their older counterparts.

**Table 28 Changes in city-wide traffic emissions**

| | *% Change in emissions* | | |
|---|---|---|---|
| | *CO* | *HC* | *$NO_x$* |
| November 96 to November 97 | -4 | -6 | -6 |
| November 97 to November 98 | -8 | -6 | -6 |
| Total change | -12 | -12 | -12 |

*(From Boulter 2000)*

Table 29 summarises the changes in traffic emissions on these links that occurred between November 1996 and November 1998. The period over which the change in total emissions is estimated corresponds approximately with that over which pollutants were measured.

On all of the relevant drive cycle links, except those covering Metz Way and Trier Way, there was a decrease in emissions of $NO_x$ and HC emissions: on Metz Way emissions of both pollutants were increased, whilst on Trier Way emissions of $NO_x$ remained unchanged. Figure 22 compares the changes in emissions of $NO_x$ and HC with changes in concentration of $NO_2$ and benzene respectively. A trend can be seen which although not statistically significant, indicates that as calculated emissions decrease measured concentrations also decrease.

### 5.4 Pollution episodes

A pollution episode can be described as a period when pollutant concentrations are elevated. Episodes can vary widely in terms of the area that they cover, the pollutants affected and their occurrence throughout the year. In the UK episodes are often categorised as winter or summer episodes.

Summer episodes occur during hot and sunny weather. Reactions between $NO_x$ and HC produce ozone and other secondary pollutants. The precursors have usually been transported by atmospheric dispersion from some distance away, often from continental Europe. Large areas of the country can be affected, but generally it is southern Britain that experiences the greatest number of summer pollution episodes.

Winter episodes occur when cold, stable weather conditions limit the dispersion of pollutants. Pollutants are in effect trapped close to their sources, and because these weather conditions tend to be sustained over several days, concentrations can then build up. Such episodes are generally observed in the larger towns and cities where traffic is the major source of emissions. Therefore, (primary) $PM_{10}$ and $NO_2$ concentrations are usually elevated during winter episodes.

There were several periods in 1998 when pollutant concentrations at the background site were elevated and these can be seen in Figure 9, Figure 12 and Figure 13. The main periods where concentrations were elevated were:

- 28th January to 3rd February – CO, NO, $NO_x$, $PM_{10}$
- 13th to 18th February – CO, $NO_2$, $PM_{10}$
- 12th to 15th May – $PM_{10}$
- 21st to 26th September – $PM_{10}$
- 16th to 18th November – NO, $NO_x$.

Examination of the National Air Quality Archive shows that some of these episodes were experienced at other sites in the West Country, e.g:

Bristol Centre

- 30th January to 3rd February – CO, NO, $NO_x$, $NO_2$
- 13th and 14th February – CO, NO, $NO_x$, $NO_2$, $PM^{\dagger}_{10}$
- 12th to 14th May – $NO_2$, $PM_{10}$
- 24th and 25th September – $NO_2$, $PM_{10}$

† *Measured using a Tapered Element Oscillating Microbalance, which differs from the Partisol in that the sample is heated to 50°C.*

**Table 29 Emissions from traffic on selected roads in Gloucester**

| Site | CO (kg/km.day) | | | HC (kg/km.day) | | | $NO_x$ (kg/km.day) | | | $CO_2$ (kg/km.day) | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | *1996* | *1998* | *Difference (% difference)* | *1996* | *1998* | *Difference (% difference)* | *1996* | *1998* | *Difference (% difference)* | *1996* | *1998* | *Difference (% difference)* |
| Metz Way | 207 | 229 | 22 (10.6) | 27 | 29 | 2 (7.4) | 43 | 44 | 1 (2.3) | 3396 | 4193 | 797 (23.4) |
| Trier Way | 463 | 390 | -73 (-15.7) | 62 | 51 | -11 (-17.7) | 60 | 60 | 0 (0) | 6435 | 6895 | 460 (7.1) |
| Abbeymead Avenue | 178 | 160 | -18 (-10.1) | 24 | 20 | -4 (-16.7) | 37 | 33 | -4 (-10.8) | 2930 | 3074 | 144 (4.9) |
| Barton Street | 223 | 199 | -24 (-10.7) | 30 | 26 | -4 (-13.3) | 41 | 40 | -1 (-2.4) | 3745 | 4013 | 268 (7.2) |
| Hucclecote Road | 181 | 162 | -19 (-10.5) | 25 | 22 | -3 (-12) | 33 | 31 | -2 (-6.1) | 2856 | 3020 | 164 (5.7) |
| Bristol Road | 293 | 257 | -36 (-12.3) | 40 | 34 | -6 (-15) | 66 | 60 | -6 (-9.1) | 5419 | 5532 | 113 (2.1) |
| Finlay Road | 328 | 296 | -32 (-9.8) | 42 | 38 | -4 (-9.5) | 79 | 62 | -17 (-21.5) | 6140 | 5872 | -268 (-4.4) |
| Cheltenham Road | 188 | 162 | -26 (-13.8) | 25 | 21 | -4 (-16) | 35 | 29 | -6 (-17.1) | 2957 | 2964 | 7 (0.24) |
| Northgate | 180 | 0 | -180 (-100) | 24 | 0 | -24 (-100) | 30 | 0 | -30 (-100) | 3045 | 0 | -3045 (-100) |
| King Edwards Avenue | 114 | 106 | -8 (-7.0) | 15 | 14 | -1 (-6.7) | 19 | 18 | -1 (-5.3) | 1733 | 1896 | 163 (9.4) |

*(Adapted from Boulter 2000)*

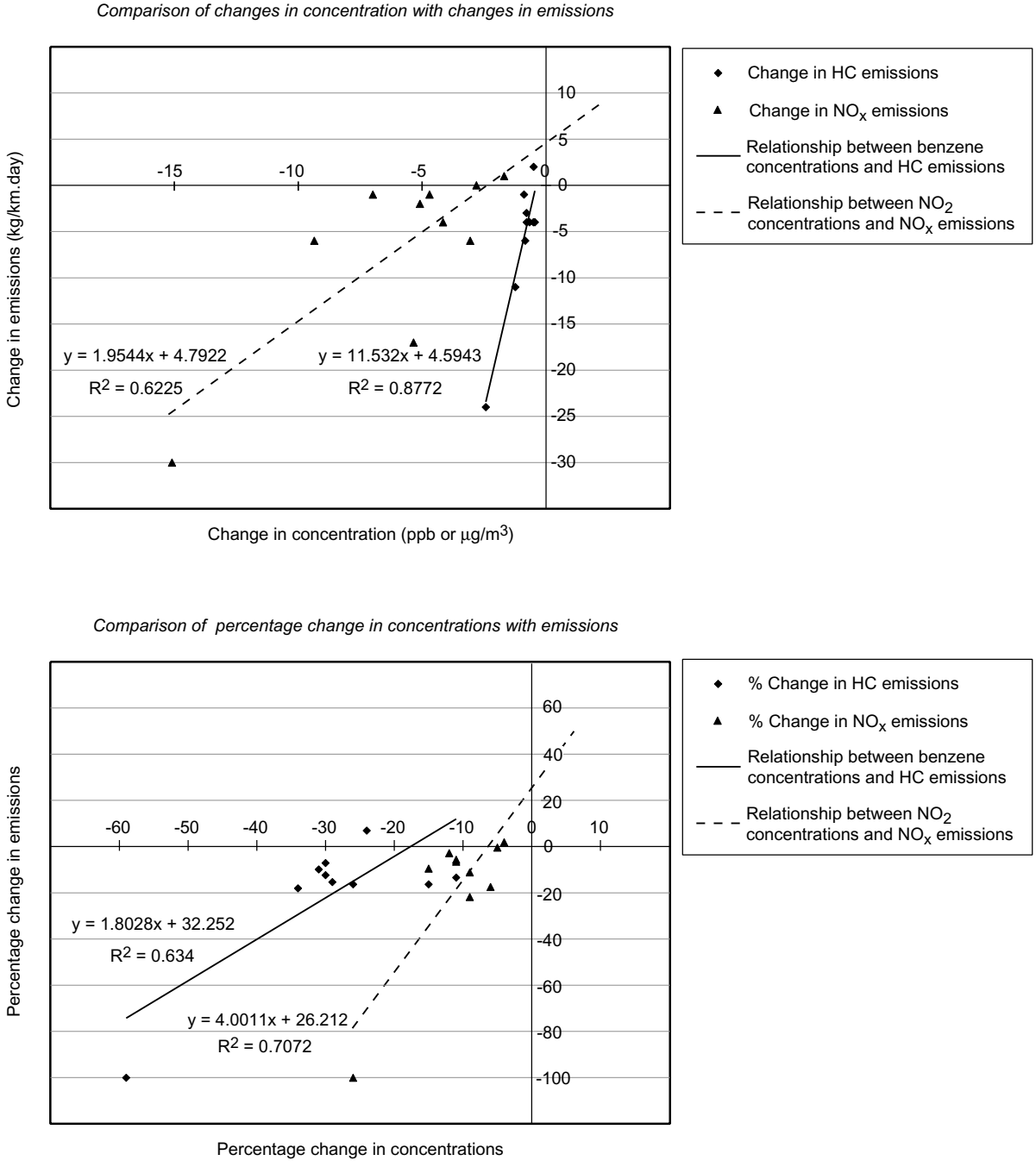



**Figure 22** Comparison of changes in concentrations with emissions

Plymouth Centre

- 31st January to 5th February – CO, NO, $NO_x$
- 12th February to 17th February – CO, NO, $NO_x$,
- 12th to 15th May – $NO_2$, $PM_{10}$

The episodes in January, February and November (Gloucester only) were generally associated with high primary pollutant concentrations (CO, NO and $PM_{10}$) followed some time later by high secondary pollutant concentrations ($NO_2$ and $PM_{10}$). The episodes in May and September were as a result of secondary processes as concentrations of the primary pollutants were not elevated to the same extent.

# 6 Summary and conclusions

A monitoring network has been set up to determine concentrations of $NO_2$, $PM_{10}$ and benzene at kerbside and background locations in Gloucester. The network comprises: 10 kerbside sites where diffusion tubes and MiniVol samplers are used to monitor $NO_2$, benzene and $PM_{10}$; a background site where continuous analysers monitor CO, $NO_2/NO_x$ and $PM_{10}$ alongside diffusion tubes and a MiniVol. The aim of the network is to monitor the effect on air quality of the Safer City Project. This document reports on the first two years (1997 and 1998) of the air quality monitoring in Gloucester.

During the period of the report a number of traffic management/calming measures were installed in Gloucester. The ones most likely to affect vehicle emissions and hence air quality are carriageway narrowings combined with cycle lanes on Finlay Road, area wide traffic calming in Longlevens (including measures on Cheltenham Road) and the closure of Northgate and Southgate in preparation for pedestrianisation. Estimates of vehicle emissions on the major routes in Gloucester showed a steady decrease, between 1996 and 1998: emissions of HC, CO and $NO_x$ by 12% (although on Metz Way $NO_x$ emissions were increased). This reduction was largely as a result of the introduction into the fleet of more catalyst equipped light-duty vehicles with significantly lower emission rates. Emissions of HC were highest on Trier Way, which has higher traffic flows. Emissions of $NO_x$ were generally highest on Finlay Road, where there are high traffic flows and a large proportion of HGVs.

In both years benzene concentrations at all of the sites were below the Air Quality Standard of 5 ppb, with the highest values seen on Barton Street and on Northgate before it was pedestrianised. The mean concentrations fell at the kerbside locations between 1997 and 1998 by 24% (if Northgate is excluded) and this reflects the general decline in vehicle emissions in Gloucester. The decrease is statistically significant. Concentrations at the background site fell by 53%. There is some evidence that as emissions of HC from traffic in Gloucester decrease measured concentrations of benzene also decrease.

For $NO_2$, concentrations measured using diffusion tubes at the kerbside were close to or greater than the Air Quality Standard of 40 $\mu g/m^3$: concentrations here fell by on average 9% (if Northgate is excluded) and the difference was significant. At the background (Elmbridge School), there was a statistically insignificant increase in mean $NO_2$ concentration of 7%. There is also some evidence to suggest that as emissions of $NO_x$ from traffic in Gloucester decrease measured concentrations of $NO_2$ also decrease.

The validity of the sampling methods was tested by comparing the results from $NO_2$ diffusion tubes and $PM_{10}$ MiniVol samplers with a chemiluminescent $NO_x$ analyser and a Partisol sampler co-located at Elmbridge School. The annual mean as calculated using the chemiluminescent data was 10% lower than the mean derived from the diffusion tube survey, but the difference is not statistically significant. The average $PM_{10}$ concentration as measured by the Partisol was 10% higher than by the MiniVol and not statistically different, which demonstrates that the two different methods of sampling are compatible. However, the limited number of MiniVol surveys did not give a reliable estimate of the annual mean or the number of exceedences of the $PM_{10}$ standard. The kerbside values in this report probably underestimate the true number of exceedences of the $PM_{10}$ standard.

During 1998, Northgate Street was closed to traffic in preparation for pedestrianisation, and here the greatest reduction in average benzene and $NO_2$ concentrations (59% and 26% respectively) were seen: both decreases were statistically significant.

On Cheltenham Road bus lanes, cycle lanes and speed cushions were introduced during the period of these surveys, resulting in a reduction in speed and traffic flow. This may account for the relatively small decrease in benzene concentrations at the monitoring site on Cheltenham Road, compared to the other kerbside sites.

At the Elmbridge School site the variation in concentrations of NO and $NO_2$ throughout the day demonstrate that even at the background site, vehicles are the main source of these pollutants. Peak concentrations occur between 7am and 10 am corresponding with a peak in traffic activity. The continuous measurements have also highlighted a number of periods where pollutant concentrations were relatively high. These episodes were also experienced in Plymouth and Bristol. Two of the episodes in May and September appear to be as a result of secondary processes as concentrations of the primary pollutants (CO and NO) were not elevated.

Differences were observed between pairs of samplers placed either side of the road, but in most cases the variation was not statistically significant. Statistically significant differences were seen on Barton Street, Bristol Road, Trier Way, Northgate Street and Metz Way. On Northgate Street the difference may be as a result of differences in sampling height; on Bristol Road, Barton Street and Trier Way, the differences may be caused by differences in vehicle operation on each side of the road; on Barton Street it may be that one side of the road is effectively sheltered from incoming clean air because it is narrow with tall buildings on both sides. None of these sites are easily relocated because of the presence of other junctions or the availability of mounting positions. In the remaining cases it is not critical that monitoring is carried

out on both sides of the road. However it is useful to have this arrangement: if a site is vandalised then there is a greater chance that the 'duplicate' on the other side of the road will be left unharmed.

The monitoring network is providing good data with which to describe air quality in Gloucester. Monitoring will therefore be continued largely as described. Some modest savings could be made be reducing the number of diffusion tube sites. However, if important traffic management schemes were implemented in the vicinity of these sites, this could compromise the usefulness of the data collected.

Measurements at the continuous background site will be continued despite their relative expense. These provide a valuable check on the validity of the surveys and helps highlight episodes when pollutant concentrations are abnormally high. This latter will be important when interpreting the effects of individual schemes where the assessment relies on limited data-sets.

The results obtained from the MiniVol samplers may underestimate the annual mean and the number of exceedences at the kerbside sites. Therefore the number of MiniVol surveys will be increased to give a better overview of the $PM_{10}$ concentration in Gloucester.

## 7 References

**Boulter P G (2000)**. *The impacts of the Safer City Project on road traffic emissions in Gloucester: 1996-1998.* TRL Report TRL444. Crowthorne: TRL Limited.

**Department of the Environment Transport and the Regions (2000)**. *The Air Quality Strategy for England, Scotland, Wales and Northern Ireland.* London: The Stationery Office.

**EPAQS (2000)**. Final reports on the recommendations of EPAQS can be found on www.environment.detr.gov.uk/airq/aqs/index.htm.

## 8 Acknowledgements

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## Appendix A: Photographs

**Plate 1** Abbeymead Avenue

**Plate 2** Barton Street

**Plate 3** Bristol Road

**Plate 4** Cheltenham Road

**Plate 5** Finlay Road

**Plate 6** King Edward's Avenue

**Plate 7** Metz Way


**Plate 8** Northgate Street

**Plate 9** Trier Way

**Plate 10** Hucclecote Road

# Appendix B: Data

**Table B1 Benzene concentrations (ppb), fortnightly means—1997 survey**

| *Date* | *Elmbridge School* | *Northgate* | *King Edwards Avenue* | *Barton Street* | *Metz Way* | *Abbeymead Avenue* | *Cheltenham Road* | *Hucclecote Road* | *Bristol Road* | *Finlay Road* | *Trier Way* |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 07/01/97 | 1.7 | 4.7 | 3.9 | 6.05 | 2.6 | 2.6 | 3.25 | 2.85 | 3.3 | 2.9 | 4.3 |
| 21/01/97 | 2.7 | 6.1 | 5.6 | 7.65 | 3.45 | 4.8 | 5.6 | 5.1 | 4.7 | 4.15 | 5.5 |
| 04/02/97 | 1.3 | 3.6 | 2.45 | 4.25 | 1.45 | 2.05 | 2.55 | 2.1 | 2.85 | 2.1 | 2.8 |
| 18/02/97 | 0.6 | 3.3 | 1.7 | 3.8 | 1.25 | 1.3 | 2.1 | 1.4 | 2.3 | 1.7 | 2.35 |
| 04/03/97 | | | | | | | | | | | |
| 18/03/97 | | | | | | | | | | | |
| 01/04/97 | | | | | | | | | | | |
| 15/04/97 | | | | | | | | | | | |
| 29/04/97 | 1.4 | 3.1 | 2 | 3.9 | 1.3 | 1.5 | 2.15 | 1.45 | 2.4 | 1.8 | 2.15 |
| 13/05/97 | 2.2 | 3.5 | 2.1 | 2.8 | 1.25 | 1.8 | 2.1 | 2 | 2.5 | 2.1 | 2.5 |
| 27/05/97 | 2.8 | 2.4 | 1.5 | 2.2 | 0.75 | 1.25 | 1.3 | 0.95 | 1.75 | 1.6 | 1.6 |
| 10/06/97 | 0.5 | 2.85 | 1.6 | 3.1 | 1.15 | 1.3 | 1.7 | 1.5 | 1.8 | 1.3 | 3.7 |
| 24/06/97 | | | | | | | | | | | |
| 03/07/97 | | | | | | | | | | | |
| 17/07/97 | | | | | | | | | | | |
| 31/07/97 | | | | | | | | | | | |
| 14/08/97 | | | | | | | | | | | |
| 28/08/97 | | | | | | | | | | | |
| 11/09/97 | | | | | | | | | | | |
| 08/10/97 | 0.7 | 3.7 | 2.7 | 3.8 | 1.85 | 2.35 | 2.7 | 2.3 | 2.6 | 2.25 | 2.85 |
| 22/10/97 | 2.5 | 6.15 | 4.35 | 6.55 | 4.6 | 4.85 | 4.85 | 4.75 | 3.8 | 4.45 | 5.35 |
| 05/11/97 | – | 4.85 | 3.3 | 5.45 | 2.2 | 2.85 | 3.45 | 3.05 | 2.9 | 2.4 | 3.3 |
| 19/11/97 | 1.8 | 5.4 | 4.75 | 6.85 | 3.3 | 4 | 4.05 | 3.6 | 3.85 | 3.7 | 5.25 |
| 03/12/97 | | | | | | | | | | | |
| 17/12/97 | | | | | | | | | | | |
| 31/12/97 | | | | | | | | | | | |

**Table B2 Nitrogen dioxide concentrations (µg/m$^3$), fortnightly means—1997 survey**

| *Start date* | *Elmbridge School* | *Northgate* | *King Edwards Avenue* | *Barton Street* | *Metz Way* | *Abbeymead Avenue* | *Cheltenham Road* | *Hucclecote Road* | *Bristol Road* | *Finlay Road* | *Trier Way* |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 070/1/97 | 46.90 | 66.00 | 61.35 | 68.25 | 62.30 | 59.95 | 61.70 | 57.90 | 73.35 | 61.20 | 69.50 |
| 21/01/97 | 43.30 | 70.45 | 57.00 | 74.95 | 63.80 | 63.00 | 62.80 | 60.10 | 75.05 | 75.45 | 69.00 |
| 04/02/97 | 34.50 | 59.45 | 42.50 | 67.50 | 54.55 | 46.55 | 60.75 | 44.45 | 96.95 | 73.65 | 64.45 |
| 18/02/97 | 21.00 | 52.80 | 34.50 | 100.05 | 50.15 | 38.45 | 59.60 | 36.50 | 72.60 | 61.60 | 55.05 |
| 04/03/97 | | | | | | | | | | | |
| 18/03/97 | | | | | | | | | | | |
| 01/04/97 | | | | | | | | | | | |
| 15/04/97 | | | | | | | | | | | |
| 29/04/97 | 20.00 | 54.80 | 38.00 | 48.40 | 35.10 | 33.85 | 45.95 | 37.35 | 62.15 | 37.35 | 35.70 |
| 13/05/97 | 22.70 | 61.50 | 42.95 | 39.30 | 38.35 | 28.50 | 48.05 | 46.45 | 73.75 | 59.75 | 45.05 |
| 27/05/97 | 22.80 | 65.45 | 39.50 | 43.75 | 36.30 | 32.70 | 45.45 | 35.90 | 49.50 | 53.25 | 37.40 |
| 10/06/97 | 10.30 | 30.60 | 27.20 | 39.00 | 28.20 | 32.20 | 28.60 | 19.20 | 33.70 | 39.05 | 11.80 |
| 24/06/97 | | | | | | | | | | | |
| 03/07/97 | | | | | | | | | | | |
| 17/07/97 | | | | | | | | | | | |
| 31/07/97 | | | | | | | | | | | |
| 14/08/97 | | | | | | | | | | | |
| 28/08/97 | | | | | | | | | | | |
| 11/09/97 | | | | | | | | | | | |
| 08/10/97 | 24.50 | 49.00 | 36.30 | 46.45 | 36.25 | 44.15 | 37.40 | 42.05 | 45.15 | 52.15 | 44.50 |
| 22/10/97 | 39.90 | 70.65 | 55.05 | 59.90 | 51.65 | 51.60 | 56.00 | 52.00 | 53.10 | 58.85 | 52.75 |
| 05/11/97 | 31.00 | 54.60 | 40.05 | 53.85 | 46.15 | 46.50 | 45.65 | 45.75 | 59.65 | 49.95 | 49.90 |
| 19/11/97 | 41.90 | 60.70 | 58.75 | 55.75 | 55.45 | 51.60 | 51.50 | 64.45 | 64.10 | 54.95 | 53.00 |
| 03/12/97 | | | | | | | | | | | |
| 17/12/97 | | | | | | | | | | | |
| 31/12/97 | | | | | | | | | | | |

**Table B3 $PM_{10}$ particulate concentrations (µg/m³), daily means—June 1997 survey**

| Start date | Elmbridge School | Northgate | Barton Street | Cheltenham Road | Bristol Road | Finlay Road | Trier Way |
|---|---|---|---|---|---|---|---|
| 17 June 97 | 36.93 | 48.43 | – | 48.47 | 42.40 | 42.19 | 38.44 |
| 18 June 97 | – | 34.08 | 25.02 | 26.11 | 33.25 | 24.31 | 25.05 |
| 19 June 97 | 16.84 | 34.51 | 23.00 | 23.15 | 28.98 | 26.13 | 20.05 |
| 20 June 97 | – | 24.93 | 5.59 | 16.01 | 17.20 | 17.50 | 15.93 |
| 21 June 97 | – | 20.42 | 15.72 | 16.59 | 12.95 | 16.24 | 13.29 |
| 22 June 97 | – | 17.87 | 21.49 | 20.60 | 18.38 | 22.78 | 14.52 |
| 23 June 97 | – | 21.60 | 22.17 | 23.74 | 24.49 | 25.96 | 18.41 |
| 24 June 97 | – | 26.48 | 18.27 | 19.08 | 22.55 | 18.27 | 18.28 |
| 25 June 97 | 14.27 | 29.45 | 17.54 | 20.12 | 17.59 | 22.95 | 15.96 |
| 26 June 97 | 14.38 | 12.40 | 16.42 | 18.69 | – | 23.93 | 18.06 |
| 27 June 97 | 26.64 | 25.96 | 27.66 | 29.75 | 25.38 | 33.46 | – |
| 28 June 97 | – | 36.04 | 37.71 | 14.35 | 27.88 | 37.60 | – |
| 29 June 97 | – | 33.76 | 34.97 | 35.93 | 34.46 | 42.50 | – |
| 30 June 97 | 20.06 | 27.56 | 26.08 | 26.99 | 28.56 | 25.16 | – |

**Table B4 Benzene concentrations (ppb), fortnightly means—1998 survey**

| Start date | Elmbridge School | Northgate | King Edwards Avenue | Barton Street | Metz Way | Abbeymead Avenue | Cheltenham Road | Hucclecote Road | Bristol Road | Finlay Road | Trier Way |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 04 Feb 98 | 1.00 | 3.45 | 2.55 | 4.80 | 1.35 | 1.95 | 2.40 | 1.95 | 2.45 | 1.60 | 2.80 |
| 18 Feb 98 | 0.70 | 3.00 | 2.00 | 4.85 | 1.50 | 1.35 | 2.25 | 1.60 | 2.35 | 1.70 | 2.40 |
| 04 Mar 98 | 0.60 | 2.85 | 1.80 | 3.65 | 1.35 | 1.45 | 1.85 | 1.75 | 1.75 | 1.65 | 2.00 |
| 17 Mar 98 | 0.90 | 2.90 | 2.30 | 4.10 | 1.55 | 2.30 | 2.50 | 2.00 | 2.35 | 1.90 | 2.50 |
| 31 Mar 98 | | | | | | | | | | | |
| 14 Apr 98 | | | | | | | | | | | |
| 28 Apr 98 | | | | | | | | | | | |
| 12 May 98 | | | | | | | | | | | |
| 26 May 98 | | | | | | | | | | | |
| 09 Jun 98 | 0.30 | 0.55 | 1.20 | 2.85 | 0.80 | 0.70 | 1.60 | 0.95 | 1.20 | 1.05 | 1.25 |
| 23 Jun 98 | 0.40 | 0.45 | 1.20 | 2.50 | 1.05 | 1.05 | 1.70 | 1.15 | 1.35 | 1.25 | 1.55 |
| 07 Jul 98 | 0.30 | 0.45 | 1.05 | 2.55 | 0.85 | 0.90 | 1.60 | 0.80 | 1.15 | 1.05 | 1.25 |
| 21 Jul 98 | 0.30 | 0.55 | 1.10 | 2.50 | – | 0.90 | 1.60 | 0.95 | 1.20 | 1.00 | 1.35 |
| 04 Aug 98 | | | | | | | | | | | |
| 18 Aug 98 | | | | | | | | | | | |
| 01 Sep 98 | | | | | | | | | | | |
| 15 Sep 98 | | | | | | | | | | | |
| 29 Sep 98 | | | | | | | | | | | |
| 13 Oct 98 | | | | | | | | | | | |
| 20 Oct 98 | 0.60 | 0.90 | 1.90 | 3.85 | 1.20 | 1.30 | 2.45 | 1.30 | 1.80 | 1.45 | 2.10 |
| 03 Nov 98 | 0.90 | 1.45 | 3.45 | 6.10 | 2.40 | 2.85 | 3.60 | 2.95 | 2.75 | 2.70 | 3.70 |
| 17 Nov 98 | 1.80 | 1.50 | 3.75 | 6.80 | 3.35 | 4.15 | 4.60 | 4.20 | 3.75 | 3.40 | 4.60 |
| 01 Dec 98 | 1.40 | 1.70 | 2.90 | 5.70 | 2.25 | 2.50 | 4.25 | 2.60 | 2.90 | 2.35 | 3.30 |

**Table B5 Nitrogen dioxide concentrations (µg/m$^3$ ), fortnightly means—1998 survey**

| Start date | Elmbridge School | Northgate | King Edwards Avenue | Barton Street | Metz Way | Abbeymead Avenue | Cheltenham Road | Hucclecote Road | Bristol Road | Finlay Road | Trier Way |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 04 Feb 98 | 47.30 | 74.15 | 53.50 | 64.20 | 58.85 | 43.40 | 66.50 | 51.25 | 72.05 | 69.75 | 60.15 |
| 18 Feb 98 | 31.10 | 52.00 | 42.40 | 57.80 | 46.25 | 37.85 | 50.50 | 35.25 | 55.20 | 50.20 | 52.90 |
| 04 Mar 98 | 31.20 | 55.50 | 47.30 | 50.85 | 43.45 | 39.35 | 47.75 | 44.45 | 48.30 | 56.90 | 43.20 |
| 17 Mar 98 | 38.70 | 64.40 | – | 63.35 | 53.15 | 48.45 | 57.25 | 53.95 | 71.75 | 58.50 | 64.15 |
| 31 Mar 98 | | | | | | | | | | | |
| 14 Apr 98 | | | | | | | | | | | |
| 28 Apr 98 | | | | | | | | | | | |
| 12 May 98 | | | | | | | | | | | |
| 26 May 98 | | | | | | | | | | | |
| 09 Jun 98 | 19.30 | 35.70 | 28.10 | 50.80 | 35.80 | 26.05 | 39.70 | 31.55 | 43.50 | 47.55 | 37.50 |
| 23 Jun 98 | 20.70 | 21.90 | 28.85 | 36.80 | 44.75 | 26.55 | 46.95 | 36.55 | 51.75 | 45.50 | 42.30 |
| 07 Jul 98 | 18.00 | 18.10 | 23.00 | 42.15 | 29.05 | 36.15 | 33.00 | 27.40 | 48.65 | 37.40 | 32.35 |
| 21 Jul 98 | – | 23.80 | 34.15 | 44.10 | 36.90 | – | 37.40 | 31.65 | 39.00 | 40.10 | 40.20 |
| 04 Aug 98 | | | | | | | | | | | |
| 18 Aug 98 | | | | | | | | | | | |
| 01 Sep 98 | | | | | | | | | | | |
| 15 Sep 98 | | | | | | | | | | | |
| 29 Sep 98 | | | | | | | | | | | |
| 13 Oct 98 | | | | | | | | | | | |
| 20 Oct 98 | 25.10 | – | 23.35 | 35.30 | 33.90 | 32.85 | 39.40 | 27.45 | – | 46.65 | 37.95 |
| 03 Nov 98 | 30.50 | 38.90 | 51.05 | 54.35 | 49.10 | 44.20 | 43.35 | 42.05 | 55.10 | 54.65 | 63.65 |
| 17 Nov 98 | 50.80 | 37.70 | 57.95 | 58.90 | 60.45 | 57.00 | 47.30 | 52.60 | 52.60 | 58.40 | 50.75 |
| 01 Dec 98 | 39.80 | 49.85 | 47.35 | 54.70 | 46.35 | 47.35 | 57.55 | 45.45 | 54.95 | 47.30 | 55.95 |

**Table B6 $PM_{10}$ particulate concentrations (µg/m$^3$), daily means—July 1998 survey**

| Start date | Elmbridge School | Northgate | Barton Street | Cheltenham Road | Bristol Road | Finlay Road | Trier Way |
|---|---|---|---|---|---|---|---|
| 17 July 97 | 15.43 | – | 38.51 | 14.89 | – | 19.81 | – |
| 18 July 97 | – | 13.79 | 40.22 | 20.28 | 18.41 | 22.53 | 16.20 |
| 19 July 97 | – | 15.50 | 40.22 | – | 12.84 | 9.27 | – |
| 20 July 97 | 19.03 | 19.57 | 24.70 | 22.16 | 35.03 | – | 18.79 |
| 21 July 97 | 18.90 | 33.37 | 42.79 | 21.59 | 44.94 | 23.57 | 16.90 |
| 22 July 97 | 15.14 | 24.34 | 22.08 | 21.12 | 32.87 | 18.93 | 16.34 |
| 23 July 97 | 10.00 | 19.12 | 16.66 | 15.04 | 24.28 | | 12.64 |
| 24 July 97 | 9.55 | 16.42 | 14.01 | 19.76 | – | 21.36 | 12.54 |
| 25 July 97 | 3.77 | 21.12 | 23.19 | 22.00 | 61.33 | 20.60 | 22.90 |
| 26 July 97 | – | 15.37 | 22.73 | 20.48 | 20.96 | 16.28 | 17.00 |
| 27 July 97 | 14.35 | 72.46 | 15.20 | 20.24 | 31.44 | 16.66 | 17.29 |
| 28 July 97 | 16.42 | 25.70 | 20.71 | 25.83 | 29.19 | 23.10 | 20.10 |
| 29 July 97 | 8.94 | 17.06 | 14.94 | 16.72 | 18.54 | 15.66 | 10.44 |
| 30 July 97 | 7.39 | 24.39 | 13.47 | 16.70 | 32.37 | 16.09 | 13.29 |

**Table B7 $PM_{10}$ particulate concentrations (µg/m$^3$), daily means—December 1998 survey**

| Start date | Elmbridge School | Northgate | Barton Street | Cheltenham Road | Bristol Road | Finlay Road | Trier Way |
|---|---|---|---|---|---|---|---|
| 04 Dec 98 | 21.58 | 22.29 | 15.41 | 15.68 | 38.74 | 18.92 | 19.09 |
| 05 Dec 98 | 27.90 | 21.05 | 33.97 | 35.36 | – | 30.97 | 31.52 |
| 06 Dec 98 | 27.09 | 14.45 | 53.63 | 26.50 | 14.99 | 46.00 | 38.74 |
| 07 Dec 98 | 29.72 | 23.23 | 39.03 | 41.10 | 41.03 | 32.28 | 36.82 |
| 08 Dec 98 | 24.20 | – | 36.46 | 22.92 | 11.31 | 37.97 | 31.22 |
| 09 Dec 98 | 31.35 | 30.92 | 40.25 | 35.07 | 40.20 | 30.70 | 35.21 |
| 10 Dec 98 | 28.16 | 34.04 | 37.25 | 24.43 | 34.65 | 33.35 | 22.00 |
| 11 Dec 98 | 17.60 | 23.54 | 28.78 | 49.23 | 29.48 | 22.32 | 25.05 |
| 12 Dec 98 | 20.77 | 26.19 | 30.89 | 19.08 | 28.64 | 27.91 | 26.67 |
| 13 Dec 98 | 20.83 | 20.49 | 23.00 | 15.94 | 16.33 | 18.16 | 20.37 |
| 14 Dec 98 | 20.04 | 12.36 | 25.78 | 14.17 | 24.34 | 22.00 | 22.67 |
| 15 Dec 98 | 23.91 | 24.76 | 32.24 | 18.67 | 26.89 | 26.07 | 17.95 |
| 16 Dec 98 | 15.71 | 28.74 | 24.46 | 15.40 | 39.38 | 25.02 | 26.51 |
| 17 Dec 98 | 22.02 | 26.34 | 27.40 | – | 34.41 | 24.33 | 26.04 |

## Abstract

TRL Ltd is monitoring the environmental effects of the Gloucester Safer City project. As part of this work, a city-wide network of monitoring sites has been set up to determine concentrations of nitrogen dioxide, $PM_{10}$ and benzene in Gloucester. The network comprises 10 kerbside sites and a background site. This document reports on the first two years (1997 and 1998) of the air quality monitoring in Gloucester.

In both years benzene concentrations at all of the sites were below the Air Quality Standard of 16.25 $\mu g/m^3$ (5 ppb). Over the monitoring period, the mean concentrations fell at the kerbside locations by 24% and at the background by 53%, which reflects the general decline in hydrocarbon emissions from traffic in Gloucester. For nitrogen dioxide, concentrations at the kerbside were close to or greater than the Air Quality Standard of 40 $\mu g/m^3$. On average concentrations fell by 9% at the kerbside, which again reflects a decline in the emissions of oxides of nitrogen from traffic in Gloucester. However over the same time period, nitrogen dioxide concentrations increased at the background site by 7%.

Air quality monitoring is to continue until the end of 2001 largely as described in this report, except for additional sampling of kerbside $PM_{10}$ and carbon monoxide.


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